Alma Mater Studiorum · Università di Bologna

Scuola di Scienze
Dipartimento di Fisica e Astronomia
Corso di Laurea Magistrale in Fisica

Science of complex systems and future-scaffolding skills: a pilot study with secondary school students

ALLEGATI

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Annexes

Annex A1 - Non-linearity of complex systems: the Lotka-Volterra model (complete version)

The Lotka–Volterra equations, also known as the predator–prey equations, are a pair of first order, non-linear, differential equations frequently used to describe the dynamics of biological systems in which two species interact, one as a predator and the other as prey. Two variables have to be considered: the number of preys (x) and that of predators (y). Both the populations change through time, so we refer to $x(t)$ as the number of preys at time t and to $y(t)$ as the number of predators at the same time. So, the equations can be written in this way:

$$\frac{dx(t)}{dt} = Ax(t) - By(t)x(t)$$
$$\frac{dy(t)}{dt} = Cx(t)y(t) - Dy(t)$$

Now we are explaining in some details the components of these equations, for a better understanding about the characteristics of the model.

$\frac{dx(t)}{dt}$ and $\frac{dy(t)}{dt}$ respectively indicate the variation of the population of preys and predators over time: they are called growth rates.

A, *B*, *C* and *D* are positive coefficients used to detail the interaction between the species:

- *A* is the coefficient of birth of preys; the bigger is *A*, the faster is the positive contribution to the growth rate of preys.
- *B* is the coefficient of predation; it indicates how fast the predators eat preys and, multiplied for both the number of preys and predators, it negatively contributes to the growth rate: indeed, the bigger is *B*, the faster *x* decreases.
- *C* is the coefficient of encounter between preys and predators; multiplied for *x* and *y*, *C* represents the growth of the predator population. It could seem similar to the coefficient of predation *B* but a different constant is used because the rate at which the predator population grows is not necessarily equal to the rate at which it consumes the prey.
- *D* is the coefficient of natural death of predators; multiplied for the number of predators themselves, it negatively contributes to the growth rate: indeed, the bigger is *D*, the faster *y* decreases.

<u>The zero-interaction model</u>

If there was not any significant interaction between the two species, we would have to set $B = C = 0$, and in this way just *A* and *D* would remain. The two equations become:

$$\frac{dx(t)}{dt} = Ax(t)$$
$$\frac{dy(t)}{dt} = -Dy(t)$$

This simplified version of the equations allows us to better understand the assumptions of the model. In absence of predators, the first equation is a typical differential equation which gives as a solution the exponential function:

$$x(t) = x_0 e^{At}$$

where x_0 is the number of preys at time *t*. The same happens for *y(t)*, with the only difference that the solution is a negative exponential:

$$y(t) = y_0 e^{-Dt}$$

where y_0 is the number of predators at time *t*.

Hence, we can highlight some assumptions of the Volterra-Lotka model:

- the prey population finds ample food at all times and, in absence of predators, grows indefinitely, since the preys do not die by natural death (Assumption 1);
- in absence of preys to eat, the predators population decreases by natural death, since its food supply depends entirely on the size of the prey population (Assumption 2).

A simulation written in Python programming language can be easily used to prove the behaviour of the model, plotting the evolutions of the moose and wolf populations. For example, with a suitable choice of parameters[1] and initial conditions, the resulting plot is shown in Figure 1. The exponential behaviour of both the time evolutions – positive for the preys and negative for the predators – is evident.

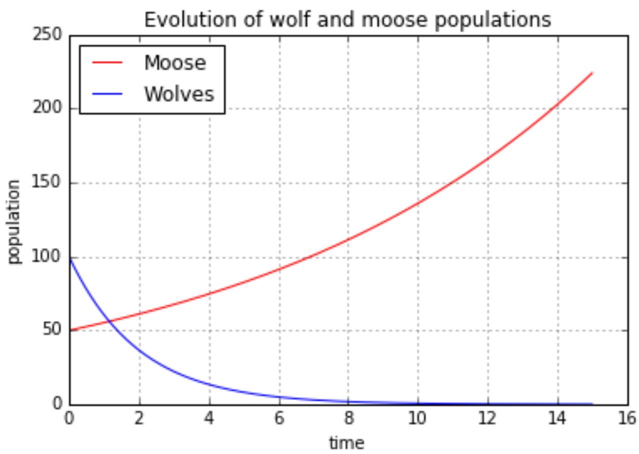


Figure 1. Exponential evolution of preys (moose) and predators (wolves) with this choice of parameters $A = 0.1$, $B = 0.00001$, $C = 0.00001$, $D = 0.5$ and initial conditions $x_0 = 50$, $y_0 = 100$.

[1] It is not possible to set $B = C = 0$ because the calculus of the equilibrium position would be impossible for the programme (division by 0 is not defined). So, one has to choose B and C so that the relation $B,\ C \ll A,\ D$ holds.

The periodic solutions of the model

Now, we can go back to the initial formulation of the complete equations of the model and, resetting the parameters at "normal" values (without B and C being near 0), the output of the programme is the periodic plot in Figure 2.

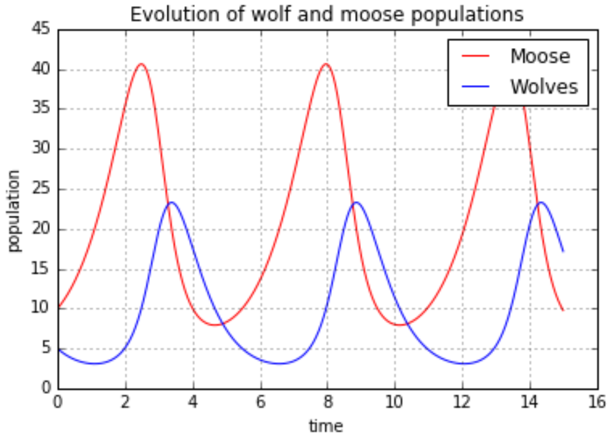


Figure 2. Periodic evolution of preys (moose) and predators (wolves) with this choice of parameters $A = 1$, $B = 0.1$, $C = 0.075$, $D = 1.5$ and initial conditions $x_0 = 10$, $y_0 = 5$.

For every running of the algorithm, the plot displays the periodic solutions of our system of equations, given the parameters and the initial conditions that we chose. These oscillations can be explained identifying in Figure 2 the subsequent phases of increasing and decreasing of populations. This procedure is reported in three steps in Figure 3.

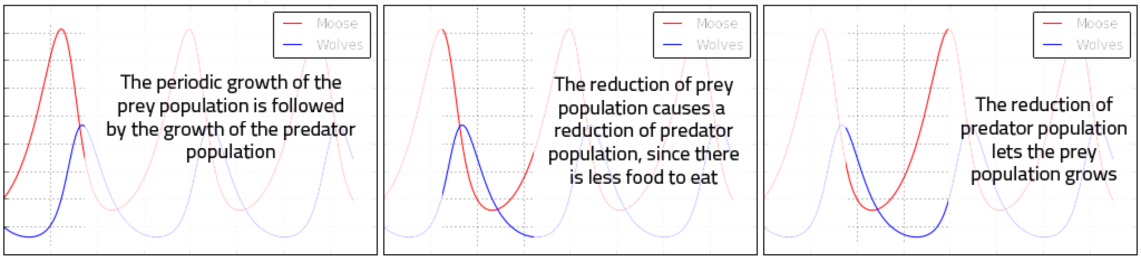


Figure 3. Comments about the periodic evolution of preys (moose) and predators (wolves), with respect to their time evolution in Figure 2.

If we stop at this stage of the analysis, we remain within a linear conception of causality: one step calls a second one which causes another one. But we could imagine to continue the reasoning begun in Figure 3 in order to see explicitly the positive feedback loop that is the cause of the time oscillation of this system. This procedure is displayed in Figure 4.

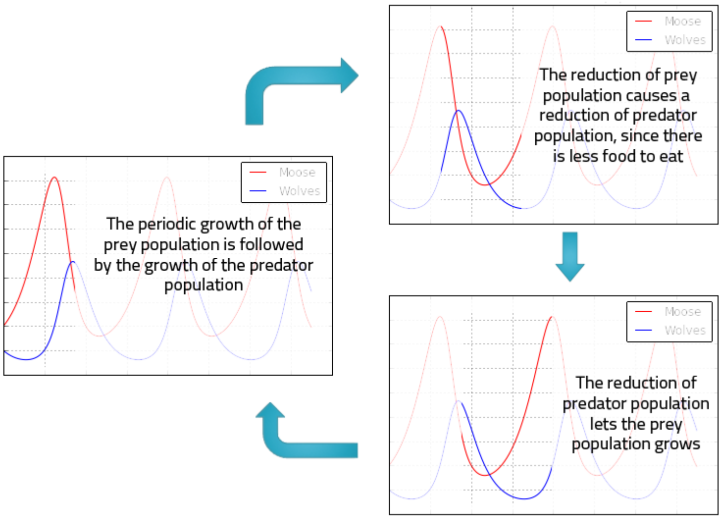


Figure 4. Reinterpretation of the linear explanation in Figure 3 as a circular positive feedback loop.

<u>Discovering the meaning of the parameters</u>

Changing the values of the parameters of the model, their meaning and role can be better understood. It is convenient to change only one parameter at each running of the script, so that its role can be separated from that of the other ones. In Figure 5, 6, 7 and 8 we respectively let A, B, C and D change; the initial conditions are set at $x_0 = 10$ and $y_0 = 5$.

The parameter A controls the birth rate of preys. In Figure 5, from left to right, A decreases and the time required for the growth of the moose population grows. In a certain sense, A controls the period of the time oscillation.

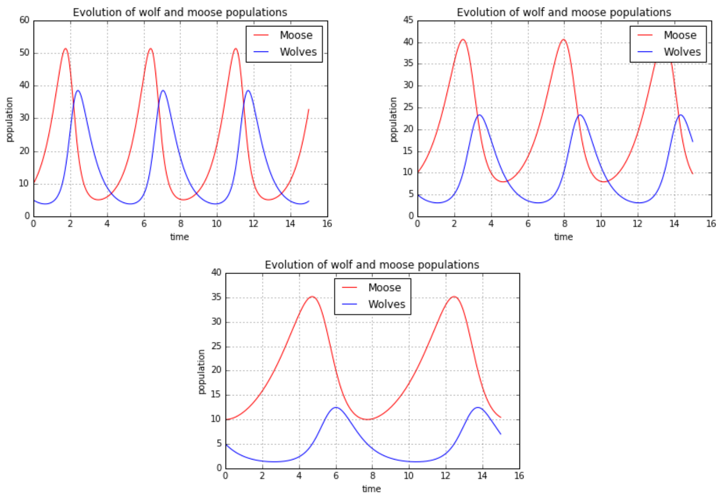


Figure 5. Dependence of the time evolution from the parameter A: 5.left) A = 1.5, B = 0.1, C = 0.075, D = 1.5, 5.centre) A = 1, B = 0.1, C = 0.075, D = 1.5, 5.right) A = 0,5, B = 0. 1, C = 0.075, D = 1.5.

The parameter B indicates how frequently the preys are eaten by the predators. In Figure 6, from left to right, B decreases; he period of the oscillations remains the same but, when

B gets smaller, the maximum value of predator population sensitively changes (blue curves are lower and lower). This is reasonable because, if the predation is very frequent, the number of predators grows up to high values, while, at the opposite, if the predation is a rare fact, the predators cannot reach an high number of samples.

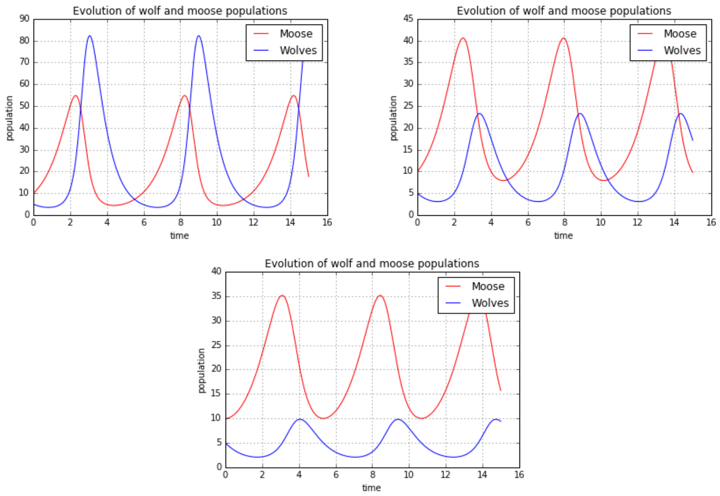


Figure 6. Dependence of the time evolution from the parameter 6: 4.left) A = 1, B = 0.04, C = 0.075, D = 1.5, 6.centre) A = 1, B = 0.1, C = 0.075, D = 1.5, 6.right) A = 1, B = 0.2, C = 0.075, D = 1.5.

The parameter *C* is the coefficient of encounter between preys and predators. About it, the same comments made above with regard to *B* hold true.

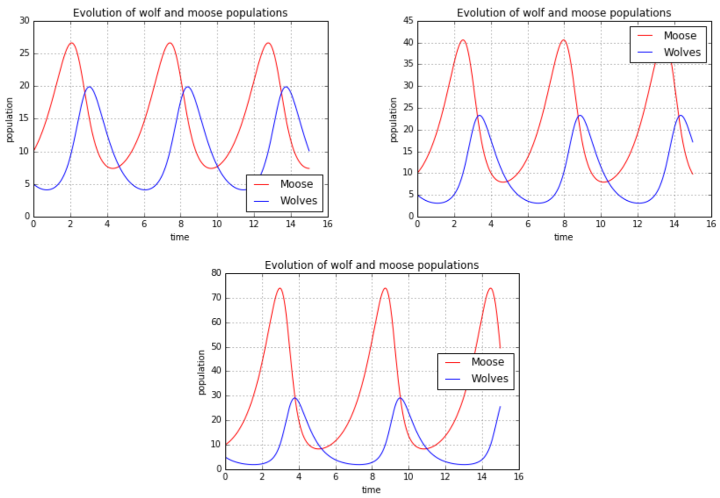


Figure 7. Dependence of the time evolution from the parameter C: 7.left) A = 1, B = 0.1, C = 0.1, D = 1.5, 7.centre) A = 1, B = 0.1, C = 0.075, D = 1.5, 7.right) A = 1, B = 0.1, C = 0.05, D = 1.5.

The parameter *D* is the coefficient of natural death of predators. An high value of *D* means that the predators die frequently, allowing preys to grow more rapidly and to reach higher values of individuals. As *D* decreases, the period of oscillation changes as well as the maximum number of preys and predators.

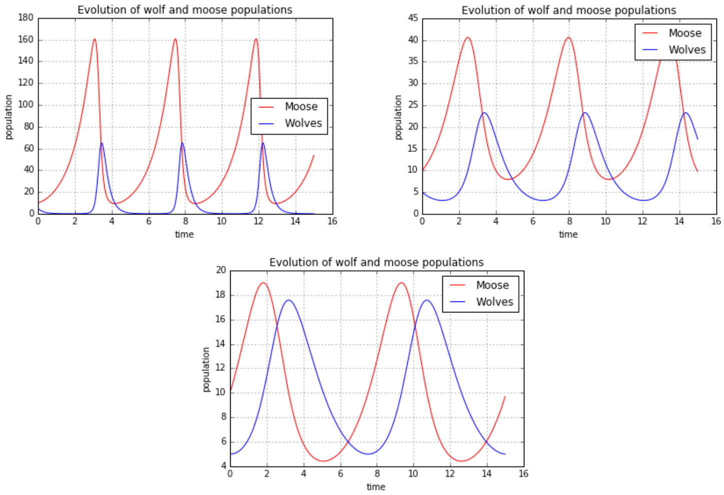


Figure 8. Dependence of the time evolution from the parameter D: 8.left) A = 1, B = 0.1, C = 0.075, D = 4, 8.centre) A = 1, B = 0.1, C = 0.075, D = 1.5, 8.right) A = 1, B = 0.1, C = 0.075, D = 0.75.

<u>From the model to the reality</u>

After having discovered the meaning and role of all the parameters of the model and its interpretation at the light of circular causality, the results of our simulation can be compared with real data. We can consider a famous example of the predator-prey relationship: the one between wolves and moose on Isle Royale, an island in Lake Superior in Michigan. This unique relationship has been subject of detailed study for over 55 years because it is considered very similar to the situation described from the model. Indeed, being an isolated island, there is little migration of animals into and out of it and, as a national park, human interaction and impact on the two species is also limited.

The applet http://www.phschool.com/atschool/phbio/active_art/predator_prey_simulation/ shows the ideal behaviour of the model (obtained with a programme like the one we used above) versus the real data measured for wolves and moose on Isle Royal. The experimental curves are reported in Figure 9.

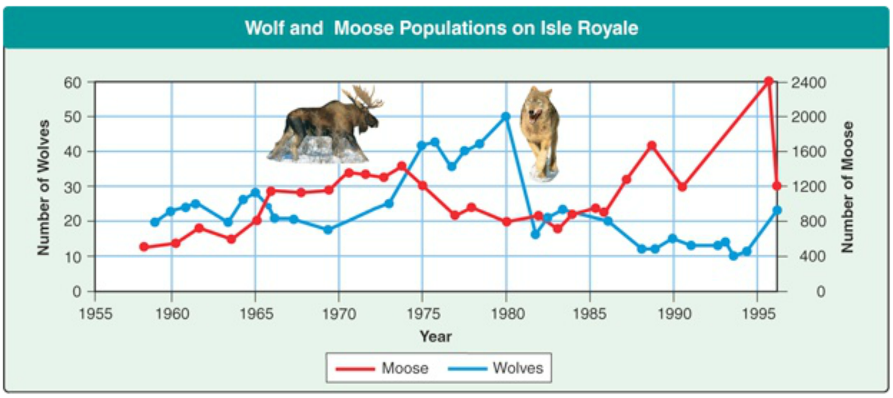


Figure 9. 40 years evolution of the wolf and moose population on Isle Royale.

The graph obtained in Figure 9 is very different to the periodic evolution showed in all the plots above. This requires a comment about the other implicit assumptions of the model that we have not noticed yet: during the process described from the model, the environment does not change in favour of one species and there are not any factors (diseases, famines, genetic mutations, fitness problems…) that cause premature deaths or damages for the one or both the populations (Assumption 3). This is not the case of Isle Royale's interaction.

As an isolated island, the Isle Royale initially had neither wolves nor moose. The moose are believed to have either swam across Lake Superior from Minnesota in the early 1900s; in 1949 a pair of wolves crossed an ice bridge from Ontario to the island during a harsh winter. But because only one pair or wolves migrated to the island, they have suffered from severe inbreeding, losing genetic variability (all the wolves' DNA on Isle Royale can be traced back to one ancestor). Inbreeding leads to mutations and fitness problems, often accompanied by violent social rejection by other wolves. So, the Assumption 3 does not hold true.

Moreover, moose prefer birch and aspen trees, which used to grow plentifully on the island, but over a century of moose browsing have been largely replaced by the less nutritious balsam fir. But also the resources of balsam fir are limited: it is observed that when the moose population grows too high, the balsam fir population crashes, leading to a crash in the moose population. This is a negative feedback loop and it makes the Assumption 1 not verified.

Also the Assumption 2 is not true for the Isle Royale case. Indeed, moose make up nine-tenths of a wolf's diet: the remaining 10% consists of snowshoe hares and beavers. So, there are not only two species in interaction and the Lotka-Volterra model cannot be reasonably applied.

Possible improvements of the model… and a sad conclusion

The model can be improved by adding parameters which take into account some elements that help in order to make the model more similar to the real situation. With the applet already mentioned, it is possible to set a value also for two other coefficients:

- habitat variability: how often factors other than the ones you are controlling, such as density-independent factors (weather), and density-dependent factors (disease) change. This parameter has value between 1, if the habitat is not so variable, and 100, if it is extremely variable;
- carrying capacity: the largest number of individuals of a population that a given environment can support. This parameter is an average percentage and it is included between 50% and 150%.

Changing their values it is possible to see the changes in the graphs with respect to the standard Lotka-Volterra. Anyway it can be easily recognized that, like all the models, through all the possible improvements with the addition of other coefficients, it can never take into account the whole complexity of the real world. Using other words: also the use of the two parameters described, that had the main goal of relaxing the validity conditions of the model, is not enough to reproduce the experimental behaviour for moose and wolves on Isle Royale.

About the Python script: structure and comments

In the followings, we report the brief Python script for the integration of Lotka-Volterra equations, adding comments about the structure and the role of the functions used. In red are written the lines of code that have to be modified by the user in order to obtain the different plots described above.

Firstly, from the library `numpy` the operation of multiplication is imported, an abbreviation for the library `pylab` is chosen and the four parameters of the model are defined at default values.

```
from numpy import *
import pylab as p
a = 1
b = 0.2
c = 0.075
d = 1.5
```

Now we have to define the function named `dX_dt`, which has `X` and `t` (set equal to 0 by default) as its arguments; this function returns an array of two components: the first component is the right side member of the preys equation, while the second component is the right side member of the predators equation. The notation `X[0]` indicates the first component of the vector `X[1]`, while `X[1]` refers to its second component.

```
def dX_dt(X, t=0):
    return array([ a*X[0] -   b*X[0]*X[1] ,
                   c*X[0]*X[1] - d*X[1]])
```

After having defined the parameters and the function to be integrated, we need to import from the library `scipy` the function `integrate`, written to integrate a system of ordinary differential equations. The 1000 components vector `t` is defined: its first component is 0, its last one is 15 and `linspace` automatically add other 998 equispaced components. `X0` is the 2-dimensional vector in which we set the initial conditions for the prey population (first component) and the predator one (second component). Now, it is possible to use the function integrate: the first argument is the function `dX_dt` that we want to integrate, the second one is the vector of initial conditions and the third one is a sequence of time points for which to solve for our function.

```
from scipy import integrate
t = linspace(0, 15,  1000)
X0 = array([10, 5])
X = integrate.odeint(dX_dt, X0, t)
```

Finally we use `Matplotlib` to plot the evolution of both populations and save the figure obtained in the same folder in which is the script file (note that if you subsequently run the script, the file is overwritten at each launch).

```
moose, wolves = X.T
f1 = p.figure()
p.plot(t, moose, 'r-', label='Moose')
p.plot(t, wolves  , 'b-', label='Wolves')
p.grid()
p.legend(loc='best')
p.xlabel('time')
p.ylabel('population')
p.title('Evolution of wolf and moose populations')
f1.savefig('moose_and_wolves_1.png')
```

Annex A2 - Non linearity of complex systems: the Lotka-Volterra model (tutorial version)

The Lotka–Volterra equations, also known as the predator–prey equations, are a pair of first order, non linear, differential equations frequently used to describe the dynamics of biological systems in which two species interact, one as a predator and the other as prey. Two variables have to be considered: the number of preys (x) and that of predators (y). Both the populations change through time, so we refer to $x(t)$ as the number of preys at time t and to $y(t)$ as the number of predators at the same time. So, the equations can be written in this way:

$$\frac{dx(t)}{dt} = Ax(t) - By(t)x(t)$$
$$\frac{dy(t)}{dt} = Cx(t)y(t) - Dy(t)$$

Now we are explaining in some details the components of these equations, for a better understanding about the characteristics of the model.

$\frac{dx(t)}{dt}$ and $\frac{dy(t)}{dt}$ respectively indicate the variation of the population of preys and predators over time: they are called growth rates.

A, *B*, *C* and *D* are positive coefficients used to detail the interaction between the species:

- *A* is the coefficient of birth of preys; the bigger is *A*, the faster is the positive contribution to the growth rate of preys.
- *B* is the coefficient of predation; it indicates how fast the predators eat preys and, multiplied for both the number of preys and predators, it negatively contributes to the growth rate: indeed, the bigger is *B*, the faster *x* decreases.
- *C* is the coefficient of encounter between preys and predators; multiplied for *x* and *y*, *C* represents the growth of the predator population. It could seem similar to the coefficient of predation *B* but a different constant is used because the rate at which the predator population grows is not necessarily equal to the rate at which it consumes the prey.
- *D* is the coefficient of natural death of predators; multiplied for the number of predators themselves, it negatively contributes to the growth rate: indeed, the bigger is *D*, the faster *y* decreases.

The zero-interaction model

If there was not any significant interaction between the two species, we would have to set $B = C = 0$, and in this way just *A* and *D* would remain. Write the new form of the equations with this choice of parameters:

This simplified version of the equations allows us to better understand the assumptions of the model. In absence of predators, the first equation is a typical differential equation which gives as a solution the exponential function:

$$x(t) = x_0 e^{At}$$

where x_0 is the number of preys at time *t*. The same happens for *y(t)*, with the only difference that the solution is a negative exponential:

$$y(t) = y_0 e^{-Dt}$$

where y_0 is the number of predators at time *t*.

Hence, we can highlight some assumptions of the Volterra-Lotka model:

- the prey population finds ample food at all times and, in absence of predators, grows indefinitely, since the preys do not die by natural death (Assumption 1);
- in absence of preys to eat, the predators population decreases by natural death, since its food supply depends entirely on the size of the prey population (Assumption 2).

A simulation written in Python programming language can be easily used to prove the behaviour of the model, plotting the evolutions of the moose and wolf populations. The parts of the codex that you need to modify during the following exercises are those related to the value of parameters *A*, *B*, *C* and *D* and to the initial conditions x_0 and y_0:

```
# Definition of parameters: default a= 1, b=0.1, c=0.075, d=1.5
a = 1
b = 0.2
c = 0.075
d = 1.5

X0 = array([10, 5])      # initials conditions: 10 moose and 5 wolves
```

Make a choice of parameters for reproducing a zero-interaction model. Note that it is not possible to set $B = C = 0$ because the calculus of the equilibrium position would be impossible for the programme (division by 0 is not defined). So, one has to choose B and

$$B,\ C \ll A,\ D$$

C so that this relation holds:

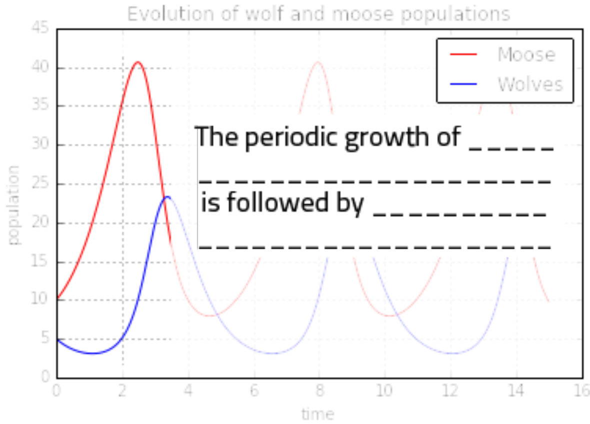
Draw the time evolution displayed by the simulation, writing also the values of parameters and initial conditions that you have set.

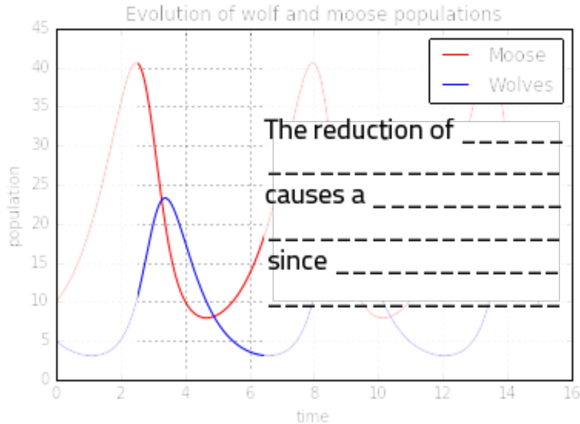
The exponential behaviour of both the time evolutions – positive for the preys and negative for the predators – should be evident.

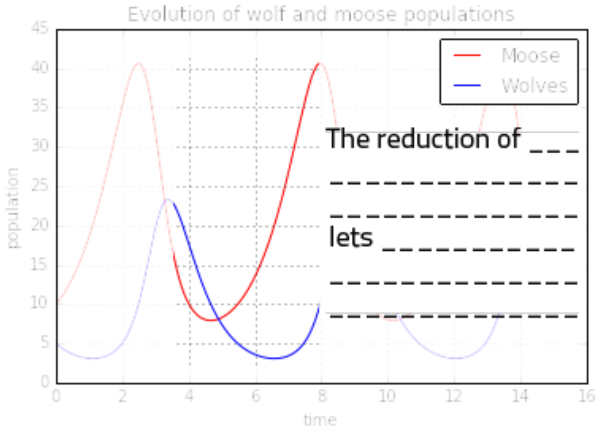
<u>The periodic solutions of the model</u>

Now, we can go back to the initial formulation of the complete equations of the model and, resetting the parameters at default values, draw the resulting plot reporting the parameters and the initial conditions that you have fixed.

For every running of the algorithm, the plot displays the periodic solutions of our system of equations. Try to explain these oscillations (increasing and decreasing of populations) adding a comment for each graph.







If we stop at this stage of the analysis, we remain within a linear conception of causality: one step calls a second one which causes another one. But we could imagine to continue the reasoning: add arrows that connect the steps above… now you can see explicitly the positive feedback loop that is the cause of the time oscillation of this system.

<u>Discovering the meaning of the parameters</u>

Changing the values of the parameters of the model, their meaning and role can be better understood. It is convenient to change only one parameter at each running of the script, so that its role can be separated from that of the other ones. Let *A*, *B*, *C* and *D* change, setting the initial conditions fixed at default value ($x_0 = 10$ and $y_0 = 5$).

Draw three plots obtained with changed values of *A* (take care of the scales on the population axis!). For each plot, report the values of *A* that you used for your simulation.

The parameter *A* controls the birth rate of preys. Look at your plots: what happens if *A* decreases? So, what you can think could be the meaning of this parameter?

Draw three plots obtained with changed values of *B*. For each plot, report the values of *B* that you used for your simulation.

The parameter *B* indicates how frequently the preys are eaten by the predators. Look at your plots: what happens if *B* decreases? So, what you can think could be the meaning of this parameter?

Draw three plots obtained with changed values of *C*. For each plot, report the values of *C* that you used for your simulation.

The parameter *C* is the coefficient of encounter between preys and predators. Look at your plots: what happens if *C* decreases? Why is it so similar to the behaviour we obtain changing *B*?

Draw three plots obtained with changed values of *D*. For each plot, report the values of *D* that you used for your simulation.

The parameter *C* is the coefficient of natural death of predators. Look at your plots: what happens if *D* decreases?

From the model to the reality

After having discovered the meaning and role of all the parameters of the model and its interpretation at the light of circular causality, the results of our simulation can be compared with real data. We can consider a famous example of the predator-prey relationship: the one between wolves and moose on Isle Royale, an island in Lake Superior in Michigan. This unique relationship has been subject of detailed study for over 55 years because it is considered very similar to the situation described from the model. Indeed, being an isolated island, there is little migration of animals into and out of it and, as a national park, human interaction and impact on the two species is also limited.

The applet http://www.phschool.com/atschool/phbio/active_art/predator_prey_simulation/ shows the ideal behaviour of the model (obtained with a programme like the one we used above) versus the real data measured for wolves and moose on Isle Royal.

What are the graphical similarities and what are the differences between the ideal plots that you obtained before and this graph of real data?

These differences requires a comment about the other implicit assumptions of the model that we have not noticed yet: during the process described from the model, the environment does not change in favour of one species and there are not any factors (diseases, famines, genetic mutations, fitness problems…) that cause premature deaths or damages for the one or both the populations (Assumption 3). This is not the case of Isle Royale's interaction.

As an isolated island, the Isle Royale initially had neither wolves nor moose. The moose are believed to have either swam across Lake Superior from Minnesota in the early 1900s; in 1949 a pair of wolves crossed an ice bridge from Ontario to the island during a harsh winter. But because only one pair or wolves migrated to the island, they have suffered from severe inbreeding, losing genetic variability (all the wolves' DNA on Isle Royale can be traced back to one ancestor). Inbreeding leads to mutations and fitness problems, often accompanied by violent social rejection by other wolves. So, what of our 3 assumptions does not hold true?

Assumption number __

Moreover, moose prefer birch and aspen trees, which used to grow plentifully on the island, but over a century of moose browsing have been largely replaced by the less nutritious balsam fir. But also the resources of balsam fir are limited: it is observed that when the moose population grows too high, the balsam fir population crashes, leading to a crash in the moose population. This is a negative feedback loop and it makes an other of the assumptions not verified. What?

Assumption number __

Also another assumption is not true for the Isle Royale case. Indeed, moose make up nine-tenths of a wolf's diet: the remaining 10% consists of snowshoe hares and beavers. So, there are not only two species in interaction and the Lotka-Volterra model cannot be reasonably applied. What of our 3 assumptions does not hold true?

Possible improvements of the model… and a sad conclusion

The model can be improved by adding parameters which take into account some elements that help in order to make the model more similar to the real situation. With the applet already mentioned, it is possible to set a value also for two other coefficients:

- habitat variability: how often factors other than the ones you are controlling, such as density-independent factors (weather), and density-dependent factors (disease) change. This parameter has value between 1, if the habitat is not so variable, and 100, if it is extremely variable;
- carrying capacity: the largest number of individuals of a population that a given environment can support. This parameter is an average percentage and it is included between 50% and 150%.

Changing their values it is possible to see the changes in the graphs with respect to the standard Lotka-Volterra. Anyway you can easily recognized that, also with these new parameters, it is impossible to fit the experimental data. What do you think is the cause of this impossibility?

Annex A3 - Non-linearity of complex systems and sensitivity to initial conditions: the logistic map

The logistic map was introduced in 1976 as a discrete-time demographic model analogous to the logistic equation. The logistic equation has the following form:

$$\frac{df(x)}{dx} = f(x)(1 - f(x))$$

and it is a first-order non-linear differential equation. The non linearity is given from the fact that the derivative does not depend only on $f(x)$ but there is also a quadratic term $f^2(x)$. The discretization of the logistic equation leads to the logistic map:

$$x_{n+1} = rx_n(1 - x_n)$$

where x_n is a number in the interval [0, 1] that represents the ratio of existing population to the maximum possible population (also called carrying capacity of the environment) and r is a positive parameter (we do not want negative populations).

It is an iterative map because it establishes the value of a variable at time n+1, by knowing the value at time n and the evolution rule. There are many ways of interpreting it: a possible way is looking at it as a curve in the plane (in this case the parabolic function can be recognized) but a second way is as a series of instructions:

- give some number x_n, subtract its square x_n^2 and multiply the result for the constant r;
- call the result x_{n+1};
- given x_{n+1} do nothing but call it x_n;
- repeat the first step with the value found in step 3.

The first three instruction together form a mapping of one number on to another:

$$m : x_n \to rx_n(1 - x_n)$$

and the addition of the fourth step results in an iterated mapping. We can use the symbol $m^n(x_n)$ to represent the n^{th} iterate of the original value x_n. The instructions require to generate a series of number, called orbit:

$$x_n, m(x_n), m^2(x_n), m^3(x_n), \dots , m^n(x_n), \dots$$

The initial value x_n is called the seed of the orbit.

<u>The demographic logistic model</u>

The simple logistic equation written above is a formula for approximating the evolution of an animal population over time. We can write again the formula distinguishing into brackets the two terms of the product.

$$x_{n+1} = (rx_n)(1 - x_n)$$

We are going to comment the two terms separately.

- rx_n: since not every existing animal will reproduce (a portion of them are male), not every female will be fertile, not every conception will be successful, and not every pregnancy will be successfully carried to term, the population increase will be some fraction of the present population. The term of proportionality r is the growth rate or fecundity and approximates the rate of successful reproduction. Limiting the model at this term, it produces exponential growth without limit.
- $(1 - x_n)$: since every population is bound by the physical limitations of its territory, some allowance must be made to restrict this growth. If there is a carrying capacity of the environment, then the population may not exceed that capacity, otherwise the population would become extinct. This can be modelled by multiplying the population by a number that approaches zero as the population approaches its limit. If we normalize x_n to this capacity, the multiplier $(1 - x_n)$ has the role explained.

Playing with the parameter *r*

By varying the parameter r several kinds of behaviour are observed. If the growth rate expressed by r is set too low, the population will die out and go extinct: in Figure 1 this behaviour is shown, because r is in the interval [0, 1].

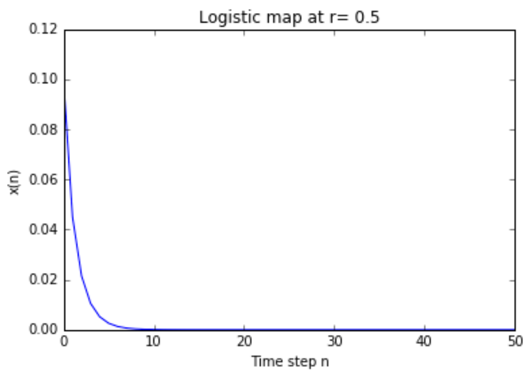


Figure 1. Extinction of the population within the 10^{th} generation for r = 0.5.

Higher growth rates might settle the population toward a stable value represented by $\frac{r-1}{r}$: in Figure 2 we observe this evolution, because r is chosen in the interval [1, 2].

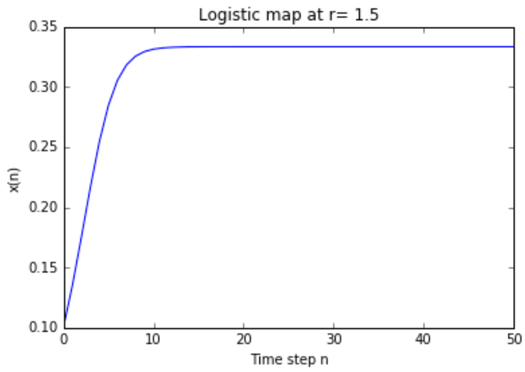


Figure 2. Stabilisation of the population toward the value x_n = 0.33, when r = 1.5.

We can give two examples of this behaviour. Yeast, a microscopic fungus used to make bread and alcoholic beverages, exhibits a curve similar to that in Figure 2, when grown in a test tube (see Figure 2A.left). Its growth levels off as the population depletes the nutrients that are necessary for its growth.
In the real world, however, there are variations to this idealized curve. An example in wild populations is that of harbour seals (see Figure 2A.right). The population size exceeds the carrying capacity for short periods of time and then falls below the carrying capacity afterwards.

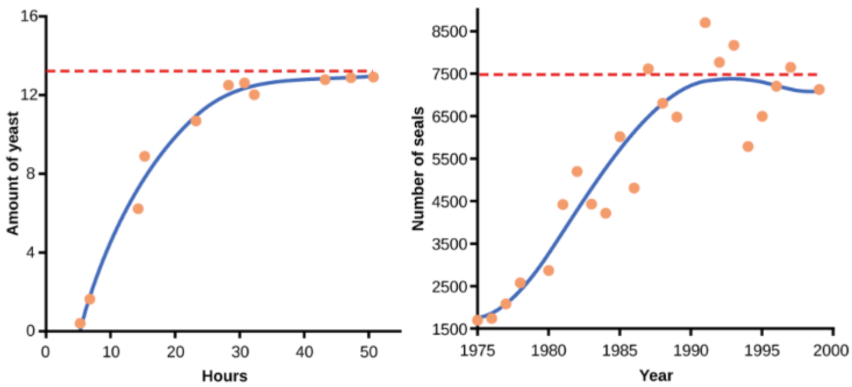


Figure 2A. Fitting ecological data with logistic model. 2A.left: yeast grown in ideal conditions in a test tube show a classical logistic growth curve (cfr. Figure 2). 2A.right: a natural population of seals shows real-world fluctuation.

Another possible behaviour is the fluctuation across a series of population booms and busts. In Figure 3 we observe three different kinds of evolutions:

- with *r* in [3, $1+\sqrt{6}$ ~3.44949] the population approaches permanent oscillations between two values dependent on *r*. We can think at this system as a switch that can stay on two states and the transition time between these two states is regular and dependent on *r* itself;
- with *r* in [$1+\sqrt{6}$, 3.56995] the population approaches periodic oscillations among 2^k values. The system is now a multi-value switch, with a sequence of possible states that repeat following always the same order;

- with r in [3.56995, 4] there are almost no more oscillations of finite period[2]: the value 3.56995 is often defined as the onset of chaos.

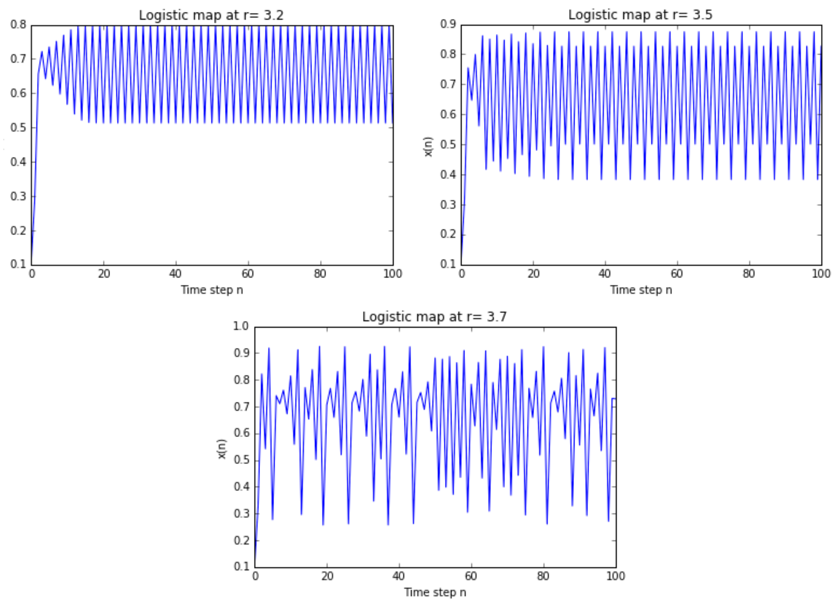


Figure 3. Fluctuation of the population across a series of booms and busts. 3.left: oscillation between two values, for r = 3.2. 3.centre: oscillation among 4 values, for r = 3.5. 3.right: chaotic behaviour without oscillations of finite period, for r = 3.7.

<u>Limit cycles and strange attractors</u>

After having showed some graphs for some values of the parameter r, it is useful to define a term and explain a concept often used in the study of complex system. An attractor is the value, or the set of values, that the system settles toward over time. For example, when r is set to 0.5 (see Figure 1), the system has a fixed-point attractor at population level 0: in other words, the population value is drawn toward 0 over time as the model iterates. Another example is shown when r is set to 3.5 (see Figure 3.centre): the system oscillates between four values. In both these cases the attractors are called limit cycles.

Passing the onset of chaos, the attractor is no more a limit cycle because chaotic systems have so called strange attractors, around which the system oscillates forever, never repeating itself or settling into a steady state of behaviour (see Figure 3.right). For a better understanding of this fact, let us see the so called bifurcation diagram, showed in Figure 4, obtained running the logistic model again across 1000 values of r in the interval [0, 4].

To read this kind of diagram, it is convenient to watch at it as 1000 discrete vertical slices, each one corresponding to one of the 1000 parameters between 0 and 4. For each one of

[2] Although most values of r beyond 3.56995 exhibit chaotic behaviour, there are still certain isolated ranges of r (called islands of stability) that display non-chaotic behaviour.

these slices, the model has been run 450 times, then the first 200 values have been ignored[3], so the final 250 generations for each growth rate remain.

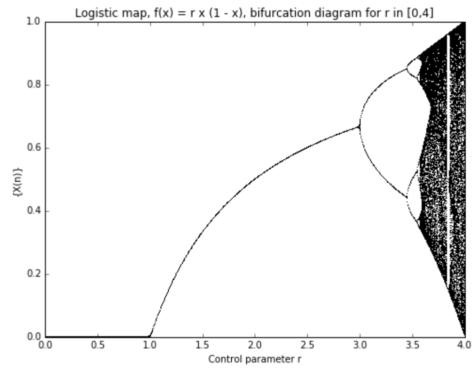


Figure 4. Bifurcation diagram for r in [0, 4].

Thus, each vertical slice depicts the population values that the logistic map settles toward for that parameter value. In other words, according to the definition given before, the vertical slice above each growth rate is that growth rate's attractor. We can reinterpret the analysis and the comments done before about the role of the parameter *r* at the light of this new representation:

- for *r* in [0, 1] the system always collapses to zero;
- for *r* in [1, 3] the system always settles into an exact, stable population level;
- for *r* in [3, $1+\sqrt{6}$ ~3.44949] the system displays an oscillation between two values;
- for *r* in [$1+\sqrt{6}$, 3.56995] the oscillation is between 4, 8, 16, 32 values (as it can be seen in Figure 5, where a zooming into the interval [2.95, 3.6] is provided);

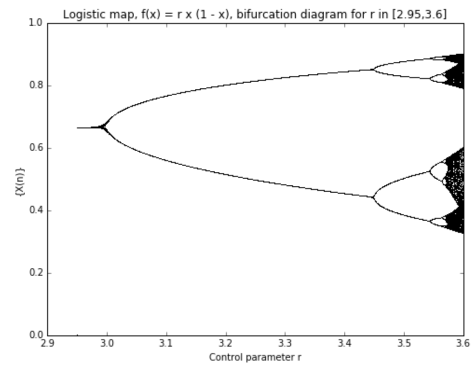


Figure 5. Bifurcation diagram for r in [2.95, 3.6]: the progressive bifurcation in 2^k values is observed; from this behaviour the diagram has taken its name.

---

[3] The first 200 values are ignored in order to avoid considering the transient phase that does not define the attractor. For example, looking at Figure 1, if also the first six generations were considered, in the bifurcation diagram we would obtain a straight vertical segment for values of *r* in [0, 1], but these values would not be significant with respect to the stable evolution of the system that shows up beyond the transient phase. With this cut of the first iterations, we see, in the bifurcation diagram, just the attractor value 0, when *r* is in [0, 1].

- for r in [3.56995, 4] the diagram shows 250 different values, so a different value for each of its 250 generations: it means that the evolution never settles into a fixed point or a limit cycle. In Figure 6 a zoom on an interval in this area is provided.

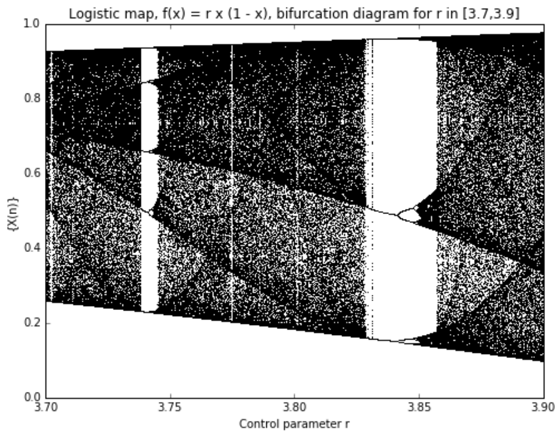


Figure 6. Bifurcation diagram for r in [3.7, 3.9]: for almost each r, there are as many different possible values of population as the number of generations.

<u>Fractals</u>

The bifurcation diagram allows us to see another important property of many complex systems: the fractal structure. In the figures above can be recognized some particular patterns that exist at every scale, no matter how much we zoom into it: this properties is called self-similarity. Starting from Figure 6, we progressively zoom in the diagram: we can recognize the same bifurcation structure shown in figures above. A part of the process of zooming in is shown in Figure 7.

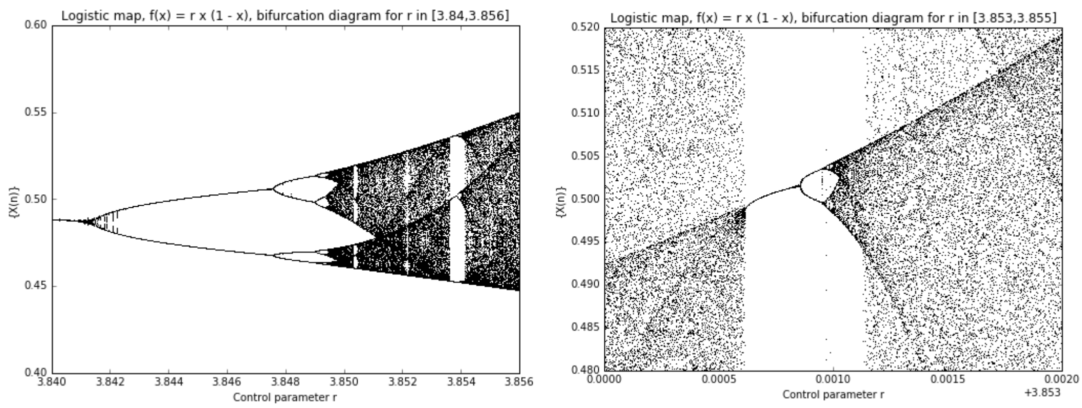


Figure 7. Zooming of bifurcation diagram: the fractal structure can be recognized.

<u>Sensitivity at initial conditions and deterministic chaos</u>

Another characteristic of the logistic model and of many other complex systems is the so called sensitivity at initial conditions. If we focus on the interval [3.56995, 4], we can look at the time series from two different, but very close, initial conditions. For example, we can use $r = 3.7$, comparing it with another value that is only 10^{-5} away from the first one. The graph in Figure 8 is obtained: we can observe that it takes only two dozen iterates before the two curves diverge far away from each other.

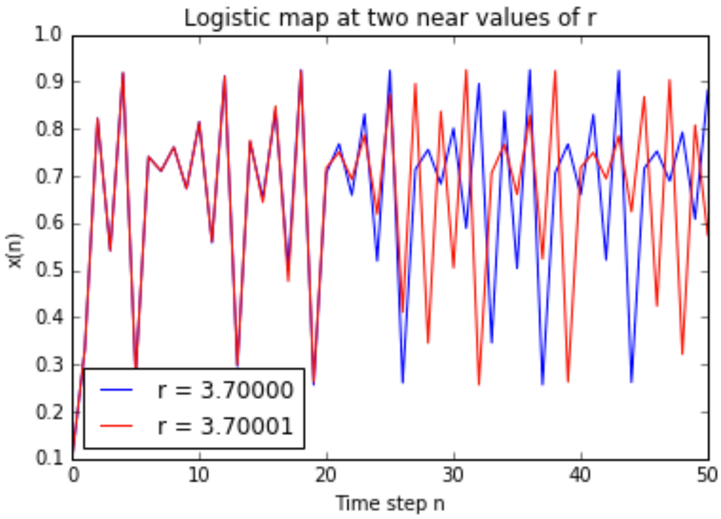


Figure 8. Behaviour of the logistic map for two near values of r.

This chaotic behaviour and this difference between the two plots are due to the non linearity of the system and to the iterative structure of the map. Indeed, recalling the formula for the map, the quadratic term causes a quadratic sensitivity to errors about initial conditions; moreover, the iterative structure implies that an initial error spreads on the whole evolution of the system. That is why, despite its deterministic simplicity, over time this chaotic system produces totally unpredictable and wildly divergent behaviour. The plots *seem* to evolve randomly but there is a fundamental distinction between chaos and randomness: the logistic model continues to follow the very simple deterministic rule we have expressed at the beginning of our analysis, but produces an apparent randomness given by the aperiodicity. This phenomenon is called deterministic chaos and was discovered by Edward Lorenz who described chaos as "when the present determines the future, but the approximate present does not approximately determine the future."

This aspect is strictly linked to the mathematical modelling of complex systems and changes the meaning of knowledge and prediction about systems. Looking at the Figure 8, we can say that if our knowledge of those two systems started at generation 40, we would have no way of guessing that they were almost identical in the beginning. With chaos, history is lost to time and prediction of the future is only as accurate as the measurements. In real-world chaotic systems, measurements of initial conditions are never infinitely precise, so errors always compound, and the future becomes entirely unknowable given long enough time horizons.

This is famously known as the butterfly effect, from the title of a conference held by Lorenz in 1972. "Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?". Now, we can answer: yes, it does. Small events compound and irreversibly alter the future of the universe.

Chaos can be observed in many physical systems, also outside the ecological context. For example, in mechanics, a system as simple as a double pendulum (see Figure 9) is a chaotic system because infinitesimal differences in the starting conditions lead to drastically different results as the system evolves.

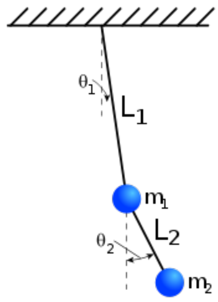


Figure 9. Schematization of a double pendulum, that consists of a pendulum with another pendulum attached to its end.

If we plot the evolution in time of the angle θ_1 of the main arm and the angle θ_2 of the second arm, changing the initial speeds of the main arm, the behaviour in Figure 10 is observed.

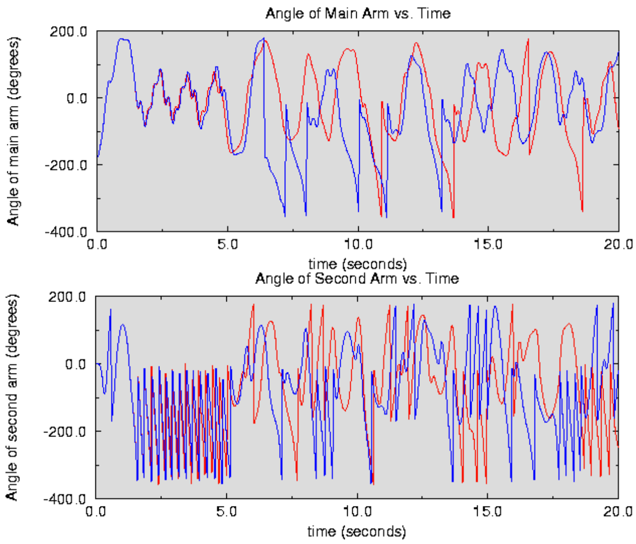


Figure 10. Time evolution of θ_1 (10.top) and θ_2 (10.bottom) for near initial conditions. The red line refers to a double pendulum with v_1 = 400.0 deg/s, the blue line to a an identical pendulum with v_1 = 400.1 deg/s.

For a short while the two pendulums stay in phase, but their behaviour quickly diverges even though their initial speeds are very similar (only 0.1 deg/sec difference in the initial speed of the main arm). This shows that the systems are sensitive to their initial conditions.

Perhaps not as obviously as this physical system has, particular electrical circuits also exhibit chaotic behaviour, starting from non-linear mathematical descriptions. Two examples are the varicap diode circuit and the Chua circuit.

Python scripts

Three Python scripts have been written in order to draw the plots reported in this work. In the followings the codes are reported with some comments; in red are written the lines of code that have to be modified by the user in order to obtain the different plots described above.

Logistic Map.py

The first script (LogisticMap.py) defines the logistic map and produces the plots from Figure 1 to Figure 3.

After having imported the plotting routines, simulations parameters are set. Particularly, a value for `r` is assigned, an array that will contain the value of population `x` is created and initialized in its first component, and the number of iterations `N` is fixed.

```
from pylab import *
r = 3.7
x = [0.1]
N = 100
```

With a `for` loop, for `N` times the value x_{n+1} is calculated and appended to the list `x`. Finally, the plot is drawn.

```
for n in range(0,N):
      x.append( r*x[n]*(1.-x[n]) )
xlabel('Time step n')
ylabel('x(n)')
title('Logistic map at r= ' + str(r))
plot(x , 'b')
show()
```

LogisticMap2NearInitialConditions.py

The second script (LogisticMap2NearInitialConditions.py) is similar to the first one but in this case two plots are drawn in a unique graph, because we want to control the sensitivity of the model to near values of the parameter r, in order to make graphs like that in Figure 8.

After having imported the plotting routine and set the parameter, initialized the array of population values and chosen the number of iteration, it is set the value of a constant named `delta` which represents the increment with respect to `x1`; an array `x2` is also initialized.

```
from pylab import *
r  = 3.7
x1 = [0.1]
delta = 1e-5
x2 = [x1[0] + delta]
N  = 50
```

With a `for` loop, for `N` times the values x_{n+1} are calculated and appended to the lists `x1` and `x2`. Finally, the plots are drawn within a unique figure.

```
for n in range(0,N):
     x1.append( r*x1[n]*(1.-x1[n]) )
     x2.append( r*x2[n]*(1.-x2[n]) )
xlabel('Time step n')
ylabel('x(n)')
title('Logistic map at two near values of r')
plot(x1, 'b', label="r = 3.70000")
plot(x2 , 'r', label="r = 3.70001")
legend(loc='best')
show()
```

<u>LogisticBifn.py</u>

The third script (LogisticBifn.py) draws the bifurcation diagrams from Figure 4 to Figure 7.

The script begins with the importation of the modules needed.

```
from numpy import *
from pylab import *
```

The logistic map's function is defined and the parameter range is set up.

```
def LogisticMap(r,x):
     return r * x * (1.0 - x)
rlow  =  3.7
rhigh = 3.9
```

The plot is prepared.

```
figure(1,(8,6))
TitleString  = 'Logistic map, f(x) = r x (1 - x), '
TitleString  +=  'bifurcation  diagram  for  r  in  [%g,%g]'  %
(rlow,rhigh)
title(TitleString)
xlabel('Control parameter r')
ylabel('{X(n)}')
```

To avoid the autoscaling that would be implicit in the plot function, we put dots at the corners of the desired data window.

```
plot([rhigh], [1.0], 'k,')
plot([rhigh], [0.0], 'k,')
plot([rlow], [0.0], 'k,')
plot([rlow], [1.0], 'k,')
```

The value of initial condition x_0 is set as `ic`; then, the number of transient generations is set (these values will be thrown away). The parameter `nIterates` sets how much the attractor is filled in, while `nSteps` sets how dense the bifurcation diagram will be. The variable `rInc` represents the increment for the following calculations.

```
ic = 0.2
nTransients = 200
nIterates = 250
nSteps =1000
rInc = (rhigh-rlow)/float(nSteps)
```

With a `for` cycle (for exploring all the 1000 values of the parameter *r*) the initial condition is set to the reference value, the transient iterations are thrown array and the next batch of iterates is stored in the array x. The plot function draws the list of (`r`, `x`) pairs as pixels.

```
for r in arange(rlow,rhigh,rInc):
      state = ic
      for i in range(nTransients):
            state = LogisticMap(r,state)
      rsweep = [ ]
      x = [ ]
      for i in range(nIterates):
            state = LogisticMap(r,state)
            rsweep.append(r)
            x.append( state )
      plot(rsweep, x, 'k,')
show()
```

References

Boeing, G. (2016). "Visual Analysis of Nonlinear Dynamical Systems: Chaos, Fractals, Self-Similarity and the Limits of Prediction." *Systems*, 4 (4), 37.

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Annex A4 – Questionnaire on the concept of feedback

The questionnaire is based on the Ted-Ed video lesson
http://ed.ted.com/lessons/feedback-loops-how-nature-gets-its-rhythms-anje-margriet-neutel#watch

Which of the following is an example of a positive feedback loop?

A. As glaciers melt, there is less white surface to reflect heat, which causes more melting
B. As plants grow, their litter creates more soil humus, which in turn makes it hospitable for more plants
C. "Violence breeds more violence" – or, a violent act by one group causes their enemy to retaliate with more violence
D. All of the above

Negative feedback is called negative because ________.

A. It counteracts disturbance
B. It causes degradation of an (eco)system
C. It has a destabilizing effect
D. It has no effect on system stability

The strength of a feedback loop is ________.

A. The sum of the positive link strengths in the loop
B. The sum of all the link strengths in the loop
C. The product of all the link strengths in the loop
D. The sum of the positive link strengths divided by the sum of the negative link strengths in the loop

If you have a feedback loop with three strong negative links, and one of those links turns into a very weak positive link, what will the resulting feedback be?

A. Strong positive feedback
B. Strong negative feedback
C. Weak positive feedback
D. Weak negative feedback
E. No feedback

How many feedback loops are possible in a food web of 20 species?

A. Up to 20
B. Around 80
C. Hundreds

D. Thousands

How do all the feedbacks together in an ecosystem create harmony? One important mechanism is:

A. The feedbacks become synchronized
B. Positive feedbacks counteract destabilizing negative feedbacks
C. Many populations interacting causes break-up of the chains of the short feedback loops
D. Destabilising positive feedbacks are counteracted by negative feedbacks

The process of erosion on a landscape is an example of positive feedback. Can you describe a feedback loop that explains this process in more detail, starting with the feedback between plant, humus, and at least one more node in the network? Hint: you will have to add more than one negative link.

Describe three examples of positive feedback and three of negative feedback, in other systems that have many interacting parts – such as economic, social, political systems.

One of the more prevalent feedback loops discussed today is one in relation to melting polar ice caps due to climate change. Is this a positive or negative feedback loop? Explain your answer.

Annex A5 - Self-organization in complex systems: the world of ants

Ants have some of the most complex social organization in the animal kingdom, living in structured colonies with different kinds of members who perform specific roles. But although this may sound similar to some human societies, this organization of the system does not arise from any higher level decisions or urban plans, but emerges from very basic rules of interaction between its parts. This kind of organization is better called, because of its properties, self-organization.

Ants have no methods of intentional communication but individual ants interact each other through touch, sound and chemical signals. These stimuli accomplish many things from serving as an alarm to other ants if one is killed, to signalling when a queen is nearing the end of her reproductive life. But one of the most impressive collective capabilities of ant colony is to thoroughly and efficiently explore large areas without any predetermined plan. Most species of ants have little or no sense of sight and can only smell things in their vicinity. Combined with their lack of high level coordination, this would seem to make them terrible explorers but there is an amazingly simple way that ants maximize their searching efficiency: by changing their movement patterns based on individual interactions. When two ants meet, they sense each other by touching antennae; if there are many ants in a small area this will happen more often, causing them to respond by moving in more convoluted, random paths in order to search more thoroughly. But in larger area, with less ants, where such meetings happen less often, they can walk in straight lines to cover more ground. While exploring their environment in this way, an ant may come across any number of things, from threats or enemies, to alternate nesting sites.

One of the most impressive capability that some species of ants have is known as recruitment: when one of these ants happens to find food, it will return with it, marking its path with a chemical scent; other ants will then follow this pheromone trail, renewing it each time they manage to find food and return. Once the food in that spot is depleted, the ants stop marking their return: the scent dissipates and ants are no longer attracted to that path.

<u>A computer simulation</u>

A lot of computer simulations have been written in order to reproduce the behaviour of ants in response at the presence of obstacles, food, caves or elements of scare. The video at this link https://www.youtube.com/watch?v=G5wb4f5n6qQ&t=29s shows the mode of operation of one of these simulations and the result is the spatial organization of ants according to pattern that seem to contradict the chaotic nature of this complex system.

Particularly interesting is the mechanism of recruitment as shown in the simulation. In Figure 1 there are some examples of patterns followed by ants to go from the food (with points) to the caves (black points), passing through obstacles (grey points).

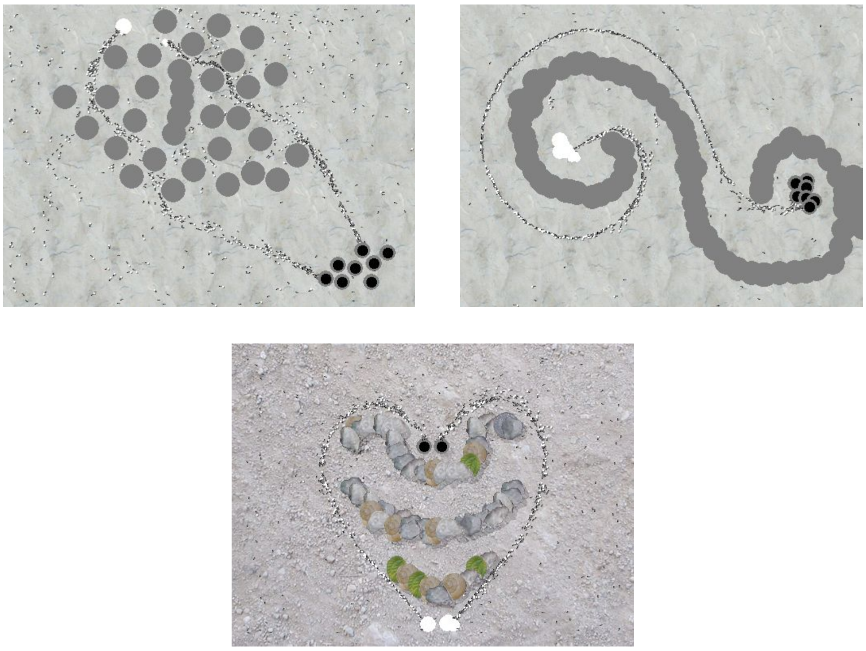


Figure 1. The recruitment mechanism makes spatial patterns emerge.

These seemingly crude methods of search and retrieval are, indeed, so useful that they are applied in computer models to obtain optimal solutions from decentralized elements, working randomly and exchanging simple information. Understanding the basis of self-organization could lead to improvements in swarm robotics, large numbers of simple robots working together, as well as self-healing materials and other systems capable of organizing and fixing themselves. More broadly, identifying the rules that ants obey could help scientists understand how biologically complex systems emerge (for example, how groups of cells give rise to organs).

References

Inside the ant colony – TED lesson by Deborah M. Gordon
https://www.youtube.com/watch?v=vG-QZOTc5_Q

https://www.theguardian.com/science/2014/apr/11/ants-self-organization-quanta

http://naturedocumentaries.org/5519/what-ants-teach-deborah-gordon-ted-talk-2014/

Annex A6 - Synthesis of the fifth IPCC report: the global warming issue

Global warming, in climatology, indicates an increase in the average temperature of Earth's surface and recorded in different phases of the climatic history of the Earth. The expression is now almost always used with heating significance due to the anthropogenic (i.e. human) contribution, decisive in the heating phase of the last 100 years. The fifth report of the *Intergovernmental Panel on Climate Change* (IPCC) in 2014 estimated that the average global surface temperature has increased by 0.85 [0.65-1.06] °C in the period 1880-2012. Most of the phenomena that cause the rise in temperature since the mid-twentieth century are considered, within the IPCC report, anthropogenic. These phenomena are responsible for an increase of the natural phenomenon of the greenhouse effect. The natural greenhouse effect is part of the complex of thermal equilibrium adjustment mechanisms of a planet (or satellite) surrounded by an atmosphere, which, if it contains certain gases called greenhouse gases indeed, produces the overall effect of mitigating the temperature the global average surface of the planet, isolating partially by large swings in temperature or that would subject the planet in their absence. For giving an idea of the phenomena regarding the Earth, in the absence of greenhouse gases, by the equation of balance between in- and outgoing radiation is one which average surface temperature of the Earth would be of about -18 °C whereas, thanks to the presence of greenhouse gases, the actual value is about +14 °C, enabling life as we know it. The greenhouse effect is man-made increase in the natural greenhouse effect phenomenon due to the emission of greenhouse gases by human activities, including industry, agriculture, livestock, transport, power plants for civilian purposes. In particular industries, transport, energy production facilities and even tourism activities contribute to increasing emissions from fossil fuels such as methane and carbon dioxide (CO2) while agriculture and livestock, more and more intensive activities, date the growing food demand, contribute most to the emission of nitrous oxide and methane. Most production of methane is indeed due to the fermentation of typical livestock manure, also grew significantly, and the fermentation of crops to submergence (for example rice). To the list of greenhouse gases should be added the chlorofluorocarbons (CFC), the only man-made gas, mainly used in the production of spray cans. This type of cans, now banned from production in different countries, have been the subject of debate between eighty and two thousand years as they are considered responsible for the depletion of the ozone layer in the atmosphere.

In addition to global warming, the emission of CO2 into the atmosphere as a result of human activity has been determining also the phenomenon known as “acidification of the seas”. As they explain on “Climalteranti”, *“For avoiding any doubts, the 'acidification' term does not mean that the sea water becomes acidic (i.e. that its pH becomes less than 7), instead it means that the pH decreases (by a few tenths) but remained above 8 that is basic or alkaline land: rather than 'acidification' should therefore strictly speaking use the term 'de-alkalization'”.*

However, the acidification mechanism is broadly explained in this way: around a third of the CO_2 emitted by human activities is absorbed by the water of the seas where it turns into carbonic acid according to the reaction $CO_2 + H_2O \rightarrow H_2CO_3$. The carbonic acid in water has a low concentration and rapidly dissociates to form carbonate and bicarbonate ions and liberating H^+ ions. More CO_2 is emitted into the atmosphere, the greater the concentration of H^+, which is measured by the decrease in pH.
The reduction in global average pH over the last two centuries or so has been recently estimated that more than 0.1 on the logarithmic pH scale corresponds to an increase of about 30% of H^+ ions. Among the most well-known effects of acidification of the seas is the damage to coral reefs but the phenomenon affects all the seas, not only tropical ones. *"And the organisms affected by acidification are just at the beginning of the marine food chain at the other end of which we are humans, not just the trendy sushi eaters but all people living from fishing and make it their main source of protein"* (http://www.climalteranti.it/2010/07/16/il-gemello-cattivo-del-surriscaldamento-globale/).
Returning to the phenomenon of global warming, the first "Statement" IPCC lists several effects attributable to it with high confidence: increased sea temperatures; the melting of the polar ice caps and mountain ranges; the increase of extreme events like heavy rainfall, increased tropical cyclones and heat waves.
As will be described later, all these phenomena contribute, in different ways, to modify the environmental scenarios, economic and social, leading to a total increase of risk[2] on the territory, with consequent increase in the social vulnerability[3] and migration of the small and large scale .
The main consequence of the increase in sea temperatures with implications on human life is a change in the composition of the fish fauna. For example, in the Mediterranean Sea there has for some years a species of tropical input (tropicalization Mediterranean), in many cases lessepsian or penetrated from the Red Sea through the Strait of Suez[4]; in the more northern basins like those Italians we are witnessing instead an increase of southern thermophilic species first found only on the North African coast (south Mediterranean). Especially in the eastern part of the Mediterranean these processes are having significant effects on the survival of native species, since that change ecosystems and the food chain.
A second consequence of global warming is the reduction of the ice in the polar caps, the permafrost5, ice on the mountain and frozen seas chains. Some implications of these phenomena that are well documented are the change of the territory in the areas concerned (including changes to the biological and agriculture network), as well as the increased risk of flooding due to the increase of the waters that flow along the rivers. The phenomenon of flooding of river basins has become in recent years a major problem in some areas of the world as well as in parts of Europe and in Italy. At this, in addition to melting ice, contributes significantly to the intensification of rainfall, other consequences of global warming also mentioned below.
Since the early 70s, the mass loss of glaciers and ice caps in Greenland and Antarctica and thermal expansion of the seas realize set of about 75% the rising of the global average sea level (high confidence). This phenomenon, together with the increase of the risk of heavy storms, can cause extensive damage on the architectural and building urban structures present on the coasts, in addition to ecological damage due to salt water intrusion in coastal aquifers, the intrusion of salt wedge estuaries, the loss or modification of the marine and coastal biodiversity. All these impacts have strong implications on

business activities conducted in the coastal areas, but also on the recreational, tourism and historical, artistic, and of all the agricultural practices carried out in the hinterland that receive irrigation drawn from sources that, intrusion, have brackish water.
As a final result of global warming is the intensification of the number and violence of extreme weather events (such as heavy rainfall, cyclones, floods, droughts, heat waves, etc.).
The intensification of the phenomenon of floods and tropical cyclones, as well as damage crops and infrastructure, increases the housing insecurity and determines both economic losses of private due to the same disaster is an increase in expenses to which public institutions have to opposite to remedy the disasters.
Finally, in this review of extreme events, it has been observed as heat waves and the lengthening of the dry spells lead to further pressure on already scarce water resources, increasing, especially in poor countries, problems of access to drinking water. This climatic phenomenon therefore has serious consequences in terms of public health, and damage to crops and thus decrease in food safety[6], as well as in terms of land degradation, desertification and causing decrease in green space.

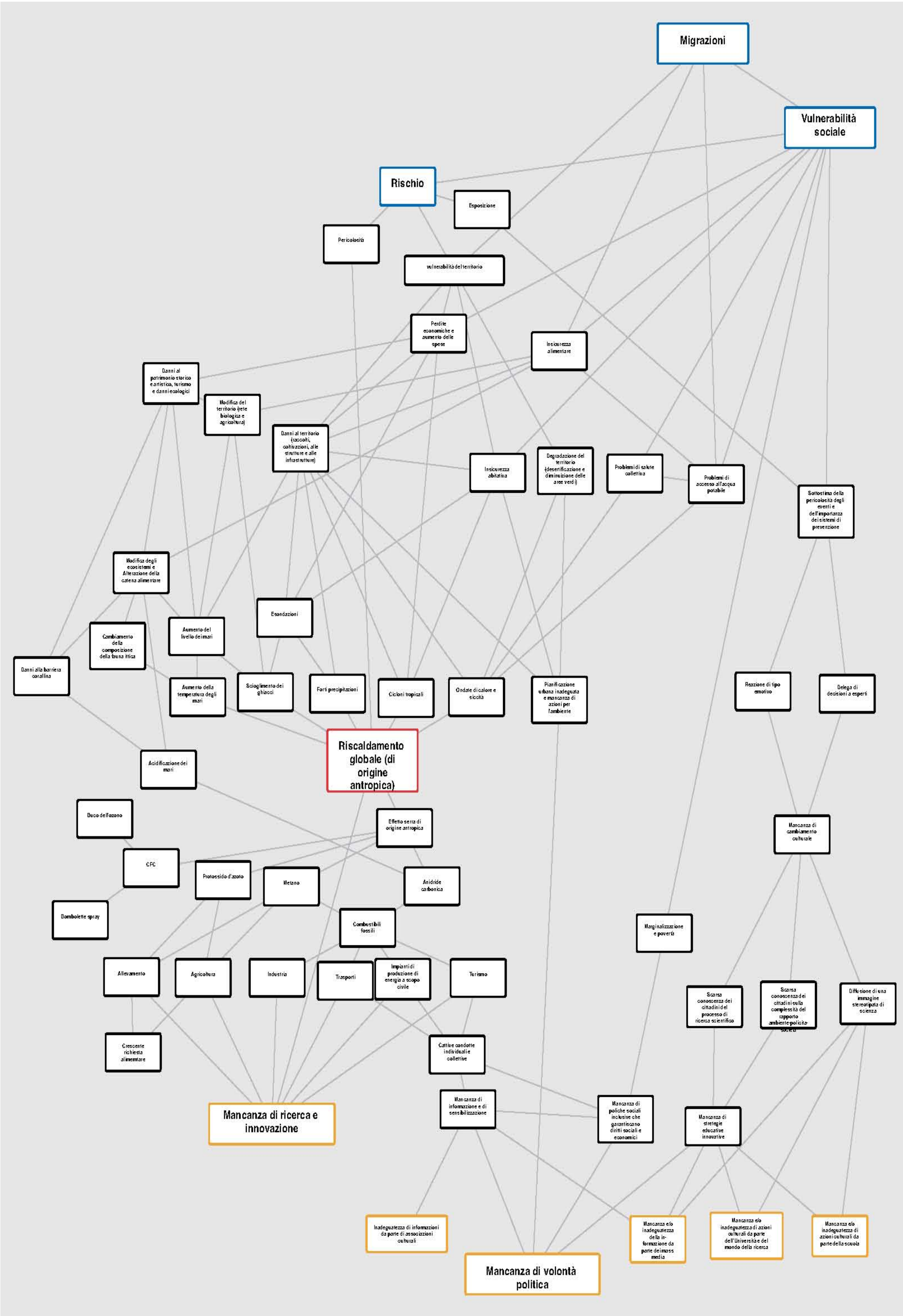
From all of the mentioned above you can well understand how the magnitude of climate change has increased in recent decades the risk of certain territories exposed to extreme events to affect the livability same in some areas even at high social vulnerability. Entire populations in some areas of the world are no (or insufficient) access to water, with the consequence of not being able to ensure the survival of their family, not being able to secure their income from agriculture or livestock (drought in the fields, die-off of farms), of not being able to have access to food. From this arises the increase of "environmental migration" and "eco-refugee problem". Even harsher climatic conditions do not push to migrate, these extreme events can still cause a deterioration of the health status of the population, resulting in increased social vulnerability.
As claimed by the IPCC, to address the problems of climate change requires action both in terms of mitigation (action aimed at developing research and technological innovation to reduce the emission of greenhouse gases, as well as actions to affect all actors, collective and individual, responsible for such issues) both in terms of adaptation (actions aimed to decrease, if not the danger of the events, social vulnerability or exposure and vulnerability of the territories). And such adaptation actions can be both structural (eg, actions to protect the environment and its safety measures and actions to ensure an adequate urban planning), is of a social nature (action to reduce the marginalization of social groups and poverty, reducing their vulnerability), both cultural (education and training aimed at changing the attitude of the individual and the community to the complexity of the phenomenon of climate change and its environmental, economic, political and social).

The fact that there are large margins for improvement even at the level of adaptation, as demonstrated by the fact that the policy could, and should, take decisive action to reduce the degradation of the land and therefore its vulnerability, engaging in a proper urban planning to regulate density housing and industrial land. To this should be added the spread by local administrations of environmental action (eg maintenance of the green, reforestation). Have a proper urban plan and promote a socially sustainable environmental policy would indeed have more livable cities, improve security of tenure and record minor damage in case of extreme events infrastructure.

More generally, the environmental phenomena impose socially inclusive policies that implement new welfare strategies to reduce the marginalization and poverty both locally and globally. Indeed, as claimed by the IPCC, a population with social rights (education, housing and health) and economic rights (work) is guaranteed a more receptive and active population with respect to mitigation and adaptation actions. In particular, there is a population able to assess the implications of their misconduct (and maybe to revisit some eating habits, transport and energy), but also to actively participate in collective actions to mitigate and develop a greater capacity to adaptation and resilience to extreme events. In order for all this to happen, however, necessary, in addition to information campaigns about the scientific results and raise awareness of the implications of their practices, innovative training strategies that induce a profound cultural change. The citizens of the twenty-first century must be guided to grasp the complexity of the relationship between environment, culture, economy, politics and society as well as to recognize the special features, even epistemological, of the scientific research process that is the basis of the study of climate change and that is directing the negotiation at international level and its repercussions in the local political level.

Without this cultural change, that the world of politics, education, research, universities and the media should encourage and pursue, continue to dominate, including citizenship, an old and stereotyped idea of science, conceived as the bearer of unquestioned certainties, whose members are experts delegate uncritically environmental impact, decisions that require a rational and shared decision making. In addition, as a result even more worrying, without this cultural change, citizenship would continue to respond to extreme events or locally taken decisions in a purely emotional way that is likely, on the one hand, underestimating the danger of the events and the importance of systems prevention and, on the other, of being helpless and increasingly vulnerable to the events themselves.

Annex A7 - Map of global warming



Annex A8 - Use and Production of Bio Fuels: the "Biodiesel story"

Transport is one of the crucial themes as far as mitigation of climate changes are concerned, as it plays a central role in the domain of greenhouse gases emissions. The WG3 report of the fifth *Intergovernmental Panel on Climate Change* (IPCC, 2014) reported that 25% emissions are a result of the energetic sector, 24% to agriculture and **stock-raising**, 21% to industry, 14% to transports and 6.4% to the building sector. The remaining 9.6% are to be attributed to other energetic sources (data provided in 2010). In this paper, we shall carry on an analysis focused on the sector of transports and, more precisely, in that area concerning bio fuels and biodiesel.

Before tackling an analysis of the core problem, we find it necessary to provide general information about "biomasses". By considering the definition provided in the Directive of the EU Parliament and European Council (EC/2009/28/ Art. 2) the word "biomass" refers to the biodegradable part of products, waste and dissolved solids of biological origin as from agriculture (including vegetarian and animal substances), forestry and connected industrial work, and then also covering fishing and aquaculture plus the biodegradable part of industrial and urban waste. During combustion, biomass emits a quantity of CO_2 into the atmosphere equal to the quantity previously absorbed by plants while processing chlorophyll photosynthesis[4] and this is why the growing and combustion cycle of the biomass is defined as "zero energy balance"[5].

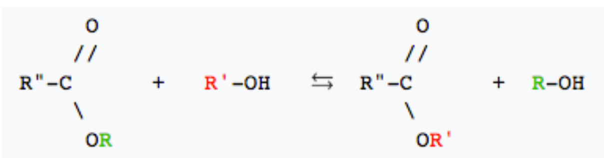
Biodiesel is obtained by squeezing and by **transesterification**[6] of oily biomass such as that from **soy seed** and **rapeseed** (**canola**). This is the bio fuel we intend to deal with, in this essay. As we already hinted at above, the use of this renewable source of energy is not necessarily favorable and it brings about consequences which may act at different levels. This is why the EU has commissioned extensive research aimed at understanding the variety of their impacts, while also quantifying their extent, in terms of both benefits

[4] The so called chlorophyll photosynthesis is a reaction which consists in the production of glucose and oxygen starting from the carbon dioxide in the atmosphere and from metabolic water, in the sunshine, as the following formula shows:

$$6CO_2 + 6H_2O + light \rightarrow C_6H_{12}O_6 + 6O_2$$

[5] Balance is actually a "zero balance" when we avoid taking into consideration any other contribution to the growing of the biomass: if, instead, we contemplate the fact that vegetable and arboreal imply the use of synthetic chemical fertilizers and phytochemicals, besides agricultural machineries, irrigation pumps and means for the transportation of the produce, it all means that a large quantity of fossil fueling is needed and it produces CO_2.That brings to the conclusion that there is no real balance as there is a clear-cut production of CO_2 because of the fossil fuels which are not renewable.

[6] Transesterification consists in the transformation of an ester into another ester by means of an alcohol. Here following, see the represented model: an ester with an alcohol in reported on the left, while, on the right, find another ester plus another alcohol:



and risks. Following here, a summary of considerations concerning the above mentioned research is provided for.

Using biodiesel for transportations, instead of gasoline, brings about a reduction of two well-known greenhouse gases emission, CO (50% reduction) and CO_2 (78,45%). The reason of the reduction can be found in the mechanism of production of the biomass itself: the **carbon** emitted during combustion is the one that already existed in the atmosphere, fixed by vegetables during their growth. The carbon is not, unlike the case with gasoline, the offset which has been sedimented under the earth's crust from time immemorial.

Moreover, a 71% reduction of the emission of aromatic hydrocarbons is also documented; these compounds, that are naturally present both in oil and in carbon, are extremely toxic to the environment, human beings and animals as well as to flora and are numbered among the substances responsible for the ozone hole.

Furthermore using biodiesel, **sulfur dioxide** (SO_2) emissions are almost totally eliminated. This gas, once entered the atmosphere, interacts with oxygen and water vapor and forms sulfuric acid[7]. This, on turn, comes back onto the earth in the form of acid rain which brings acidification of the ground and of water resources, so causing severe damage to the natural environment in many industrialized regions.

Very important is also the reduction (50%) in the emission of particulates. These are held responsible for severe diseases in man's respiratory and circulatory systems. This is why it has become indispensable to introduce anti-particulates filters to vehicles. As to the greenhouse effect, instead, an increased quantity of particulates contributes to the increasing of aerosol[8, that] helps the average of the global radiative forcing to decrease[9], partially compensating greenhouse effect.

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[7] The chain of reactions that leads to the formation of acid rain is herewith reported and discussed. Sulphur dioxide in the atmosphere SO_2 is oxidized, so forming a reaction intermediate:

$$SO_2 + OH\bullet \rightarrow HOSO_2\bullet$$

As the intermediate is highly reactive exactly because of the unpaired electron (•), there immediately is one more reaction:

$$HOSO_2\bullet + O_2 \rightarrow HO_2\bullet + SO_3$$

In the presence of water, Sulphur trioxide SO_3 becomes rapidly converted into Sulphuric acid H_2SO_4:

$$SO_3 + H_2O \rightarrow H_2SO_4$$

[8] Atmospheric aerosol is composed by liquid or solid particles suspended in the air. It may form out of natural origins (ex: volcanoes) or anthropogenic (ex: emissions from industries and from transports) and can influence climate in multiple complex modes, because of its interaction with the radiation and with the clouds, either in terms of cooling or in terms of warming. Altogether, models and observations indicate that aerosol of anthropogenic origin has, on average, exerted an influence of cooling on the earth since pre-industrialization, the which has partially made up for that medium global warming due to the greenhouse gases, which would have occurred in case its influence were missing. The envisaged reduction of emissions of anthropogenic aerosol, undertaken by political acts aimed at making the quality of air healthier, could, in the future, "unmask" this warming (IPCC, 2014).

[9] Radiative forcing, W/m^2, is defined as the difference between solar radiation absorbed by the Earth and the reflected radiation: a positive radiative forcer brings greater radiation into the system and contributes to

The use of biodiesel is also associated with the increasing emissions of **nitric oxides** (NO_X) to the discharge (10 - 15%), which are greenhouse gases. It is however important to stress that, by considering the whole production chain, the biodiesel supply chain emits about 20% nitric oxide less than the oil supply chain. A number of nitric oxides are then reduced, among which N_2O_3 (dinitrogen trioxide) and N_2O_5 (dinitrogen pentoxide) which are water-soluble. Because of atmospheric humidity they may form nitrous acid and nitric acid both found in acid rain.

In order to examine the problem in the view of a balance among the various impacts, it is not enough to restrict the field of the analysis to the emissions deriving from the use of bio fuel. An investigation of the consequences deriving from its production process is necessary.

Biodiesel is produced in countries different from those that make use and benefit of it, mainly in African Countries (Locke & Henley, 2013).

An example of effect of the production process is the following: the conversion of terrains destined to the growing of plantations into areas where biodiesel is produced implies an increase of the price of raw materials in the Third World (compared to high transport costs of food imported from other Countries), resulting in the increase of food insecurity[10] both from the point of view of availability and of access to food.

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its warming, while a negative one involves a larger quantity of radiation coming out and so contributing to the cooling of the system. Radiative forcing is influenced by a compound of greenhouse gases, and this is why IPCC (2014) defined it as "the influence a given factor plays in altering the balance between in-going and out-coming energy of the system Earth-atmosphere and it indicates the importance of that factor as a potential modifier in the field of climate change".

[10] In 1996, the *World Food Summit* defined food security as a situation when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). The 2009 *World Summit on Food Security* extended this definition, describing the four pillars of food security:

- availability: is the supply side of food security, determined by the level of production, stock levels and imports of food in the local area. Availability of foraged foods may also be important in certain contexts. Weather, yields, soil conditions, planting decisions, transport and storage infrastructure and a change in the trade regime can all affect availability;
- access: is the economic and physical access to available food, mainly from the **household** perspective. This can be from **purchases**, gifts or transfers of food. Households' economic access to food is determined by overall household income, disposable income for food and food prices. Ease of physical access to markets to acquire food is influenced by the proximity of markets and other food sources (fields, forests etc.) and the existence and quality of infrastructure;
- use: is the way individuals are able to consume food, which has a direct impact on nutritional status and is closely linked to **feeding** practices, preparation and distribution of food between household members;
- stability: is the maintenance of food security through time while an individual or household may temporarily be food-secure, outside shocks such as food price volatility, unemployment or harvest failures may undermine food security. Shifting demographics within a household, such as the birth or death of a child or other household member, may also affect the stability of food security over time.

Still considering the use of terrains, the spreading technique of monoculture for the production of biodiesel has implied a reduction in biodiversity and has enhanced the risk of growing species of insects and bacteria which strongly damage **crops**. As a consequence, it causes an increase of the price of the few raw materials left. An extensive use of monoculture also raises the risk of soil erosion and the progressively increase of its vulnerability; this contributes to the increase in food insecurity from the point of view of stability, because both local economics and populations come to face times of shortage in the production of crops. The increased vulnerability of agricultural lands caused by insects and parasites also involves a larger use of pesticides which contain nitrous oxide (N_2O), a greenhouse gas that adds to the ozone hole.

The introduction of biomass cultivations might however support the production of crops of owners of small lands and land administrators, who may sell and/or hire their own lands or reach to agreement with large companies: the companies provide technical knowledge about the production of biomass (fertilizers, agrochemical products, a variety of seeds), and/or adequate technological means and, in exchange, they owners or administrations guarantee the companies preferential treatment when buying raw material. This innovation may increase crops and, consequently, the availability of food products, thus conveniently contributing to improving food security[11], even if this would happen only to the involved social class, which means to a small section of the population.

Finally, the presence of cultivations for biodiesel, managed by large companies, may require to enhance the building of social facilities such as roads, electricity networks, paid by the company itself or by the government. This general improvement may, on turn, bring about advantages in traveling, so also favoring working and studying opportunities, as well as an easier way of reaching market places. This would also increase both economic and physical access for people to food stock.

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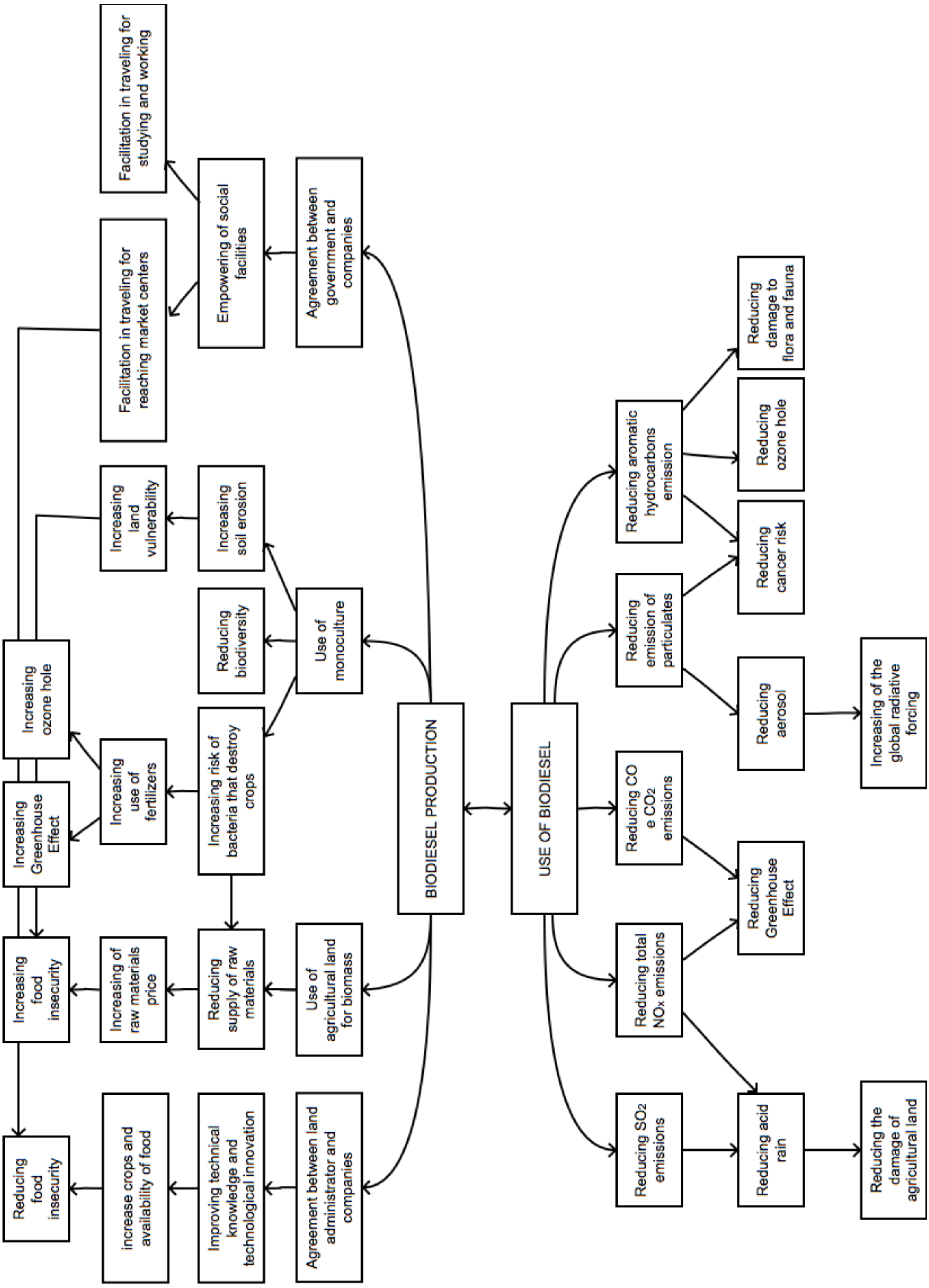
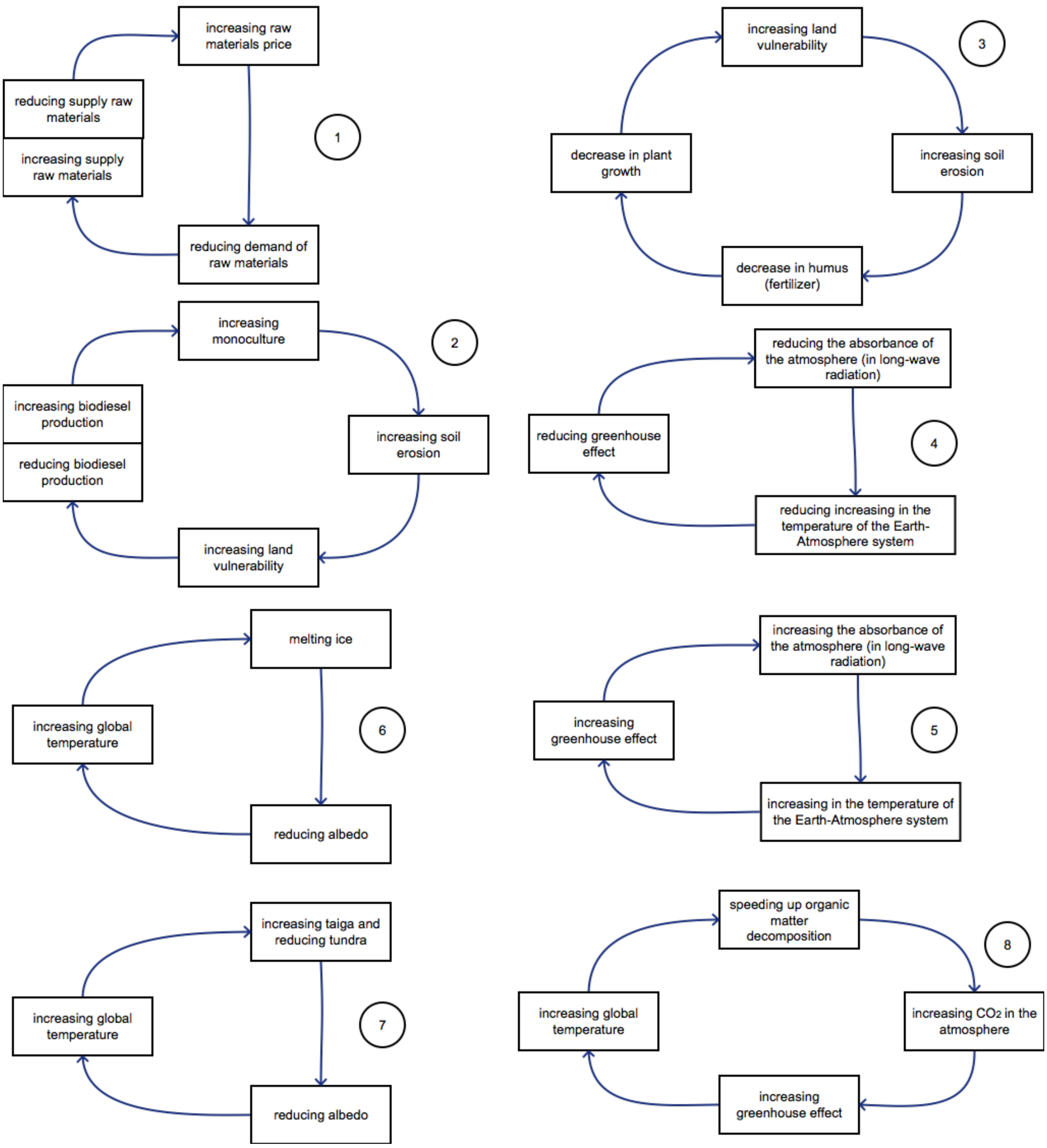
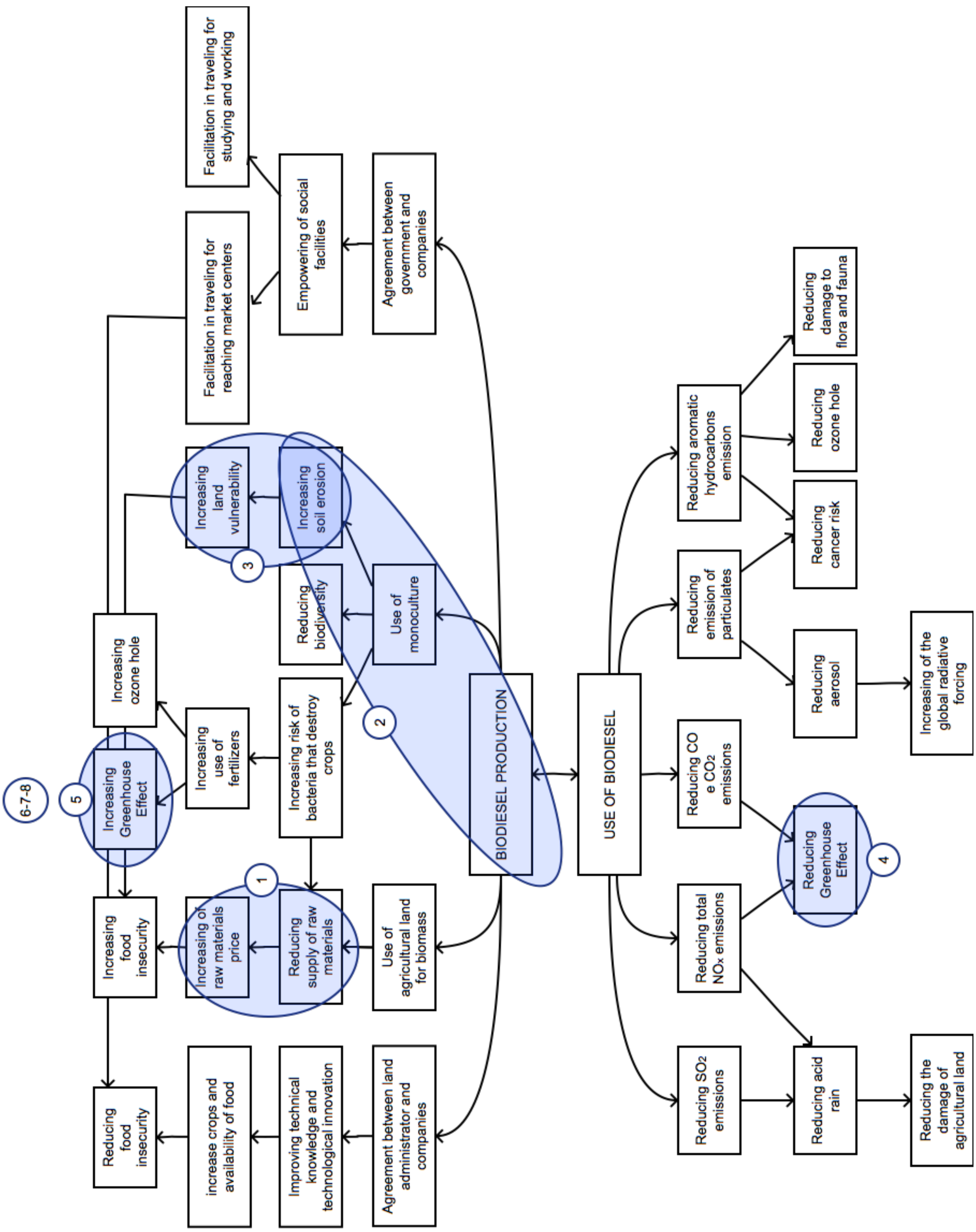
Annex A9 - Cause-effect map of the "Biodiesel story"



Annex A10 - Feedback loops for the "Biodiesel story"



Annex A11 - Cause-effect map of the "Biodiesel story" with the feedback areas highlighted



Annex A12 - The Fishback Game: rules of the game

In order to play the game you need:

- 4 players
- 30 fish cards
- 60 money cards
- 24 cards of 6 different types
- price chart
- table for rounds and year marker (a seed or a little coin is perfect!)

Setup

Prepare 24 fishes on the table, forming the pool.

Put at the corner of the table 60 money cards, forming the bank.

Give each player the 0$ card.

Rules

The game is structured on 10 rounds (10 years), and every round has 8 different phases:

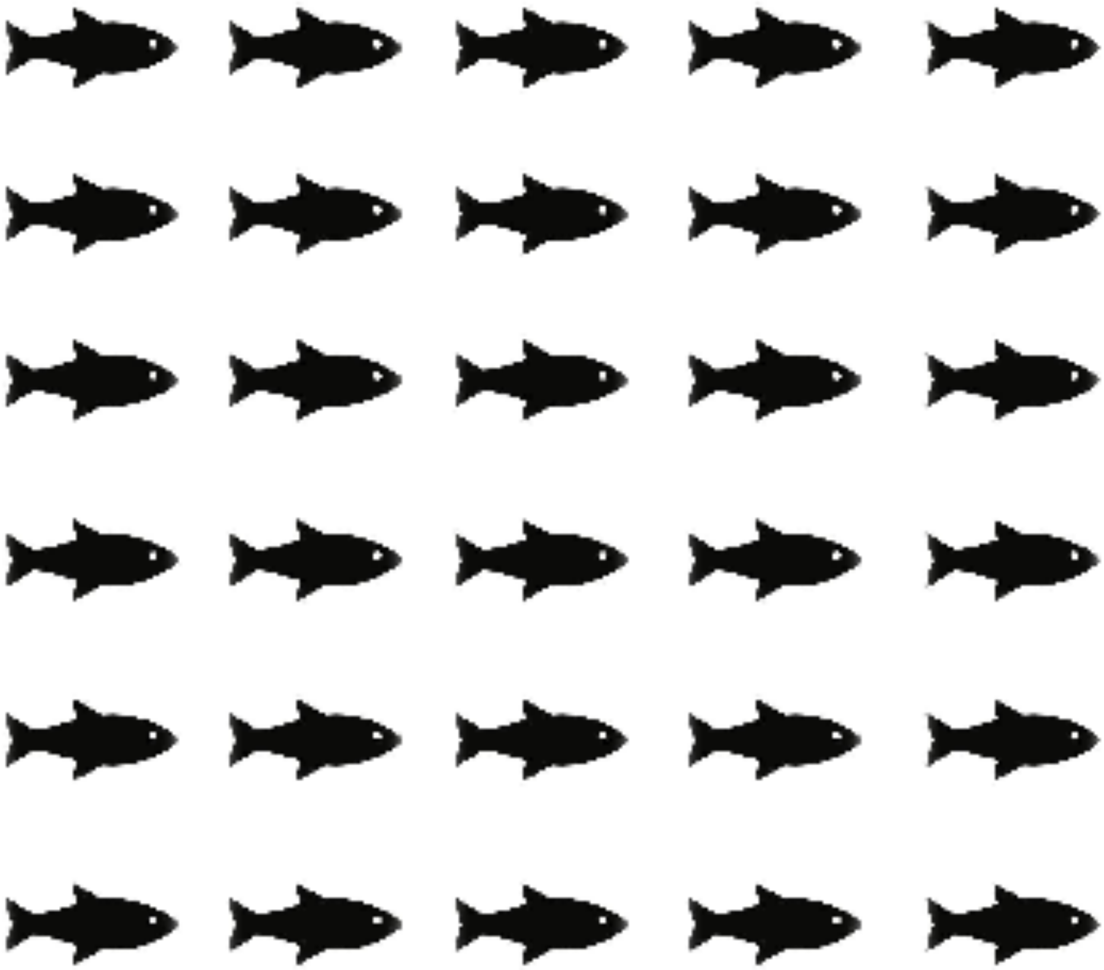
- fishing expedition: all players, at the same time, play one card among the ones they acquired;
- determination of priority: players can invest extra money, among the ones they acquired, to take priority in the harvest phase; they can do so bidding freely and the highest bidder gets the priority and gives the money to the bank (this phase is not necessary but it may be useful in time of scarcity later in the game);
- harvest: starting from the player who has won the priority (or from the youngest player in case there has not been assigned any priority) and proceeding clockwise, players catch the number of fish corresponding to the technology card they played; if the condition "more than 15 fish in the pool" on a card is not met at the beginning of a player's turn, the businessman-player will not catch any fish;
- determination of market price: determine the price of fish for the year by looking at the price chart line corresponding to the total number of fish caught by all players this year;
- income: each player gats from the bank an amount equal to the market place multiplied by the number of fish he caught this year;

- investment: starting from the player who has won the priority and proceeding clockwise, players can decide to acquire other cards by paying the cost reported on the top right corner; the cards a player buys are never discarded and return in player's hands, so at every expedition phase they decide which one to use;
- regeneration: for each 3 remaining fish in the pool, add 1 fish up to a maximum of 30;
- end year: move the year marker to the next space to keep trace of the rounds; if the marker is on the last year, the game ends and the winner is the player with most money; otherwise the player with the priority passes it to the player on his left and a new year starts.

Aim of the game

The game can end before the 10^{th} round if all resources have been exhausted or after 3 consecutive turns with scarce harvest (less than 7 fishes on the market): in these cases everybody loses.

Annex A13 - The Fishback Game: printable material



$ 0

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

$ 0

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

$ 0

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

$ 0

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

$ 3

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

$ 3

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

$ 3

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

$ 3

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

$ 5

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

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CATCH

IF POOL > 15
WHEN YOU START COLLECTING

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CATCH

IF POOL > 15
WHEN YOU START COLLECTING

$ 5

CATCH

IF POOL > 15
WHEN YOU START COLLECTING

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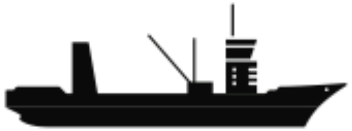
$ 8

CATCH

$ 8

CATCH

$ 8



CATCH

$ 8

CATCH

$ 10

CATCH

$ 10

CATCH

$ 10

CATCH

$ 10

CATCH

HARVEST Count fish caught by all players this year		PRICE Per fish Same for all players
>10	→	$ 1
7-10	→	$ 2
<7	→	$ 3

Game over after 3 consecutive turns with scarce harvest (less than 7 fish overall)

FIRST YEAR					
					LAST YEAR

Annex A14 - The Fishback Game: feedback loops

For a brief introduction at the concept of feedback in the science of complex systems, the video at the following link is suggested:
https://www.youtube.com/watch?v=inVZoI1AkC8.

Negative feedback loops

Definition: with negative feedback, we mean the situation in which the results of a system soften its causes.

- A first balancing loop is the one that tries to move the present state toward the desired state (the limit of thirty fishes) through reproduction, balancing in this way the loss because of fishing and natural death of fishes.
- A second negative feedback is the law of demand, which is a general law in macroeconomics. It states that, as the price of a good increases, quantity demanded decreases; conversely, as the price of a good decreases, quantity demanded increases. In our situation, the more we fish, the bigger is the offer and the smallest is price of every fish; this causes, at the following round, less fishing activity which brings to less offer and, then, to an higher price of fish, and so on. This feedback loop should be a deterrent against overfishing, so that the market price does not decrease.

Positive feedback loops

Definition: with positive feedback, we mean the situation in which the results of a system strengthen its causes.

- A first reinforcing loop is the so called “rich gets richer” with regard to the fact that who has got more cards can fish more and receives more money, so he can buy other important cards that allow to fish a lot and receive a lot of money.
- In scarcity periods (when few fishes can be fished) the market is empty, so that there is a big temptation to extract the remaining resources in order to reach a higher gain: a positive feedback loop raises because there is scarcity of fishes, so the fishing activity is limited; but the gains are big and this causes a prosecution in fishing activities, worsening further the scarcity.

Annex A15 - Probable, possible and desirable futures for the Town Irene

Irene is a small country town of about 8.000 inhabitants run-through by a large communication road. It counts three commercial areas, operating in the food sector. It is situated few kms away from an important commercial area which, though, is under the jurisdiction of a different Municipal Administration.

The first of its commercial areas in the center, right on one side of the main road, has a large parking area and is managed by the Degli Esposti family who sells homemade selected products. It is a well furnished and very looked-after shop, and there is a small coffee bar next to it. The two facilities, shop and coffee bar, stand in as favorite meeting points for the whole community, as there are only few other shops nearby. Because of the economic crisis, business has not been, one would say, in full sail, in recent years, and the profit margin has progressivly gone down. Ensured stability has been possible thanks to the fact that family managing has allowed a reduction of costs in the employement of personnel, still assuring an unchanged carefullness of both space and offer.

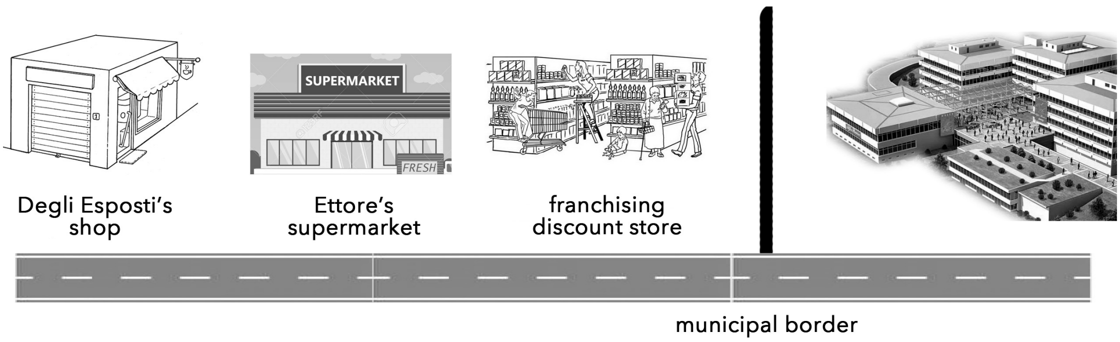
There is a small supermarket at a short distance away from the small town, but still on the main road, towards an artisanal area, where more similar activities can be found. The owner, Ettore, who has managed the activity for many years, has six employees but, though being allowed permission by the existing urbanistic regulations, he has never renovated his offer nor enlarged his place, so to extend the range of available products. The reason why is to be found in his approaching retirement age and the scarse money possessed to invest. These have caused the owner to go on along a minimal strategy.

In a rather near future, the management may be taken over by an entrepreneur or by a large chain. Though this has not happened yet, one can believe that a potential investor may find the area appealing, exactly by virtue of its possible extension and renovation. Despite the vicinity to the commercial area, the town planning scheme features an extensive expansion and even doubling the existing surface of the supermarket, in a district already compromised from the environmental point of view.

Finally, farther off the town center, about 2 kms away from the supermarket, there is a small discount store belonging to a large chain, where 10 employees work. The present Urban Planning Regulations would not allow any possibility of expansion here. The chain owners wish they could double the surface and add a nearby parking lot where now there is an agricultural field, but they should have an alteration of the urban regulations approved by the Municipal Council.

The investment would be directed towards the realization of an innovative unit, destined to the sale of biologic unpacked products (meat, fruit, vegetables, dairy products), plus annexed storage unit. A big photovoltaic plant would be installed on the roof. Being the discount market and the biologic shop close to each other, would imply the employement of 4 more people only.

Before asking for an urban plan alteration, the chain owners has taken into consideration the hypothesis of buying the above mentioned supermarket where urban regulations would already allow the realization of the project. This event would avoid the possibility for a new competitor to come by, yet, on the other hand, this would imply the necessity to increase costs for more needed employees. As a consequence, this view has been rejected and an alteration of the urban plan has been requested.



Activity 1: Analysis of the situation and identifications of scenarios

Activity 1a)

Imagine you are the public administrator requested to make a choice on whether to grant the plan alteration asked for by the owner of the discount.

Before you make a decision, analyse and outline a planning scheme of the situation aknowledging a) the stakeholders, b) their needs and interests, c) the existing interactions between them. Use a map as a mean for outlining your analysis.

If you think you need more data to have a more precise view of the urban and social situation of *Irene*, introduce these "missing data" or provide a context to the problem as you wish, making your choices explicit.

Activity 1b)

Starting from the plan scheme of the present situation, now make sense of any potential effects (social, economic, occupational, environmental) which the two options may arise (expansion allowed or denied). Identify and describe two probable scenarios at 2025: the first will have to illustrate a probable condition of evolution of the system as a consequence of *granted expansion*; the second must envisage a probable situation of evolution after a *denied expansion*.

Probable Scenario after YES	
Probable Scenario after NO	

Activity 2: Identification of *positive and negative feedbacks* arising from given scenarios.

Beside the already identified probable scenarios, we now supply you with two more *possible* scenarios in the view of an evolution of the town Irene from 2017 to 2025. We now ask you to detect, at least, one outcome from the positive and/or the negative feedback for each of the given scenarios and to justify it.

Scenario 3:

In 2025 the town has become an attractive center thanks to its many commercial activities which have developed beyond the commercial area, all along the large communication road. Important commercial chains and outlet shops attract people from outside the area and have offered young people more than 100 jobs, but the historical centre has become progressively empty. There is still a coffee bar left which has been seeing only the elderly people of the town, while the young, thanks to the time they have to spare, tend to move to nearby towns.

Feedback (indicate whether it is a positive or a negative one)	

Scenario 4:

In 2025 the town has become a centre of attraction for a local and diversified tourism, thanks to the gastronomic offer of special homemade products the shops and the restaurants make; indeed they are still present in the centre and very looked-after, though not exclusive. The farmers of the area have entered agreements with the supermarkets and with some of the shops that sell A-Products (km0) and they stand street stall markets in the historical center, twice a month, that attract even whole families with children, then also young people, drawn by creative artistic events organized near the market. There are now two coffee bars.

Feedback (indicate whether it is a positive or a negative feedback)	

Activity 3: *Desirable Future*

Discuss with the members of your group in order to find a catchphrase that characterizes Irene as the ideal town where to live or to visit in 2025. Also provide a description in terms of '*desirable scenario*'.

Catchphrase: Scenario 5:

Your group and you plan an action which you may undertake (as singles and/or as a group) in the present, in order to favour the realization of your desired scenario. As you plan the action to undertake, describe: a) who you are and the position you hold when realizing the action (for ex.: political decision maker, private citizen, an association, society, company or firm, a bank, the headmaster of a school, etc.), b) what you intend to do, c) why you think this action favours the realization of your desirable scenario.

Who we are:
What we do:
Why the action favours the realization of the scenario:

Activity 4: The decision

Will you allow expansion or not? Why?

Annex A16 - Pre-questionnaire (Q_1)

Name: ___________________ Surname: _____________________ Date: ___________

1. We often hear about climate change and/or global warming and, not infrequently, we discuss the reality of these phenomena. To what extent do you believe that these phenomena are real?

□ Very much □ Enough □ Little □ Not at all □ I don't know

→If you answered "Not at all", please justify your answer: ……………………………
…………………………………………………………………………………………
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2. By referring to the items listed below, to what extent do you think they are **causes** of the climate change?

		Very much	**Enough**	**Little**	**Not at all**	**I don't know**
A	Accumulation in the atmosphere of GHE produced by individuals					
	A.1. Transports					
	A.2 Food					
	A.3 House energy					
B	Accumulation in the atmosphere of GHE produced by the industries					
C	Livestock					
D	Intensive agriculture					
E	The ozone hole					
F	Deforestation					
G	Pollution (specify what you intend: _________________)					
H	Nuclear energy					
J	Other (specify: ________________________)					

Please, justify your answer:
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3. What are the phenomena of which you've heard as **consequences** of the climate change? Which of these phenomena scares you the most?
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4. Is there anything that you have changed in your lifestyle thinking to climate change?

□ Yes □ No

4.a. If you answered *"yes"*, please explain in what sense:
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……………………………………………………………………………………………………

4.b. If you answered "*no*":

□ You really would like something but you do not anything because:
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……………………………………………………………………………………………………

□ You are not doing anything and you won't do anything because:
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5. How much have you learned about climate change, from each of the following sources?

	Very much	**Enough**	**Little**	**Not at all**
Television				
Internet				
Books or scientific magazines				
Radio				
Movies				
School				
Family and friends				
Environmental associations				
Conferences and/or museums				
Seminars and/or events				

6. How much do you trust the following sources of information about the issue of climate change?

	Very much	**Enough**	**Little**	**Not at all**
Scientific programs on television				
Scientists				
Museums of science or natural history				
Family and friends				
Politicians				
Environmental associations				
University professors				
School teachers				
TV news				
TV reports on weather				

7. You've surely heard about greenhouse effect, what is it? Try to explain, with your words, the mechanism that is at the base of this phenomenon.
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8. In physics or generally in science, you have certainly heard about system. How would you define it? What properties do you identify? You can help yourself by providing some examples.

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9. You have surely heard the word feedback. In what contexts have you heard it? What meaning do you ascribe to this word? Have you ever heard about it referring to science? In your opinion, what does it mean when it is referred to physical systems? Try to give some example.

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10. What does it mean, in your opinion, to make predictions (relating to climate but not only)?

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Annex A17 - Intermediate questionnaire (Q_2)

Name: ____________________ Surname: _________________ Date: ________________

1. Thinking at the activities done so far, how would you define a "system"? Help yourself by trying to provide examples.
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2. Thinking at the activities done so far, has your idea changed with respect to the word "feedback"? If so, what new meanings do you attribute to it?
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2.a What is a positive feedback? How would you define it?
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2.b What is a negative feedback? How would you define it?
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2.c Given the following examples, indicate if they are positive or negative feedbacks and justify your answer.

Example	Feedback	Justify your answer
Sweating regulates the body temperature in this way: when the environmental temperature grows, also the body heat grows and this causes perspiration; however, sweat, evaporating, reduces the body temperature.		
The mechanism of **usury** is the following: initial economic requirement, demand for a loan with very high interest rates,		

inability to repay the loan, worsening of initial economic need and increase of the debt.		
The **water level regulation mechanism in the water flush tank** works as follows: the increase in liquid level in the tank causes float lifting, which in turn acts on a valve by closing the water flow.		
The **propagation of the nervous impulse** occurs as follows: the depolarization of a nervous cell makes the inflow of sodium grow in the cell which, in turn, increases the depolarization.		

2.d Write at least another example of positive feedback and at least another example of negative feedback: choose the field you prefer (economic, social, physical, biological, …) and draw the relative schematic representation.

3. What does it mean making prediction when referred to climate change? What have you learnt about this aspect from the activities that have been carried out so far in the course?
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4. What advantages and disadvantages have you found in using simulations to address the concepts of the science of complex systems?
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Annex A18 - Introduction to Logical Framework Approach

Developed in the late 1960's, the *Logical Framework Approach* (LFA) is at the same time an analytical process and a set of tools designed to support project planning and management. It has been described as an 'aid to thinking' because its aim is to give structure to the analysis so that important questions can be asked, weakness identified and decision makers can make informed decisions based on their improved understanding of the project rationale, its intended objectives and the means by which objectives will be achieved".

The stages of LFA

The LFA can be divided in two main macro-stages which in turn are divided in secondary steps:

1) *macro-stage of analysis* consists of:
   I) Stakeholder analysis, in order to identify and characterize influent stakeholders within the project;
   II) Problem analysis, in order to identify key-problems, constraints and opportunities and to determine cause-effect relationships;
   III) Objectives analysis, in order to develop solutions from the identified problems;
   IV) Strategy analysis, in order to identify different options to achieve solutions, with the aim of selecting the most appropriate one;
2) *macro-stage of planning* consists of:
   V) Developing *Logical Framework matrix* (LFm), in order to define project structure, test its internal logic and risks, formulate measurable indicators of success;
   VI) Activity scheduling, in order to determine the sequence and dependency of activities, estimate their duration and assign responsibility;
   VII) Resource scheduling, in order to develop input schedules and a budget.

The scheme above has not to lead someone to think that LFA is a banal algorithm, a set of linear step to execute in sequence one after one other: rather, analysis and planning are iterative processes which expect that one returns back at a certain phase more and more time during the study.

In the followings, the first five phases of LFA are briefly illustrated and exemplified, referring to an issue of river water pollution and its impact on income and health.

I) Stakeholder analysis

With the word *stakeholder* are considered all those individuals, groups of people, institutions or firms that may have a significant interest in the success or failure of the project in exam. During this step of the analysis macro-stage, the key questions are 'Whose problems or opportunities are we analysing?' and 'Who will benefit or loose-out, and how, from a proposed project intervention?'.

To support stakeholder analysis a variety of tools can be used: some suggested options are stakeholder analysis matrix, SWOT matrix, Venn diagrams and spider diagrams.

The stakeholder analysis matrix (Table 1) is a flexible tool because the type of information collected, analysed and presented in the columns of such a matrix can be adapted to meet the needs of different circumstances.

Stakeholder and basic characteristics	Interests and how affected by the problem(s)	Capacity and motivation to bring about change	Possible actions to address stakeholder interests
Fishing families: c.20,000 families, low income earners, small scale family businesses, organised into informal cooperatives, women actively involved in fish processing and marketing	• Maintain and improve their means of livelihood • Pollution is affecting volume and quality of catch • Family health is suffering, particularly children and mothers	• Keen interest in pollution control measures • Limited political influence given weak organizational structure	• Support capacity to organize and lobby • Implement industry pollution control measures • Identify/develop alternative income sources for women and men
Industry X: Large scale industrial operation, poorly regulated and no-unions, influential lobby group, poor environmental record	• Maintain/increase profits • Some concern about public image • Concern about costs if environmental regulations enforced	• Have financial and technical resources to employ new cleaner technologies • Limited current motivation to change	• Raise their awareness of social and environmental impact • Mobilise political pressure to influence industry behaviour • Strengthen and enforce environmental laws
Households: c.150,000 households discharge waste and waste water into river, also source some drinking water and eat fish from the river	• Aware of industrial pollution and impact on water quality • Want to dispose of own waste away from the household • Want access to clean water	• Limited understanding of the health impact of their own waste/ waste water disposal • Potential to lobby government bodies more effectively • Appear willing to pay for improved waste management services	• Raise awareness of households as to implications of their own waste disposal practices • Work with communities and local government on addressing water and sanitation issues
Environmental protection agency: Etc	etc	etc	etc

Table 1. Stakeholder analysis matrix.

The SWOT matrix (Table 2) is used to analyse the internal strengths and weaknesses of an organization and the external opportunities and threats that it faces; in the reported example - related to the river water pollution issue - the organization considered is a fishing cooperative.

Strengths	Weaknesses
• Grassroots based and quite broad membership • Focused on the specific concerns of a relatively homogenous group • Men and women both represented • Provide a basic small scale credit facility	• Limited lobbying capacity and environmental management skills • Lack of formal constitutions and unclear legal status • Weak linkages with other organizations • Internal disagreements on limiting fishing effort in response to declining fish stocks
Opportunities	**Threats**
• Growing public/political concern over health impacts of uncontrolled waste disposal • New government legislation in preparation on Environmental Protection – largely focused on making polluters pay • The river is potentially rich in resources for local consumption and sale • New markets for fish and fish products developing as a result of improved transport infrastructure to nearby population centers	• Political influence of industrial lobby groups who are opposed to tighter environmental protection laws (namely waste disposal) • New environmental protection legislation may impact on access to traditional fishing grounds and the fishing methods that can be employed

Table 2. SWOT matrix.

The Venn diagram (Figure 1) is useful for analysing and illustrating the nature of relationships between key stakeholder groups. The dimension of circles indicates the relative power of each group, whilst the spatial separation indicates the relative strength or weakness of the interaction between different groups. In the practice of LFA, Venn diagrams are commonly used as a participatory planning tool with target groups to help them profile their concept of such relationships: in this way, the dimension of circles becomes the *perceived* relative power of each group and the spatial separation becomes the *perceived* relative strength or weakness of the interaction between different groups. In the reported example the perspective chosen is that of fishing families.

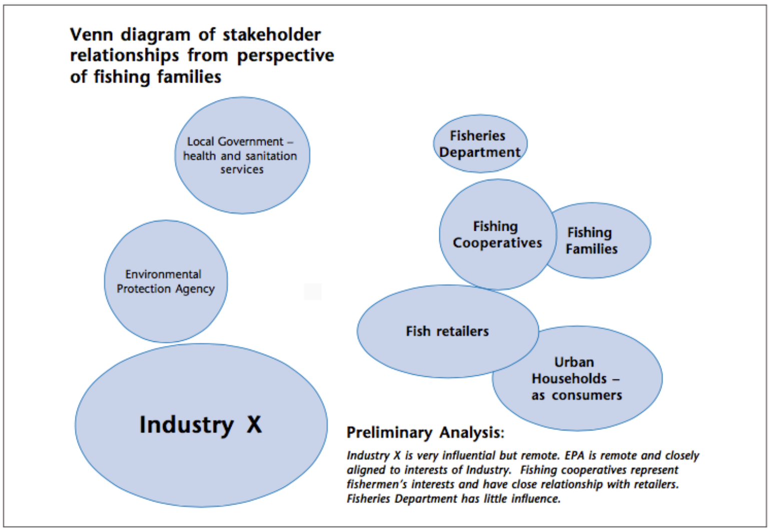

Figure 1. Venn diagram.

The spider diagram (Figure 2) can be used to help analyse and provide a visual summary of institutional capacity; in the reported example there is the analysis of the Environmental Protection Agency (EPA). The result of the analysis is that the EPA has relatively strong (~3) technical and financial management skills, that its policy and planning systems are also fairly robust (~2) but that has some critical shortcomings (~1) in terms of transparency and accountability, its relationship with other agencies and with its clients.

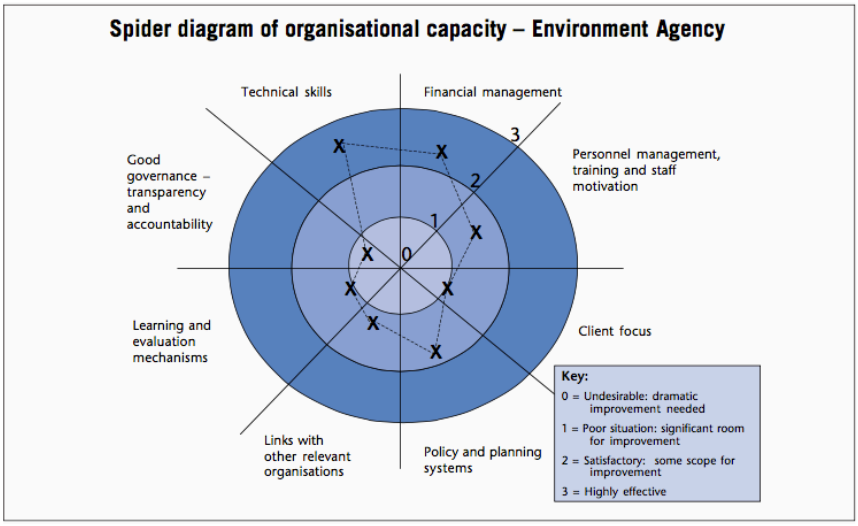

Figure 2. Spider diagram.

The stakeholder analysis and the subsequent phase of problem analysis are closely connected as part of the initial situation analysis; because of this mutual connection between them, they should in practice be conducted in tandem rather than one after the other.

II) Problem analysis

The main goal of this step of the analysis stage is to identify the negative aspects of an existing situation and establish the cause-effect relationships between the identified problems, answering the question 'What are the problems?' and 'Whose problems?'. After having define the framework and the subject of analysis, it follows the identification of the major problems faced by target groups and beneficiaries, then the problems are visualized in form of a diagram called a 'problem tree' which summarize the cause-effect relationships. The tree (Figure 3) should provide a robust but simplified version of reality: it does not contain nor explain the complexity of every cause-effect relationship because, if it did, it would be useless in addressing the subsequent steps in the analysis.

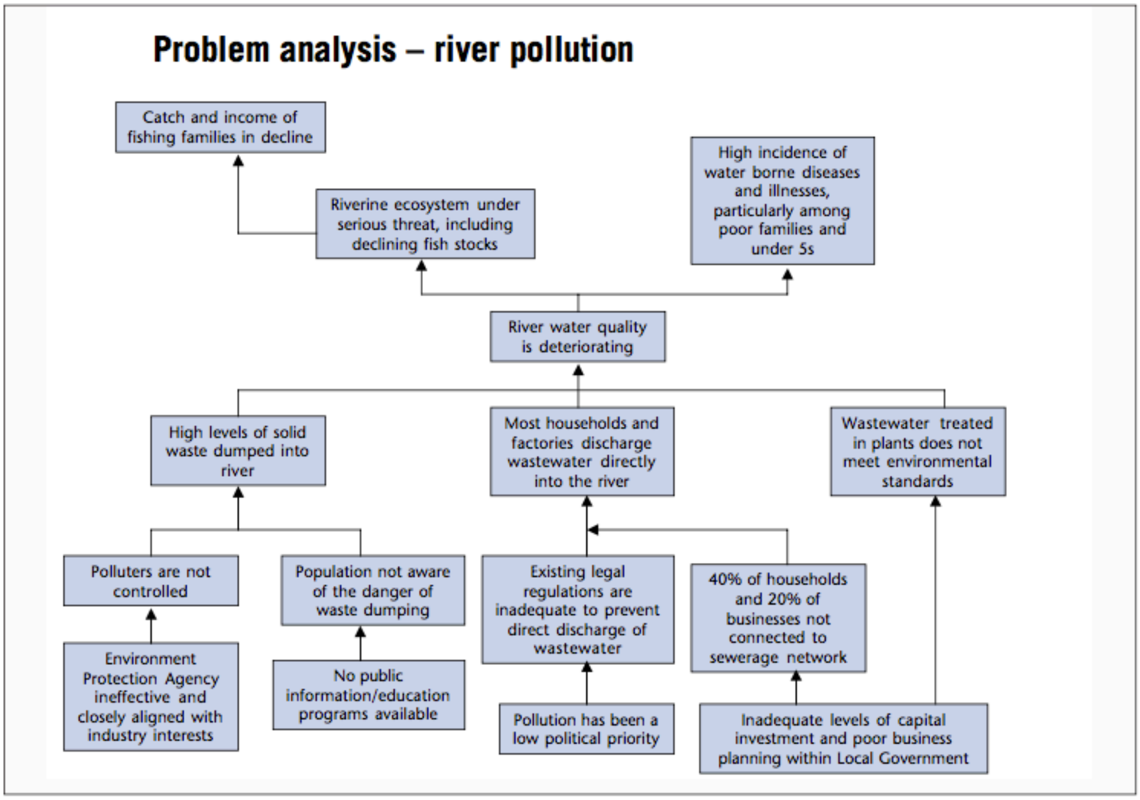

Figure 3. Problem tree.

III) Objectives analysis

After having analysed stakeholders and problems, it is necessary to describe the situation in the future, once identified problems have been removed. In this phase, the first thing to do is reformulating all negative situations of the problem analysis into positive situations that are at the same time desirable and realistically achievable; secondly, the cause-effect relationships of the problem tree are transformed in means-ends linkages that ensure the validity and completeness of the hierarchy of objectives.

The product of this phase of analysis is a diagram called ‘objective tree’ (Figure 4). Its structure is the same of the problem tree in Figure 3 and the difference consists in the fact that the negative situations (like ‘river water quality is deteriorating’ and ‘polluters are not controlled’) in the problem tree are expressed as positive achievements (like ‘river water quality is improved’ and ‘polluters are effectively controlled’) in the objective tree.

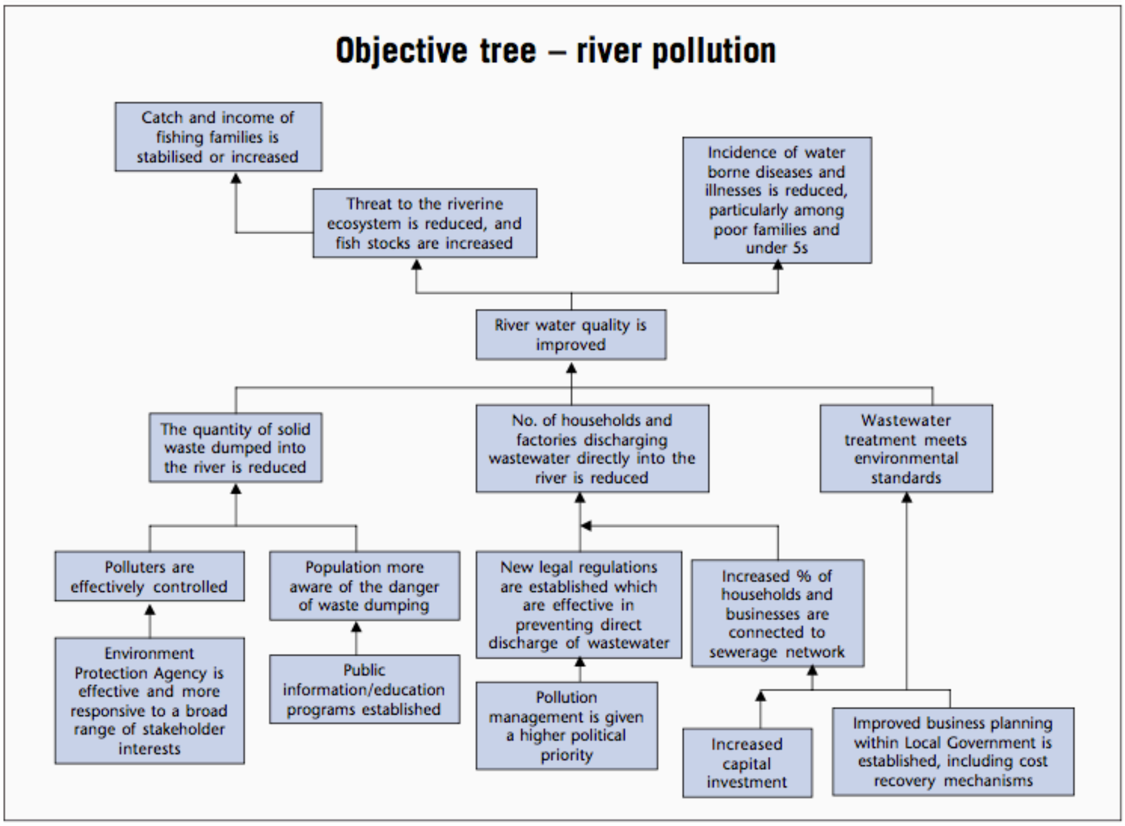

Figure 4. Objective tree.

IV) Strategy analysis

This analytical stage is considered the most difficult and challenging, as it involves synthesising a lot of information in order to make a complex judgement about the best implementation strategies to pursue. The main question that can guide the strategy analysis is ‘What is the combination of interventions that are most likely to bring about the desired results and promote sustainability of benefits?’. In practice, a number of compromises often have to be made to balance different stakeholder interest, political demands and practical constraints such as the likely resource availability.

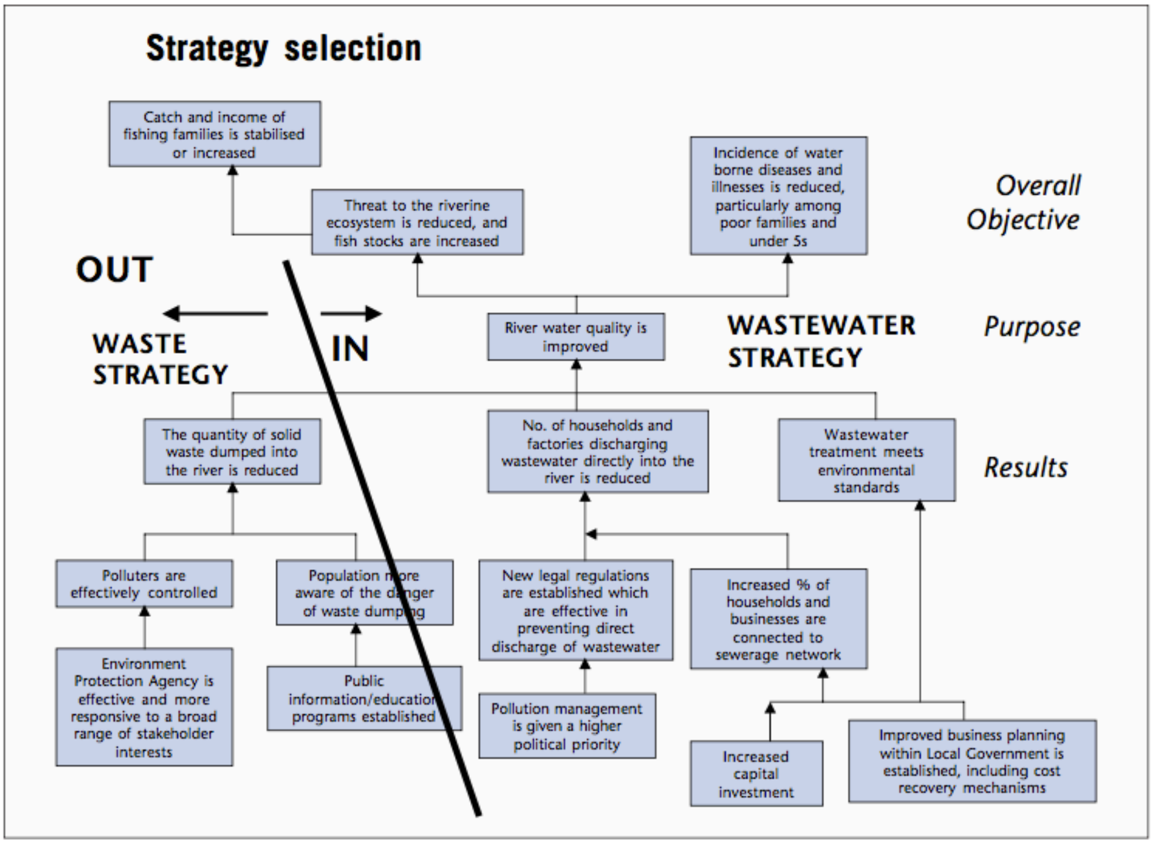

Figure 5. Objective tree equipped with strategy selection.

The key criteria for strategy selection could include expected contribution to key policy objectives (e.g. poverty reduction, economic integration), benefits to target groups, complementarity with other ongoing or planned programmes, capital and operating cost implications, financial and economic cost-benefit, contribution to institutional capacity building, technical feasibility, environmental impact.

The result of the strategy analysis with regard to our specific issue is summarised in Figure 5. The starting point is the objective tree on which it is indicated the choice made to focus the project primarily on a waste-water strategy. During the moment of strategy selection, a distinction between results, purpose and overall objective is done and it is reported also on the objective tree.

V) Developing *Logical Framework matrix*

The result of the stakeholder, problem, objectives and strategy analysis are used as the basis for preparing the Logical Framework matrix (also called *Logframe matrix*). The basic matrix consists of four columns and three-four rows; the information contained in each column and row is summarized in the table in Table 3.

Project Description	Indicators	Source of Verification	Assumptions
Overall objective: The broad development impact to which the project contributes – at a national or sectoral level (provides the link to the policy and/or sector programme context)	Measures the extent to which a contribution to the overall objective has been made. Used during evaluation. However, it is often not appropriate for the project itself to try and collect this information.	Sources of information and methods used to collect and report it (including who and when/how frequently).	
Purpose: The development outcome at the end of the project – more specifically the expected benefits to the target group(s)	Helps answer the question 'How will we know if the purpose has been achieved'? Should include appropriate details of quantity, quality and time.	Sources of information and methods used to collect and report it (including who and when/how frequently)	Assumptions (factors outside project management's control) that may impact on the purpose-objective linkage
Results: The direct/tangible results (good and services) that the project delivers, and which are largely under project management's control	Helps answer the question 'How will we know if the results have been delivered'? Should include appropriate details of quantity, quality and time.	Sources of information and methods used to collect and report it (including who and when/how frequently)	Assumptions (factors outside project management's control) that may impact on the result-purpose linkage

Table 3. Information contained in the Logframe matrix.

It is important that the matrix includes only the project overall objectives, purpose and results, so that activities and the details of inputs and budget are described and documented separately: this is particularly useful because they are usually subject to regular review and change, and their inclusion in the Logframe matrix would mean that the matrix must be revised more frequently than is often the case to keep it current and relevant.

As all the process of LFA, also the preparation of a Logframe matrix is an iterative process; anyway, there is a general sequence which is often followed to completing the matrix: it is illustrated in Table 4, where an additional row, for a concise description of the activities, has been attached.

Project Description	Indicators	Sources of verification	Assumptions
Overall objective 1	8	9	
Purpose 2	10	11	7
Results 3	12	13	6
Activities 4 *(optional inclusion in the matrix)*	*Not included*	*Not included*	5 *(optional inclusion in the matrix)*

Table 4. General sequence for the completion of a Logframe matrix.

The first column describes the means-ends logic of the entire project, also called the 'intervention logic'. Reading it from the top down, we can say that if we wish to contribute to the overall objective, then we must achieve the purpose; if we wish to achieve the purpose, then we must deliver the specified results; if we wish to deliver the results, then the specified activities must be implemented; if we wish to implement the specified activities, then we must apply identified inputs or resources. Some example, about our issue of river water pollution, of how to write statements in the first column are written in Table 5.

Objective hierarchy	Example of how to write statements
Overall objective	To contribute to improved family health, particularly of under 5s, and the general health of the riverine eco-system
Purpose	1. Improved river water quality
Results	1.1 Reduced volume of waste-water directly discharged into the river system by households and factories 1.2 Waste-water treatment standards established and effectively enforced
Activities *(may not be included in the matrix itself, but rather presented in an activity schedule format)*	1.1.1 Conduct baseline survey of households and businesses 1.1.2 Complete engineering specifications for expanded sewerage network 1.1.3 Prepare tender documents, tender and select contractor 1.1.4 Identify appropriate incentives for factories to use clean technologies 1.1.5 Prepare and deliver public information and awareness program 1.1.6 etc

Table 5. Examples of how to write statements in the first column of the Logframe matrix.

The fourth column regards the assumptions, that are external factors that have the potential to influence the success of a project, but lie outside the direct control of project managers. Once the activities have been carried out and if the assumptions at this level hold true, results will be achieved; once these results and the assumptions at this level are fulfilled, the project purpose will be achieved; once the purpose has been achieved and the assumption at this level are fulfilled, contribution to the achievement of the overall objectives will have been made by the project.

The probability of these assumptions holding true needs to be further analysed to help assess not only the project's feasibility but also how risky the project is. A useful way of assessing the importance of assumptions during design is with the assumptions assessment flowchart shown in Figure 6.

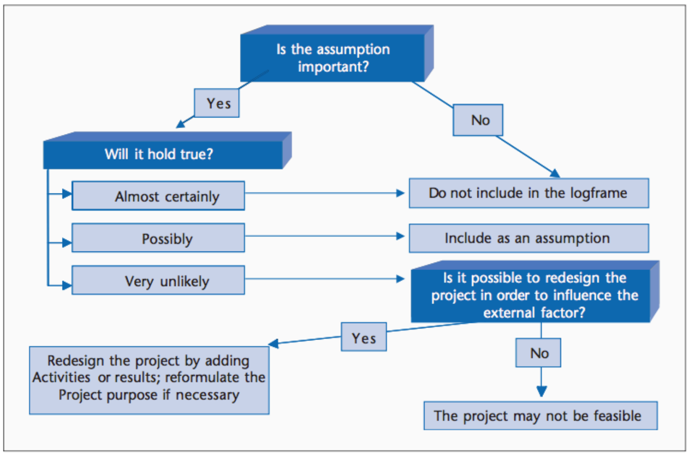

Figure 6. Assumptions assessment flowchart.

An example of assumptions that can be made about our issue of river water pollution is shown in Figure 7.

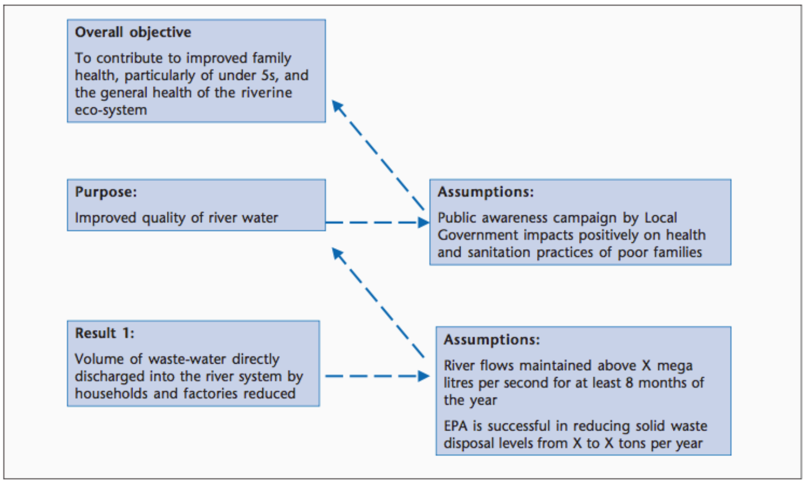

Figure 7. Example of assumptions.

The second column of the Logframe matrix contains the indicators that might be used to measure and report on the achievement of objectives; their complete name is Objectively Verifiable Indicators because their aim is giving information that is the same if collected by different people. They are formulated in response to the questions ‘How would we know whether or not what has been planned is actually happening or happened? How do we verify success?’. In order to write good OVIs, it is suggested to think to them as SMART: indeed they have to be Specific to the objective it is supposed to measure, Measurable, Available at an acceptable cost, Relevant to the information needs of managers and Time-bound. A specification about the measurable feature has to be done: the indicators may provide not only quantitative but also important qualitative information, such as the opinions of target groups.

The third column gives the sources of verification that help to test whether or not the indicators can be realistically measured at the expense of a reasonable amount of time, money and effort. A well-written source of verification should specify how the information should be collected and the available documented source, who should collect the information and how regularly it should be provided.

The most important indicators and means of verifications, from the project manager’s perspective, are the result and purpose ones; indeed it is not generally the responsibility of the project itself to collect information on the contribution of the project to the overall objectives. In Table 6 in shown an example of possible indicators and sources of verification for the purpose of the river water pollution reduction project.

After having briefly described each column and row, an example of how key elements of the draft Logframe matrix might look for the river water pollution reduction project is shown in Table 7.

Project description	Indicator	Source of Verification
Purpose Improved quality of river water	**The Indicator:** Concentration of heavy metal compounds (Pb, Cd, Hg) and untreated sewerage **The Quantity:** Is reduced by 25% compared to levels in 2003 **The Quality:** And meets established national health/pollution control standards **The Time:** By end of 2006	Weekly water quality surveys, jointly conducted by the Environmental Protection Agency and the River Authority, and reported monthly to the Local Government Minister for Environment (Chair of Project Steering Committee).

Table 6. Example of an indicator and a source of verification.

Project description	Indicators	Means of Verification	Assumptions
Overall objective To contribute to improved family health, particularly the under 5s, and to improve the general health of the riverine eco-system	- Incidence of water borne diseases, skin infections and blood disorders caused by heavy metals, reduced by 50% by 2008, specifically among low-income families living along the river	- Municipal hospital and clinic records, including maternal and child health records collected by mobile MCH teams. Results summarized in an Annual State of the Environment report by the EPA.	
Purpose Improved quality of river water	- Concentration of heavy metal compounds (Pb, Cd, Hg) and untreated sewerage; reduced by 25% (compared to levels in 2003) and meets established national health/pollution control standards by end of 2007	- Weekly water quality surveys, jointly conducted by the Environmental Protection Agency and the River Authority, and reported monthly to the Local Government Minister for Environment (Chair of Project Steering Committee)	- The pubic awareness campaign conducted by the Local Government impacts positively on families sanitation and hygiene practices - Fishing cooperatives are effective in limiting their members exploitation of fish 'nursery' areas
Result 1 Volume of waste-water directly discharged into the river system by households and factories reduced	- 70% of waste water produced by factories and 80% of waste water produced by households is treated in plants by 2006	- Annual sample survey of households and factories conducted by Municipalities between 2003 and 2006	- River flows maintained above X mega litres per second for at least 8 months of the year - Upstream water quality remains stable
Result 2 Waste-water treatment standards established and effectively enforced	- Waste water from 4 existing treatment plants meets EPA quality standards (heavy metals and sewerage content) by 2005	- EPA audits (using revised standards and improved audit methods), conducted quarterly and reported to Project Steering Committee	- EPA is successful in reducing solid waste disposal levels by factories from X to X tons per year
Etc			

Table 7. Example of key elements of a draft Logframe matrix.

Evaluation criteria developed with LFA

With the development of its analysis tools, LFA provides also some criteria for the evaluation of the project itself. They are described in the followings:

- relevance: measures the appropriateness of project objectives to the problems that it was supposed to address, and to the physical and policy environment within which it operated;
- efficiency: indicates the fact that the project results have been achieved at reasonable cost (this criterion requires comparing alternative approaches to achieving the same results, to see whether the most efficient process has been adopted);
- effectiveness: is an assessment of the contribution made by results to achievement of the project purpose and how assumptions have affected project achievements;
- impact: measures the effect of the project on its wider environment and its contribution to the wider policy or sector objectives;
- sustainability: refers to the assessment of the likelihood of benefits produced by the project to continue to flow after external funding has ended, and with particular reference to factors of ownership by beneficiaries, policy support, economic and financial factors, socio-cultural aspects, gender equality, appropriate technology, environmental aspects and institutional and management capacity.

The links between the evaluation criteria and the Logframe objective hierarchy is represented in Figure 8.

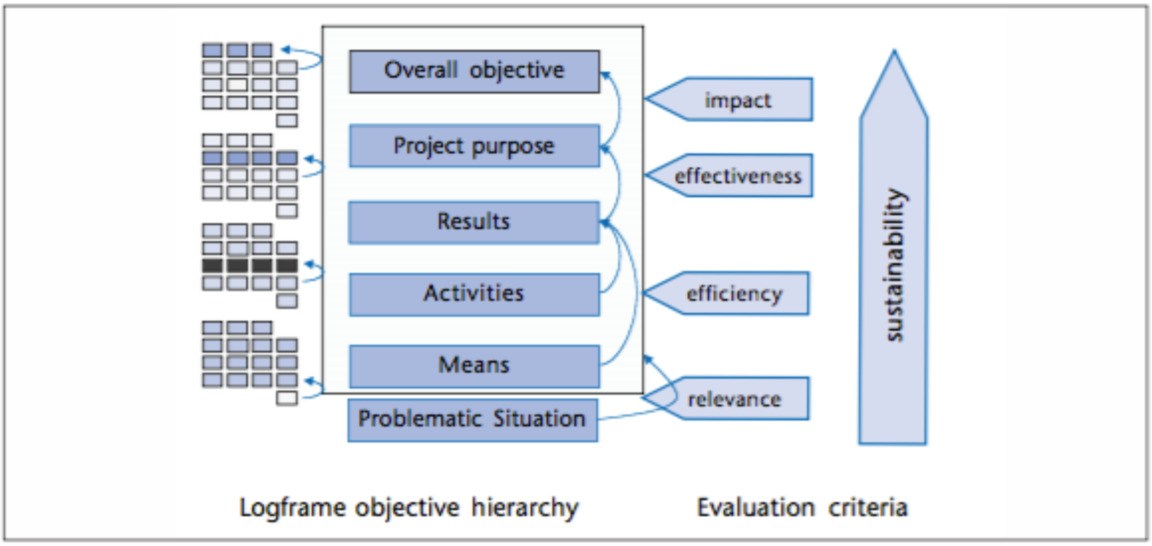

Figure 8. Representation of the links between evaluation criteria and the Logframe.

Strengths and common problems with the application of the LFA

The LFA does not presume to provide magic solutions to complex problems because, like every other analytical tool, has not only strengths but also difficulties. Some of these points are summarised in Table 8.

Element	Strengths	Common problems/difficulties
Problem analysis and objective setting	• Requires systematic analysis of problems, including cause and effect relationships • Provides logical link between means & ends • Places the project within a broader development context (overall objective and purpose) • Encourages examination of risks and management accountability for results	• Getting consensus on priority problems • Getting consensus on project objectives • Reducing objectives to a simplistic linear chain • Inappropriate level of detail (too much/too little)
Indicators and source of verification	• Requires analysis of how to measure the achievement of objectives, in terms of both quantity and quality • Helps improve clarity and specificity of objectives • Helps establish the monitoring and evaluation framework	• Finding measurable and practical indicators for higher level objectives and for projects with 'capacity building' and 'process' objectives • Establishing unreaslistic targets too early in the planning process • Relying on 'project reports' as the main 'source of verification', and not detailing where the required information actually comes from, who should collect it and how frequently
Format and application	• Links problem analysis to objective setting • Emphasises importance of stakeholder analysis to determine 'whose problems' and 'who benefits' • Visually accessible and relatively easy to understand	• Prepared mechanistically as a bureaucratic 'box-filling' requirement, not linked to problem analysis, objective setting or strategy selection • Used as a means of top-down control – too rigidly applied • Can alienate staff not familiar with the key concepts • Becomes a 'fetish' rather than a help

Table 8. Strengths and common problems with the application of the LFA.