Istituto Superiore per la Protezione e la Ricerca Ambientale

AUTONOMOUS PROVINCE OF TRENTO
Provincial Environmental Protection Agency

LAKE SHOREZONE FUNCTIONALITY INDEX (SFI)

A tool for the definition of ecological quality

as indicated by Directive 2000/60/CE

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INDEX

1. Introduction

The international literature offers a vast bibliography on riparian fluvial areas, including numerous contributions on vegetation and fauna, on ecological function, re-naturalization and reclamation of the buffer strip, on the planning value, consolidation actions and so on (Vidon & Hill, 2006; Hatterman et al., 2006; Naiman & Decamps, 1997; Naiman et al., 1993). Although, studies on the role of the lake's riparian area are often only poorly and marginally treated (Keddy & Fraser, 1983, 1984, 2000; Zhao et al., 2003; Hazelet et al., 2005; Marburg et al., 2006; Hwang et al., 2007; Ostojic et al., 2007).

The coastal habitats have many natural elements interlinked with the lake ecosystem to form an ecological web. For example, the vegetation, the sediments and the detritus play an important role in the vital cycles of fish and coastal fauna (McDonald et al., 2006; Dudgeon et al., 2006; Malm Renofalt et al., 2005).

The lakes are affected by the chemicals coming from the watershed's streams, that, like in the case of nitrogen and phosphorus, affect actively (and often negatively) the trophic-evolutionary processes of their waters. (Premazzi & Chiaudani, 1992; Chapman, 1996).

To date, classic limnology studies failed to focus on the simple functionality of the lake riparian zones.

The riparian zone has an important role in protecting and buffering the degradation of the aquatic ecosystem derived by human activities (Cobourn, 2006). Land uses that consisted in the elimination of riparian vegetation, often caused environmental stresses, increased instances of no-point source pollution, and resulted in morphologic alterations and habitat destruction (Schultz *et al.* 1993, 1995).

Studies by Osborne and Kovacic (1993) have shown that the riparian zone, (both herbaceous or shrub/arboreal types), can efficiently intercept the nutrients coming from nearby agricultural areas, diminishing by over 90% the nitrogen and phosphorus contents in both superficial and sub-superfical waters flowing into the water body.

There are many and dissimilar interests on the lake's environments. For example, the waterfront owners often see the lake shorezone as a resource to be exploited: a lake, beside having a great naturalistic value, also guarantees numerous opportunities for water activities, such as swimming and aesthetic satisfaction, which can be exalted by proper lake ecosystem management and protection policies.

Such vision requires a the creation of a system of indicators, and thus indices, that are able to support and guide land planning policies and management choices. Following the success of the IFF (Index of Fluvial Functionality – Siligardi *et al.,* 2007), a new model was created in order to been able to calibrate the efficiency of the lake shore zone, using biotic and abiotic descriptors that are easily surveyed (Broocks et al., 1991; Keddy & Fraser, 2000; Lin et al., 2000; Dale & Beyele, 2001; Danz et al., 2005; Brazner et al., 2007). The need for a new index was also supported by the request of the Water Framework Directive 2000/60/CE that, to define the ecological quality state, places side by side the evaluations of biological elements with the evaluation of hydro-morphological elements.

2. The lake shore environments and the Water Framework Directive 2000/60/CE

The Water Framework Directive (WFD) 2000/60/CE defines the elements of quality (EQ) to classify the ecological state of water bodies of any typology. Among the EQ to be determined, there are biological elements and hydro-morphological elements which, for lakes, consist in the hydrological regime (quantity and dynamics of the water flow, water percolation, and residence time) and the lake morphology (variation of depth, substrate's characteristics and shore's structure) (CIS, 2003). Concerning the lake-shore-zone, the document "*The Horizontal Guidance Document on the Role of Wetlands*" contained in the framework directive (CIS wetlands WG 2003) is the most important reference to article 1 of the Water Framework Directive in which the wetlands are described as depending directly on the ecosystem of internal superficial water bodies (such as lakes).

The ecosystem of the lake-shore-zone located the closest to the water is commonly called *wetland*: this is an area with a characteristic lakeshore ecotone, with a gradient going from the surrounding land to the aquatic environment and that varies with periodic changes in water levels (including flooding). In the CIS document the lake-shore-zone is clearly associated to the wetlands, *sensu Directive*, and nevertheless it is consider as an integral part of the lake, able to influence the related ecological status. Consequently, diverse water-related WFD objectives and obligations do consider the lake-shore-zone as well (CIS Wetlands WG 2003, page 10 to 13).

However, the Directive does not provide for wetland's environmental objectives and for such reason, at the Copenhagen's meeting on November 2002, the Member States defined that tampering the shorezone is an environmental impacting act for the ecological state of the water body. Thus, wetland or, in our case, shorezone management is considered an integral part of the Basin Plans and the conservation and extension of wetlands and lake-shore-zones may be the instrument to reach the WFD objectives. These considerations have been acknowledged by the CEN Technical Committee 230/WG2 "Water Analysis" and by Member States and others such as Switzerland.

The looking into the different methods used by the Member States immediately showed the absence of standard and consistent methods in the EU.

Definite EQ and measurement program to be included in the Plans of the water management for each hydrogeographical District, were needed to reach the environmental objectives defined by the WFD on environmental protection policy and sustainable use of the water bodies.

The hydro-morphological quality elements are of fundamental importance in the analysis of water bodies, in particular those classified as highly modified (HMWB) or artificial, that risk not to reach the environmental objectives required by the Italian government Basin Programs.

It is therefore very important to develop and apply indices such SFI (or the similar IFF for rivers) since they offer an answer on the state and ecological potential of a water body (lake, river), regarding as well the hydro-morphological aspects.

3. The lake shore-zone: ecology and function

The "lake shore-zone" extends around the lake with a defined width and has various ecological functions which depend on many environmental factors.

The morphology and characteristics of the lake shores are very important being functional elements for the ecological dynamics of the water bodies and for its biodiversity. The morphological characters, apparently not influential on the qualitative processes, are very important in evaluating the functionality of the coastal areas. Moreover, even the topography of the land surrounding the lake influences land-lake exchanges: the greater is the geometric complexity of the lakeshore profile, the minor is the nutrient input derived by limnological processes, since the geometric complexity reduces the content of BOD, COD and TP (Hwang, 2007).

The lake-shore riparian ecosystem, even if less obviously than the fluvial one, guarantees a conspicuous supply of water that contributes to the growth and survival of plants, insects, animals and microorganisms, therefore increasing biodiversity and consequentially functionality (Giller, et al., 2004). Plants constitute an element of structural and taxonomic diversity and are able to moderate seasonal water flows by storing water and by regulating the amounts of sediment and nutrients inputs (Smith and Hellmund, 1993).

Topography, climate and the soil geological composition greatly influence the structure and extension of the lake shore-zone. Likewise, the lake shore-zone vegetation controls considerably the water flow, nutrients and sediments inputs, and the diffusion of animals and plants towards the lake from the surrounding area (Malanson, 1993b; Naiman et.al., 1993). Different amounts of nutrients are derived on the diverse land uses, which could be agricultural, industrial, urban, uncultivated or other.

The vegetation strip along lake is therefore considered a transition zone between the surrounding area and the water body in both a topographic and functional point of view (Pinay et al., 1990; Smith & Hellmund, 1993; Malanson, 1993b; Vidon & Hill, 2006; Hazelet et al., 2005) and it plays an important role in shore protection (Maynard & Wilcox, 1997; Ostendorp, 1993)

Maintaining an healthy vegetated lake shore-zone is important as it intercepts the waters (both superficial and subterranean) coming from the surrounding watersheds that carries nutrients that would otherwise enter into the lake without obstacles (Burt et al., 2002; Van Geest et al., 2003).

It is also very important that area close by the shore, where the macrophytes are at the base of the trophic web. The biodiversity of the macrophyte community depends on the variation of factors such as depth, water level fluctuation, granulotory and exposure to the waves (Keddy & Reznicek, 1986; Keddy, 1990; Ostendorp, 1991; Wilcox & Meeker, 1992).

Besides these ecological functions, the lake shore has also a human recreational function, by being highly attractive to tourists (Bragg *et al.*, 2003; Wilcox, 1995).

The following definitions are used by the SFI for the different portions of the Lakeshore zone:

- Shoreline: the line on the shore where water and soil make a contact. This portion can be bare, herbaceous or have a more complex vegetation such as stumps, logs, branches, root systems, bed of reeds or other;
- Littoral zone: the section of the lake along the shore in correspondence to the euphotic (well illuminated) zone which generally coincides with the limit of presence of submerged macrophytes; it often hosts phytobenthic and zoobenthos communities and it is a refuge for many aquatic and non-aquatic animals. Many fish species choose this area for eggs deposition and development (Baker, 1990; Doyle, 1990; Pollock *et al.*, 1998; Bratli *et al.*, 1999; Wetzel, 2001; Roth *et al.*, 2007);
- Riparian zone: the land area immediately adjacent to the lake with ecotonal functions that is formed by both terrestrial and aquatic habitats and that guarantees an high level of biodiversity (Wetzel, 2001). It can significantly affect the quality determined by other hydro-morphological, biological or physical elements and in return can be influenced by flooding and wave action.
- Lakeside zone: the land portion that interacts with the lake environment; it does not have an ecotonal structure and/or function but it is mainly a terrestrial environment.

The scientific community lacks a general agreement to indicate and define the ecologically functional strip, and expressions such as the ones describes above (lakeside zone, riparian zone, littoral zone and shoreline) do not completely reflect the significance of the ecotonal zone. For example, while for the CIS Wetlands Group (CIS, 2003) the word "*shorezone*" describes the littoral zone, especially for natural lakes, other scientists define it differently, giving to it a stronger stress on its ecological functions rather then on its geographic and morphologic characteristics (Schmeider, 2004).

The word "lake-shore", lately used in literature to indicate that area with a morphological and functional role of ecotone, includes both the littoral zone and the riparian zone (Ostendorp *et al.*, 2004) (figure 1).

Therefore, the term "lakeshore" is used here to indicate the transitional area (ecotone) that links the terrestrial environment to the pelagic one (Naiman & Decamps, 1997)

By **"lake-shore-zone" it is meant the topographical strip situated around the lake that includes part of the littoral zone (up to a maximum depth of 1 m) and the strip of land that extends up to 50 m from the shoreline.**

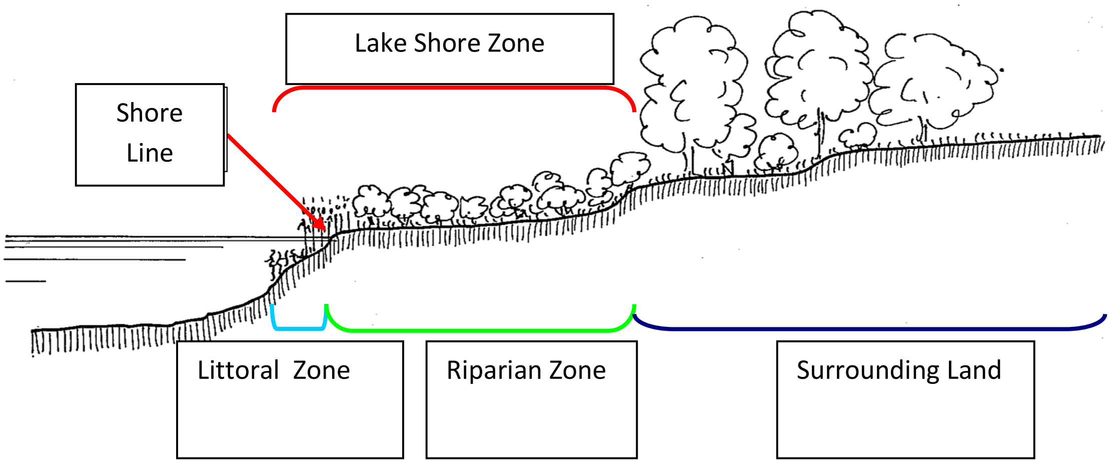


Figure 1 - scheme of the different lake-shore-zones

The natural lake-shores can have different characteristics that depend on the vegetation and geology, genesis, age, depth and lake shape, geomorphological processes, sedimentation delta, wave action and water level changes.

Lake-shores have an ecotone role, separating and simultaneously relating the terrestrial and the aquatic habitats, regulating their sink-source fluxes (Farina, 2001). In fact, they work as filters able to tampon and depurate waters (littoral and riparian) rich in nutrients (Hatterman *et al.*, 2006; Cirmo & McDonnell, 1997; Krysanova & Becker, 2000; Lin *et al.*, 2002).

The lake-shore-zone is quite important for the different functions that it has for the lake ecosystem:

1) **Filter**: the rain and run-off are slowed down by the vegetation that facilitate the infiltration, sedimentation and pollutant capture (Pinay *et al.*, 1990) (Fig. 2).

2) **Erosion protection** –the tree roots retain the lake-shore soil preventing or reducing the erosion processes caused by the natural action of waves or induced by swimmers (Heckman, 1984).

3) **Nutrients removal** – nutrients, such as the nitrogen or the phosphorus coming from the surrounding watersheds, can be intercepted by the root systems of the lakeshore zone vegetation, metabolized and stored in leaves, trunks, and roots (Pinay *et al.*, 1990; Vanek, 1991; Vought *et al.*, 1993, 1994; Shultz *et al.*, 1995; Push *et al.*, 1998). Phosphorus is the main limiting nutrient in lakes and can favor eutrophication processes in lake waters. Its removal can occur by three different solutions:

    a) deposition in lake sediment;

    b) absorption and sink of dissolved phosphorus (i.e. orthophosphate) in bottom sediment particles (Triska *et al.*, 1993; Vought, 1993);

    c) uptake of nitrogen and soluble orthophosphate by suction operated by the root apparatus of the lakeshore zone vegetation (Vought, 1993, 1994) (Fig. 2).

The efficiency of the tampon zone changes with the different seasons, when duration and intensity of the water fluxes vary; for example, a lake-shore-zone vegetation composed by deciduous plants has an higher filter efficiency and nutrients removal capacity during the vegetative period (spring-early fall) than during physiological dormancy (late fall-winter) (Mitsch & Grosselink, 1986).

4) **Temperature control** – The shade produced by the tree foliage attenuates the solar irradiation, controlling the water temperature along the coast, where often the fauna settles and egg deposition occurs (Gregory et al., 1991).

5) **Habitat** – The vegetated lake-shore-zone furnishes an ideal habitat for many species of animals (fish, amphibians, reptiles, birds, mammals, insects, etc.) offering refuges and the food necessary for survival and reproduction (Callow and Petts 1994). It is particularly important for fish habitat and it is therefore an element that need to be protected when aiming to the maintenance of the fishing resource.

6) **Anthropic value** - A healthy vegetated lake-shore-zone is important for naturalistic and aesthetic points of views. Sometimes it also have cultural, historical and archaeological reasons when historically importance.

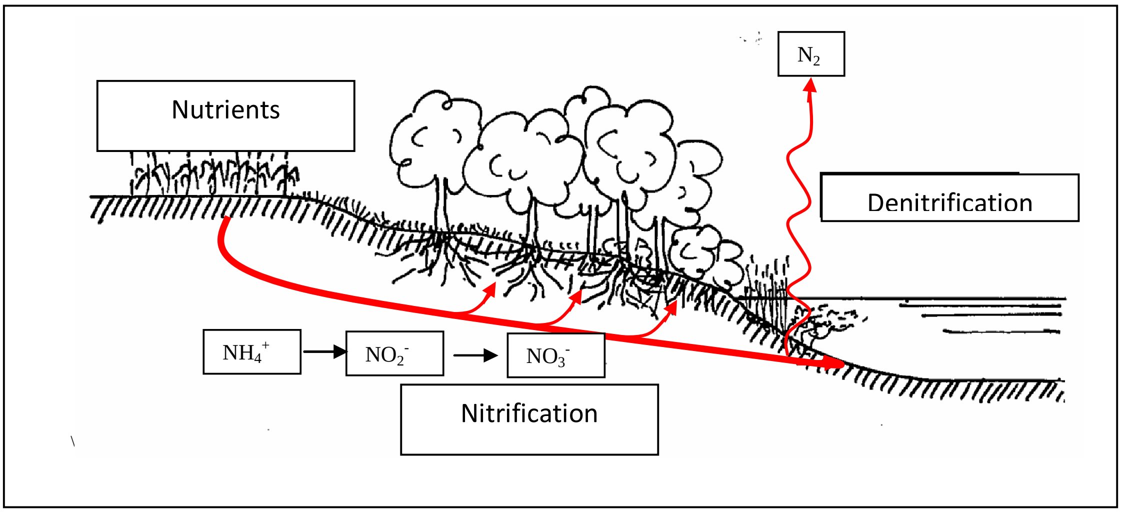


Figure 2 - Representation of the tampon function of the lake-shore-zone

4. Shore-zone Functionality Index (SFI): introduction

4.1 Methodological approach

A work group was officially instituted by APAT, now ISPRA, to create a new method able to satisfy the necessity of indices for the evaluation of the functionality of the lake-shore-zones.

After a first classic approach based on consolidated experience of the IFF (Fluvial Functioning Index) (Siligardi *et al.,* 2007), the work group, wanting to include bioindicators and new available technologies, included in model *Machine learning*, artificial intelligence and *fuzzy logic,* as inspirations of the new ecosystem vision.

Only two approaches are possible when evaluating the functionality of an important ecological structure, the integrity of a community, or other characteristics of closely related entities:

- The first approach consists in the recognition of the recurring typologies and their successive interpretation with the attribution *a posteriori* judgment (a quality score or a classification value –which is not based on a scheme that distinguishes what is desirable from what is not). This approach was used for the development of the CAM algorithm (Classification of Marine Waters), adopted to evaluate the data from the coastal marine water monitoring program (coordinated by the Environment Departement -www.minambiente.it).
- The second approach consists in the a priori evaluation of the quality and the functionality of the observed parameters, done during field work by technicians. Practically, a personal judgment is given to the different parameters surveyed. Afterwards, this information is entered into a database and used to run the SFI model based on a classification tree.

After trying different explorative techniques (as ordinance and hierarchy classifications) and self organizing maps, an approach based on the **classification tree** was adopted to treat the data collected to create a

Shorezone Functionality Index, after trying different others traditional techniques, such as *Hierarchic classification*, *neural net analysis (Self Organizing Maps*), and modern analysis such as Machine Learning (Scardi et. al., 2008). For an introduction to the ecological applications of the method please refer to Fielding (1999).

The classification tree allows to link unequivocally a set of observations on the structure of the lake-shore-zone to an evaluation of its potential functionality, in other words, its apparent capacity to protect the water body from the no-points-source inputs coming from the adjacent watersheds.

Ecologists and naturalists can easily understand the method, as it generates a binary tree that has the same structure as the dichotomic tree used to identify species.

The solution, which is not the only possible or necessary the most efficient, was chosen because it was considered optimal considering the explorative nature of the work completed. In particular, the main objective was to elaborate an easily applicable method that functioned on rather limited set of field observations.

The workgroup therefore created a field form to collect the largest number of parameters and indicators to identify the most significant information for the proposed objectives.

The form is divided into three groups of parameters:

1) general parameters
    a) topographical
    b) morphological
    c) climactic
    d) geological
    e) others
2) ecological parameters
    a) vegetation type
    b) size
    c) continuity
    d) interruption

3) socio-economical parameters
    a) general
    b) land use
    c) infrastructure
    d) tourism
    e) tourist infrastructure
    f) productive activities

4.2 Characteristics of the classification trees

A *classification tree* is a binary tree that represents a group of rules that are applied to classify multi-variate observations. Each *classification tree*' s "leaf" represents a more or less frequent type of observation and more leaves can belong to the same class; therefore these can be considered as a subgroup of the classes recognized by the system.

Once organized, the *classification trees* can be used to classify objects or observations following sequentially the rules associated to each tree's fork, until reaching the leaves.

These can be more or less pure, depending whenever or not they contain objects and observations classified in an incorrect way. Generally, obtaining pure leaves implies a reduced capacity to generalize the tree (*overfitting*). In other words, if the tree overfits defined existing cases used for its creation, the generated rules are associated too closely to these particular cases and became useless when other slightly different cases must be classified. On the contrary, if the tree structure and the rules that it contains are simple, the probability that the tree is efficient even when classifying new cases, increases. For this reason, in many cases, the tree is "trimmed" once developed, with the goal to reduce its complexity and to increase, whenever possible, its generalization capacity.

Among all the *Machine Learning* techniques, the *classification tree* is the one that can be used more easily by a general public. In fact, the complexity of the algorithms that are used to run the trees is completely transparent to the final user and to the developer.

In particular, among the advantages of a *classification tree,* the following are important:

- they are easy to put together, since algorithms are generally efficient and tested (e.g. C4.5, ID3, CHAID, etc.) and able to autonomously estimate the optimal structural parameters for a tree;
- they are easily understood, graphically represented and interpreted, unlike other machine learning techniques such as artificial neural nets and non-linear regressive models;
- their practical application does not require calculations of any type but only the verification of a group of simple logical conditions;
- they can manage efficiently both quantitative variables and semi-quantitative or nominal variables, while other methods do not always treat efficiently the latter;
- they are particularly efficient in managing cases of interactions between variables, which are resolved by appropriately partitioning the defined space of the considered parameters;
- they can suggest which parameters are more important in determining the classification; this does not require any added analysis but only a visual inspection of the tree structure.

4.3 Development of the SFI survey form

The SFI form and its parameters were defined between 2004-2009 in a series of attempts which began with the identification of a wide range of parameters that could be associated to the lake-shore-zone functionality. The first group of parameters were narrowed after using the preliminary form on some lakes: this process brought to the elimination of those parameters that resulted pompous and insignificant.

The parameters were also selected on the basis of their easily availability for all types of lakes; for example meteoclimatic information was excluded because not always available.

The initial use of an “experimental form” made it possible to evaluate the difficulties of compiling it, to better define the required parameters and to improve the methodology in assigning scores. Through field work, it was also possible to make a preliminary protocol for the correct interpretation of the form. The SFI parameters, latter described in this book, were defined during this first phase.

5. Shore-zone Functionality Index (SFI): protocol

5.1 Preliminary Investigations

It is important to do a preliminary investigation before going out in the field in order to have a basic understanding of the environment to be surveyed. Maps of the lake and the surrounding environment are therefore useful to have a perspective of the lake in its entirety, to investigate land uses, to identify roads and access points to the river. These maps will also be used in the field to annotate the location of the homogeneous stretches found.

Useful information for thematic maps includes: vegetation, land use, soil type, altitude, bathymetry, aerial photos, etc. A scale of at least 1:10,000 is recommended for the fieldwork, as it provides a certain amount of details necessary for the environmental analysis.

It is also advisable to use aerial photography to complement the thematic maps.

5.2 *Survey forms for the SFI parameters*

The parameters considered useful for the determination of the SFI are collected into a “field card”, subdivided into two different forms. The first form is about the lake in general while the second form contains information about the ecological and morphological characteristic of each homogeneous stretch found in the field.

The homogeneous stretch is identified in the field through direct observation and with the aid of the maps created during the preliminary analysis.

The place where shore-zone clearly changes, especially changes regarding the human impact’s weight (i.e. artificiality of the shore-zone) or the shore-zone vegetation structure (i.e. composition, width…), indicates the end of an homogeneous stretch and the start of a new one. In this case, a new form is filled for the new stretch.

There is not a pre-established length to be used for the homogeneous stretch, which could be kilometers long, but it must be at least equal or superior to the Minimal Detectable Stretch (MDS). The size of the MDS depends on the size of the lake, the weight of anthropic impacts, the structure and shape of the lake shore-zone, etc.

Generally, in the case of large lakes (perimeter above 50 km), the minimum stretch to be sampled cannot be less than 200 meters, with the exception of stretches with particular characteristics or anthropic impacts that would require the filling out of another card.

The information requested for the first form (Table 1) is gained from cartographic, bibliographical, or monitoring campaigns sources. This information is not used when assigning the SFI value, but is important for the general knowledge and understanding of the lake structure.

	INDICATOR	Parameter expression	typology
TOPOGRAPHICAL	origin[1]	-	category
	type[2]	-	category
	location[3]	-	category
	latitude	degree, minutes, seconds	number
	longitude	degree, minutes, seconds	number
	altitude of lake	meters asl	number
	average altitude of catch basin	meters asl	number
MORPHOLOGICAL	area of catch basin (SB)	km^2	number
	shore slope	degree or percent	number
	development of shore line	-	number
	area of lake (SL)	km^2	number
	volume	Km^3	number
	maximum depth	meters	number
	average depth	meters	number
	average residence time	years	number
	tributary/effluent capacity	m^3/second	number
	SB/SL relationship	-	number
	level changes	-	presence/absence
CLIMATIC	precipitation	mm/year	number
	average maximum Jan. temp.	degree centigrade	number
	average maximum July temp	degree centigrade	number

	main geological type of the substrate[4]	-	category
OTHER	thermic cycle[5]	-	category
	summer transparency (Secchi disk)	meters	number
	trophic classification using indicator principles[6]	-	category

[1]= *tectonic, volcanic, glacial, oxbow lake, landslide, endorheic, coastal, seasonal, other*

[2]= *artificial, open natural, natural large, natural closed, natural regulated, other*

[3]= *alpine (mountain), pre-alpine (half mountain), lowland*

[4]= *calcareous, magma, metamorphic, sedimentary, other*

[5] = *holomitic, monomitic, dimitic, polymitic, meromitic, amitic, other*

[6] = *ultraoligotrophic, oligotrophic, mesotrophic, eutrophic, hypertrophic*

Table 1 - First part of IFP card: general data

The second form refers to the conditions of each single homogeneous stretch of the lake shore-zone, considering the parameters showed in the following table. (Table 2).

	Parameter	Typology	Value	Notes
1	width of lake shore-zone	category	0,1,2,3,4,5	
2	characterization of lake-shore vegetation			
2.1	cover/composition %	numerical	% - from 0 to 1	Σ = 1 except in particular cases
2.2	hygrophilous and non-hygrophilous vegetation	numerical	% - from 0 to 1	Σ = 1
2.3	exotic species presence	numerical	% - from 0 to 1	
2.4	heterogeneous arboreal-bush vegetation	numerical	from 0 to 1	
3	continuity of lakeshore vegetation	category	0, 0.5, 1	
4	interruption within lake shore-zone	numerical	from 0 to 1	
5	typology of anthropic uses in lake-shore-zone	category	0, 0.5, 1	
6	main use of surrounding land	category	0, 1,2,3	
7	infrastructure	numerical	from 0 to 1	
8	emerged lake-shore-zone	numerical		
8.1	average slope	category	0,1,2,3,4,5	
8.2	slope comparison between emerged/submerged areas	category	0,1	
9	shoreline profile	numerical		
9.1	concavity and convexity	numerical	from 0 to 1	
9.2	complexity	numerical	from 0 to 1	
10	shoreline artificiality	numerical	from 0 to 1	
11	apparent channeling of run-off	category	0, 0.5, 1	
12	personal judgment	category	0,1,2,3,4,5	

Tab. 2 – Useful parameters for the SFI with indications of the typology and evaluation.

All the information necessary to fill the form are collected in the field, using Table 3. The methodology to express each parameter is specified each time.

It was decided to use a scale based on numerical scores for facilitate the statistical elaboration; the scores were chosen considering a range of values that estimate the different weight of each parameter.

As it is described in the methodology section, not all parameters will be part of the resolution set and identification of level of functionality; however, it is opportune to fill out the form in its entirety to have a complete inventory of the characteristics of the lake shore-zone that allows other possible elaboration and that can be used in planning and management projects.

It is also possible that (as often happens with any qualitative or semi-qualitative indexes based on heuristic processes and fuzzy logic) the application will be re-calibrated few years from now.

Date
Lake
Form Number
Delimitation of stretch
Photograph number
Surveyors
GPS coordinate

Lake shore-zone
The boundary of the lake shore-zone is determined by …………….

1. width of lake shore-zone	
0 m	0
1-5m	1
5-10m	2
10-30m	3
30-50m	4
>50m	5
2. characterization of lake-shore-zone vegetation	
2.1 cover/composition % (expressed from 0-1)	
trees %	
shrubs%	

reeds%	
grasses%	
bare soil%	
2.2 Hygrophilous and non-hygrophilous vegetation (expressed from 0-1)	
hygrophilous (helophytes, riparian shrub and riparian arboreal species)	
non-hygrophilous (other species)	
2.3 Presence of exotic species (expressed from 0-1)	
exotics %	
2.4 Heterogeneousness of arboreal-shrub vegetation	
diversified	1
intermediate	0.9-0.7
monospecific	0.6
autochthonous hygrophilous arboreal-shrub species >2/3	
diversified	0.5
intermediate	0.4-0.3
monospecific	0.2
autochthonous hygrophilous arboreal-shrub species < 2/3 and autochthonous arboreal-shrub < 2/3	
autochthonous relevance	0.1
exotic prevalence	0
arboreal-shrub vegetation absent	0
3. Continuity of the lake-shore vegetation	
arboreal and shrub zone	
absent	0
discontinuous	0.5
continuous	1
wet reed zone	
absent	0
discontinuous	0.5
continuous	1
dry reed area	
absent	0
discontinuous	0.5
continuous	1
4. Presence of interruption on the lake-shore zone	
absent	0
intermediate	
present along the whole stretch	1
5. Typology of anthropic uses within the lakes-shore zone	
uncultivated meadows or unpaved streets, etc.	0
sparse urbanized, cultivated meadows, etc	0.5
urbanized area	1

6. Main Use of nearby territory	
woods and forest	0
meadows, forests, arable land, uncoltivated	1
seasonal cultures and/or permanent ones and sparse urbanization	2
urbanized area	3
7. Infrastructure	
Provincial/state roads	
absent	0
intermediate	
present along the whole stretch	1
Railroads	
absent	0
intermediate	
present along the whole stretch	1
Parking	
absent	0
intermediate	
present along the whole stretch	1
Tourism related infrastructure	
absent	0
intermediate	
present along the whole stretch	1
8. Emerged portion of lakeshore zone	
8.1 average slope	
flat	0
slightly noticeable slope	1
obvious but can be overcome without problems	2
significant but can be overcome with trails or ramps	3
strong slope, roads or trials with bends	4
extreme, vehicles cannot drive	5
8.2 comparison between slope of emerged and submerged area	
not consistent	0
consistent	1
9. Shore profile	
9.1 concavity and convexity	

concavity	
absent	0
intermediate	
present along the whole stretch	1
convexity	
absent	0
intermediate	
present along the whole stretch	1
9.2 complexity	
absent	0
intermediate	
present along the whole stretch	1
10. Shoreline artificiality	
absent	0
intermediate	
present along the whole stretch	1
11. Apparent channeling of run-off	
no prevalent direction for the flow	0
intermediate	
all the run-off converges in a single point	1
12. Personal judgment	
excellent	1
good	2
average	3
below average	4
very bad	5

Table 3 - Parts 1and 2 of the SFI form to be used in the field

5.3 Sampling methodology

The data collection for the entire lake (Part 1) can precede the field inspection.

The filling out of Form 2 is done exclusively in the field, with different forms referring to different homogeneous stretches. As soon as a “significant change” occurs, even in only one of the sampled parameters, a successive homogeneous stretch should be identified for a new card.

By “significant change” is meant the any significant change of one or more of the parameters, for example: changes in the width or typology of the lakeshore zone, changes in the presence of infrastructure or interruptions that are absent in the previous stretch, changes in complexity or artificiality of the shore, etc. Changes in the concavity and/or convexity parameter are often not enough to decide to compile a new form if all the other parameters remain constant. In the case of shorelines with frequent depressions and inlets, it is better to take into consideration the surveying scale (and therefore the length of the minimum stretch length to be sampled), to make an adequate stretches subdivision.

For practical and safety reasons, it is also advisable to have at least two people doing the survey, which also guarantees a reciprocal scientific validation.

The form should be compiled walking along the shore of the monitored stretch. The fieldwork should be done during the vegetative season as information regarding the lakeshore zone vegetation is requested. In the case of steep stretches or stretches with dense shore vegetation, for which access by foot is difficult, it is recommended to go along the lake with a boat to survey possible vegetation interruptions and natural or artificial shore condition.

It is useful to take photographs during the field work that can be linked to the filled form. For a more precise delimitation of the stretches, it is recommended to use the GPS to register the stretch’s starting and ending point coordinates. GPS lines are also very important to import the data into a GIS database, which can greatly enhance cartographic representation and spatial analysis.

The necessary material for the application of the method consists of:

- trekking clothing and adequate personal safety equipment
- maps scale 1:10,000 of the lake
- orthophoto maps (aerial maps geometrically corrected to have an uniform scale)
- an adequate number of forms to be filled out
- digital camera

- pencils and erasers
- paper to note things of particular interest
- metric cord
- fishing boots
- optic telemeter laser (advisable)
- GPS

Tablet PC with incorporated GPS are very useful to directly geo-reference the stretches and to mark them on a digitalized technical card. This kind of data can be easily downloaded, re-organized, and elaborated.

5.4 The approach

The application of the classification tree to the data regarding the parameters of the shore zone of different lakes (for a total of 450 forms collected) allowed to draft a first hypothesis on the evaluation of the slake shore zone functionality.

The use of the classification tree was then made simpler by a Windows platform that requires only the data relative to the essential descriptors. In the list of the parameters considered by the classification tree to evaluate the lake shore zone functionality, only 9 resulted being decisive to classify each stretch:

- Shore artificiality
- Vegetation cover
- Interruption of the lake-shore-zone
- Concavity of the shore profile
- Reeds presence
- Arboreal species presence
- Road Infrastructure
- Heterogeneity of arboreal vegetation
- Non-hygrophilous species presence

It should be specified that even the information regarding the parameters not included in the actual classification tree is anyway useful as they compose a database of the morphological and ecological characteristics of the lake-shore-zone, some of which correspond to the qualitative elements required for the classification of the ecological state of lakes (EC Directive 2000/60/CE).

Figure 3 shows the classification tree used. There can be different pathways throughout the classification tree depending on the values given to the parameters.

For each leaf and node, the probabilities of falling in any of the functionality classes are signed, 1 being excellent and 5 being very bad. The grey underlined line in the table representing each leaf and node, represent the most probable class.

When classifying a stretch of lake shore, the first parameter that is verified (at the root located on the top on the classification tree figure) is the degree of artificiality of the shore (either <0.22 or >0.22). From here, the next parameter that will evaluate the functionality level is the vegetation and the environmental fragmentation.

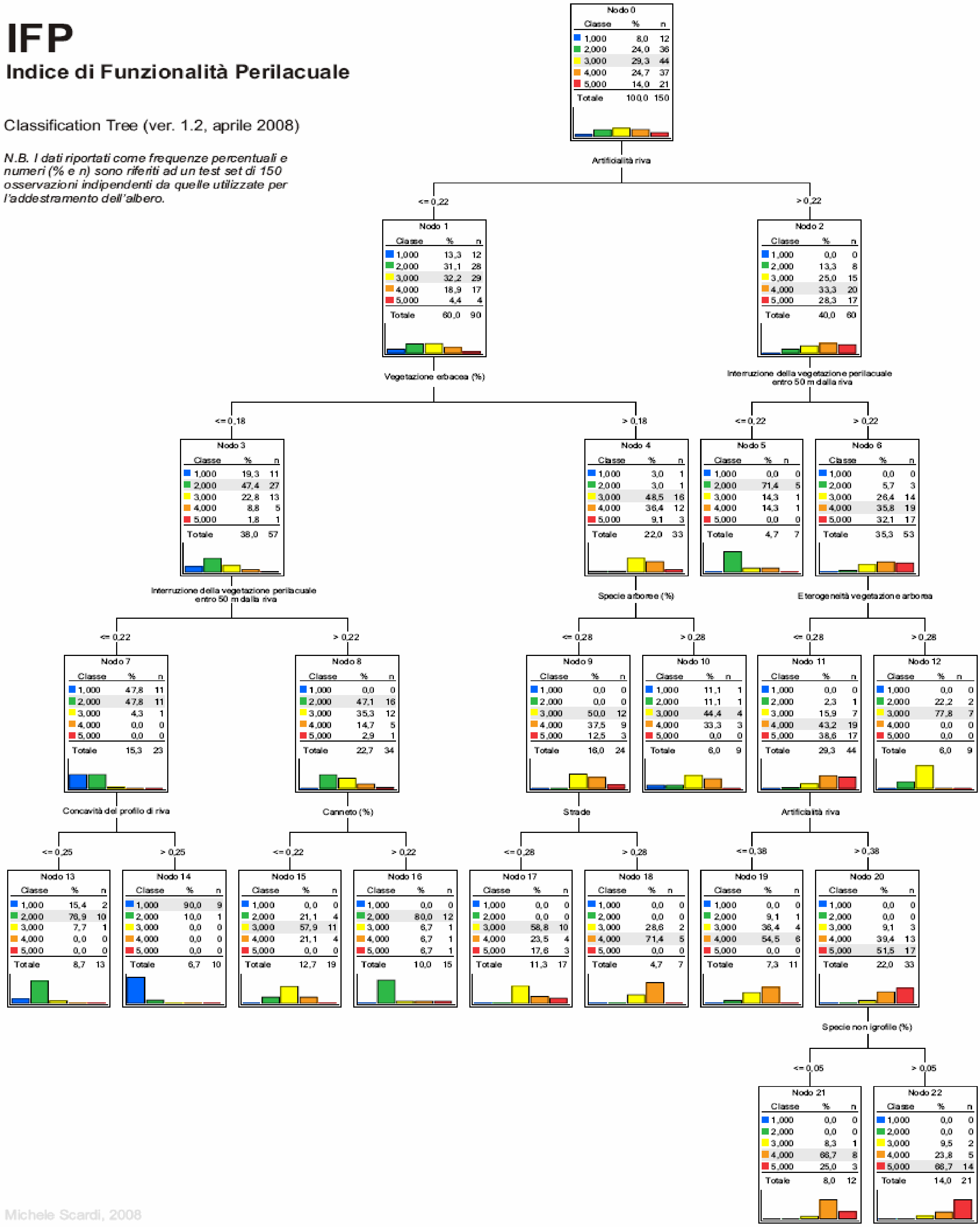


Figure 3 - Classification tree for the determination of the lake-shore levels of functionality with the relative percentages.

The SFI software calculates directly, for each stretch, the functionality level and the probability of being assigned to each of the level.

For this reason, it is important to emphasize how some attributes are considered more than once in different parts of the tree (i.e.. *% grasses*). This also reflects an optimal use of all the information available.

The Cohn test (Cohen, 1960) was carried out to check the correlation level between the results obtained through direct observation (based on expert judgment) and the outcome modeled by the application, (table 4).

	Predicted Class					
True Class	1	2	3	4	5	sum
1	10	5				15
2	6	39	19			64
3		26	42	13	4	85
4			6	16	14	36
5			5	8	4	17
sum	16	70	72	37	22	217

Table 4 - Agreement of the theoretic results, derived from the application of the model, and the ones based on personal judgment.

The results showed a K value of 0.673 ($p<0.01$), meaning that the results obtained though direct observation resulted to be substantially similar to those obtained through the model (Landis & Koch, 1977). The 51.2% of the cases were estimated correctly, and the 95.9% of the cases were estimated with an error of only one functionality level. Therefore, only a 4.1% of the cases had an error above this margin and these errors were anyway relative only to classes 3, 4 and 5.

5.5 Levels and Functionality maps

The final score is divided into 5 functionality levels, expressed in Roman Numerals, raging from I, stretches with an excellent functionality, to V, indicating a very bad functionality level (F.L.).

This method does not have any intermediate positions, likewise other indices, because of the nature of the classification tree: each case will in fact fall into a specific node at the end of the classification tree (at the bottom of figure 3). Each node describes a percentage of the probability the stretch falls into each of the five functionality levels. The higher percentile will determine the final judgment to be adopted for the whole shore stretch. In the case the node itself does not have a prevalence in any particular levels, it will be the operator's work to choose the most probable level of functionality.

LEVEL	JUDGMENT	COLOR
I	excellent	BLUE
II	good	GREEN
III	sufficient	YELLOW
IV	fair	ORANGE
V	poor	RED

Tab. 5. Functionality Levels and relative judgment and color for reference.

For the cartographic representation, each functionality level is associated to a conventional color (table 5). In the case the data was collected with a GPS, the geographic coordination can be transferred into a GIS (Geographic Information System) and represented using the conventional colors. To graphically represent the functionality level, a buffer along the lake shores is created and then colored depending on the Functionality Levels assigned (Fig. 4). It is suggested to use a scale of 1:10,000 or 1:25,000 for a detailed representation, and a scale of 1:50,000 for a general view. It is opportune, to be able to use the obtained data in an operative and punctual manner, to learn to read the map as well as to examine in detail the SFI results and the scores given to the different parameters. This can help emphasizing which environmental components are more compromised and thus consequentially support future environmental rehabilitation policies.

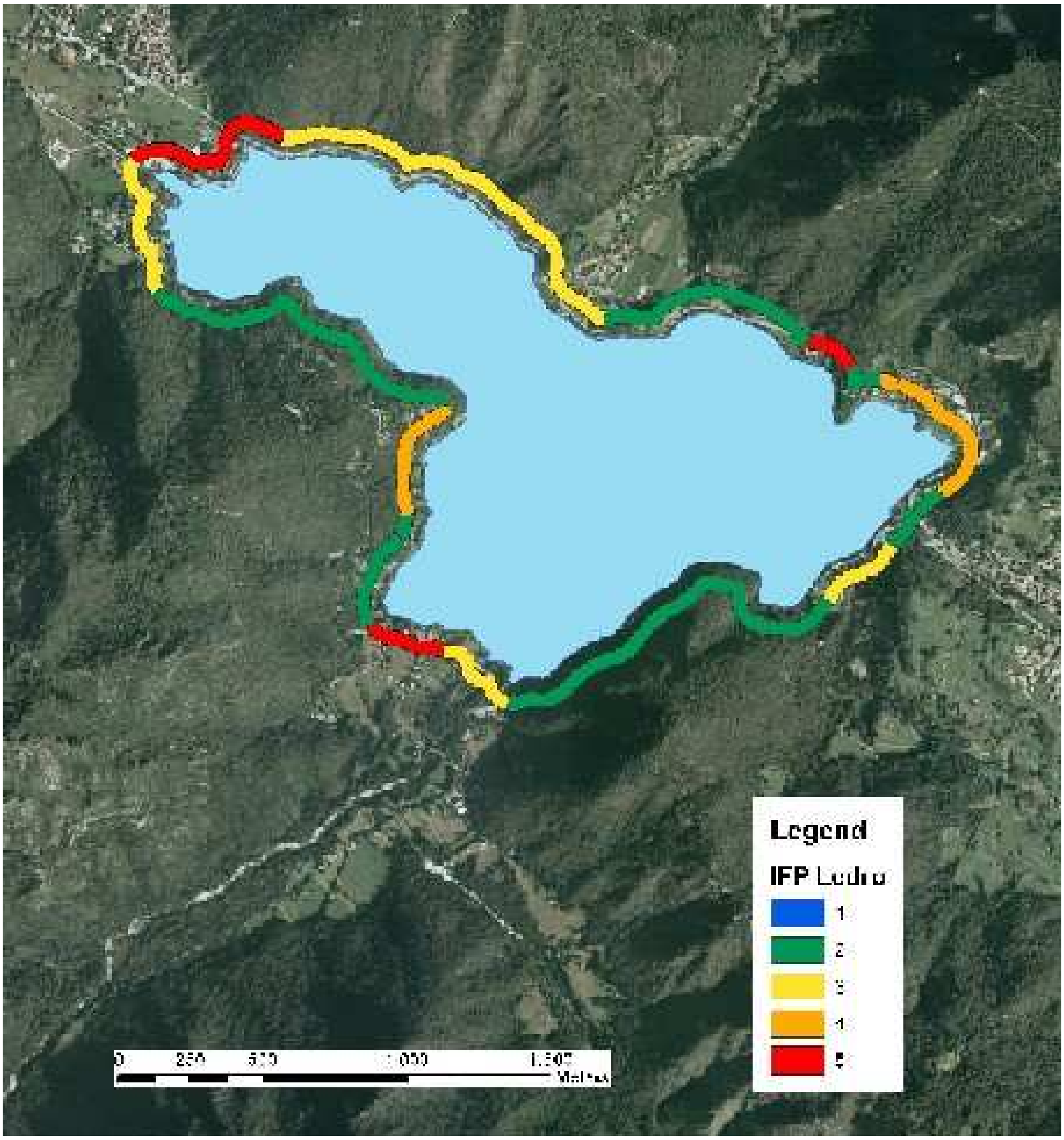


Fig. 4 - Example of a lake shore zone functionality map (Ledro Lake, Trentino)

6. How to fill out the field form

The following paragraphs describe the criteria and reasoning needed to answer each of the 12 parameters used to fill the field form. It is therefore very useful to bring this manual during field work and to refer to the following sections when compiling the form.

Table 6 shows for each parameter and subparameter, what is the area that the operator needs to consider, what is the typology (category or numerical) of the answer and its value range, and finally where to find more information on this manual. .

		Parameter	Area	Typology	Value	page
1		width of lake shore-zone	Shore Zone 0-50 meters	category	0,1,2,3,4,5	
2		characterization of lake-shore vegetation				
	2.1	cover/composition %		numerical	% - from 0 to 1	
	2.2	hygrophilous and non-hygrophilous vegetation		numerical	% - from 0 to 1	
	2.3	exotic species presence		numerical	% - from 0 to 1	
	2.4	heterogeneous arboreal-bush vegetation		numerical	from 0 to 1	
3		continuity of lakeshore vegetation		category	0, 0.5, 1	
4		interruption within lake shore-zone		numerical	from 0 to 1	
5		typology of anthropic uses in lake-shore-zone		category	0, 0.5, 1	
6		main use of surrounding land	Surrounding Territory 0-200 meters	category	0, 1,2,3	
7		infrastructure		numerical	from 0 to 1	
8		emerged lake-shore-zone	ShoreZone 0-50 meters	numerical		
	8.1	average slope		category	0,1,2,3,4,5	
	8.2	slope comparison between emerged/submerged areas		category	0,1	
9		shoreline profile	Shore Profile	numerical		
	9.1	concavity and convexity		numerical	from 0 to 1	
	9.2	complexity		numerical	from 0 to 1	
10		shoreline artificiality		numerical	from 0 to 1	
11		apparent channeling of run-off		category	0, 0.5, 1	
12		personal judgment	.	category	0,1,2,3,4,5	

As previously described in chapter 3 (page 9 "the lake shore zone: ecology and function"), the **lake shore zone** is the transitional area that links the terrestrial environment to the pelagic one (Naiman & Decamps, 1997). For the purpose of this index, this consists of that "topographical strip situated around the lake that includes part of the littoral zone (up to a maximum depth of 1 m) and the strip of land that extends up to 50m from the shoreline". The limit of 50 meters was set because literature reviews show how the buffer strip located between 30-50 meters from the shoreline functions a 95% of its capacity.

Wet reeds and submerged hygrophilous species (see an open list on page 41, chapeter 6.2.2, table 7) are considered part of the lake shore zone. In this case, the 50 meters strip will move landward from the external limit of the reeds or of the vertical projection to the ground of the canopy of the hygrophilous species.

In the case of lakes with reeds extending hundreds of meters lakeward from the shoreline (i.e Neusiedl lake, Austria), the full extend of the reeds can be included in the lake shorezone as it all has an ecotone function. Therefore, in this case, the lake shore zone will extend more than 50 meters from its lakeward limit.

In the case of an impermeable wall built along the shoreline, the lake shorezone width will be zero, as the wall prevents any buffer function.

Permeable walls that allow permeability do not represent a limit for the lake shore zone.

Artificial beaches, fertilized English garden are considered artificial structures just like the impermeable wall, but to differenciate them from cemented walls, they will be evaluated with a width from 0-5 meters.

When answering the questions (6 and 7) about the **surrounding territory,** the area that needs to be considered goes from the shoreline (thus, this does NOT include reeds or other hygrophilous species) to 200 meters inland. These questions are meant to evaluate the amount of human presence and the use of the territory. To answer these questions areal/satellite maps of the surrounding territory are very useful. (do not forget to add a scale bar when preparing the maps!).

The questions about the **shore profile** (9 to 11) regard the general shape of the external identified limit of the lake shore zone in the identified homogeneous stretch. Reeds may therefore increase the level of complexity of the shore (in the case of absence of impermeable walls).

The shoreline artificiality refers to a visual estimation of the level of anthropic influence along the shore, while to answer the questions about the apparent channeling run-off it is useful to have maps with countour lines to identify areas of fluxes concentration.

6.1 Width of the lake-shore-zone

1. width of lake shore-zone	
0	0
1-5m	1
5-10m	2
10-30m	3
30-50m	4
>50m	5

Objectives of the question

The goal is to evaluate the cumulative width (in a orthogonal direction with respect to the water body) of all those formations (such as helophytes, hydrophytes, riparian and autochthonous shrubs, trees) able to carry a buffer function.

Principles

The efficency of the vegetation located in the shore zone is not only related to the complexity and diversity of the formations present, but also to its width. A shorezone width smaller than 30 meters, even when formed by trees and shrubs, can not efficiently carry out its function. The typology of vegetation cover also affects the level of functionality, therefore when estimating the width of the lake shorezone it is important to exclude that component that lack any buffer function.

What to look

First of all, it is necessary to identify unequivocally the lake-shore-zone. As already defined in Chapter 3, it corresponds to the zone that extends from the lake shores (the contact line between the aquatic and the terrestrial environment up to 1 meters water depth) landwards for a maximum length of 50 m. It includes functional vegetation formation in both the riparian and the littoral zones (Fig. 1). It can continue in forests and woods in the surrounding territory (to a maximum extend of 50 meters) or end earlier in the presence of an interruption. Interruptions are those structures of formation that limit the buffering power of the riparian zone. Examples are: roads, dirt roads that interrupt the vertical projection of the vegetation canopy, managed field, infrastructures, etc

An impermeable wall on the shoreline is considered as an interruption since it, reducing the width of the lake shorezone to zero.

In the case of artificial or natural basins that are characterized by considerable and periodic changes in water level (causing the emergence of wide littoral areas), the shoreline considered should be the one of the maximum water level, recognizable by the separation between the temporarily submerged part and that portion colonized by stable vegetation.

The presence of wet reeds is to be considered within the lakeshore zone (only in the absence of impermeable walls on the shoreline). The internal limit towards the lake corresponds to the portion of the lake up to a depth of 1 m (Fig. 5). Within this zone there can be found both helophytes and hydrophytes.

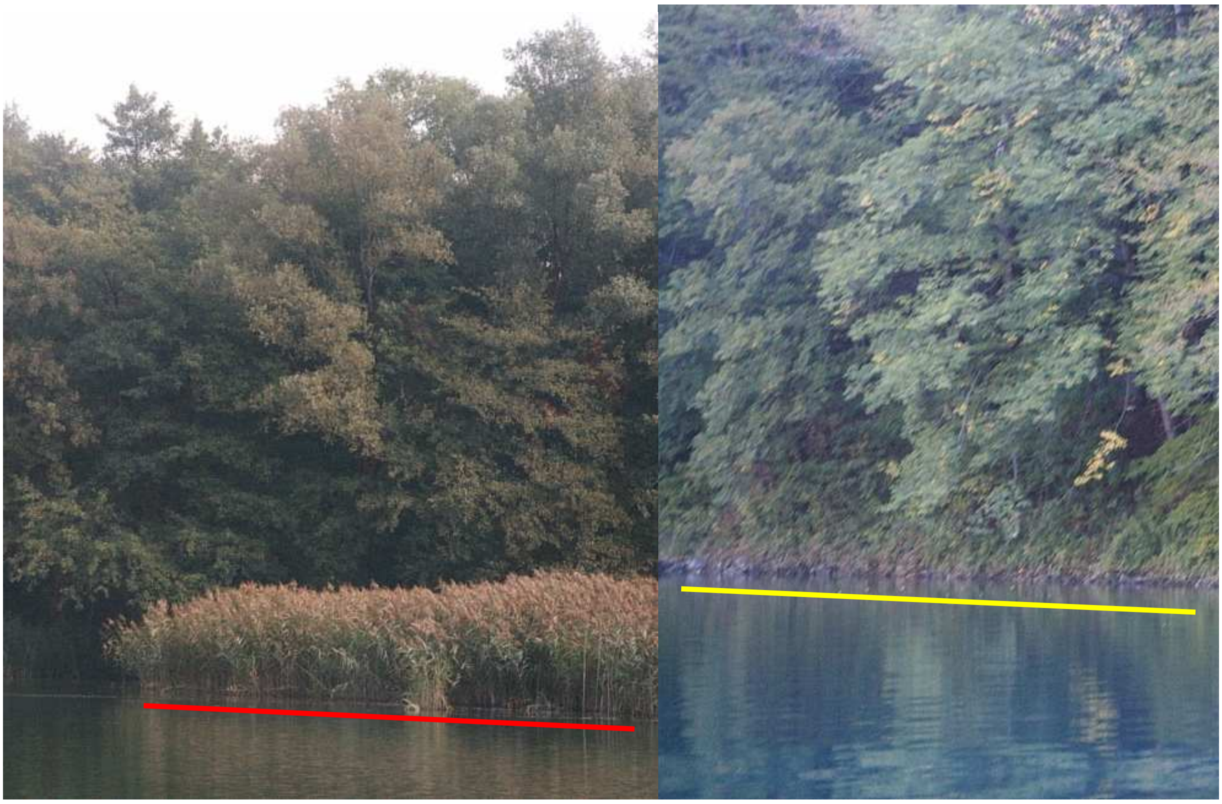


Fig. 5 - Internal border of the lakeshores zone in the absence (yellow line) or in the presence (red line) of wet reeds.

Helophyte are semi-aquatic plants with the base and perennial buds submerged and with stem and leaves in the air; they are usually present on the lake and river banks, swamps and marshes where reeds are. Common examples are Typha (*Typha latifolia, Typha longifolia*), the Carex *(Carex riparia, Carex flacca*) and the marsh reed (*Phragmites australis*), the marsh reed (*Schoenoplectus lacustris*) the marsh Rumex (*Rumex hydrolapathum*), the water lily (*Iris pseudacorus*) and rice (*Oryza sativa*).

Hydrophytes are perennial aquatic plants whose buds are either submerged or floating; they are divided into rooted, with a root system attached to the bottom (e.g. *Potamogeton* spp, *Nymphaea alba, Callitriche spp., Ranunculus spp.*, etc) and floating that do not have anchoring roots and float on the water surface (e.g. *Lemna spp., Utricularia spp.*, etc.).

The width of the lake shore zone (trees, shrubs, wet or dry reed, etc.) is estimated in meters as a projection, on the horizontal plane, of the vegetation canopy. In the case of cliffs on the lake, it is considered lake shore zone only that portion next to the lake, excluding the rocky walls. If the lake shore zone is herbaceous, its width is evaluated only if it is represented by spontaneous formations, while mowed meadows or urban parks are excluded. In the presence of artificial beaches with mowed gardens, the width of the lake shore zone will be noticeably decreased. It could happen that the lakeshore zone has large trees, even scarce, under which there is a non-hygrophilous herbaceous growth; in this case, only the arboreal vegetation is considered while the herbaceous cover is not considered in the evaluation of the width.

How to answer:

Based on the width of the zone the following values are assigned:

0) the width of the functional formations is below a meter or inexistent or with only bare soil (little pebbles or sand). The answer is 0 (zero) also in the presence of infrastructures, impermeable walls or soil impermeabilization that reach the shore in the absence of reeds;
1) the width of the functional formations is between 1-5m;
2) the width of the functional formations is between 5-10m;
3) the with of the functional formation is between 10-30m;
4) the width of the functional formations is between 30-50m;
5) the width of the functional formations is more than 50m.

For survey purposes, the presence of impermeable walls, which is thus able to obviously affect the transverse continuum, is a limiting factor for the width of the lake shore zone vegetation (Fig. 6).

Whenever there is a band of well consolidated hygrophilous vegetation behind the permeable wall along the coast line (e.g. strip of willows and alder), the wall is considered only as an interruption (see page 6.4) and the vegetation is evaluated on its cover and composition.

Consequently, in the case of permeable walls or of other artificial structures that guarantee the permeability and the transversal continuity with the surrounding territory, the vegetation present landward from the wall is considered as lakeshore zone vegetation.

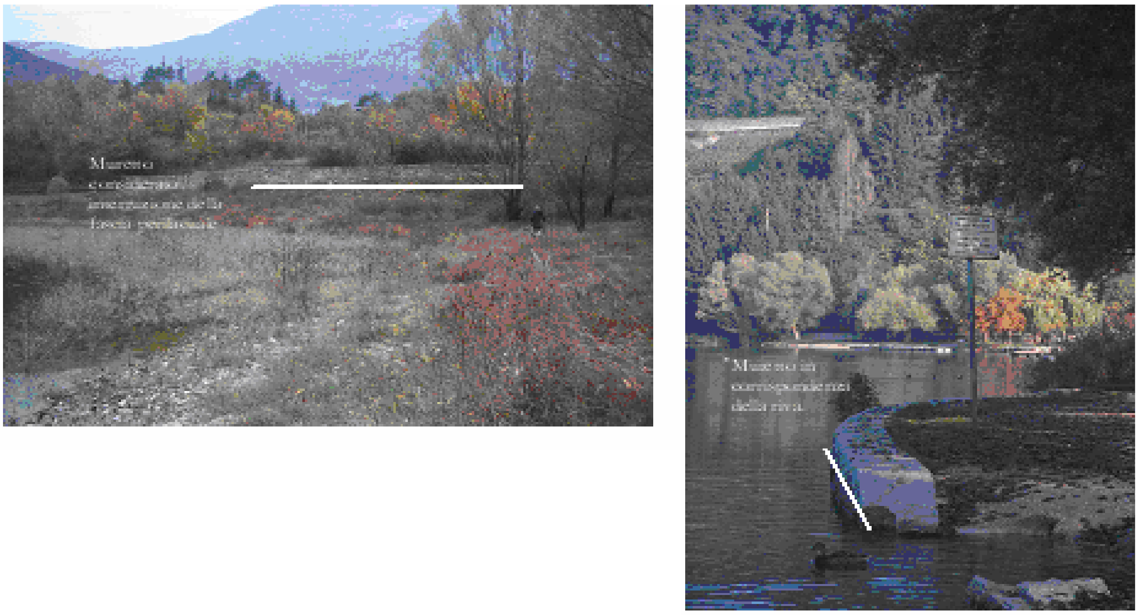


Fig. 6: two examples of walls that represent an interruption of the lake shore zone. In the first case (above) the wall is not directly adjacent with the lake shore, while in the second case (right), the wall is right on the shore profile.

6.2 Characterization of the lake shorezone vegetation

Objectives of the question

The following 3 parameters (composition/cover of the vegetation, percentage presence of hygrophilous and non-hygrophylous vegetation, presence of exotic species) are meant to describe the structure and composition of the lake shorezone.

Principles

The functionality of the lake shorezone depends on both its width and its composition/structure. Presence of grasses or bare soil will decrease the buffer functionality of the shorezone, while reeds and shrubs have higher filtering capabilities. Similarly, hygrophilous species indicate the presence of a riparian zone, which improved the buffering capability of the shorezone, while presence of exotic species is penalized.

6.2.1 Composition/cover

What to look

The composition of the vegetation of the lake shorezone is expressed in terms of cover with respect to the surface occupied by the zone itself (percentage value, then transformed into number from 0 to 1) of the vegetation categories showed in the table:

2.1 cover/composition % (expressed from 0-1)	
trees %	
shrubs%	
reeds%	
grasses%	
bare soil%	

How to answer

In a homogenous stretch there could be meadows or beaches, reeds areas and/or tree areas: in this case each category will be analyzed and given a percentage. For example, if there is a zone composed of 75% “reeds” and 25% “arboreal species”, the values assigned will be 0.75 for the first and 0.25 for the second. The sum of the value given to the single categories will sum to 1, with the exception of the shore artificialization that will result with a total of 0 (as later described). Categories that are not present for at least 5% (value of 0,05) of the lake shore zone, will be given a value of 0 (zero).

The attribution of the percentages must start from the estimate of the portion of trees and shrubs, followed by the other categories beyond the projection of their canopy. Grass beneath the vertical projection of the tree canopy will not be considered. Therefore, in the case of large trees above a bed of grass, the “arboreal” and “shrubs” cover percentages will first be evaluated, and the remaining percentage value will the attribuites to “grass” and/or “bare soil”).

In alpine and pre-alping lakes, if the lake shorezone is a natural environment that continues in the surrounding woodlands and forests, only the first 50 meters inland from the lake shores must be considered. If the identified lakeshore zone has an extension less than 50m, when limited by anthropic uses *(i.e a road),* the composition/cover percentage must be calculated only until the anthropic interruption.

In lowland, endoheic lakes, where the surrounding territory is mainly flat, the areas to be considered will correspond with the identified shore zone that has an ecotone function.

Whenever the lake shorezone is simply composed of a garden, the stretch will be given only a percentage in the category of “grass” (grass=1); in the case of a sandy or gravelly beach, the stretch will have a value of “bare soil” equal to 1. Artificial, fertilized gardens, like the ones found in cured touristic beaches or English gardens, will fall into the “bare soil” categories.

In the absence of vegetation in the lake shore zone, the answer of 1 will be given to the “bare soil” category, and 0 to all the others; in the case of infrastructure (e.g. wall, impermeable walls and embankments) or soil impermeabilization (e.g. harbour, parking area) on all the shore stretch, the value of 0 (zero) is given to all the categories.

Impermeable soils within the lake shore zone, such as cemented tennis courts, pools, housing or other, are considered in the “bare soil” category.

All the helophytes, such as *Carex* species, *Sparganium* species and *Phragmites* species, fall in the “reeds” category.

The hydrophytes with roots, submerged or with floating leaves and flowers possible present in the portion of the lake adjacent to the shore, as for example lilies (*Nymphaea alba*), yellow pond lilly (*Nuphar lutea*) and water chestnut (*Trapa natans*), are not considered into the lake shore zone and will therefore not be taken into account when filling the SFI form.

PLEASE NOTE: The “grass” category is important for the classification tree as it defines the route after the second node (see figure 4). In fact, for a “grass” value equal or less than 0.15 (15%), the route in the tree will go to the left, while values above 0.2 (20%) will lead to the right of the classification tree, with obvious differences in the resulting final evaluation (see Classification Tree, Figure 3).

For these reasons, in the case of a shore zone with a grass coverage borderline between 15-20%, the technician needs to evaluate carefully which percentage to attribute, as this component will result in route changes in the classification tree and thus in the final evaluation of functionality. The best approach is to identify the 20% limit (or 1/5 of the stretches surface free from the protection of tree-cover) and to decide whether the “grass” portion is superior or inferior to this limit and thus indicate it with a value of $\geq$0.20 (20%) if superior, and $\leq$0.15 (15%) if inferior.

6.2.2 Hygrophilous and non-hygrophilous vegetation

What to look

The presence of hygrophilous versus non-hygrophilous vegetation is estimated in this question and estimated in a percentage value (transformed in number from 0 to 1 as for question 6.2.1, the sum must be equal to 1).

2.2 Hygrophilous and non-hygrophilous vegetation (expressed from 0-1)	
hygrophilous (helophytes, riparian shrub and riparian arboreal species)	
non-hygrophilous (other species)	

How to answer

The category "hygrophilous vegetation" includes the helophytes, the shrub and arboreal species that are strictly riparian. An incomplete list of these is given in Table 7.

Whenever the whole stretch consist of "bare soil", a value of 1 will be given in the "not hygrophilous" category. The same value is given in the presence of impermeabilization of the soil (blockage of water flows) throughout the entire stretch and in the case of impermeable walls which do not have any hygrophilous species behind it; in the case of a permeable wall or in presence of hygrophilous species, an intermediate value will be given as the wall only represent an interruption (see page with 6.1).

HYGROPHILOUS SPECIES	***family***	**Common name**
Alnus glutinosa **Gaertn.**	Betulaceae	Common alder
Carpinus betulus **L.**	Corylaceae	European or common hornbeam
Cornus sanguinea **L.**	Cornaceae	bloodtwig dogwood
Euonymus europaeus **L.**	Celastraceae	European spindletree
Frangula alnus **Mill.** (=*Rhamnus frangula* L.)	Rhamnaceae	glossy buckthorn
Fraxinus excelsior **L.**	Oleaceae	Ash; also European Ash or Common Ash

***Fraxinus oxycarpa* Bieb.**	Oleaceae	Raywood ash
***Populus alba* L.**	Salicaceae	White poplar
***Populus canescens* (Aiton) Sm. (=*P. albo-tremula* Auct.)**	Salicaceae	Gray poplar
***Populus nigra* L.**	Salicaceae	Black poplar
***Prunus padus* L.** (=*Cerasus padus* DC.=*Prunus racemosa* L.)	Rosaceae	European bird cherry
***Quercus robur* L.** (=*Quercus peduncolata* Ehrh.)	Fagaceae	English Oak, Truffle Oak, Pedunculate Oak
***Salix apennina* A. Skortsov** (=*Salix nigricans* Sm. var. *apennina* Borzi)	Salicaceae	Arctic willow
***Salix cinerea* L.**	Salicaceae	Grey Willow; also occasionally Grey Sallow
***Sambucus nigra* L.**	Caprifoliaceae	Elder or Elderberry
***Ulmus laevis* Pallas** (= *U. effusa* Willd.)	Ulmaceae	European White Elm, Fluttering Elm, Spreading Elm and, in the USA, Russian Elm
***Ulmus minor* Miller** (= *U. campestris* Auct. non L.; *U. carpinifolia* Suckow)	Ulmaceae	Field Elm
***Viburnum opulus* L.**	Caprifoliaceae	Guelder Rose, Water Elder, European Cranberrybush, Cramp Bark, Snowball Tree

Tab. 6 - List of some hygrophilous species that characterize riparian environments of lakes. Please note that this is an open list.

6.2.3 Presence of exotic species

What to look

In riparian environments there could also be exotic arboreal, shrub and herbaceous species. By "exotic" it is meant those species that are not-native, invasive or alien. The percentage of presence is recorded for this question.

2.3 Presence of exotic species (expressed from 0-1)	
Exotics %	

Table 8 is an open list of the most common exotic species found in alpine and pre-alpine environments. (Table 7).

	EXOTIC SPECIES	***family***	***Common name***
ARBOREAL	***Robinia pseudoacacia* L.**	Fabaceae	Black locust
	***Ailanthus altissima* (Miller) Swingle**	Simaroubaceae	Tree of Heaven
	***Prunus serotina* Ehrh.**	Rosaceae	Black cherry
SHRUBS	***Buddleja davidii* Franchet**	Scrophulariaceae	Orange eye butterflybush
	***Amorpha fruticosa* L**	Fabaceae	Desert false indigo
	***Acer negundo* L.**	Aceraceae	Boxelder, Maple, Maple Ash
	***Reynoutria japonica* Houtt.**	Polygonaceae	
	***Phytolacca americana* L.**	Phytolaccaceae	American Pokeweed
	***Sycios angulata* L.**	Cucurbitaceae	Single seeded cucumber
	***Humulus scadens* (Lour.) Merril**	Moraceae	Japanese hop
	***Solidago gigantea* Aiton**	Compositae	Late goldenrod, great goldenrod
	***Amaranthus retroflexus* L.**	Amaranthaceae	Redroot amaranth, redroot pigweed, red rooted pigweed, common amaranth, common tumble weed
	***Ambrosia artemisiifolia* L.**	Compositae	Annual ragweed

	***Artemisia verlotorum* Lamotte**	Compositae	Chinese mugwort
	***Bidens frondosa* L.**	Compositae	Devils beggartick
	***Helianthus tuberosus* L.**	Compositae	Jerusalem artichoke, sunroot, sunchoke, earth apple, topinambur
	***Arundo donax* L.**	Graminaceae	Giant cane
	***Impatiens glandulifera* Royle**	Balsaminaceae	Policemans helmet

Table. 8 – List of some exotic species used in SFI. Please note that this is an open list.

How to answer

For the SFI purpose, the presence of exotic species is evaluated with a percentage value (later expressed in a value from zero to one). The attribution is done on the same shore zone stretch identified when answering the composition/cover question.

In the presence of an impermeable wall along the shoreline, a value of 1 is given for exotic specie.

6.2.4 Heterogenous arboreal and shrub vegetation.

Objectives of the question

This question evaluates the percentage presence and the diversification of the autochthonous hygrophilous arboreal-shrub vegetations. Higher values are given in cases of higher vegetatation cover and higher diversification, while presence of exotic species and monospecific crops, and low autochthonous cover are penalized.

Principles:

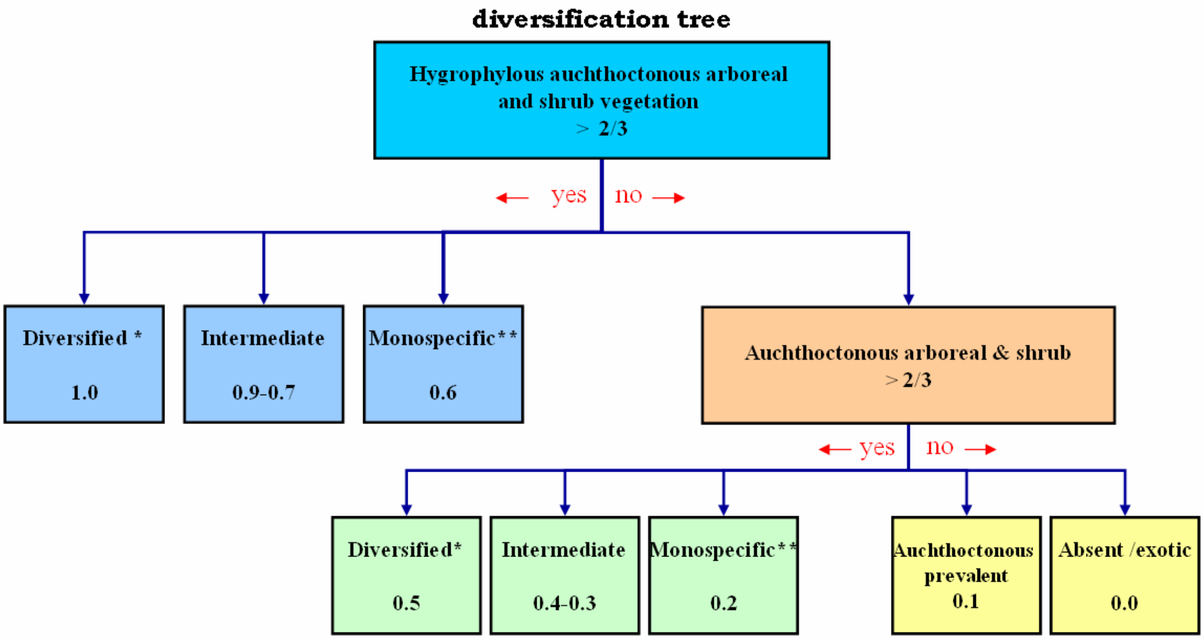
The heterogeneity is a eco-systematic element that determines the general functionality. A monospecific vegetation cover, even if formed by hygrophilous species, does not guarantee that biodiversity needed for a functional transitional corridor, while a diversified cover produce an environment able to carry out the ecological functions of an ecotone unifying two different ecosystems.

What to look

The evaluation starts by looking at **all** the trees and shrubs present in the shore zone. From here, follow the diversification tree (Fig. 7) to decide which path to follow along the tree.

If more than 2/3 of all the present trees and shrubs are represented by hygrophilous autochthonous arboreal and shrub vegetation (including the reeds), the path will move to the left, and the level of diversification will be estimated.

If the presence of hygrophilous autochthonous vegetation is less than 2/3 in the evaluated shore zone stretch, then the next question will evaluate the percentage of coverage by the autochthonous arboreal shrub vegetation, considering both the hygrophilous and the not-hygrophilous species (right branch after the first node of tree in Fig. 7). If this coverage is greater than 2/3 of the total arboreal and shrub cover, then the next question will evaluate the level of diversification (on the left after the second node). If the coverage is less than 2/3, then the next question will evaluate the prevalence of autochthonous versus exotic species (on the right after the second node).



(*) "diversified cover" consists of at least three different types of trees and/or shrubs
(**) mono-specific cover" is assigned when one specie is clearly predominant over the others, with a presence of at least more than 90%.

Fig. 7 - Scheme for attribution of values relative to heterogeneous arboreal and shrub vegetation present.

How to answer

Just by following the tree path described in Fig.7, a result from 0 to 1 will be automatically given for arboreal and shrub vegetation. In the cases of the leaves of "intermediate" values, the final score (ranging from 0.9 to 07 and from 0.4 to 0.3), will be evaluated by the operator considering the case study.

The following table reviews the results:

2.4 heterogeneousness of arboreal-shrub vegetation *(when the covering by autochthonous hygrophilous arboreal-shrub vegetation is >2/3)*	
diversified	1
intermediate	0.9-0.7
monospecific	0.6
autochthonous hygrophilous arboreal-shrub species >2/3 *(Cover by autochthonous hygrophilous arboreal-shrub vegetation < 2/3, with autochthonous > 2/3)*	
diversified	0.5
intermediate	0.4-0.3
monospecific	0.2
autochthonous hygrophilous arboreal-shrub species < 2/3 and autochthonous arboreal-shrub < 2/3 *(Cover by hygrophilous autochthonous arboreal-shrub vegetation < 2/3, with autochthonous < 2/3)*	
autochthonous relevance	0.1
exotic prevalence	0
arboreal-shrub vegetation absent	0

When estimating the diversification in the arboreal-shrub vegetation community, it is useful to take in consideration that:

- A "diversified cover" consists of at least three different types of trees and/or shrubs whose distribution is homogenous throughout the stretch (that is, their presence is distributed in an significantly equal way);
- "Mono-specific cover" is assigned not only when a single vegetation type is present but also when one specie is clearly predominant over the others, with a presence of at least more than 90%.

6.3 Continuity of lake shore vegetation

Objectives of the questions

The objective is to evaluate the continuity of the functional vegetation present in the lake shore zone, individuating eventual longitudinal interruptions. With this parameter it is evaluated whenever the lake shore vegetation (arboreal and shrub, wet and dry reeds) is continuous or if it is interrupted by different man-made structures built for various reasons (i.e.. to tie a boat), beaches, areas of access to the lake, areas where the reeds is cut, etc.

Principles

The efficiency of the shore zone vegetation is also related to its cover continuity. The interruptions in the ecological continuum, either natural or artificial, can compromise, at different levels, various ecological functions. The continuity os the lake shore vegetation guarantees connectivity in both aquatic and terrestrial environments and produces an efficient buffer zone that could be compromised by vegetation gaps.

What to look

The continuity of the arboreal and shrub formations refers to the vertical projection on the horizontal plane of the canopy and is interpreted longitudinally (Fig 8).

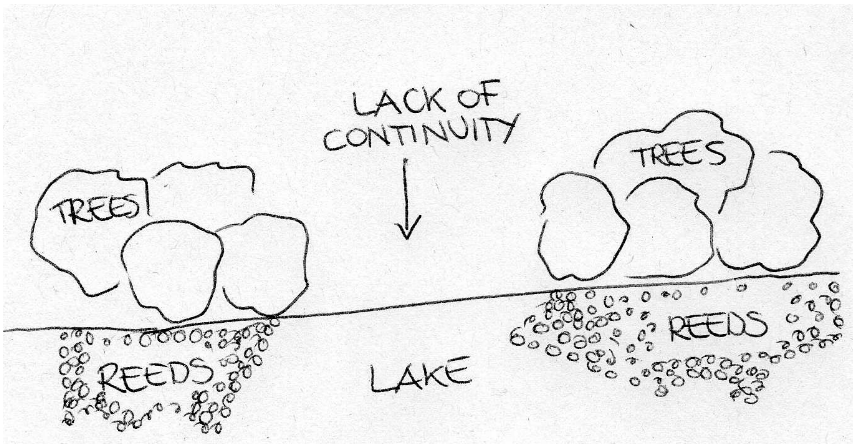


Figure 8. Example of discontinuity in the shorezone.

A numerical score indicating the continuity of the stretch vegetation (0: absent; 0.5: discontinuous; 1: continuous) is given for each of the three categories identified (arboreal and shrub vegetation, dry reeds, wet reeds) as shown in the following table. In the case of figure 8, a value of 0.5 (discontinuous) will be given for both the arboreal and shrub zone and the wet reed zone, while, being absent, the dry reed zone will receive a value of 0.

3. Continuity of the lake-shore vegetation	
arboreal and shrub zone	
absent	0
discontinuous	0.5
continuous	1
wet reed zone	
absent	0
discontinuous	0.5
continuous	1
dry reed area	
absent	0
discontinuous	0.5
continuous	1

How to answer

To answer correctly this parameter, the technician needs a good capacity to understand the studied area; for example, small interruptions along a long stretch should not be taken into consideration if their overall loss of superficial or hyporheic connectivity is almost insignificant. Generally, a value of 0.5 is given whenever the interruptions are more than the 10% of total length of the stretch; if there are many more interruptions and the area covered by the vegetation is lower than 10% of the length of the stretch, the continuity is considered absent and the score will be 0 (zero).

A stream or river entering into the lake is not considered an interruption: the right and the left bank of the stream will be unified to consider the homogeneous shore zone stretch as continuous.

6.4 Presence of interruption within the lakeshore zone

Objectives of the question

This question evaluates the presence of interruptions within the whole area of the lake shore zone identified.

Principles

An interruption is any intervention or work that in any way can reduce, affect, or limit the functionality of the vegetation in the lake shore zone.

What to look

The interruption can happen in a linear form parallel to the coast (e.g. trails, roads, railroad tracks, etc.) or exist in more or less regular spaces within the area (i.e. house gardens, vegetable plots, cultivated fields, managed meadows, parking areas or other infrastructures). Whenever the riparian vegetation and the identified lake shore zone is thinner that 50 meters, the interruptions to be considered are only those that occur within this area while the other interruptions belong to the surrounding land, as already described in 6.1).

4. Presence of interruption on the lake-shore zone	
absent	0
intermediate	
present along the whole stretch	1

How to answer

Interruptions will be:

0) Absent: when nothing reduce, affects of limit the functionality of the lake shore zone

0.1-0.9) Intermediate: if the interruption affects only a portion more or less extended of the stretch, an intermediate score is assigned (see following examples).

1) Present along the whole stretch: the following are considered as a single and constant interruption: lack of any arboreal-shrub vegetation, an area composed of only grass or bare soil, in the presence of an impermeable wall with a well-consolidate hygrophilous vegetation area nearby

If there are only reeds, it is necessary to evaluate their interruption due to the widening of the beaches or the presence of artificial structures (wharfs, platforms for swimmers, etc.)

The unpaved streets and trails are not considered as interruptions of the lake shore zone if they do not compromise the continuity of the trees canopy. The unpaved streets or trails that act as simple passageway with limited amount of traffic and with an insignificant impact on the landscape and structure of the lake shore zone, are not considered neither interruptions nor tourist infrastructure (see section 6.7). The unpaved trail is not considered as an interruption even in the case of modest consolidation interventions (for example following the criteria of naturalistic engineering) that does not compromise the natural development of the lake shore zone vegetation.

The unpaved roads are considered as interruptions only when they have modest to elevated anthropic interventions (severe cutting back of vegetation, ridges terracing, substantial modification of the shores natural morphology, presence of supporting walls, etc.)

6.5 Typology of anthropic uses within the lake shore zone

Objectives

The following question describes the type of interruption present in the identified width of the lake shore zone,

5. typology of anthropic use within the lakes-shore zone	
uncultivated meadows or unpaved streets, etc.	0
sparse urbanized, cultivated meadows, etc	0.5
urbanized area	1

Principles

The lake shore zone functionality is affected differently depending on the degrees of human activity, which ranges from high in urbanized areas to low in cases of unpaved streets or uncultivated meadows.

What to look

The whole area of the identified stretch (length = the limits of the shore zone stretch; width = up to 50 meters inland, restricted in the presence of interruptions).

How to answer

If there is more than one type of interruption (linear running parallel to the coast or more or less regular spaces within the lake shore zone areas), the value to be assigned is the one that corresponds to the **most prevalent typology**. This is done by evaluating its impact on the functionality of the lake shore zone, its extension and distance from the coastline. For example, a very large managed meadow is less impacting than a production industry that occupies a smaller area. In this case we should assign a value of 1.

Value will be:

0) The value of 0 in the presence of uncultivated land, trails or unpaved roads, vegetable plots or family garden, managed meadows, hedges, playground, filtrating parking;

0.5) The value of 0.5 is given in the presence of sparse urbanization, cultivated meadow, non-intensive cultivations, asphalt road, impermeable parking, impermeable wall that anyway allows the hygrophilous vegetation to develop (see sections 6.1 and 6.4); municipal roads that have a significant amount of minor traffic are considered as paved road and receive a value of 0.5.

1) The value of 1 in the presence of an urban area, productive centers, seasonal and perennial intensive cultivations, extraction of inert substances, primary infrastructure, impermeable wall without the presence of hygrophilous vegetation behind it. Provincial and state roads, railroad tracks and big parking area are also considered primary infrastructure and are therefore given a value of 1. Shore zone with impermeable walls on the shoreline will also fall into this category.

6.6 Prevalent use of surrounding area

Objectives

The question wants to evaluate indirectly the repercussions on the shore zone functionality given by modification of the surrounding soil that can increase the inputs of nutrients, organic matter, pollutants. The area that regards this question is not anymore the shore zone (0-50 meters) but goes inland up to 200 meters from the shoreline (therefore not considering the reeds).

Principles

The soil permeability and its vegetation cover favor the infiltration of rain water, bringing numerous advantages to the lake water quality. This function is compromised with different soil uses (such as agriculture, wood crops, urbanization) which reduce the soil permeability and canalize the water into artificial collectors.

What to look

Since we are now considering that area that extends from the shore up to 200 meters inland, orthogonal and satellite imageries are very useful to answer this question, especially since from the shore the presence of trees or other high structures may hide structures behind. The area chosen for each homogeneous stretch is therefore stretched from the max. original 50 meters to 200 meters, and the prevalent typology will be chosen for that stretch.

How to answer

A value from 0 to 3 is attributed depending on the amount of human presence in the extends up to 200 m from the shore. It is possible that an area will have a different percentage of presence of two or more categories: in this case, the value attributed will be the one of the **prevalent** category. The following table shows the categories and the respective value attributed.

6. Main use of nearby territory	
woods and forest, meadows (for steppe lakes)	0
meadows, uncultivated land, uncultivated meadow for pasture	1
seasonal and/or permanent cultivation and sparse urbanization	2
urbanized area	3

0) The first category includes broad leaf woods and/or conifers, Mediterranean scrub, or trees placed outside the altitudinal limit for woody species.

1) The second category refers to situations in which man-made works, despite being modifiers of the morphological stretches, permit a balanced co-presence of human activities and natural environments. In this case, animal farming is restricted and the arable cultivations have a marginal and secondary role when compared to the remainder of the natural habitat. Also fall in this category the recently cut copse, gravelly area, human-made prairies/pastures (those below the altitudinal limit of trees), uncultivated areas in which advanced natural re-colonization is occurring (those not only composed by synanthropic or pioneer species).

2) The third category refers to intensive cultivations that have profoundly altered the area by reducing the diversity and making it monotonous. Agriculture is industrialized and there is an elevated use of fertilizer and pesticides. Typical seasonal cultivations are: rice, corn, wheat, beets, vegetables, flowers, small fruits, etc. Typical permanent cultivations, those that require agricultural practices during the entire vegetational phase and beyond, are: orchards, vineyards, poplars are included. Tourist campsites, boathouses and coverings for paddle boats are also included in this category.

3) In the fourth category there are areas that are urbanized or anyway completely artificial. An urbanized area consists of a group of housing (but more of 10 normal sized buildings), productive structures, infrastructure or services.

6.7 Infrastructure

Objectives of the question

To evaluate the presence (quantity and the typology) of infrastructures.

Principles

Infrastructures are artificial elements that affect the shoreline naturality and functionality, decreasing the capacities of natural ecological processes.

What to look

This parameter takes note of the presence of infrastructures such as provincial/state roads, railroad tracks, and parking lots within the first 200m inland from the shore. For each of these infrastructures, a value between 0 (absence) and 1 is given depending on their absence (0) or presence. A value of 1 is given if the infrastructure is present constantly along the entire homogenous stretch, while intermediate values are given when it does not affect the entire stretch.

7. Infrastructure	
Provincial/state roads	
absent	0
intermediate	
present along the whole stretch	1
Railroads	
absent	0
intermediate	
present along the whole stretch	1
Parking	
absent	0
intermediate	
present along the whole stretch	1
Tourism related infrastructure	
absent	0
intermediate	
present along the whole stretch	1

For this parameter, municipal roads with a low amount of traffic (which in section 6.5 were considered as an interruption of the lake shore zone) are not considered as infrastructure.

The following paragraphs describe different kind of tourism-related insfrastructures.

All the tourism-related infrastructures that are present within the 200m from the shore needs to be considered. They include all those infrastructure that aim the access to the lake and passage and/or stopping along the shores, such as: gangways along the lake, facilities, bicycling lanes, campsites, beaches for swimming, piers, etc. Even for this category, the value of 0 indicates absence and 1 presence along the entire stretch; intermediate values are given when the tourism-related infrastructure interfere with only part of the homogeneous stretch (for example, there are some little wharfs/piers within the homogeneous stretch).

Unpaved trails are not considered as tourism-related infrastructures if they function simply as transit ways (not normally utilized by tourists) but mainly by and do not particularly impact the natural state of the shores.

Unpaved streets and trails are considered as tourism-related infrastructure if they were specifically built with that aim. The suspended gangways along the lake are considered tourism-related infrastructure but not as interruptions (see section 6.4) as they are permeable and have a small effect on ecological function of the zone, unless they are accompanied by consolidation intervention or support on the shores (little walls, terracing…).

Table 9 is an aid for the operator to give values: it schematically represents some different types of anthropic interventions and how the SFI consider them as interruption of the lake shore zone or infrastructure within 200m of the shores.

ELEMENTS PRESENT WITHIN THE REFERENCE ZONE	INTERRUPTION (section 6.4)	TYPOLOGY of ANTHROPIC USE IN THE LAKE SHORE ZONE (pgf. 6.6)	TOURISM-RELATED INFRASTRUCTURE (pgf. 6.9)	ROAD INFRASTRUCTURE (pgf. 6.8)
a) *unpaved trail that does not compromise the transversal continuity, that does not have considerable impacts and is not used as a tourism infrastructure*	*0*	*0*	*0*	*0*
b) *unpaved trail or other man-made object in the lake shore zone that compromises the transversal continuity due to the presence of support walls, non relevant as a tourism infrastructure.*	*X*	*0*	*0*	*0*
c) *unpaved trail in the lakeshore zone that compromises the transversal continuity with the presence of support walls, relevant as tourism infrastructure.*	*X*	*0*	*X*	*0*
d) *unpaved trail that does not compromise the transversal continuity but is relevant as tourism infrastructure.*	*0*	*0*	*X*	*0*
e) *paved municipal road in the lakeshore zone.*	*X*	*0.5*	*0*	*0*
f) *municipal road between 50m to 200m from the shore.*	*0*	*0*	*0*	*0*
g) *provincial or state road between 50m to 200m from the shore.*	*0*	*0*	*0*	*X*
h) *provincial-state road in the lake shore zone.*	*X*	*1*	*0*	*X*

ELEMENTS PRESENT WITHIN THE REFERENCE ZONE	INTERRUPTION (section 6.4)	TYPOLOGY of ANTHROPIC USE IN THE LAKE SHORE ZONE (pgf. 6.6)	TOURISM-RELATED INFRASTRUCTURE (pgf. 6.9)	ROAD INFRASTRUCTURE (pgf. 6.8)
i) *urban park within the lake shore zone.*	*X*	*0*	*X*	*0*
j) *urban park between 50m to 200m from the shore.*	*0*	*0*	*X*	*0*
k) *tourism-related campground within the lake shore zone.*	*X*	*0.5*	*X*	*0*
l) *tourism-related campground between 50m to 200m from the shore..*	*0*	*0*	*X*	*0*
m) *along-the-lake gangway, including suspended ones, permeable*	*0*	*0*	*X*	*0*
n) *floating structure for tying boats, detached from shore that does not interfere with the lake shore zone.*	*0*	*0.5*	*1*	*0*

Tab. 9 - Scheme that aid the evaluation of the impact of viability elements on the continuity of the lake shore zone. “X” is a vale between 0.1 and 1 and can be assigned in response to the percentage of the stretch affected by such infrastructure.

6.8 Emerged lakeshore zone

Objectives of the questions

The following 2 parameters (average slope and slope comparison), describe how gently or abruptly the terrestrial environment meets the aquatic one.

Principles

The way in which the land enters into the lake affects whenever the terrestrial inputs will be superficial or hyporheic (see figure 8).

What to look

To answer these questions, it is necessary to look at the first 50 meters upland from the shore, regardless of the presence of any interruption that may have limited the area used to answer the previous shore zone questions, down to the slope of the first submerged meters (the most external area of the littoral zone). Even in the case of greater slopes closer to the shore, possibly due to consolidation interventions on the shores, the average slope value is always used.

6.8.1 Average slope

How to answer

By “average slope” it is meant the average slope of the 50 emerged meters of the homogeneous stretch.

8.1 average slope	
flat	0
slightly noticeable slope	1
obvious but can be overcome without problems	2
significant but can be overcome with trails or ramps	3
strong slope, roads or trials with bends	4
extreme, vehicles cannot drive	5

To correctly answer this question it is useful to consult a map of the area with contour lines.

A discrete value is assigned from 0 to 5 based on the grade of the zone’s slope:

0) if the zone is flat;

1) if the zone has a barely noticeable slope

2) if there is an obvious slope but can be passed over without any problems (the trails or roads that run perpendicularly to the shore)

3) if there is significant slope that can be passed over with trails or ramps

4) if there is a strong slope (the roads or trails proceed with hairpin bends)

5) if there is extreme slope that cannot be passed by vehicles and with great difficulty by foot at the maximum; in this section fall also rocky formations that fall shear to the lake surface.

6.8.2 Slope comparison between emergent/submerged lakeshore zone

How to answer

This parameter evaluates what is the correspondence between the slope of the area that is above water (first 50m) and the slope of the first submerged meters (the most external area of the littoral zone) (Figure 9). The number 0 is assigned if the slopes differ and the number 1 if they are consistent. It is useful to consult a map with the altimetry of the area surrounding the lake and lake bathymetry to correctly answer this question.

8.2 comparison between slope of emerged and submerged area	
not consistent	0
consistent	1

Due to the enormous amount of possible cases, only in the case of great difference in slope the stretch will be considered discordant.

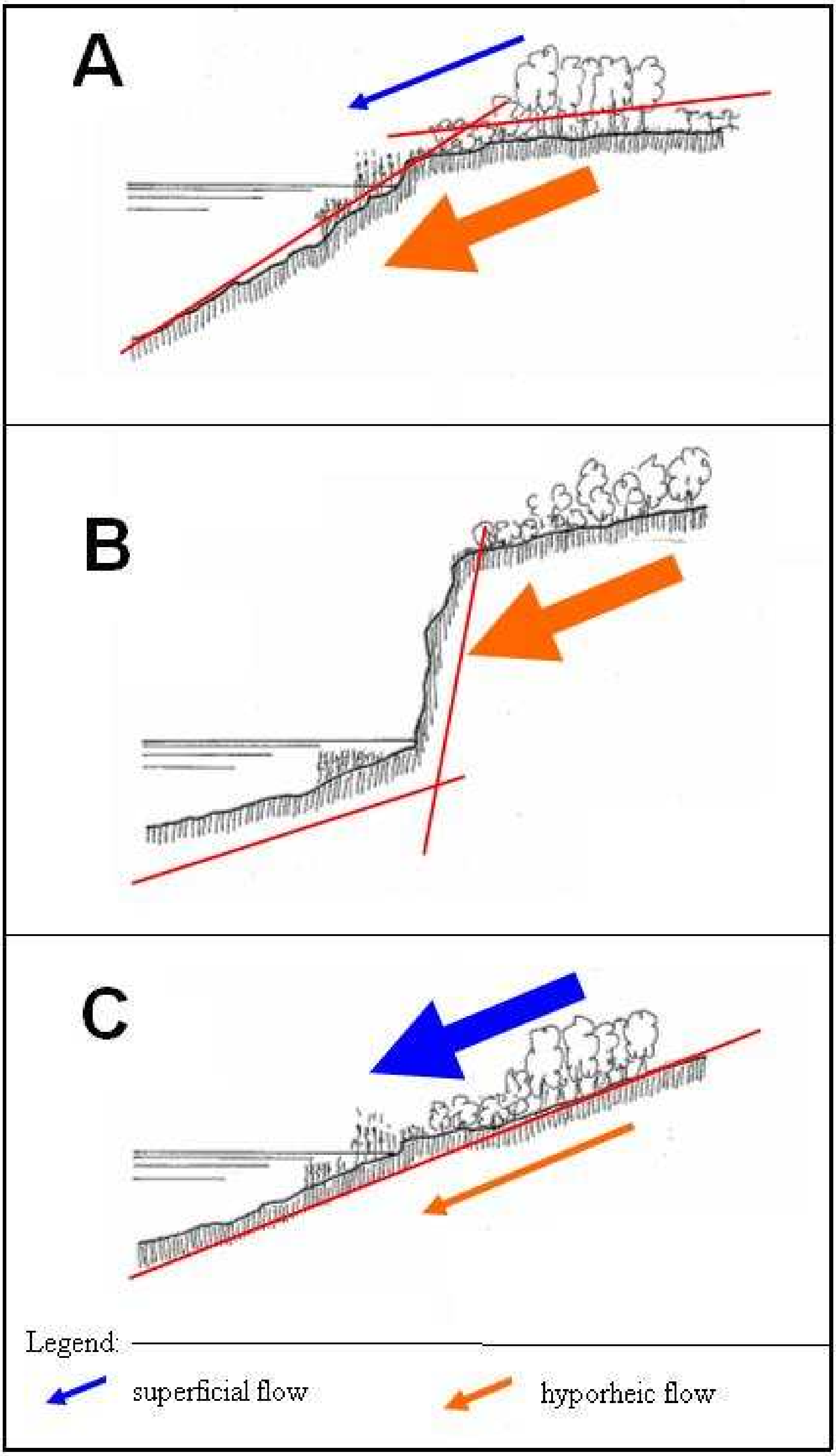


Figure 9 - Example with slope concordance (C) or not in accord (A,B) between the lake shore zone and the littoral zone.

6.9 Shore profile

The following 2 questions (concavity and convexity, complexity) regard the shore profile meant as the limits between the wet portion and shore.

6.9.1 Concavities and convexities

Objectives of the question

To evaluate the presence of concavities and convexities that may act as dispersion or a point of concentration of inputs entering into the lake. The presence or lack of concavity (or of basins and inlets) and of convexities (or promontories) of the shore profile is evaluated in each homogeneous stretch.

Principles

These parameters, together with “apparent channeling of run-off”, are surveyed to identify those cases where nutrient loads concentrate. A high concavity profile along the stretches favors the accumulation of nutrients and/or pollution when paired with a considerable slope of the surrounding land. Concavities in flat areas do not produce run-off concentration.

What to look

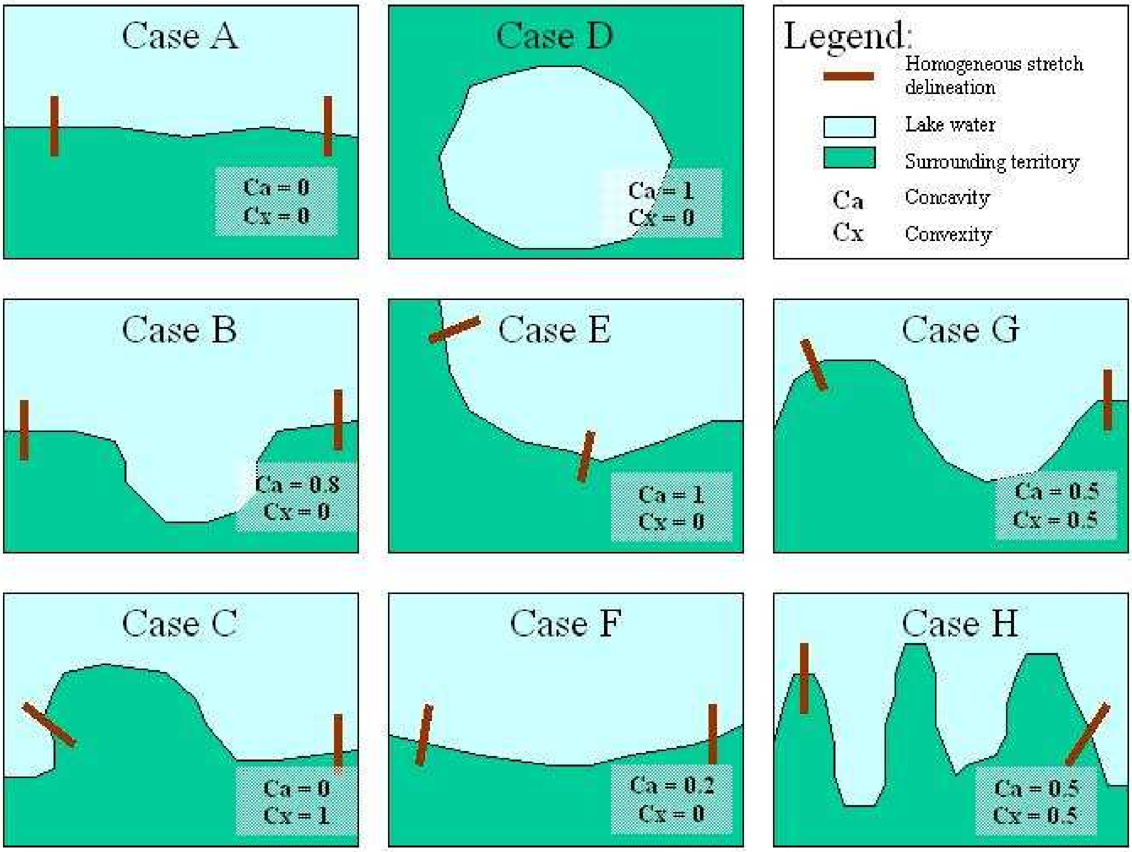
The answer is given for each homogeneous stretch identified, but it is still useful to look at maps of the area to better understand the general trend of the shore. The all area will be considered and the presence of concavities (coves), inlets will be acknowledged on the form.

How to answer

The value of 0 indicates the lack of concavity or convexity (a straight line), the value of 1 indicates a continuity in either concavity or convexity, while the intermediate values indicate that the concavity or convexity is present only along a part of the stretch or that the bending is very gentle.

9.1 concavity and convexity	
concavity	
absent	0
intermediate	
present along the whole stretch	1
convexity	
absent	0
intermediate	
present along the whole stretch	1

The following figure (figure 10) shows different cases of concavity and convexity:



- **case A**: An almost linear shore profile gets very low concavity and convexity (0 for both parameters if profile is completely straight);
- **case B:** A stretch with a single inlet leads to a concavity value of 1 and convexity 0;
- **case C:** A stretch with a single promontory leads to a concavity value of 0 and convexity 1;
- **case D:** A round shaped lake, especially if small, without significant concavities or convexities, has a concavity value of 1 (as if it were a single concavity where the flow ends converging).
- **case E:** A stretch with a single inlet leads to a concavity value of 1 and convexity 0;
- **case F:** An almost linear shore with a little concavity (0.2);
- **case G:** A stretch with different inlets and promontories has a concavity and convexity value of 0.5 each
- **Case H:** A stretch with different inlets and promontories has a concavity and convexity value of 0.5 each

6.9.2 Complexity

Objectives of the question

This question records the presence of undulation along the shore profile.

Principles

The more the shore profile is complex, the more is the possibility to have an higher biodiversity. The complexity in fact increases the presence of different biological niches that can be occupied by different species.

What to look

For each homogeneous stretch, the lakeward limit individuated of the shore zone is evaluated to answer this question. This includes hydrophylous species like reeds that are found up to 1 meter depth. Although, a wet reed is not considered for the complexity evaluation if separated from the land by an artificial impermeable infrastructure along the shore, such as cemented walls (Fig. 11).

Instead, the wet reed is considered as part of the complexity of the shore in the absence of artificiality of the shore (natural condition).

How to answer

The score of 0 indicates lack of complexity, while the score of 1 indicates that the entire profile has complexities; intermediate values are given if only part of the stretch shows elements of complexity. The evaluation of the complexity is based on the estimation of the relationship between the undulation of the shore line and the distance of the direct imaginary line of its extremes.

9.2 complexity	
absent	0
intermediate (from 0.1 to 0.9)	
present along the whole stretch	1

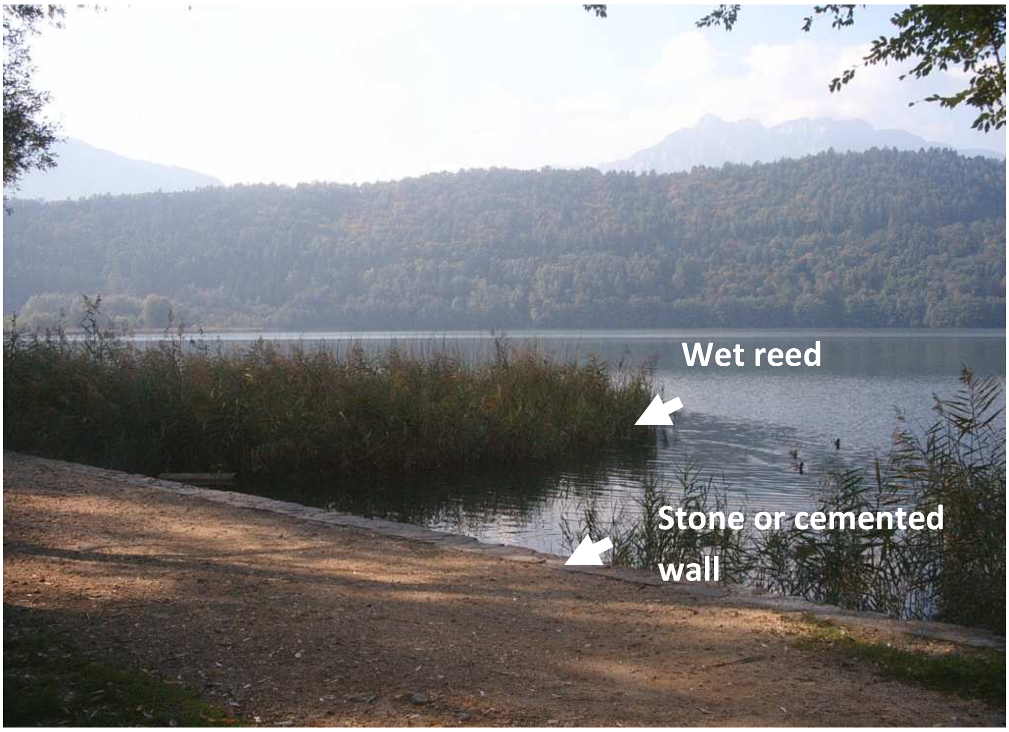


Fig. 11 - Artificial shore with no complexity due to the presence of the little wall that coincides with the shoreline.

It is not easy to visually estimate the complexity of the shore, and therefore figure 12 reproduces some examples that can be used during for comparison during field work. The shore profile closer to the real situation will give the complexity value (Cmx) to be used for the evaluation.

The Complexity Index (Ic) was estimated on different lakes using cartographic analysis, with the formula:

$$Ic = 1 - Rc$$

weere Rc is the relationship between the imaginary shortest line between two points of shore and the actual coastline curved existing between the two points (AB/shore length).

Values for high complexity do not generally pass Ic values of 0.5, with the exception of artificial lakes in very narrow valleys and with various little lateral small valleys could.

A very complex coast, with a score of 1 in the complexity parameter, consist of a coast line with a Ic value that is more than or equal to 0.33. This happens when the imaginary straight line between two points of coast is equal to or inferior to 2/3 of the real coast line.

Thefore, the Ic value corresponds to different complexity values:

- 1: with Ic>0.33
- 0: with Ic=0
- Intermediate values in the other cases.

The following cases (figure 11) are practical examples of Ic values (Ic = 1 – Rc) with relative complexity values:

- Case a) Ic = 1 - 0.67 = 0.33, complexity value=1
- Case b) Ic = 1 - 0.7 = 0.3, complexity value=0.8
- Case c) Ic = 1 – 0.8 = 0.2, complexity value=0.5
- Case d) Ic = 1 – 0.9 = 0.1, complexity value=0.2

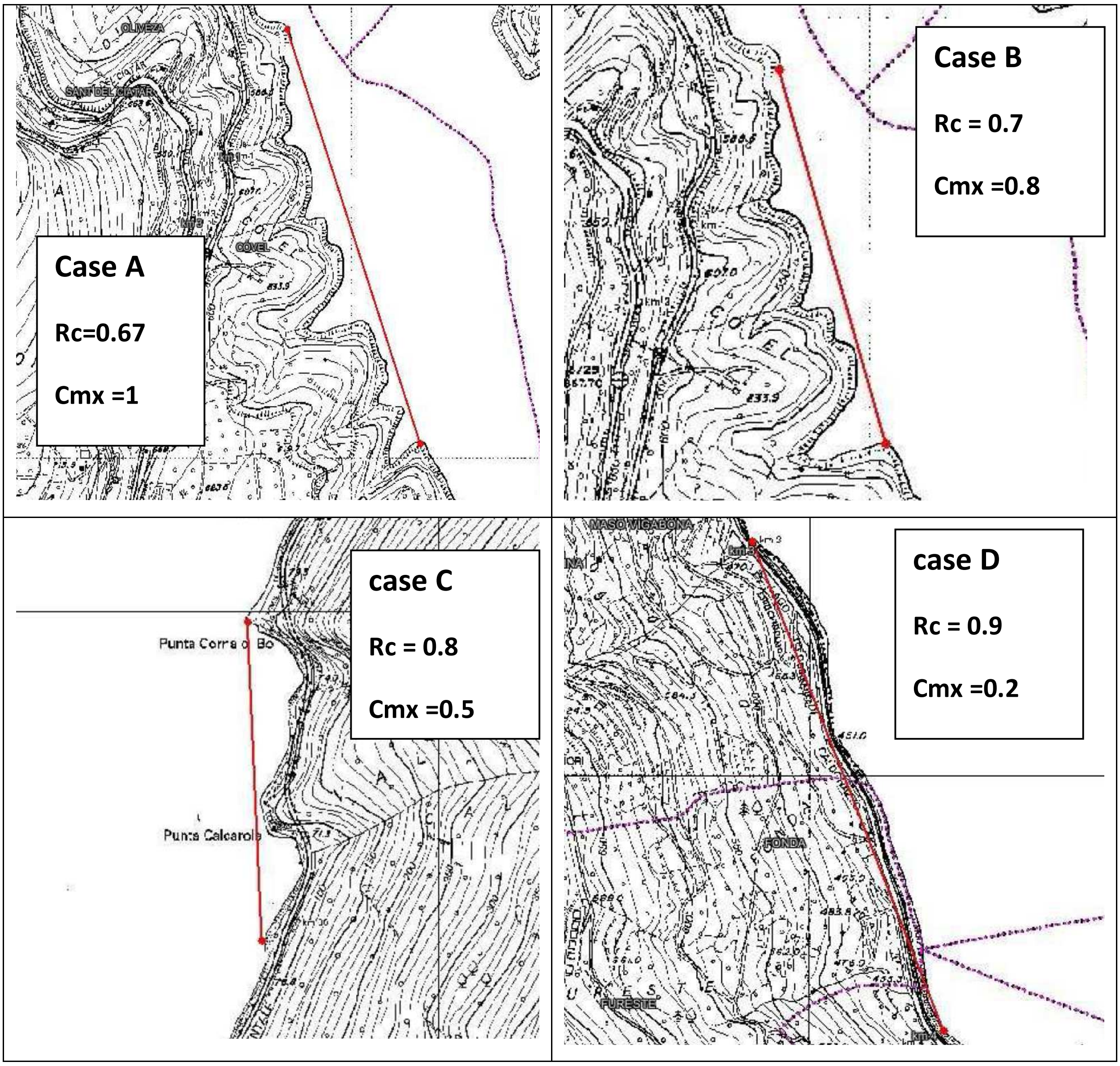


Figure 12 - Rc examples and four different coast lines with correspond complexity (Cmx) value.

6.10 Shore artificiality

Objectives of the question

This parameter evaluates the presence of artificiality along the shoreline (contact between water and land) including little stone walls, cement structures or other support structures.

Principles

The continuity and nutrients flowing into the lake from the surrounding territory is highly affected by the artificiality's level of the shore, that can change its amount of permeability: for example, a wooden retaining wall will be more permeable, and therefore less artificial, than a cemented wall (Figure 13).

What to look

Along the whole stretch, the amount and degree of artificiality along the shoreline will be considered. Example of shore artificiality are: impermeable walls, artificial beaches, retaining walls, wooden or rocky walls.

Suspended wharfs are considered an element of artificiality only when they represent an interruption for the hygrophilous species. If the reeds can grow beneath them, that are not considered.

10. shoreline artificiality	
absent	0
intermediate (from 0.1 to 0.9)	
present along the whole stretch	1

How to answer

The score is given based on the presence or absence, the typology of the extension, etc.:

0) absence of artificiality

0.1-0.9) Intermediate score: an artificial and impermeable shore that affects part of the homogeneous stretch; an artificial shore that is still permeable

1) the artificiality affects the entire stretch; the shore permeability/connectivity is drastically reduced or destroyed.

PLEASE NOTE: When giving intermediate value, particular attention needs to be taken if the artificiality levels fall between 20-25%, as it will divert the classification tree direction in the first node (critical shore artificiality value of 22%). In fact, an artificiality is equal to or less than 0.20 (20%) will lead to the left of the classification tree while a value equal to or more than 25% will lead to the right, consequently changing the final judgment.

Figure 13 - Different level of permeability and artificiality of supporting walls along the shore.

6.11 Apparent channeling of the run-off

Objectives of the question

This parameter evaluates the presence or absence of a prevalent direction for the superficial running of water towards the lake (run-off), which could be convergent into a single point into the lake (like in the case of lake with high concavity), or may enter perpendicular to the shore (the case of lakes with straight shore lines in flat areas).

Principles

The run-off is related to the transport of nutrients from the surrounding territory to the lake. It can concentrate or be dispersed depending on the nearby topography.

What to look

To answer this parameter is useful to use the map of the surrounding territory. The contour lines and the morphology of the territory, as shown in the field maps, can be used to identify the lines of maximum slope, where the run off happens (figure 13). The advisable map scale is 1:10.000, which allows to easily dividing the lakeshore in areas of single channeling intensity. The evaluations will then be taken on the individual homogeneous stretches during the survey.

11. apparent channelling of run-off	
no prevalent direction for the flow	0
intermediate (from 0.1 to 0.9)	
all the run-off converges in a single point	1

How to answer

The run-off is divergent in the case of a "turned bowl" morphology (i.e. the ridge on top of a hill), and convergent in the opposite case (i.e. toward the lower point in a valley).

The evaluation is done as follows:

0) (zero) in the case in which the run-off is divergent (Fig. 14 case **A**) or the surrounding territory is completely leveled and thus without any confluence of run-off towards the lake

0.5) in the case of parallel runoff (Fig. 14, case **B**);

1) if the run-off converges (Figure 14, case **C**)

It the case of small (compared to the lake territorial morphology), homogeneous stretches belonging to a single divergent or convergent system, the same answer will be assigned to all the stretches.

Differently from the concavity and convexity parameter, where it was required to reason bi-dimensionally on the profile of the shoreline, for the channeling of the run-off parameter it is necessary to reason three-dimensionally, considering the slope of the surrounding territory, evaluating the distance between the contour lines in the technical map.

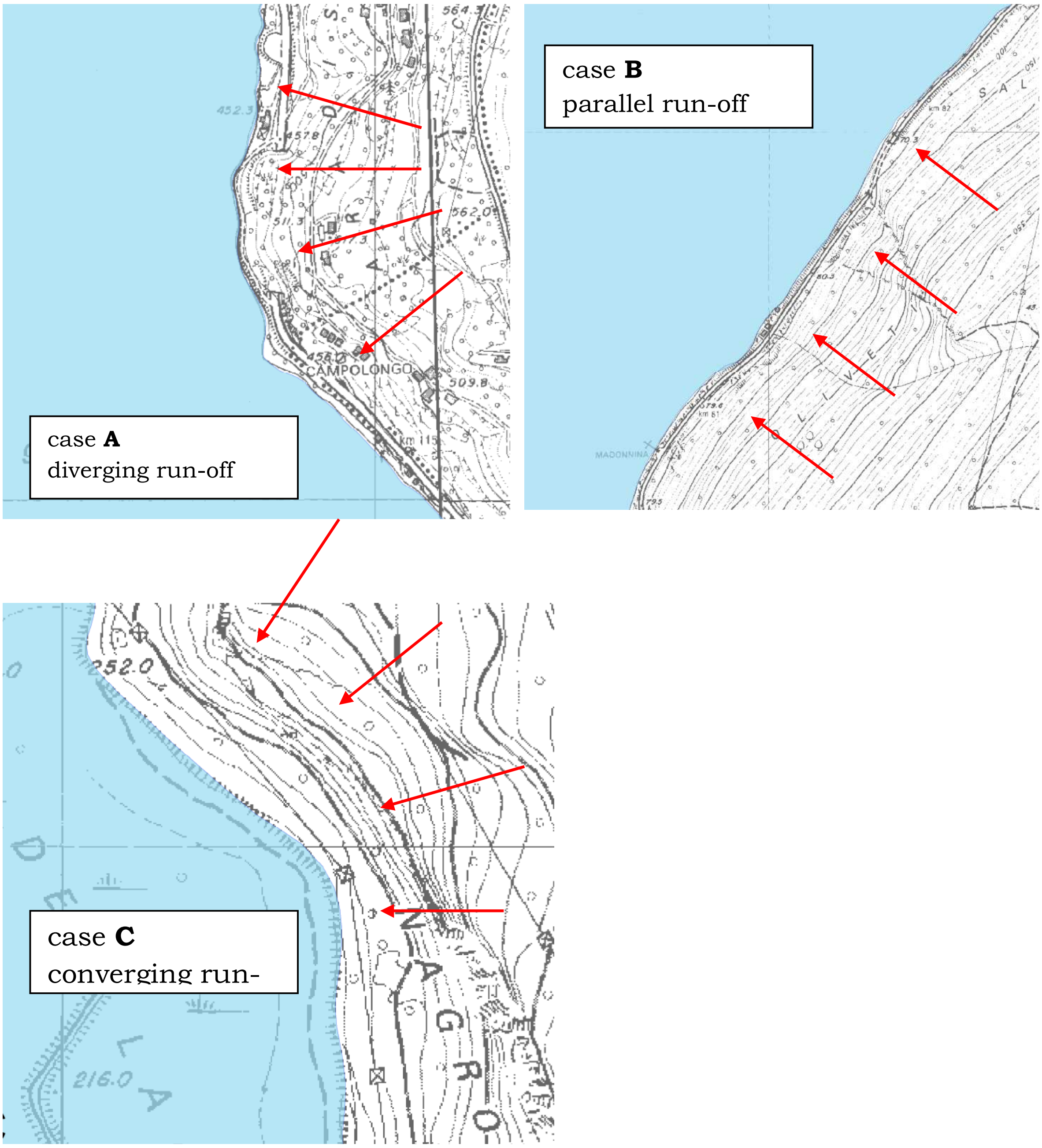


Figure 14 - Representation of different run-off models

6.12 Personal evaluation

Objectives

After compiling the form and looking one by one the main parameter, it is asked to do a personal evaluation. It is based on our own perception on how, overall, the area we are in can be more or less functional. The personal evaluation parameter is used to further develop and validate the SFI method: incongruence between the personal evaluation parameter and the result given by the classification tree are therefore not important for the overall SFI result.

Principles

Our mind can express rapidly feeling of “good looking” or “ugly”, based on non-codified variables analysis. For example, we can all express a positive or negative evaluation on a person, a painting, a dress, but when asked to identify the intrinsic motives for the evaluation, that is what we like or dislike, often we are unable to do so. This is because our mind takes in the entirety of parameters and summarizes them into an evaluation, and it is not able to break down the analysis and recreate it as the sum of different details. Similarly, the operator should express the personal evaluation of each stretch, without being influenced by the answers given previously.

What to look

The homogeneous stretch should be looking at as a whole, and a consideration on its capacity as buffering strip should be recorded in the form. Remember that the evaluation refers to the functionality of the stretch, and not on how it looks (a nice English garden with a big tree shadowing on a picnic table on a wonderful sanded beach may look pleasant, but probably does not have a high depurative power for terrestrial inputs).

How to answer

The expression of personal evaluation is indicated with a number from 1 (excellent) to 5 (poor) (see Tab. 5.1 Functionality Levels and relative judgment and color for reference). It must be formulated on the immediate impression of the field operator using an ecological-functional logic.

12. Personal judgment	
excellent	1
good	2
average	3
below average	4
very bad	5

7. Lakeshore functionality and naturalness

The previous chapters focused on the importance of the lake shore zones as transitioning ecotones between two ecosystems for their ecological functionality roles, and not really for their natural characteristics. It is important to study the ecotone, as it regulates the energy flow between two ecosystems, their homeostatic response and their resilience.

To think and act considering the "functionality" is always more important to design and carry out conservation projects for both the shore zone and the lake itself.

Generally, conditions of maximal naturalness correspond to maximal functionality, with few exceptions: lakes above the altitudinal arboreal vegetation limit (the absence of riparian arboreal vegetation leads to reduced SFI values even in conditions with maximum naturalness); lakes is rocky canyons with thus missing riparian vegetation (reduced functionality); lakes with "anomalies" such as lakes fed by sulphuric, thermo-mineral or saline springs, etc.

The lakes with high naturalness and low SFI levels are particularly vulnerable because, when under pressure, they have limited resilience and reduced homeostatic capacity. These are high risk lakes where minimal stresses could cause great environmental problems.

Therefore, the SFI evaluation does not correspond to the naturalness evaluation; in fact, as previously shown, a high naturalness can correspond to a low functionality, and it is much harder to hypothesize the opposite. It is thus not possible to convert, using a "conversion scale", the SFI values into a naturalness judgment.

The SFI methodology furnishes information organized in a database, collected in a standardized way, which facilitate data storage, retrieval and analysis for also future methodologies.

There is a need to obtain from SFI a distinct evaluation for each natural referenced lake type conditions, as described in the Directive 2000/60 EU.

In other words, the *SFI real functionality* needs to be compared to the *potential functionality*, this last one given by the natural references condition.

The relationship between the real and potential functionality, defined as *relative functionality*, gives an idea of the lake naturalness, as indicated from the Directive Framework.

The comparison between the natural referenced condition and the relative functionality, could improve the SFI application efficiency by providing synthetic additional information that can be used for management.

However, the identification of the reference conditions for each single stretch, which gives the potential functionality value used to calculate the relative functionality, is a delicate process that is based on the competency and intellectual honesty of the surveyor. The use of incorrect or ethically wrong references could result into a non-trustworthy judgment of lake naturalness, leading to foreseeable consequences in the preservation, management and planning for the aquatic systems.

8. Ending remarks

The Lake Shorezone Functionality Index was developed to be conceptually coherent with the indication of the Directive 2000/60/CE. The main objective was to create an useful, immediate instrument for the territorial planning of area near lakes.

Existing guides that focus on the management and protection of the lakeshore (i.e. www.d.umn.edu/˜seawww/quick/ns.html and www.kelowna.ca/CM/Page360.aspx) do not evaluate or quantify the lake shore zone functionality.

The current SFI version was calibrated after the application on different natural and artificial lakes types located in the Italian Alpine and Mediterranean ecoregions, as foreseen by the Work Groups of Directive 2000/60/CE.

The SFI wants to evaluate the lake shore zone functionality efficiency in removing nutrients from diffuse sources. In fact, despite the growing number of publications in the last ten years, the present knowledge on the tampon capacity of the lake riparian zone is yet inadequate. There are still few published works on the lake environments and incomplete works investigating the role of these transitional environments in containing phosphorous.

Consequently, the major SFI limitations are:

- Field work is necessary to collect the parameters requested in the manual, as existing data are generally incongruent.
- The parameters are not directly measured, but they are estimated; thus is not possible to verify the answer with direct studies or experimentation, i.e. measuring the flows going throughout the studied riparian zone.

Today, the elevated capacity of the riparian ecotones in keeping and removing the nutrients is well documented and numerous studies done in Great Britain, France, Sweden, Denmark, Canada and the United States have shown that the riparian zone causes a remarkable reduction, up to 90% of the nitrogen load coming from agricultural activities.

The management of water bodies needs adequate tools for evaluation of the ecosystem services. The decisions regarding territorial planning of the environments next to lakes and the management of the water resource should be based on the results of such indices.

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