B.10 Software for assessment and quantification of ecosystem services

Part 3

Qualitative dynamic models

Making Good Natura
LIFE+11 ENV/IT/000168

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Report of action B.10:

Software for assessment and quantification of ecosystem services

Part 3: Qualitative dynamic models

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Index

Index of tables

Index of figures

1 Qualitative dynamic models for Natura 2000 site management

The flows of ecosystems services provided by Natura 2000 sites depend in a complex way on many variables related to ecological (chemical, physical, biological) and socioeconomic processes, which interact at different levels in the scales of time and space. It is not practical to understand the full complexity of these relationships, especially on the basis of the data usually available for these sites. However, a system dynamics (SD) approach makes it possible to distinguish major variables and their cause-effect relations, and to visualise their recurrent dynamics.

An assumption of system dynamics is that system behaviour emerges from its structure (cause-effect relationships + feedback loops) rather than from the values of single variables. Indeed, the aim of this approach is to understand the behaviour of complex systems in time, considering internal feedbacks and delays that influence the behaviour of the whole system. The approach is essentially qualitative, although it may include simulations based on differential equations, since even the results of numerical simulations are interpreted qualitatively. The typical question that can be answered by a SD model is: if A increases (e.g. due to natural causes or management), what happens to B or C over time? Or what management strategy is better: A or B?

Here we propose simplified models of the systems underlying the various ecosystem services. These models have various aims:

- to represent the main variables involved in site management and in the process of reproduction of the ecosystem service
- to understand and visualise any feedbacks between possible management measures and system variables
- to reveal any implicit assumptions that would be deleterious for the aims of enduring development and protection of biodiversity in Natura 2000 sites
- to sustain collaboration promoting convergence of ideas, knowledge, interests and positions, based on discussion between stakeholders
- to facilitate the definition of management problems and strategies from new, possibly intersectoral perspectives (e.g. tourism, landscape ecology, conservation of biodiversity)
- to provide managers with a body of knowledge on which to develop specific models for their sites and to simulate management scenarios.

In other words, the general aim is to sustain site management through improved understanding of the complex dynamics involved and the possible consequences of acting on the system. The models proposed have major limits to bear in mind:

- they are hypothetical and generic, based on theories and assumptions derived from general notions of ecology and environmental economy and not from local data;
- they are incomplete: they do not include all the variables involved but mainly those linked to possible management measures (e.g. “productive area” rather than “mean temperature”);
- the variables have dummy values with an essentially qualitative meaning (often zero stands for minimum quantity or value, 1 or 10 stand for maximum quantity or value).

For more specific use, such as the definition of local actions and quantitative simulation of possible effects, these models are not sufficient and could even be misleading, since they require validation and verification with real data and probably also reformulation with new variables.

Besides for a good understanding of the system, the most appropriate use for these models, as presented here, is for effective communication and discussion between stakeholders. In a hypothetical meeting with the various stakeholders, these models could be useful for communicating and considering system complexity (e.g. feedbacks) in a medium-to-long time frame (dynamics).

2 System dynamics models: brief instructions for use

System dynamics models arose as management tools for comparing strategies (Is strategy A better than strategy B?) or scenarios. They are not prediction tools and do not allow the exact value of a variable at a future time to be forecasted. The aim of SD modelling is to obtain insights into the problem/system and its recurrent dynamics and to identify lever points on which to act to change the dynamics (Forrester, 1994; Senge, 1990).

There are two main tools: causal loop diagrams (CLD) that describe causal relationships between variables, and stock-flow diagrams (SFD) that enable the dynamics of stock variables (reserves, stocks or any quantity that accumulates) to be simulated and hence the behaviour of the system in relation to management scenarios. These two types of diagram have standard symbols and specific terminology. For details see the abundant literature online (e.g. Pruyt 2013 is complete and instructive). Application of SD modelling to the assessment of ecosystem services (ES) has advanced and become widespread in the last ten years (Batker et al., 2010; Costanza et al., 2007; Costanza & Voinov, 2001).

Figure 1: Examples of causal loop diagrams: model of new product adoption and model of growth/decline of a life insurance company (from Wikipedia.org).

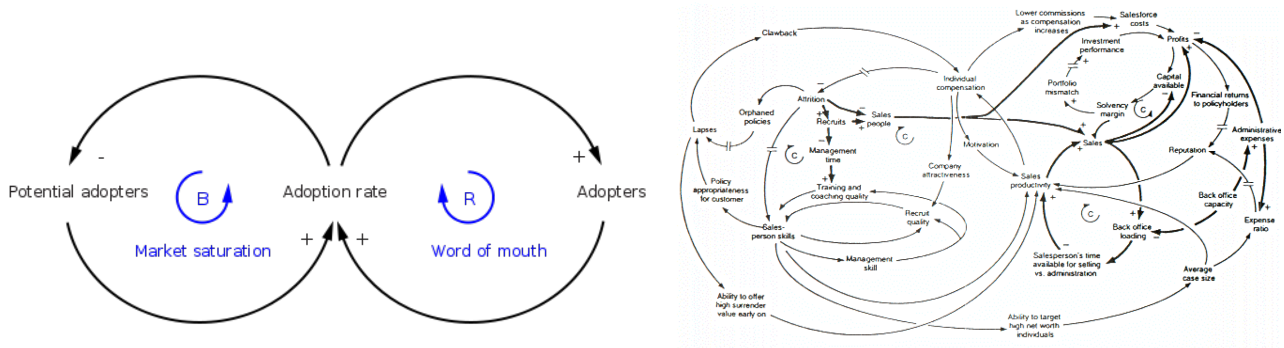
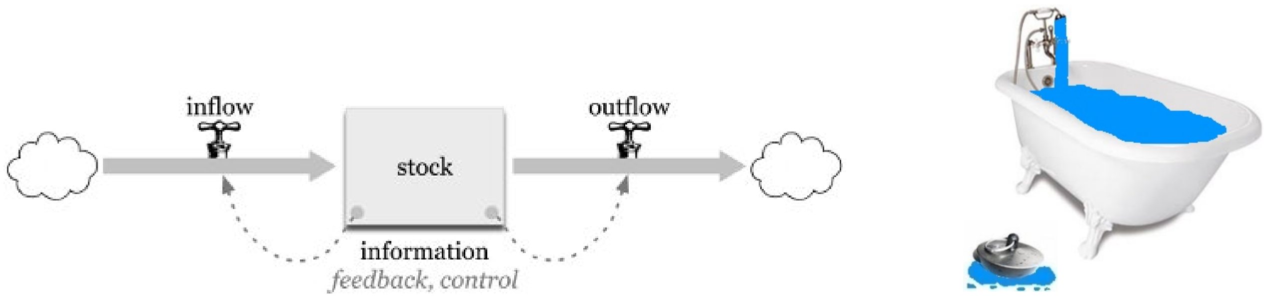


Figure 2: Example of stock-flow model and bathtub metaphor explaining the elements: flows - tap and drain; stock - water level).



We now present stock-flow models for a selection of ecosystem services in increasing order of complexity instead of in the order of the Common International Classification of Ecosystem Services (CICES) table. For the more complicated models, we first give a simplified version, introducing the elements later. Simplification of the processes and approximation of the variables with dummy values is justified by the fact that the model is only based on general ecological processes.

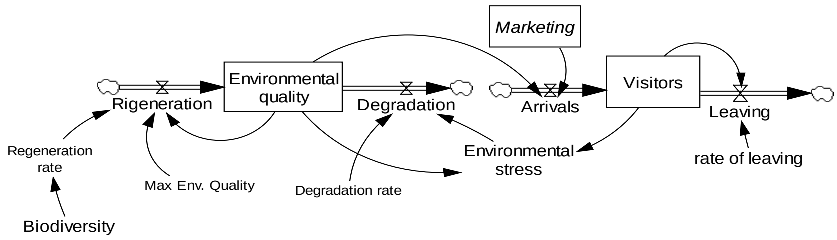
3 Example of qualitative dynamic modelling for the Val Grigna (SCA IT2070303) area

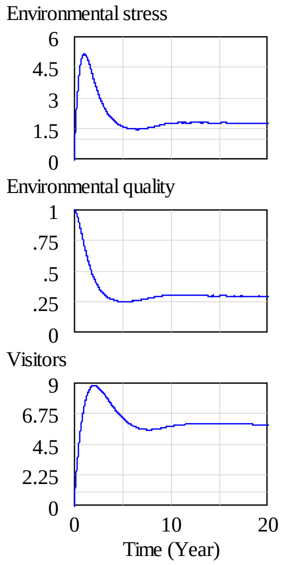
Here we advance an example of dynamic model that shows the relationships between the main variables of the ecosystem service "recreational value" (C2). A possible model of service C2 for a Natura 2000 site is explained in more detail in the next section.

The aim of this model is illustrative. To achieve a quantitative model on which to build precise scenarios requires up-to-date local data and is beyond the scope of this manual. The qualitative model is however useful to determine the type of information most useful to collect in order to manage the dynamics of a site and may help administrators to target field studies. As mentioned above, the system dynamics approach makes it possible to visualise any feedbacks in the system caused by hypothetical actions or assumptions.

The Val Grigna site extends for 2873 ha in the Regional Forest of the same name in Brescia Province. It is included among the sites of the "Alpine" biogeographical region. The pre-Alpine mountain area includes the so-called Massiccio delle Tre Valli between 1000 and 2207 m of altitude. The site is accessible (a necessary condition for service C2) by tracks and is equipped with areas (e.g. summer pastures), which act as arrival and/or transition points for organised tours. The area exemplifies a type of site with high naturalness, facilitated access and limited possibility of anthropisation for physical reasons (altitude, slope). Under such conditions, management variables are essentially reduced to three: *environmental quality, visitors, marketing*.

Ecosystem service C2 is assessed via the indicator number of *visitors,* understood as the potential number. This number depends on the *environmental quality* of the site that attracts and determines visitors, but can also generate *environmental stress* with a negative effect on *environmental quality* (negative feedback). *Environmental stress* is linked to *environmental quality,* since visitors presumably have more impact visiting an area of high *environmental quality* (e.g. a peat bog or species-rich meadow) than an area of less value (e.g. a coppiced wood). *Environmental quality* may decay (due to *environmental stress*) or regenerate through the contribution of various ecosystem processes sustained by the level of *biodiversity*. The latter determines the *maximum environmental quality* and influences the *regeneration rate*, though not in a deterministic way (see equations §9.1). On the other hand *marketing* contributes to bringing more visitors in relation to the level of *environmental quality*.





This simplified model does not consider investments to sustain environmental quality (see model C2-2, §8.2) or infrastructure supporting attractivity (see model C2-3, §8.3), but already suggests a likely dynamics of the system: environmental quality will decline with the number of visitors, which is in turn linked to marketing. The relation between marketing and loss of environmental quality is not always considered, like other relations visible in more complex models. If this aspect is discussed among stakeholders and considered in the planning and management of the site, management may become more effective.

Dynamic modelling of the problem/system suggests points to investigate. The arrows in the model indicate causal links between variables than can be explored. The need to have data on certain aspects of visitors emerges: number of visitors, areas visited/enjoyed, specific impact of each visitor (in different areas), ecosystem regeneration capacity (of different areas).

As an example of further study, *environmental stress* may have various forms, ranging from direct compression of soil, to noise and disturbance of fauna, indirect triggering of erosion and changes in land cover and land use. Similarly, environmental quality may have various dimensions in the case of C2, correlated with visitors' perceptions, such as number of "remarkable" floral species, presence of "charismatic" animal species, and landscape composition.

Below we provide instructions for interacting dynamically with the proposed model. Using the free software Vensim PLE it is possible to interact with the model, changing variables and following the effects on related variables.

4 Interacting with Insight Maker (online)

Insight Maker is a general web-based tool for modeling and simulating (as reported by the website insightmaker.com: “free modeling and simulation in your browser”). It is an "interactive learning environment" of easy access and use, where anyone (even without experience) may use the models published and in turn publish own models, possibly taken from other users and adapted or improved. Insight Maker is effective to show the possible use of the system dynamics approach in many fields, including the scope of the management of Natura 2000 sites. Searching through published models (click on **Explore Insights** at the top, then **Search** "natura2000") it allows access to some of the models described in the following chapters. Clicking on **Step Forward** one can follow a presentation of the model (storytelling mode); with **Simulate** one can simulate the described dynamics or editing the magnitudes of variables (at the right, likewise with channels of a audio mixer).

Figure 3: Start page of Insight Make (left) and the published models (right).

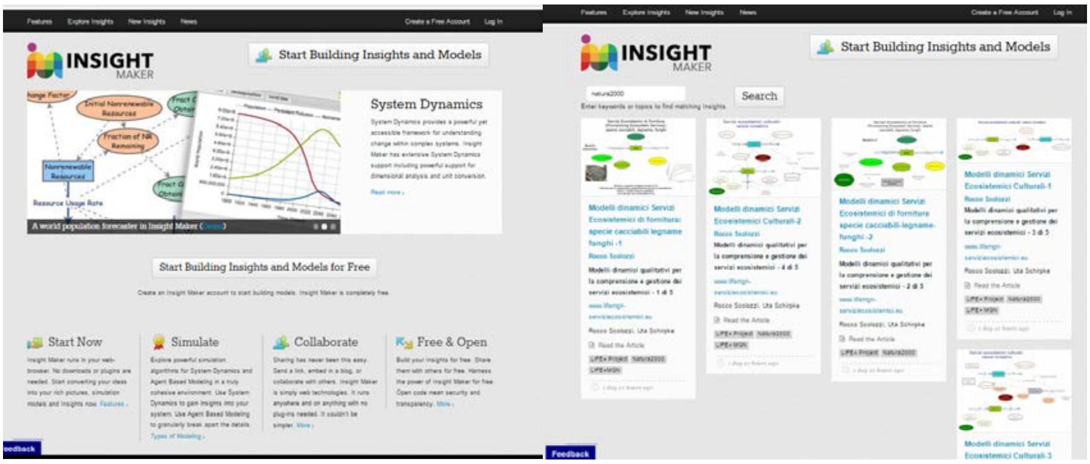
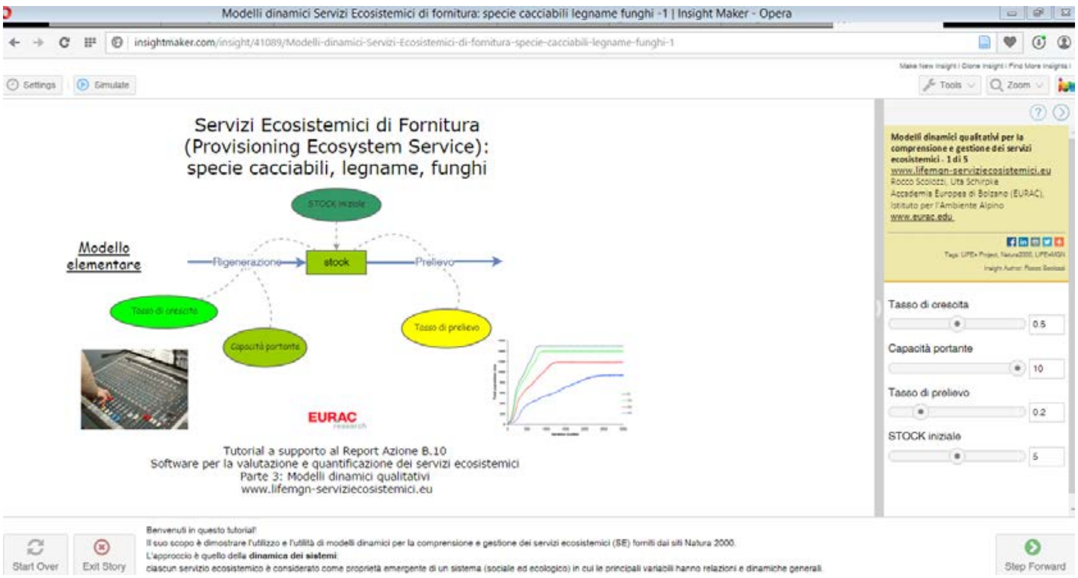


Figure 4: Model and presentation/narration (see bar at the bottom and button Step Forward).



5 Interacting with the dynamic model in Vensim

Vensim is a system dynamics modelling software available in various versions. The free personal learning edition (PLE) sufficient for the present context can be downloaded at: http://vensim.com/free-download/ (after free registration for the newsletter).

Once installed, the screen appears as in Figure 3. The *Help* function provides an exhaustive series of manuals and links to examples (in the installation folder). For single button functions, see the guide and/or manual. Here we describe the essential operations for interacting with models.

Figure 5: Interface window of the software Vensim PLE (6.3D).

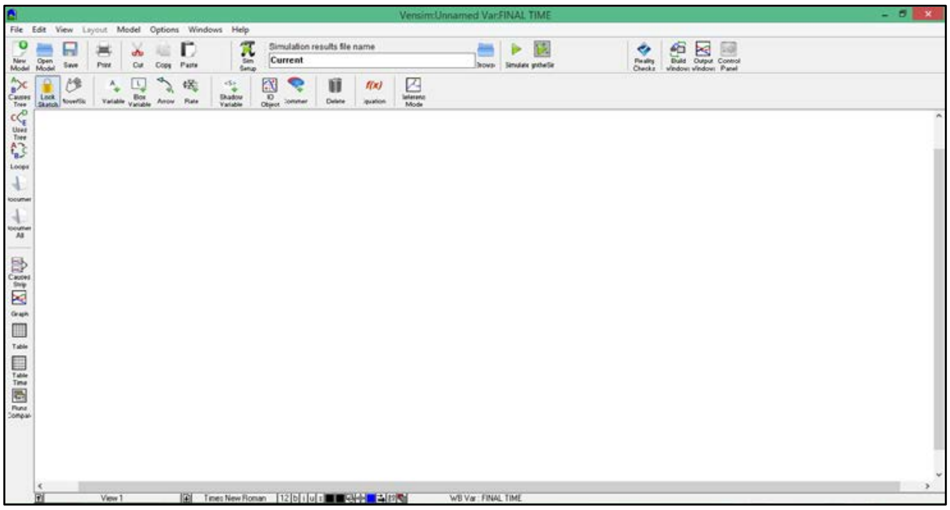


Figure 6: OPEN MODEL loads the file *C2-1.mdl* (see also Fig 3); SYNTHESIM activates the cursors for modifying the values of variables.

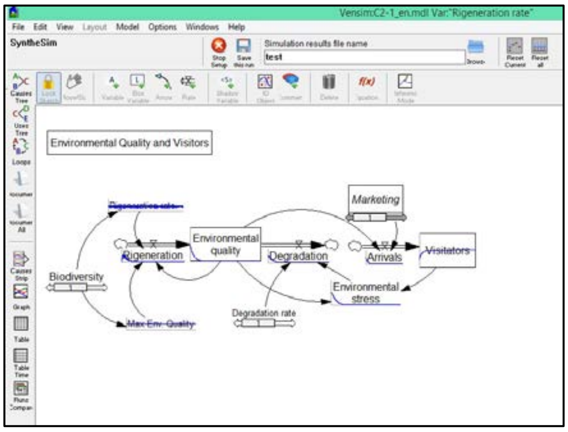


Figure 7: RESET ALL restores the initial values of the model; STOP SETUP exits interactive mode.

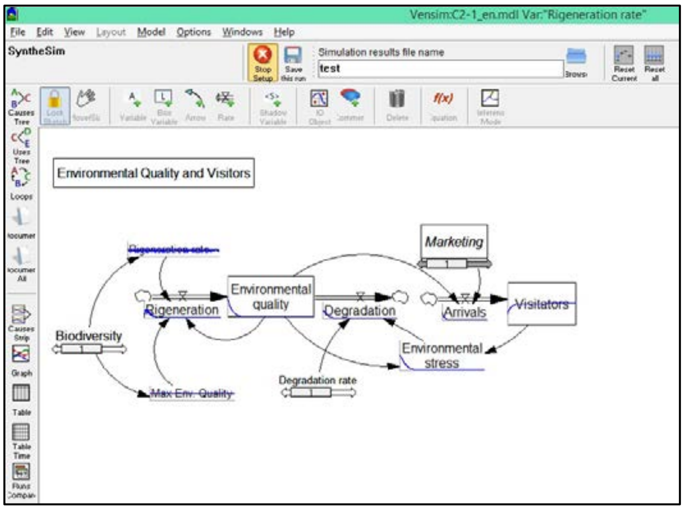
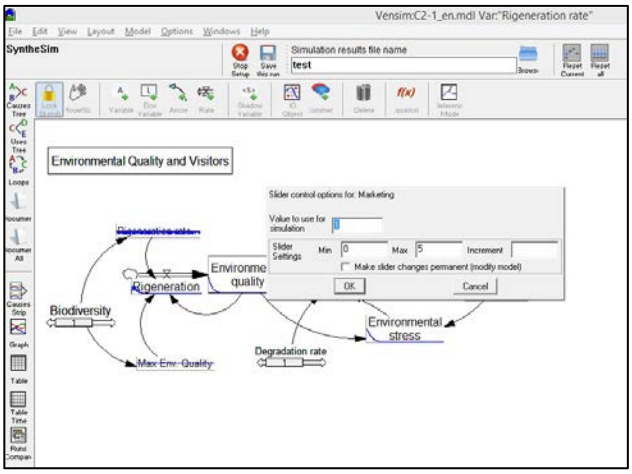


Figure 8: Click cursor bar to define the range and current value of a variable.



Once the software is installed, the model loaded and SyntheSim mode activated, variables can be modified in two ways: moving the cursors (right-left) or clicking the cursor bar and manually changing the range and initial value.

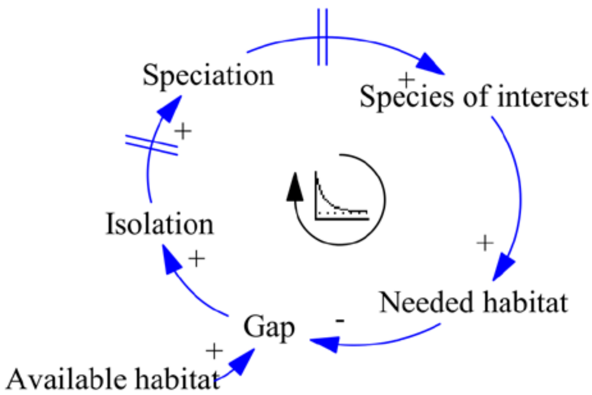
The model is qualitative but sufficiently realistic. Experimenting with different variations of the "management" variables it is possible to visualise the effects on associated variables and deduce useful indications. For example, increasing marketing increases the number of visitors but environmental quality collapses. The level of biodiversity turns out to have a limited capacity to resist the collapse of environmental quality if the rate of degradation is relatively high (e.g. > 0.1).

6 Renewable resources without quantitative withdrawal: medicinal plants (F6), genetic resources (F7)

The ecosystem service that supplies medicinal plants and genetic resources sustained by Natura 2000 sites has value in terms of biological diversity and a present or future source of useful molecules and genes. Thus the species of interest have intrinsic value because they are rare or threatened, as well as in terms of quantity of individuals or potential products. In this context, the category "species of interest" may also include intermediate forms of ecological specialisation without being actual species (groups of organisms that cannot interbreed), in which *local* or rare *varieties* (e.g. Adamello goat) can be of interest today (e.g. for conservation) or in the future (e.g. genetic improvement). Unlike other supplies, the unit of value is the species itself, which is why we assume that there is no significant withdrawal (individuals of a species can be withdrawn, but not an entire species).

The number of species may increase through the process of speciation, i.e. the natural evolutionary process by which new species or local varieties emerge from pre-existing ones. This process requires *isolation* of populations of the original species and their survival and adaptation for a period sufficient to differentiate. Simplifying, the appearance of new species or varieties requires space and resources (functional *habitats*) to maintain them. In other words, the number of species may increase if there are sufficient resources (food, space) to keep new populations sufficiently separate.

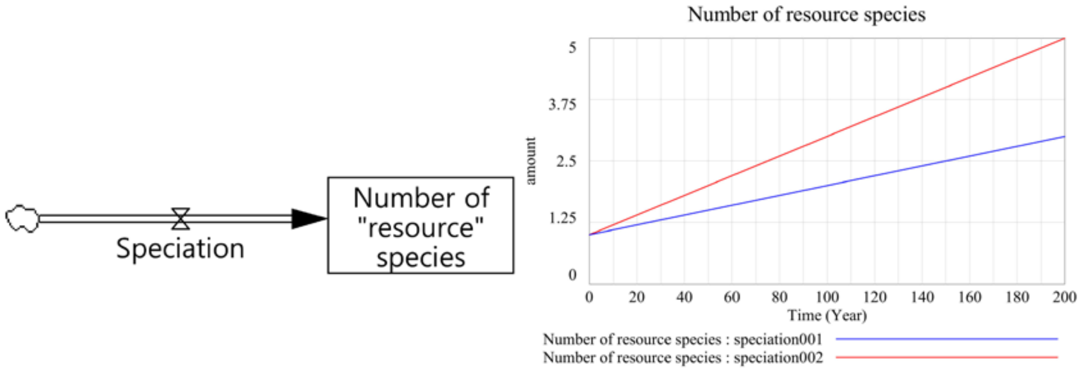
Figure 9: Speciation process: negative feedback tends to stabilise the number of species in an area.



In a super-simplified model, the speed of appearance of new species depends on the speciation rate; in the proposed model we assume a new species (or local variety) every 100 years (0.01/year). This is a medium rate, closer to that encountered among plants than among animals: for example 150 years for the plant *Mimulus cupriphilus,* whereas animals require at least 30-40 generations, e.g. 250 years for the Faroe Islands house mouse.

Equations of model F6-7.1:	
1.1	Number of resource species = Speciation; (initial value = 1)
1.2	Speciation = 0.01

Figure 10: Model F6-7.1: Number of species (or local varieties) of interest in relation to speciation rate (0.01 red line, 0.02 blue line).

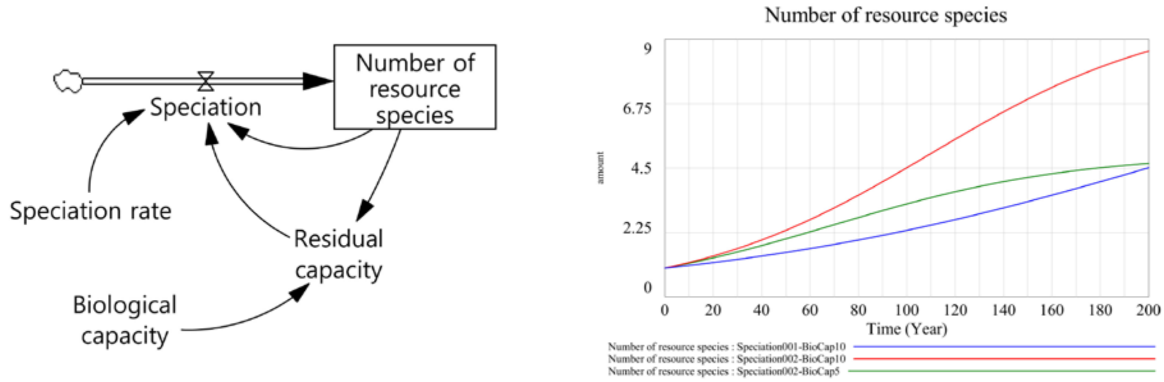


In a slightly more realistic model, we consider a bounded area composed of a limited mosaic of ecosystems (a generic Natura 2000 site), in which the growth of the number of species is limited by available resources. Indeed, the dynamics of speciation in a given area is similar to the process of reproduction of a renewable resource, characterised by a logistic growth curve in which the exponential phase is limited by factors such as saturation or resource limit. Here we call the set of conditions suitable for the evolution of new species *biological capacity*. The formation of new species occurs until the biological capacity to host new species is exhausted: the logistic growth curve is simulated by model F6-7.2.

Equations of model F6-7.2:		
2.1	Number of resource species = Speciation; (initial value = 1)	[species]
2.2	Biological capacity = 10 *maximum number of new species in specific area (arbitrary value)*	[species]
2.3	Speciation rate = 0.01 *Theoretical mean speciation rate*	[species/year]
2.4	Residual capacity factor = 1 - (Number of resource species/Biological capacity) *when number of species reaches biological capacity the factor is zero (speciation ceases)*	
2.5	Speciation = Speciation rate * Number of resource species * Residual capacity factor	

It is evident that as speciation rate varies (e.g. in Figure 11, from 0.01 to 0.02), “saturation” is reached sooner (in about 80 years, green line, instead of 200 years, blue line); as biological capacity increases, the maximum number of species increases (red line) but speed only partly increases (the red line has a maximum just after 100 years, compared to 80 years for the green line).

Figure 11: Process of speciation: varying speciation rate (blue: 0.01; red: 0.02) and biological capacity (red: 10; green: 5).



Specifically, the capacity to host new species depends in turn on at least two variables: habitat richness, in which new species can be expected to differentiate, and mean area, assuming it as a proxy indicator of the probability of isolation, since if new habitats are too small to host new populations they do not contribute to differentiation. On the other hand, isolation may be man-made (e.g. interruption of habitat continuity by deforestation or physical barriers such as dams and roads) or an intentional result (e.g. cultivation of local varieties or raising of local breeds), in which case the variables involved change and the process may be modelled as for supply of F1 or F2 (see below, section 8).

Equations of model F6-7:

3.1 Number of resource species = Speciation; [initial value =1]

3.2 Speciation = Speciation rate * Number of resource species * Residual capacity factor

3.3 Mean habitat size = 5 [dummy value, scale 1-10]

3.4 Habitat richness = 5 [dummy value, scale 1-10]

3.5 Biological capacity = INTEGER(SQRT(Habitat richness * Mean habitat size))
*The value is rounded off to the integer of the square root of richness * size; maximum habitat richness =10; maximum mean habitat size = 10.*

3.6 Population isolation = 1 [dummy value, scale 1-10; no isolation = 10, maximum isolation = 1]

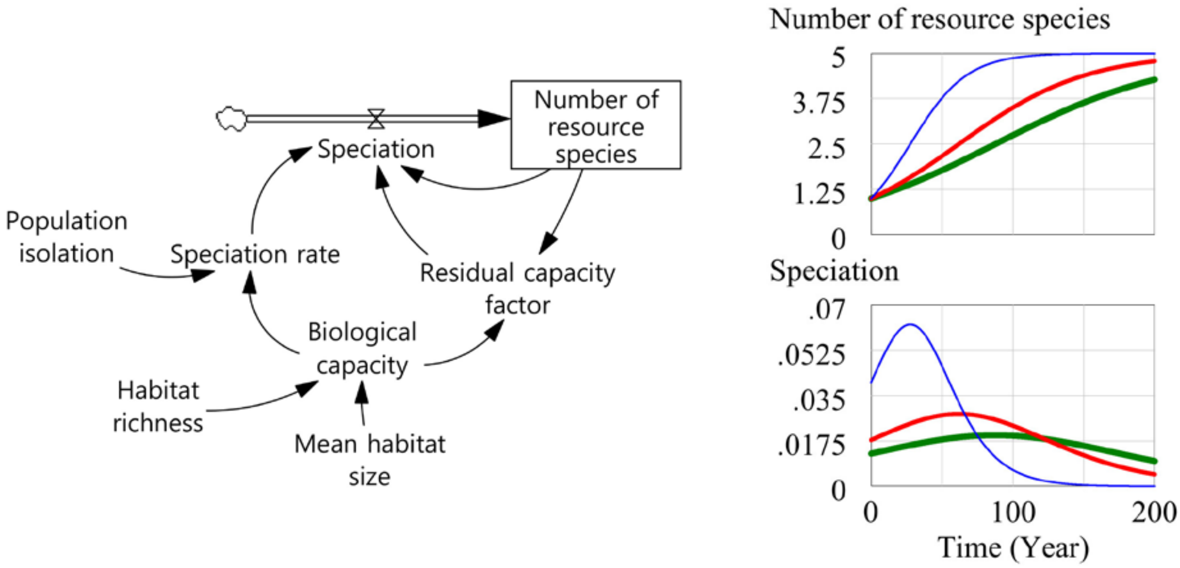
3.7 Speciation rate = SQRT(Population isolation * Biological capacity)/100
Theoretical mean speciation rate with a value of 0.01 for minimum isolation (1) and maximum biological capacity (10).

3.8 Residual capacity factor = 1 - (Number of resource species/Biological capacity)
When the number of resource species reaches biological capacity the factor = 0, so speciation ceases.

Useful considerations on supply of F6 and F7

Speciation rate increases with increasing isolation (in Figure 12 the blue line reaches saturation before the highest points of the red and green lines), up to the maximum number of species allowed by biological capacity. This depends on habitat richness and mean size.

Figure 12: Model F6-7: speciation in relation to isolation, habitat richness and mean habitat size (degree of isolation: blue line-5, red line-1, green line-0.5).



Applications of the model

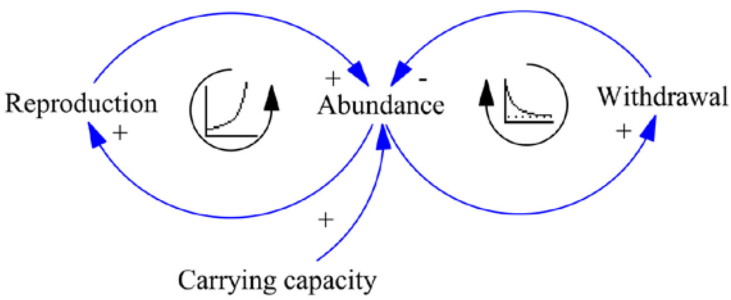
Although an increase in species can hardly be planned or managed, the model can be useful:

- for understanding the process of speciation and explaining it to the stakeholders of a site,
- for showing the importance of habitat size and richness,
- for comparing the capacity of different sites to sustain different or even rare species.

7 "Naturally" renewable resources: Faunistic resources (F3), wood (F4), mushrooms (F5)

The supply of F3, F4 and F5 resembles the process of reproduction of a renewable resource, characterised by logistic growth, but in this case the limit to growth is also influenced by "external" factors, such as withdrawal, depending on the abundance of the resource. Indeed, the *catch* per unit effort spent fishing (F3) (e.g. number of fishermen or nets) depends on the abundance of fish. In other words, if the number of fish declines, so does the catch. The same is true of mushrooms (F5): the rarer the species, the smaller the amount collected. In general, the supply of an ecosystem service is sustainable if the withdrawal rate is less that the reproduction rate. The process is illustrated by the causal loop diagram of Figure 13 and the super-simplified model of Figure 14 (model F3-4-5.1).

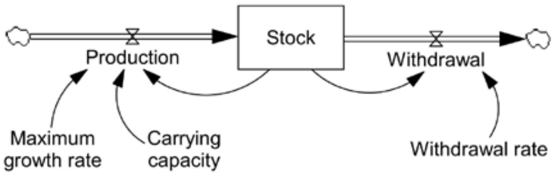
Figure 13: Simplified causal loop diagram of reproduction of natural resources such as fish, game and mushrooms.

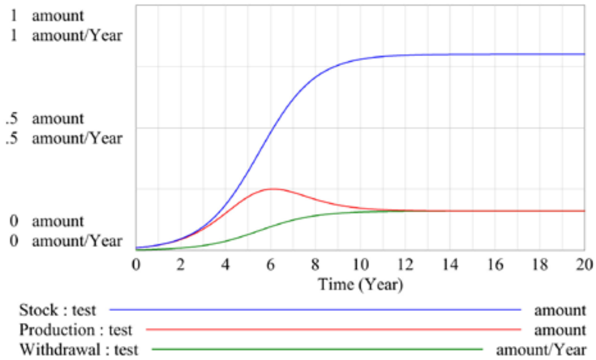


Equations of model F3-4-5.1:

4.1	Withdrawal = Withdrawal rate * Stock	[kg/year]
4.2	Production = Maximum growth rate * Stock * (1-Stock/Carrying capacity)	[kg/year]
4.3	Stock = Production – Withdrawal	[kg]
4.4	Maximum growth rate = 1	[1/year]
4.5	Withdrawal rate = 0.2	[1/year]
4.6	Carrying capacity = 1	[kg]

Figure 14: Model F3-4-5.1 of renewable resource for which withdrawal is related to abundance of resource.



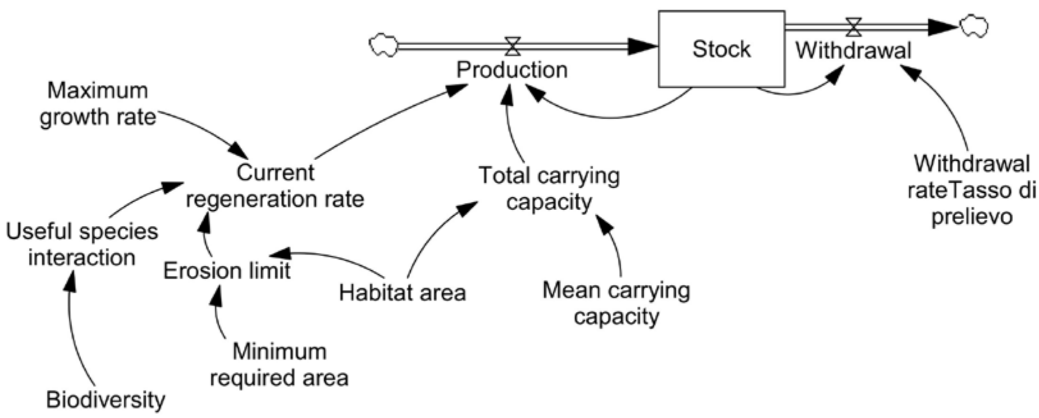


In this general model, accumulation of the resource is related to *production* and *withdrawal*, and production in turn depends on *maximum growth* or (resource-specific) *regeneration rate* and the *carrying capacity* of the environment. In this relationship, *(1-stock/maximum production)* limits growth up to the carrying capacity (when stock = carrying capacity, the denominator cancels out production).

For a given area (Natura 2000 site), the *total carrying capacity* is related to the *habitat area* and the theoretical *mean capacity* per unit area. The mean capacity can be deduced from a statistical mean, but for a specific site the current level of *biodiversity*, which is the maximum number of individuals currently sustainable, also plays a role. To simulate this influence, the variables are considered as three multiplier factors (equations of model F3-4-5). On the other hand, the *current growth rate* also depends on the specific conditions of the area, as well as on the theoretical (species-specific) *maximum growth rate.* Here the level of biodiversity comes into play through a process of *interaction with useful species,* to which is added a minimum area limit factor, under which the resource cannot reproduce. This lower limit, known as the (biodiversity) *erosion limit,* depends on the relationship between current *habitat area* and specific *minimum required area*.[1] In other words, we assume that if the productive area (habitat) is one tenth of the minimum area, the regeneration rate is zero. Since the *useful species interaction* factor is difficult to estimate, it is approximated by a pseudo-random value with normal distribution centred on the level of *biodiversity*.

[1] The minimum required area is the area necessary to maintain the survival of at least a minimum viable population (MVP) of the species. Species-specific reference values, or reference values by mean size category of the species, can be obtained by metapopulation studies (Verboom, Foppen, Chardon, Opdam, & Luttikhuizen, 2001).

Figure 15: Model F3-4-5: biodiversity influences growth rate (by interaction with useful species) and carrying capacity.

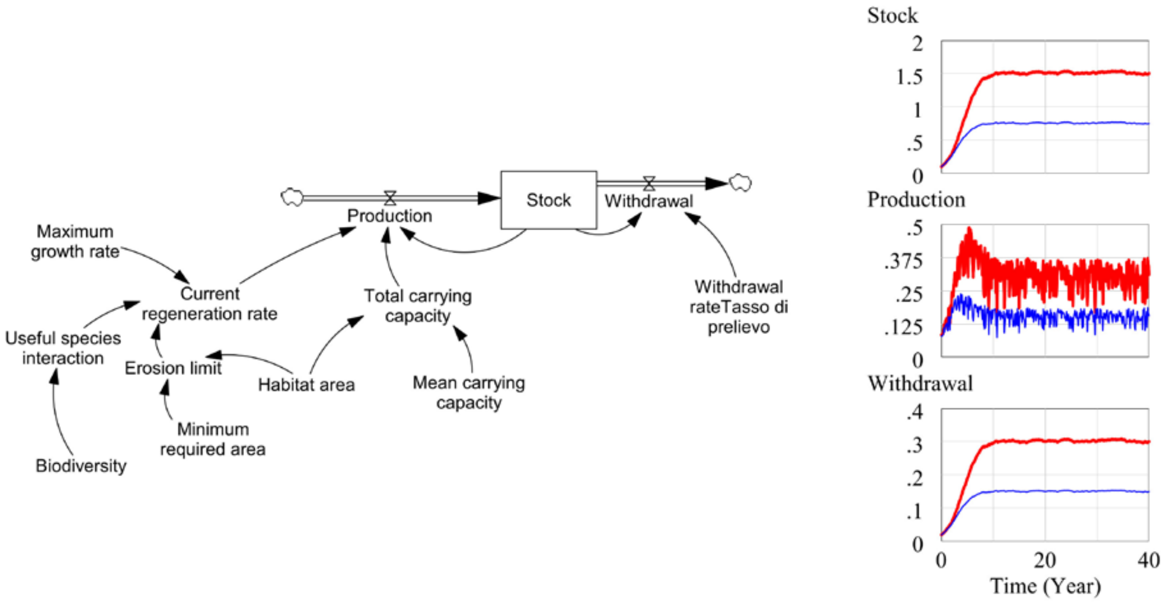


Equations of model F3-4-5:		
5.1	Production = Current regeneration rate * stock * (1 - stock/Total carrying capacity) *using kg or multiples (100 kg, 1000 kg) does not modify dynamics*	[kg/year]
5.2	Total carrying capacity = Habitat area * Mean carrying capacity *is mean (expected) production per unit area*	[kg]
5.3	Mean carrying capacity = 1 *sustainable biomass per unit area of the resource species, scalable according to species*	[kg/km^2]
5.4	Habitat area = 1 *current required habitat area with arbitrary initial value*	[km^2]
5.5	Current regeneration rate = IF THEN ELSE(erosion limit < 0.1, 0, maximum regeneration rate * Useful species interaction) *the resource regenerates if the area exceeds a minimum arbitrary threshold (ratio of current area to minimum required area, 1:10)*	[1/year]
5.6	Maximum growth rate = 1 *is equivalent to 100%, or 1 kg per year for every kg of biomass present that year*	[1/year]
5.7	Useful species interaction = RANDOM NORMAL(0.4, biodiversity, biodiversity, 0.2, 222) *pseudo-random value with normal distribution centred on biodiversity value*	[Dmnl]
5.8	Erosion limit = Habitat area/Minimum required area	[Dmnl]
5.9	Minimum required area = 0.1 *minimum area to sustain a viable local population (or MVP), scalable according to the resource species*	[km^2]
5.10	Biodiversity = 1 *qualitative scale from 0 to 1 (= 100% of local species present)*	[Dmnl]
5.11	Withdrawal = Withdrawal rate * Stock	[kg/year]
5.12	Stock = INTEG(+Production - Withdrawal, 0.1) *stock of the resource with initial value 0.1*	[kg]
5.13	Withdrawal rate = 0.2 *withdrawal as % of stock (arbitrary value, 20% of stock)*	[1/year]

Useful considerations on supply of F3-F4-F5

The simulation shows that if habitat area doubles, the stock of useful species (e.g. game, fish) increases until a new equilibrium between withdrawal and regeneration is reached. Interestingly, although the contribution of *biodiversity* to *regeneration rate* is random (with increasing oscillations Figure 16), the values of stock and withdrawal do not oscillate in a proportional manner and reach a relatively stable equilibrium value all the same. This is typical of stock variables that tend to "dampen" changes in auxiliary variables.

Figure 16: Model F3-4-5, supply of ecosystem services F3-F4-F5 with different required habitat areas: 1 km^2 (blue), 2 km^2 (red).



Applications of the model

This model is suited for simulating the dynamics of any environmental resource that naturally regenerates (or requires negligible intervention on the ecosystem) and the quantity of which depends on carrying capacity and withdrawal. The model can also be useful:

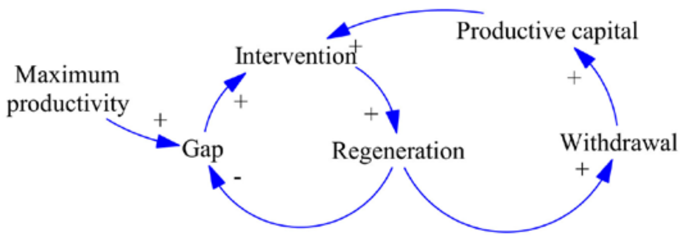
- for understanding the process of reproduction of the resource and for explaining it to stakeholders of a site,
- for demonstrating the importance of required habitat area and local biodiversity for supply of the service.

When regeneration and withdrawal depend significantly on human intervention, as in the case of crops or pastures that require investments, fertilisation and other agricultural operations, the model should contain other (socioeconomic) elements, as described below.

8 "Cultivated" renewable resources: Permanent and annual crops (F1), pasture and forage (F2)

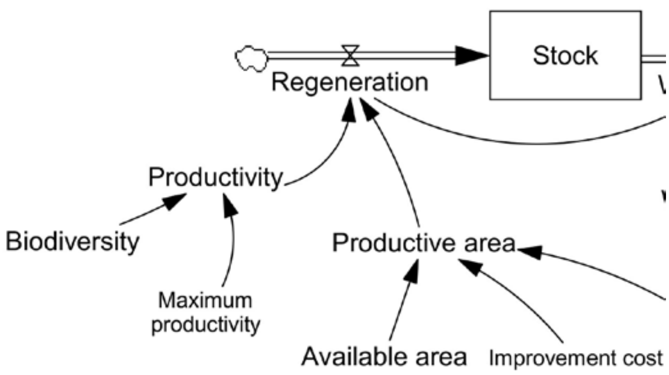
The reproduction of renewable resources such as agricultural products (food, forage, pasture) depend on constant investments by the recipient (Figure 17). The supply of "cultivated" ecosystem goods depends on intervention (fertilising, weed removal and other agricultural operations) and active withdrawal, which imply ongoing costs and investments. The model developed for the previous ES therefore requires further elements to reflect reality, although its dynamics remain the same.

Figure 17: Simplified causal loop diagram of reproduction of "cultivated" natural resources.



Specifically, for a given area, regeneration of an agricultural resource (that accumulates in the variable *stock*) depends first of all on specific *productivity* of the resource (say forage) and on the *productive area.* Unlike hunting and fishing, there is no "minimum functional area" below which the process ceases. In other words, we assume that even a few square metres can be cultivated without the supply service ceasing. In turn specific productivity depends on conditions ensured by an optimal level of local biodiversity, especially for pastures and grasslands (e.g. interaction with useful species). The productive area may not be the same as the available area because, as in the case of pastures/grasslands, they require maintenance (e.g. removal of shrubs) or improvement (e.g. fertilisation, harvest, crop rotation), which have a cost per unit area.

Figure 18: Model F1-2 (first part): variables influencing regeneration of "cultivated" resources.

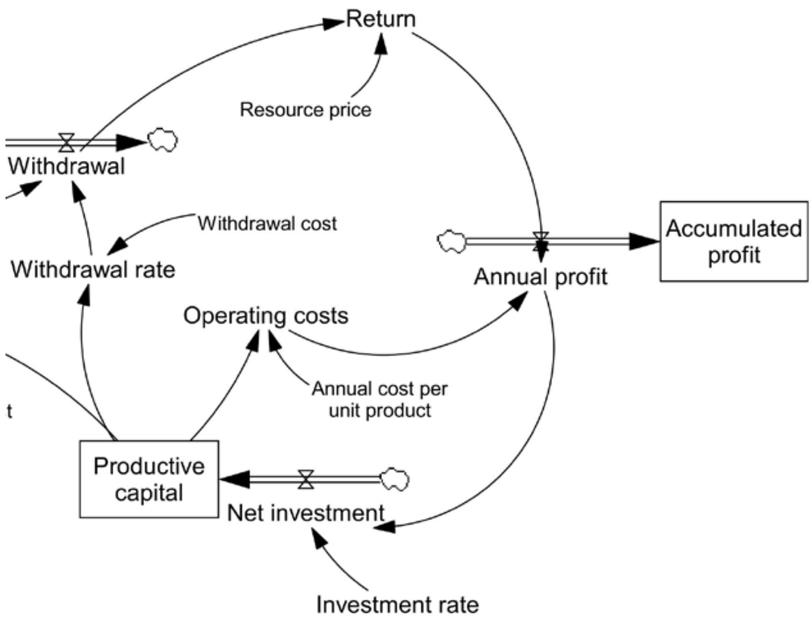


Equations of model F1-2 (first part):		
6.1	Stock = Regeneration - Withdrawal kg or multiples thereof (100 or 1000 kg)	[kg]
6.2	Regeneration = Productivity * Productive area	[kg/year]
6.3	Productivity = Maximum productivity * RANDOM NORMAL(0.5, Biodiversity, Biodiversity, 0.1, 222) *dependence of maximum productivity on biodiversity (pseudo-random)*	[kg/(year*km^2)]
6.4	Biodiversity = 1 *qualitative scale from 0 to 1 (= 100% of local species present)*	[Dmnl]
6.5	Maximum productivity = 10 *mean productivity, dummy initial value: 10 kg/year.km^2*	[kg/(year*km^2)]
6.6	Available area = 10 *unit area, arbitrary initial value*	[km^2]
6.7	Productive area = MIN((Productive capital/2)/Improvement cost, Available area) *the productive area depends on agricultural operations (e.g. fertilisation, weed/shrub control) made possible by productive capital (half for improvement e.g. pasture/grassland, half for harvest/resource use), but is limited to the available area*	[km^2]
6.8	Improvement cost = 1 *cost per unit area of maintenance and/or improvement (e.g. fertilisation, shrub removal)*	[€/km^2]

Withdrawal also depends on continuous investment (in machinery, labour, here called *Productive capital*) to transform the process of primary production (e.g. turf) into an economic resource; in other words, the animals must be brought to pasture or the hay must be harvested and brought to the stables. In the model, *Productive capital* (measured in €), makes *Withdrawal* (kg/year) possible at a rate, the upper limit of which is determined by the *Regeneration rate,* so in the equation we have a minimum function included between two rates (see 6.10).

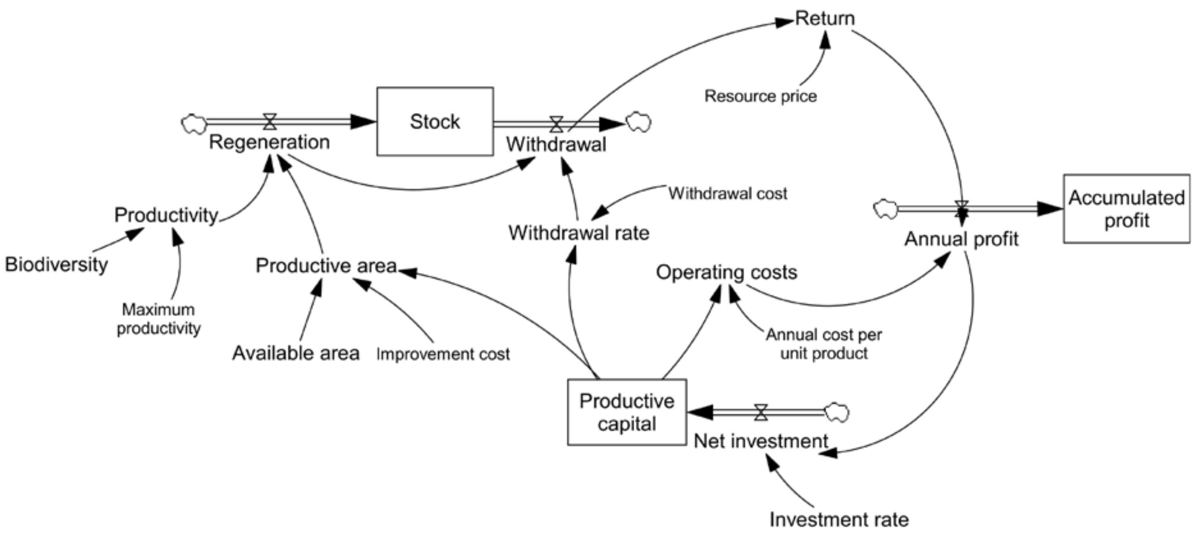
The tons per year of product from the productive areas of the site enable *Withdrawal* (kg/year) that in relation to *Mean price* (€/kg) produces an *Annual return* (€/year). The reference to euros is merely indicative; if we consider multiples of euros (€1000 or €10,000) the dynamics between variables does not change. When applying the model to a particular case, real data and references can be used. Net return (subtracting *Operating costs)* gives *Annual profit* accumulating in the variable *Accumulated profit.* Operating costs in turn depend on *Productive capital* and on *Annual cost per unit product,* which is equivalent to mean annual cost (in €) per € of productive capital (e.g. cost of maintenance of machinery and labour). Part of the annual profit is usually reinvested at a *mean investment rate* in new *Productive capital.*

Figure 19: Model F1-2 (second part).



Equations of model F1-2 (second part):		
6.9	Withdrawal = MIN(Regeneration, Withdrawal rate) *it is assumed that Withdrawal cannot exceed the Regeneration rate*	[kg/year]
6.10	Withdrawal rate = (Productive capital/2)/Withdrawal cost *possible withdrawal depends on capital, which is assumed to be equitably distributed between withdrawal and improvement (see above, 6.7)*	[kg/year]
6.11	Withdrawal cost = 0.2 *it is assumed that withdrawing 1 kg per year costs €0.20*	[(€*year)/kg]
6.12	Productive capital = INTEG (+Net investment, 1) *integral of the variable Net investment with initial value 1*	[€]
6.13	Net investment = Investment rate * Annual profit	[€/year]
6.13.1	Investment rate = 0.1 *initial investment of 10% of Annual profit is assumed*	[Dmnl]
6.14	Annual profit = max(0, Annual return – Operating costs) *profit (difference between costs and returns) cannot be negative*	[€/year]
6.15	Operating costs = Annual cost per unit product * Productive capital *operating and maintenance costs of productive capital*	[€/year]
6.16	Annual cost per unit product = 0.1 *assuming that €1 of productive capital costs €0.10 per year*	[1/year]
6.17	Accumulated profit = INTEG (+ Annual profit, 0) *(integral of the variable Annual profit with initial value 0)*	[€]
6.18	Return = Mean price * Withdrawal	[€/year]
6.19	Resource price = 1 *initially assuming a sales price of €1 per kg*	[€/kg]

Useful considerations on supply of F1 or F2



The system, as modelled, reaches equilibrium in a brief time. As in previous cases, doubling of productive area also doubles the withdrawal possible (

Figure 20). Interestingly, when the investment rate is doubled, an equilibrium in annual withdrawal is reached sooner but accumulated profit is less (

Figure 21). This is explained by the fact that investment beyond a certain threshold does not proportionally increase returns, because returns are limited by “natural” annual productivity. Increased investment is therefore wasted and reduces profit. If the price per unit resource is increased, accumulated profit increases up to the limit of productivity (

Figure 22).

Figure 20: Trend of annual withdrawal and accumulated profit in relation to area: x1 (blue) and x2 (red).

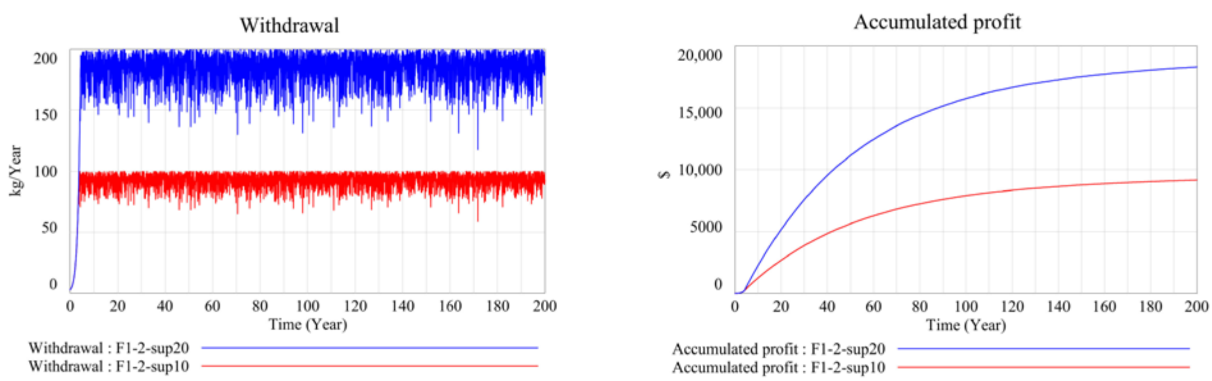


Figure 21: Trend of annual withdrawal and accumulated profit in relation to reinvestment rate: 20% (blue), 40% (red).

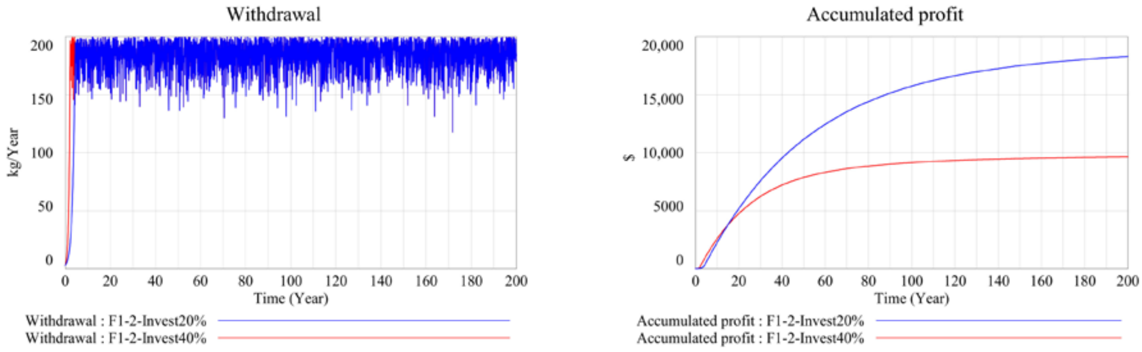
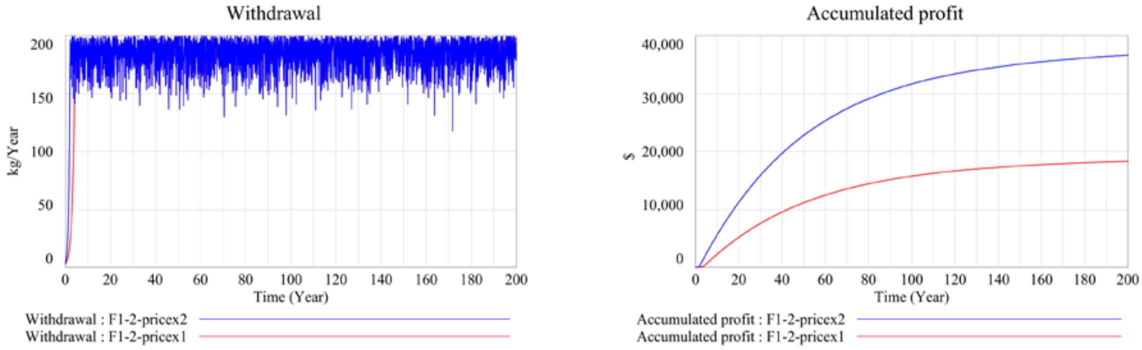


Figure 22: Trend of annual withdrawal and accumulated profit in relation to prices: x1 (blue), x2 (red).



Applications of the model

The causal loop diagram and the semi-quantitative model may be useful:

- for understanding the process of supply of the service and for illustrating it to stakeholders;
- for showing the role of biodiversity, management variables (productive capital, profit) and their interactions.

The model, calibrated with real data, can be used as basis for comparing economic (e.g. variations in mean prices) and ecological scenarios (e.g. variations in productivity).

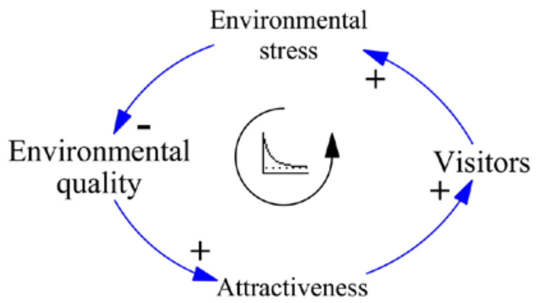
9 C2 - Recreational value

The recreational value of an area is only expressed if the area is accessible and can be visited, i.e. only if the visitor or tourist can enjoy features such as views on the spot. Access depends not only on geography but also on special infrastructure (e.g. hiking trails, mountain huts) that facilitate the visit or enable recreational activities. This ecosystem service therefore partly depends on the natural component (ecosystems that offer recreational spaces and opportunities) and partly on the work of humans (enabling access and enjoyment of said spaces).

The recreational value of Natura 2000 sites in particular depends on many factors according to the context, and various levels of human intervention and/or naturalness can be distinguished. For example, in remote areas (e.g. high altitude), human intervention is generally limited to the opening and maintenance of access tracks. In flat areas, such as river beds, naturally more accessible, recreational value may depend more on artificial structures (e.g. bird watching towers) that make one site more attractive than another in the same area.

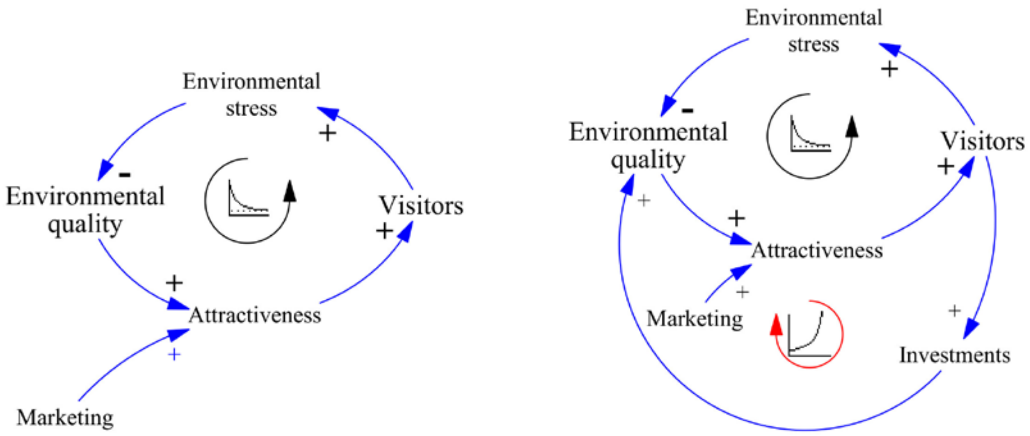
In the relation between the recreational value of a site and its biodiversity, here for brevity called "environmental quality", there is a recurrent dynamic typical of nature tourism: the number of visitors/tourists increases (decreases) with increasing (decreasing) environmental quality, but their increase sooner or later affects environmental quality. In system dynamics terms, the process includes a negative feedback cycle that reduces environmental quality with respect to its initial value before the arrival of visitors (Figure 23).

Figure 23: Elementary model of recreational value service: negative feedback reduces Environmental quality and number of Visitors.



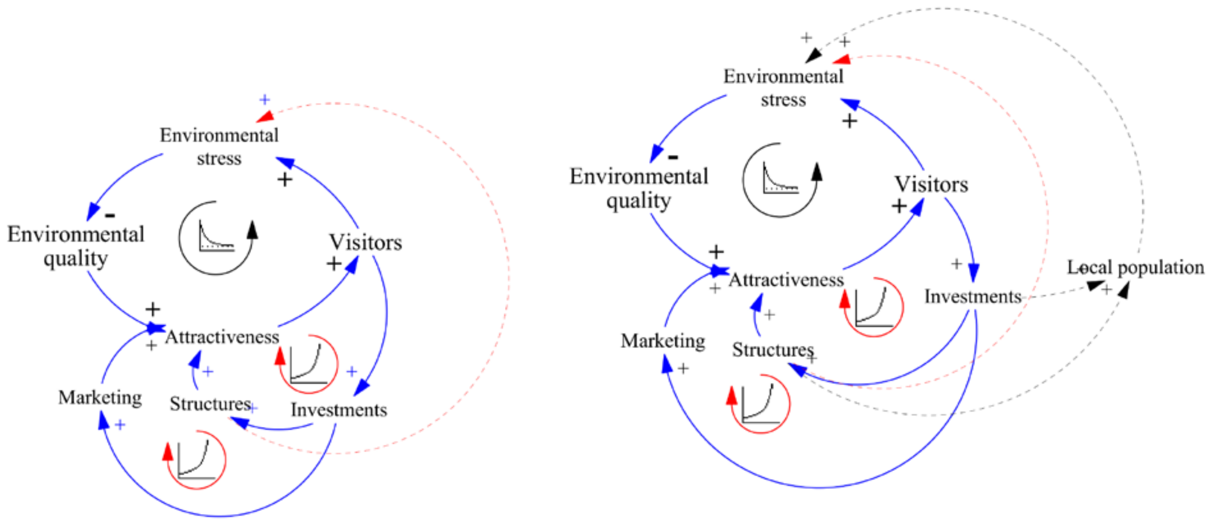
In a basic model, the variables that link *visitors* and *environmental quality* are *attractivity* and the level of *environmental stress,* namely the set of negative impacts on the functionality of the area to host its biodiversity (Figure 23). As already mentioned, attractivity may in some cases increase through *marketing* (left, Figure 24). On the other hand, the number of visitors can locally provide resources for *investments* for improvement or maintenance of *environmental quality* (right, Figure 24). This creates two opposite feedback loops: a negative one tending to stabilise the system and a positive one tending to promote indefinite growth; the two can strike a balance that can result in sustainability of the recreational service.

Figure 24: Causal diagram with a negative loop (left, model C2-1), and with two opposite loops (right, model C2-2).



Unsustainable dynamics may occur if *investments* are aimed at increasing *attractivity* through *marketing* and *structures* for recreational activity, without proportionally increasing or maintaining *environmental quality*. In these conditions, two feedback loops, decoupled from *environmental quality,* can be created (Figure 25), and may destabilise the system: decreasing (or cancelling) the stabilising function of the feedback between *environmental quality* and *visitors*, and leading to a rapid increase in environmental stress (no longer controlled internally by the system). Dynamics that are even worse for lasting environmental quality may occur when *investments* and *structures* attract new human settlement and population.

Figure 25: Model C2-3 (left) and model C2-4 (right) with feedbacks potentially independent of environmental quality.

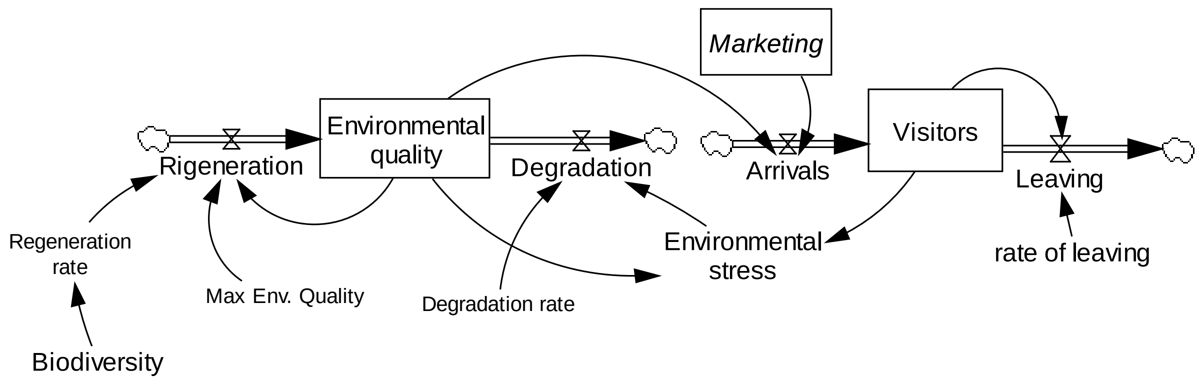


Considering these dynamics, different types of socio-ecological system, in which ecological and human variables are interdependent, can be distinguished (Resilience Alliance, 2008), as shown in Table 1.

Table 1. Three models of increasing complexity (according to different socio-ecological systems) for recreational services.

Model	Type of system	Key variable	Management variables
C2-1	Remote areas with reduced human presence	• Environmental quality • Visitors	• Marketing
C2-2	Natural areas with margin for environmental improvement	• Environmental quality • Visitors	• Marketing • Investments on environment quality
C2-3	Areas where infrastructure could be developed	• Environmental quality • Visitors • Infrastructure	• Marketing • Investments on environment quality • "Artificial" attractivity

9.1 Model C2-1



Equations of model C2-1		
7.1	Arrivals = Marketing*Environmental quality	[visitors/year]
7.2	Biodiversity = 0.8 *Biodiversity level, initially supposed to be lower than1 (or 100% of local species)*	[Dmnl]
7.3	Degradation = Degradation rate * Environmental stress *The level of quality lost per year due to Environmental stress and Degradation rate*	[quality/year]
7.4	Degradation rate = 0.1 *Level of environmental quality lost per annual visitor (or multiple)*	[1/(visitors*year)]
7.5	Environmental quality = INTEG(+Regeneration-Degradation, 1) *Level of environmental quality, between 0 and 1, with initial value 1*	[quality]
7.6	Environmental stress = Visitors*Environmental quality *Function of number of visitors and quality level*	[quality* visitors]
7.7	Leaving = visitors * Rate of leaving	[visitors/year]
7.8	Marketing = 10 *equivalent to saying that marketing "attracts" a new visitor per year for the level of environmental quality*	[visitors/(quality*year)]
7.9	Maximum environmental quality = 1 *associated to the maximum level of local biodiversity*	[quality]
7.10	Rate of leaving = 0.5 *Rate of leaving or of "not returning", or in other terms, 50% of visitors do not*	[1/year]

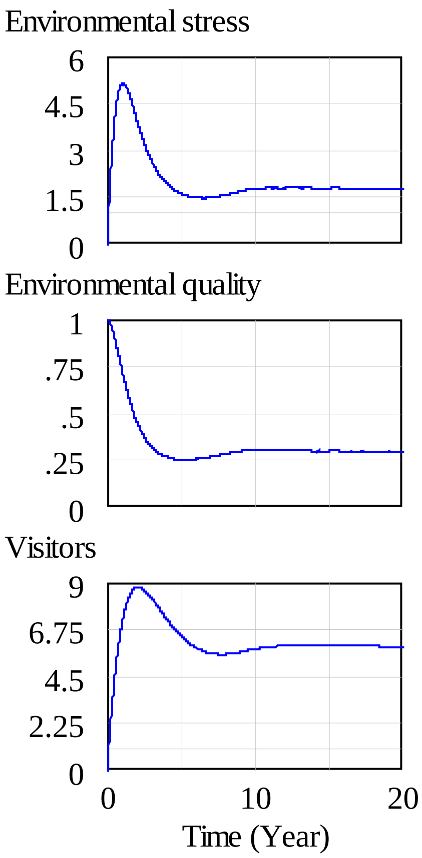
	return a second year or do not recommend it to others	
7.11	Regeneration = Regeneration rate * Environmental quality * (1- Environmental quality/Maximum environmental quality) *value limited by Maximum environmental quality*	[quality/year]
7.12	Regeneration rate = RANDOM NORMAL(0.5, Biodiversity, Biodiversity, 0.2, 222) *Pseudo-random number with distribution "centered" on biodiversity level (minimum 0.5), it approximates the randomness of ecological process*	[1/year]
7.13	Visitors = INTEG (+Arrivals-Leaving, 0) *Initial value 0, but can be scaled with real data*	[visitors]

As in previous models, certain variables are defined in qualitative terms, the meaning of which is more important than the value. The definition of *environmental stress* indicates that the impact of a given number of visitors depends on the level of environmental quality; in other words, the environmental stress caused by a visitor is greater in a site with maximum environmental quality than in a degraded site. The number of visitors is initially set at 0 and oscillates around a level of equilibrium depending upon marketing success and environmental quality, realizing the negative (stabilizing) feedback loop in the Figure 22. In absolute terms, these are not realistic numbers, but it should be recalled that: i) the variables can be scaled with real data, ii) once calibrated, the dynamics between them generally does not change.

Useful considerations from model C2-1

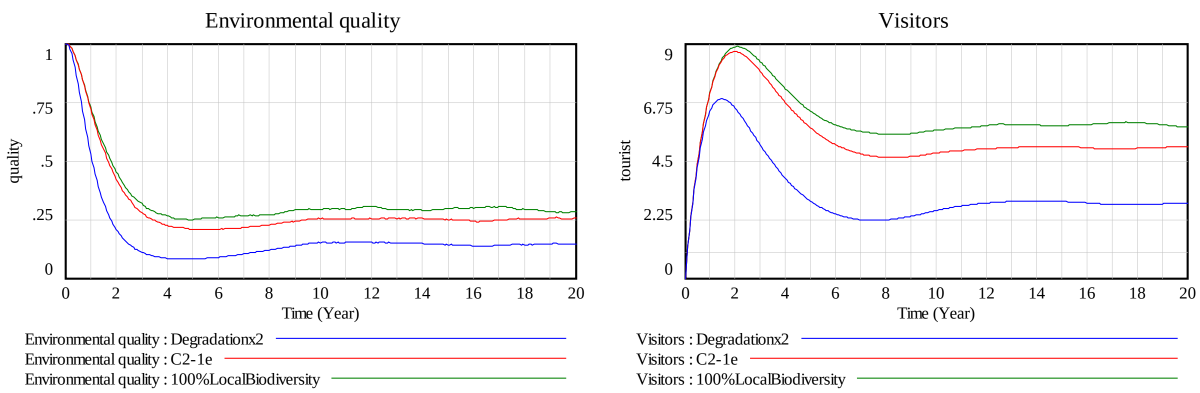
Depending on the negative feedback loops between key variables, the system stabilises to a lower value of environmental quality and a "sustainable" number of visitors in relation to the regeneration rate and environmental degradation.

Figure 26: Dynamics of the main variables in a system in equilibrium (model C2-1).



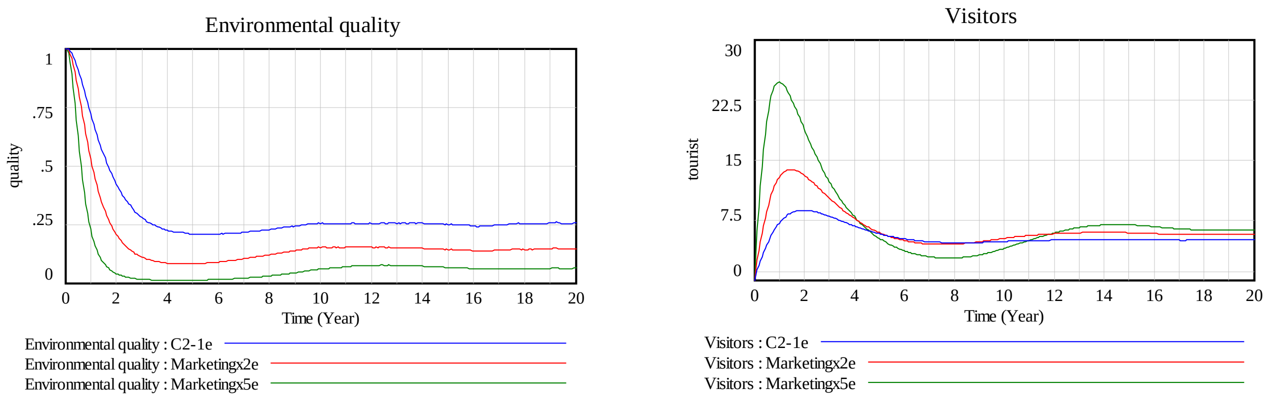
With doubling of the degradation rate, *environmental quality* and *visitors* reach equilibrium values that are almost half those of initial conditions (red line and green line in Figure 27**Error! Reference source not found.**). With the hypothesis of maximum biodiversity (say 100% of expected local species), in other words +20% in the regeneration rate, these values would increase proportionally (green line).

Figure 27: Dynamics of Environmental quality and Visitors in scenarios with different regeneration or degradation rates.

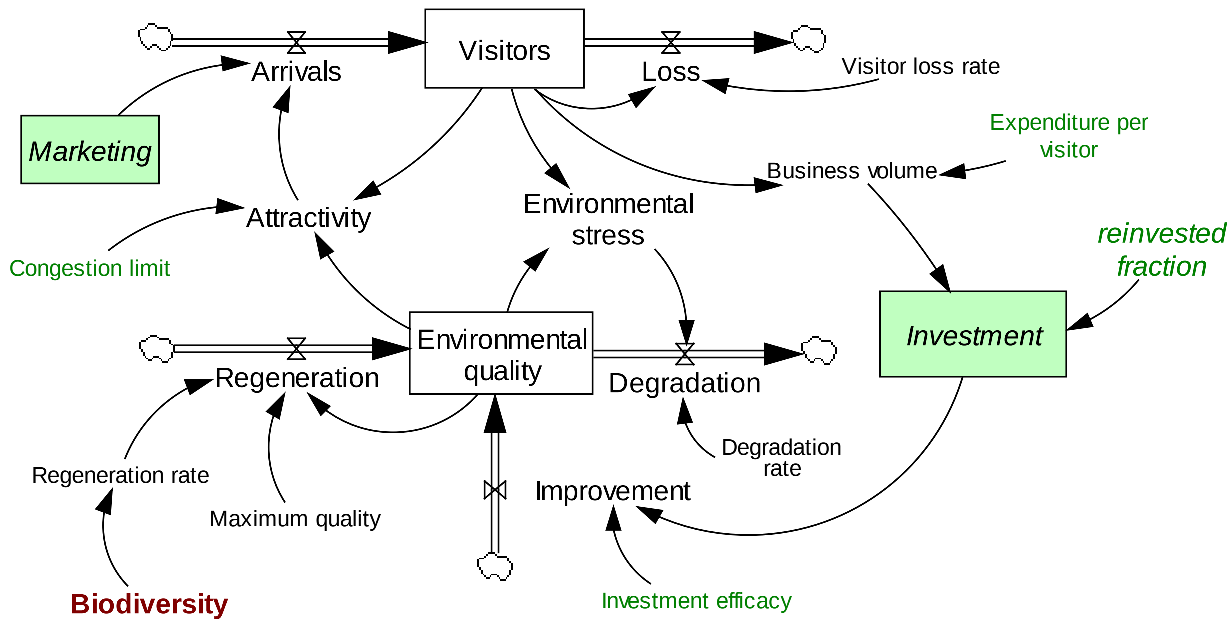


The dynamics of environmental quality and number of visitors oscillates to reach an equilibrium, which is also related to management variables. If marketing is doubled (e.g. through a publicity campaign), environmental quality decreases (by about 50%), but the number of visitors does not increase proportionally, rather the dynamic shows a larger oscillation, finally reaching close values.

Figure 28: Dynamics of Environmental quality and Visitors in scenarios with different marketing levels.



9.2 Model C2-2



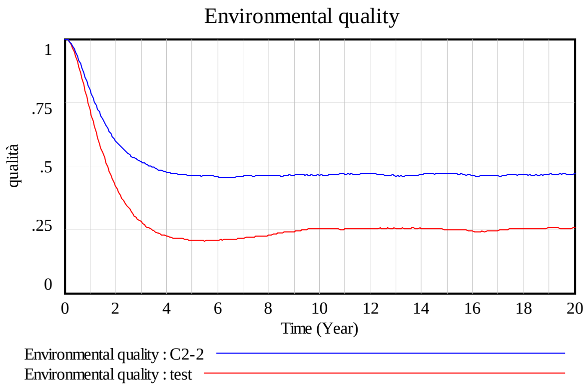
Equations of model C2-2:

8.1	Arrivals = Marketing * Environmental quality	[visitors/year]
8.2	Attractivity = Environmental quality*(1-Visitors/Congestion limit)	[Dmnl]
8.3	Business volume = Visitors * cost per visitor	[€]
8.4	Biodiversity = 0.8 *Biodiversity level, initially supposed to be lower than1 (or 100% of local species)*	[Dmnl]
8.5	Congestion limit=20 *Maximum number of other visitors tolerated by one visitor*	[visitors]
8.6	Degradation = Degradation rate * Environmental stress *The level of quality lost each year due to Environmental stress* and *Degradation rate*	[quality/year]

8.7	Degradation rate = 0.1 *Level of environmental quality lost per annual visitor (or multiples)*	[1/(visitors*year)]
8.8	Environmental quality = INTEG(+Regeneration-Degradation+Improvement, 1) *Level of environmental quality, between 0 and 1, with initial value 1*	[quality]
8.9	Environmental stress = Visitors * Environmental quality *Function of number of visitors and quality level*	[quality* visitors]
8.10	Expenditure per visitor = 1 *mean expenditure per visitor, initial dummy value €1*	[€/visitor]
8.11	Improvement = Investments * Investment efficacy	[1/year]
8.12	Investments = Business volume * Fraction reinvested *Investments to improve environmental quality*	[€]
8.13	Investment efficacy = 0.1 *Increment in quality per € invested per year*	[quality /(€*year)]
8.14	Loss = Visitor loss rate * Visitors	[visitors/year]
8.15	Marketing = 10 *equivalent to saying that marketing "attracts" 10 new visitors per year per increment in environmental quality level*	[visitors/(quality* year)]
8.16	Maximum quality = 1 *associated to the maximum level of local biodiversity*	[quality]
8.17	Regeneration = Regeneration rate * Environmental quality * (1- Environmental quality/Maximum environmental quality) *As in the previous models, value is limited by Maximum environmental quality*	[quality/year]
8.18	Regeneration rate = RANDOM NORMAL(0.5, Biodiversity, Biodiversity, 0.2, 222) *Pseudo-random number with distribution "centred" on biodiversity level (minimum 0.5)*	[1/year]
8.19	Reinvested fraction = 0.1 *Fraction of sales figures reinvested in environmental improvements, initial value 10%*	[Dmnl]
8.20	Visitors = INTEG (+Increase-Loss, 0) *Initial value 0, but may be scaled with real data*	[visitors]
8.21	Visitor loss rate = 0.5 *Rate of leaving or of "not returning", or in other terms, 50% of visitors do not return a second year or do not recommend it to others*	[1/year]

In this model, we consider *investments* in *environmental quality* (eg. maintenance, environmental remediation or compensation of tourism impacts), from the partial reinvestment of the revenues obtained from the expenditure of the tourists / visitors on the site. Another new element is the variable *attractiveness*, dependent on the *environmental quality* and limited by the number of visitors according to a threshold of *congestion* (the number of other visitors tolerated by the individual visitor). Again, the values are purely fictitious and should be integrated and calibrated by means of field surveys.

Figure 29: Dynamic of the *environmental quality* in the model C2-2 (blue line) and the model C2.1 (red line).

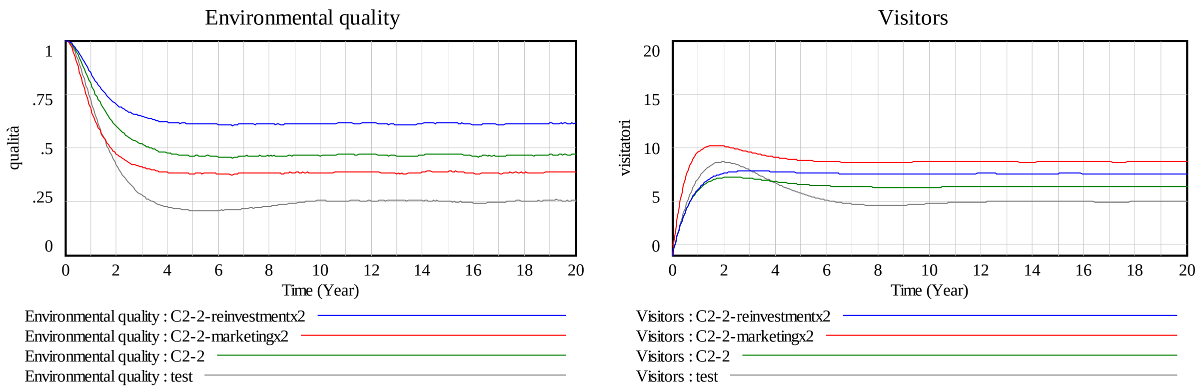


Useful considerations from model C2-2

The *investments* in the environmental improvement partially compensate the negative impact of visitors on *environmental quality*. As shown in the Figure 27, this variable reaches an equilibrium value higher than in the previous model (C2.1). Here, in the model C2.2 two compensatory mechanisms act in the system: congestion and investment.

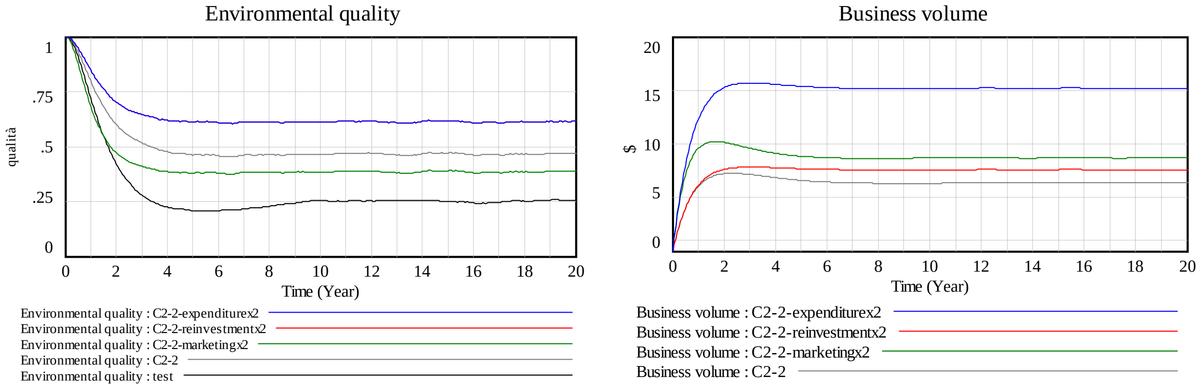
As above, it is interesting to simulate scenarios in which variables change. For example, if we double marketing efforts, environmental quality decreases, but less than in the previous model (Figure 30), because it is compensated by improvements induced by higher investments (funded by higher incomes, due to higher number of visitors). Another interesting element is the relation between environmental quality and fraction reinvested: beyond a certain investment rate, environmental quality may be greater than initially.

Figure 30: Dynamics of environmental quality in Model C2-2 with changes in marketing and reinvestment rate.



This model includes different variables (cost per visitor, fraction reinvested, marketing) that can guide management and/or local development strategies. Considering possible changes in investments, cost per visitor and marketing, the model provides answers to questions such as: what strategy most increases the volume of business and at what price for environmental quality?

Figure 31: Dynamics of *environmental quality* and *business volume* with changes in marketing, reinvestment rate, and expenditure per visitor.

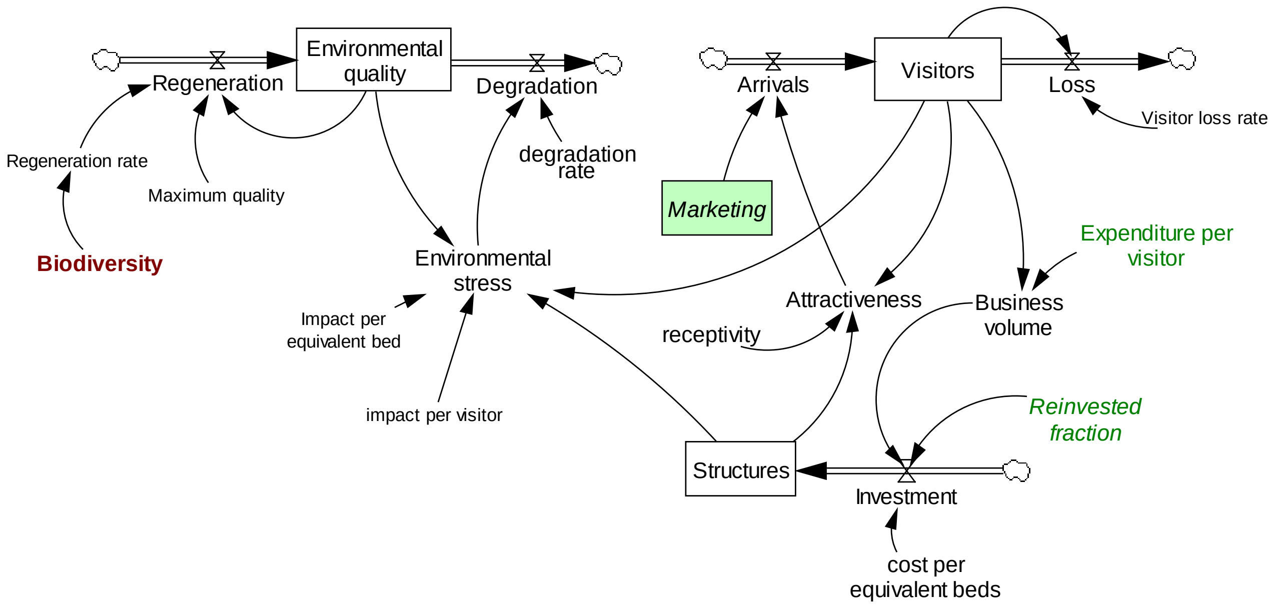


In the model C2-2, the best strategy appears to be that increase spending per visitor: it increases the environmental quality (with an impact identical to that derived the option of doubling the rate of re-investment of revenues) and increase revenues (on condition to keep other variables unchanged, eg. the rate of re-investment in environmental quality).

9.3 Model C2-3

As mentioned above, in certain situations the number of visitors may depend only on external inputs, such as investment in artificial attractions (or structures) and in marketing, which builds "artificial" instead of "natural" attractivity. When *visitors* and *environmental quality* are decoupled, as in the model C2-3, the environmental quality of the system becomes eroded. The dynamics of environmental quality may be aggravated if environmental stress due to the number of visitors and structures is added to that of an increasing local population (e.g. motivated by job availability). We now show a system model without the variable population, since the dynamics are the same.

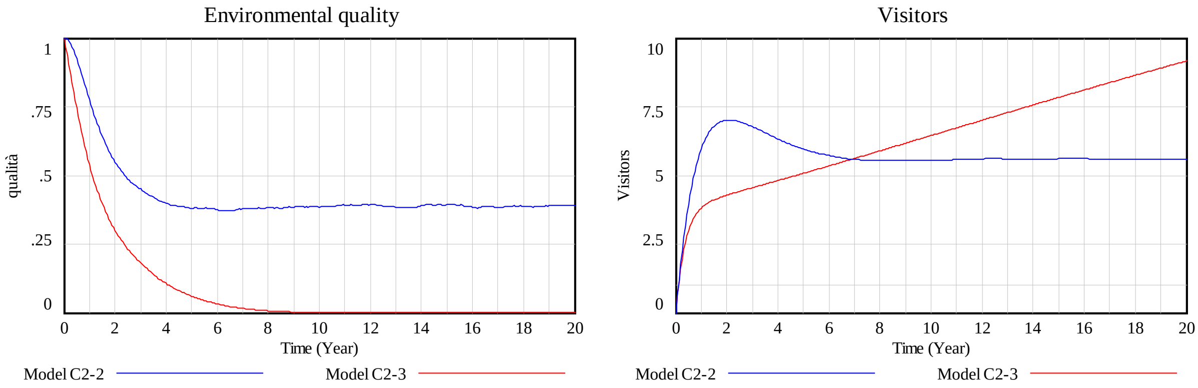
Figure 32: Model C2-3: the variable *Visitors* and *Structures* are connected by positive feedback loop, but not influenced by the *Environmental quality*.



The model C2-3 includes the variable *structures*, measured in terms of number of equivalent visitors or beds or recreational spaces equipped for visitors. The variable *attractiveness* is simplified as free spaces/beds, or the difference between the number of available places and the current number of visitors, assuming that a greater number of free spaces is more attractive. In such model, each *visitor* and each *structure* determines its own specific impact that sum in generating *environmental stress*.

Finally, the system represented by the model C2-3 has a positive feedback loop, as shown in Figure 23, that is not offset by any negative feeback; from the simulation, we can see how *visitors* and *structures* can grow indefinitely until destroy *environmental quality*.

Figure 33: Dynamics of *environmental quality* and *visitors* in model C2-3 (green line), model C2-1 and C2-2.



Useful considerations from model C2-3

The structure of the model determines the possible dynamics between the variables in question. Specifically, the presented model shows the unsustainable dynamics of recreational use in the absence of investments for environmental maintenance and/or improvement, in other words, in absence of negative feedback loops stabilizing the system.

In general, some of negative loops cannot be totally controlled, such as congestion effect (see C2-2); others are crucial issue for management, such as investment in environment conservation or maintenance; both these types should be at least considered and possibly investigated at site level for effective local policies. Although most of the presented trends are intuitive and well known, the diagram and semi-quantitative scenarios, resulted from system dynamics approach, provide clear and relevant information that can be shared with stakeholders and agents in the tourism sector for planning purposes.

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