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Short report about the use of STELLA™ to develop a model for GBR's ecosystem services

Abstract

Ecosystem services (ES) are defined as the "direct and indirect contributions of ecosystems to human well-being"[1]; they represent a wide array of benefits that ecosystems provide to mankind in the forms of goods (*i.e.* products) and services (*i.e.* functions). In few words, ecosystem services are what nature donates to human for exploitation[1].

According to Millennium Ecosystem Assessment (MEA)[2], there are four main categories of ecosystem services:

- **Regulating services**: benefits obtained from the regulation of ecosystem processes such as climate and water regulation or erosion control;
- **Provisioning services**: products useful for humans derived from ecosystems such as food, fiber, fuels, and natural medicines;
- **Supporting services**: services necessary for the production of all other ES, for example: nutrient cycling, soil formation and primary production.
- **Cultural services**: non-material benefits such as spiritual enrichment, meditation, recreation and aesthetic experiences.

ES have a considerable economic value, not surprisingly economists and scientists speak about "natural capital"[3], indeed the nature gives to mankind the means for its survival and well-being (food, water, materials, pollination, climate regulation, fuels and so on…).

Usually MEA identifies five components that together lead to the well-being of mankind[2]:

1. materials for a good life;

2. health;
3. good social relations;
4. security and safety;
5. freedom and choice.

Now it should be clear that ecosystems and their services affect the quality of human life, in fact if the ability of ecosystems to provide services is compromised, the access to well-being will be forbidden[1]. Fortunately, to date, the importance of seas and oceans for human health and well-being is fully recognized[4].

In our work-group we decided to move on the Great Barrier Reef to analyze and model through STELLA™ the ecosystem services available on the whole Reef, focusing in particular on biotic resources.

Materials and methods

To analyze and model the ES offered by the Reef, we used STELLA™, a software created to show the behaviour of a system. This program was conceived to develop and help to share the capacity of understanding the function of a system starting from the built of models, through the use of some tools. Its features make it suitable to be applied to systems made of elements linked by interdependent relations.

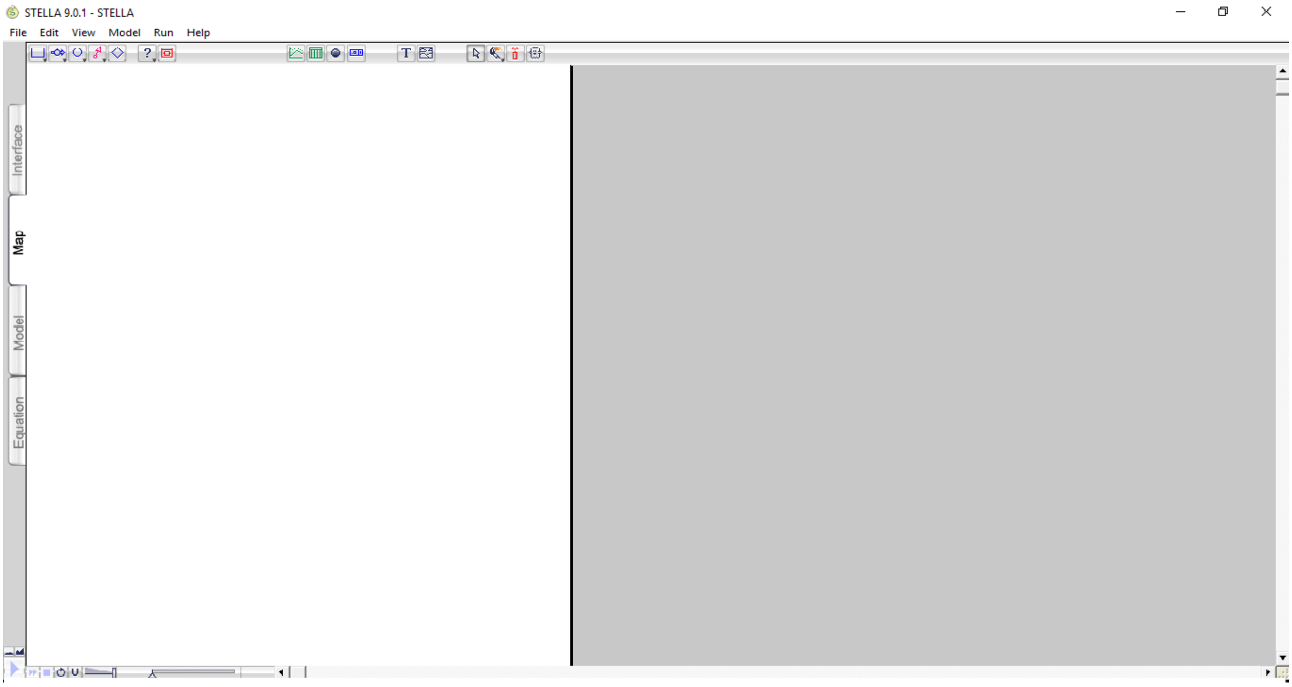

Fig 1. Home screen of STELLA™.

We decided to set the time-scale from 2020 to 2040.

Discussion

We divided the analysis of the ecosystem services among the four members of the team, modelling a real situation in which we are a company that would invest in the Great Barrier Reef.

We established a budget of ten thousand dollars for provisioning, regulating and cultural services. For supporting services only, we have taken into account the company's fear of investing the same amount of dollars compared to others, due to the long time scale of these services.
We modified our graphic representation, not considering a liner relationship between increase and decrease like previous models developed during the lessons.
In this case, we want to highlight an exponential representation. Therefore, we added other two converters from stock to increase flow and decrease flow.
This means that our flows depend on two factors: the percentage of all our biotic resources and the amount of dollars that we have over the time.

Provisioning services

As said above, provisioning services are products very useful for humans, that are mined directly from the ecosystems (food, fuels, materials, medicines…). These products can be used as well as they are harvested or they are first transformed in usable forms.

Among the factors that can increase the value of provisioning services we included:

1. **Fisheries** and **aquaculture**. They are very spread along the Reef providing food for human consumption such as: fishes, molluscs (clams, scallops, cephalopods, oysters), crustaceans (crabs, lobsters, shrimps)[5]. Coral reefs support the life of thousands of different species of animals; it has been estimated that fisheries on reefs constitute about the 7% of global fisheries and about 6 million tons of fish per year are caught in this ecosystem, so the economic incomes due to fisheries are very important, not surprisingly the economy of some countries rely exclusively on coral reefs, so the presence of this ecosystem is essential for the survival and well-being of these people.
2. **Jewelry** and **aquarium industry**. Corals and mother-of-pearl have a great value in jewelry and aquarium industry since they are appreciated by a lot of people for their beauty[5]. Other reef-associated animals are collected and sold as souvenirs[1].

3. **Natural medicines**. Some marine animals associated to reefs possess the capacity to produce chemicals that can be exploited by human to treat diseases[6]. There were discovered anticancer, anti-inflammatory, painkillers, and other useful substances that can be extracted from organisms thriving in coral reefs, such as corals, molluscs, and sponges.
4. **Raw materials**. Coral reef can provide humans with some building materials such as lime, cement and mortar. In some countries the coral itself is used as building stone[1].
5. **Fuels**. Coral reefs can provide also oil and gas, but taking into account the biotic resources it's important to underline the role that microalgae have in producing biodiesel, even if actually the cost of its production are still elevated[7].

Among the factors that can decrease the value of provisioning services we included the concept of "overexploitation of the ecosystem" due to:

1. **Overfishing**. Animals are intensively fished and so they have no time to reproduce and grow, with a consequent decreasing in population and biodiversity;
2. **Removal of natural habitat**. The removal of habitat decreases incredibly the richness of species. For example, it has been noted that the removal of sponges as bycatch of trawling fishery affects the composition of fauna[1];
3. **Absence of active management**. In some areas of the GBR there is not so much control and management of resources;
4. **Open access**. Along the reef there are areas that are completely unregulated; they lack any form of control, so anyone can go and get resources without any control from authorities.

In the following figure is showed the STELLA™ model for the provisioning services:

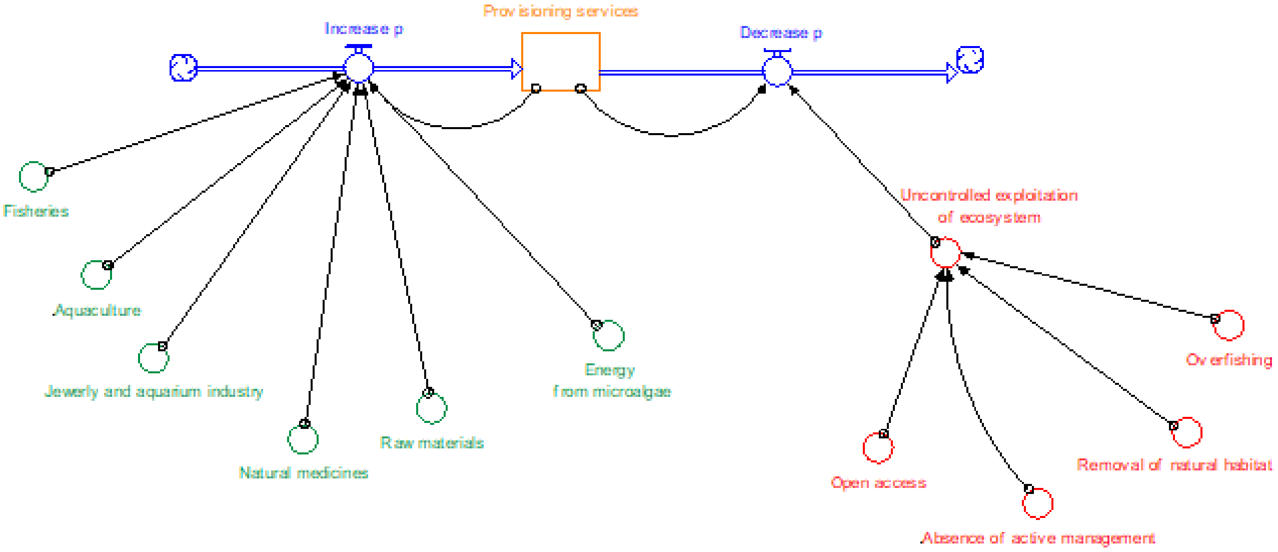

Fig 2. STELLA™ model for provisioning services.

Here, instead, are shown the equations related to the provisioning services:

Provisioning_services(t) = Provisioning _services(t - dt) + (Increase_p - Decrease_p) * dt
INIT Provisioning_services = 10.000 dollars
INFLOWS:
Increase_p = (Aquaculture+Fisheries+Jewerly_and_aquarium_industry+Raw_materials+Natural_medicines+Energy_from_microalgae)*Provisioning_services

OUTFLOWS:
Decrease_p = Uncontrolled_exploitation_of_ecosystem*Provisioning_services

Fig 3. Model equations for the provisioning services

The following table shows the provisioning services' converters for the increase flow:

Fisheries	0.8
Aquaculture	0.6
Jewerly_and_aquarium_industry	0.5
Natural_medicines	0.4
Raw_materials	0.7
Energy_from_microalgae	0.2

The following table, instead, shows the provisioning services' converters for the decrease flow:

Uncontrolled_exploitation_of_ecosystem	
Open_access	0.3
Absence_of_active_management	0.6
Removal_of_natural_habitat	0.2
Overfishing	0.8

The following figure shows the graph related to the provisioning services:

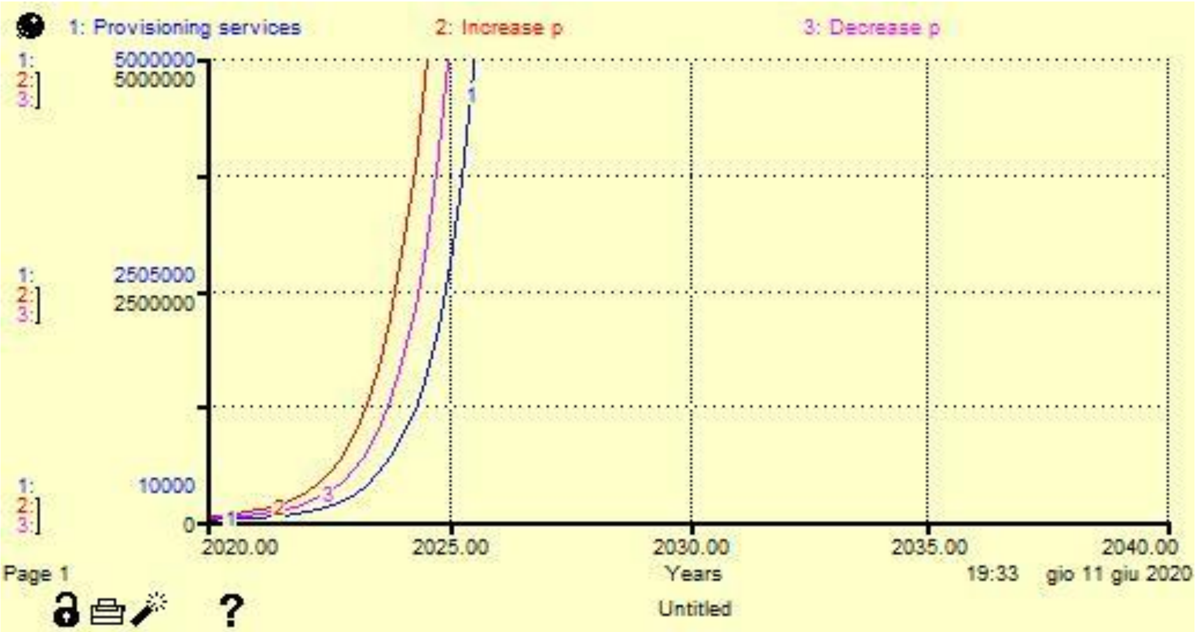

Fig. 4 Graph of provisioning services

The graph illustrates a rapid increase of the value of provisioning services after just five years, according to the values added in the equations.

Regulating services

Regulating services are the benefits obtained from the regulation of ecosystem processes, precise ecological functions that ensure the productivity and resilience of ecosystems.

The following figure shows the STELLA™ model for the regulating services:

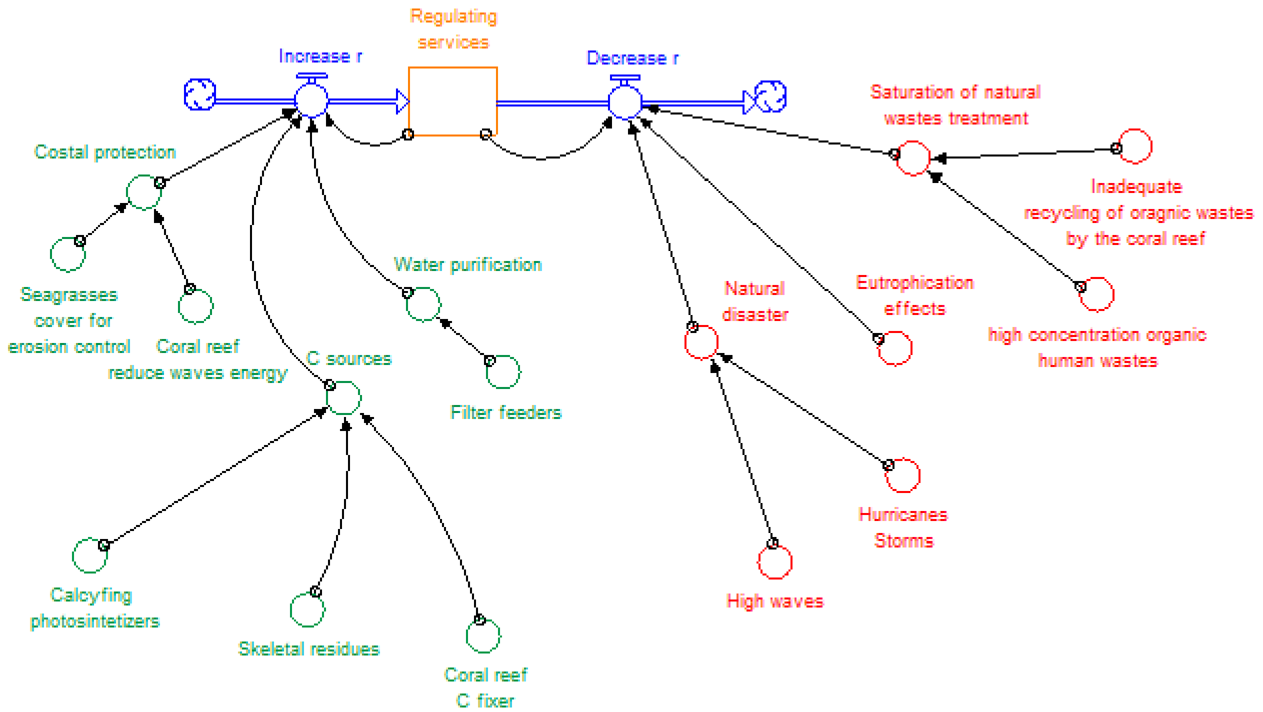

Fig. 5 STELLA™ model for regulating services

This figure shows the equations that describe our regulating services for the stock and the two flows:

Regulating_services(t) = Regulating_services(t - dt) + (Increase_r - Decrease_r) * dt INIT Regulating_services = 10.000 dollars INFLOWS: Increase_r = (C_sources+Costal_protection+Water_purification)*Regulating_services OUTFLOWS: Decrease_r = (Eutrophication_effects + Natural_disaster + Saturation_of_natural_wastes _treatment)*Regulating_services

Fig. 6 Model equations for the regulating services related to the Great Barrier Reef. dt has a value of 0.25, given by STELLA™.

The following tables show the regulating services' converters for the increase flow:

Costal_protection = Coral_reef_reduce_waves_energy + Seagrasses_cover_for_erosion_control	
Seagrasses_cover_for_erosion_control	0.6
Coral_reef_reduce_waves_energy	0.9

C_sources_= Calcyfing_photosintetizers + Coral_reef_C_fixer + Skeletal_residues	
Calcyfing_photosintetizers	0.6
Coral_reef_C_fixer	0.6
Skeletal_residues	0.4

Water purification = Filter_feeders	
Filter_feeders	0.4

The following tables shows the regulating converters for the decrease flow:

Natural_disaster = High_waves+Hurricanes_Storms	
High_waves	0.3
Hurricanes_Storms	0.5

Eutrophication_effects	0.8

Saturation_of_natural_wastes_treatment = High_concentration_organic_human_wastes+Inadequate_ recycling_of_organic_wastes_by_the_coral_reef	
High_ concentration_organic__human_wastes	0.4
Inadequate_recycling_of_organic_wastes_ by_the_coral_reef	0.6

Among the factors that can increase the value of regulating services, we considered:

1. **Costal protection**

The presence of coral reefs can reduce the damage caused by hurricanes, storms, acting as a barrier, a physical protection that weakens and dissipates the energy of waves and currents.
Indeed, coral reefs are able to absorb 90% of energy from wind-generated waves[8], preventing damage to other ecosystems and human settlements.

Vegetative seagrasses cover plays an important role for costal erosion control, protecting the land and offering biological support for other ecosystems. As previously described, seagrasses create a shoal-like effect, by tending to trap sand and sediment so that the bottom of the ocean floor becomes shallower as the seagrass spreads.

2. **Carbon sources**

The role of coral reef systems in the global carbon cycle is still controversial and subject of considerable discussion[9][10]. The most important biogeochemical processes in the coral reef system are photosynthesis and calcification. The sink/source behaviour of coral reefs is also controlled by the balance between these two processes.

Coral reefs have an active role in regulating gas balance, being C fixers and CO_2 releasers[11][12].

Calcifying photosynthesizes are, at the same time, sink (with photosynthetic processes) and source (with respiration) of CO_2. They are also able to produce $CaCO_3$ thanks to different types of structures and broken skeletal residues contribute to generate sand.

3. **Water Purification**

Coral reefs can be a source of impurities in fresh water, so the role of corals, sponges and other filter feeders is fundamental to consume particulate matter suspended in water column[13].

Therefore, they have an active role for regulate water quality and turbidity.

Among the factors that can decrease the value of regulating services, we considered:

1. **Natural disaster**

Hurricane winds and storms move sediment from bays into marsh areas, revitalising nutrient supplies, but in this case, we supposed to have waves from large hurricanes can reduce a reef to rubble. The ability of corals to recover from severe storms is widespread discussed. Generally, the more delicate ‘branching’ corals are more vulnerable to wave damage than corals with a ‘massive’ or ‘boulder-like’ growth form. Consequently, massive corals tend to dominate coral communities in areas regularly exposed to oceanic swells, while delicate species thrive in low energy areas such as lagoons and back-reef areas.

2. **Eutrophication effects**

Eutrophication effects is one of the most impacting on the GBR, mainly derived from the estuarine eutrophication, for which we have an enrichment of water in nutrients that causes structural changes to the ecosystem[14].

3. **Inadequate recycling of organic wastes by the coral reef**

We hypothesized that an inadequate recycling of organic matter by the coral reef and the high concentration of organic human wastes could generate a saturation of natural wastes treatment.

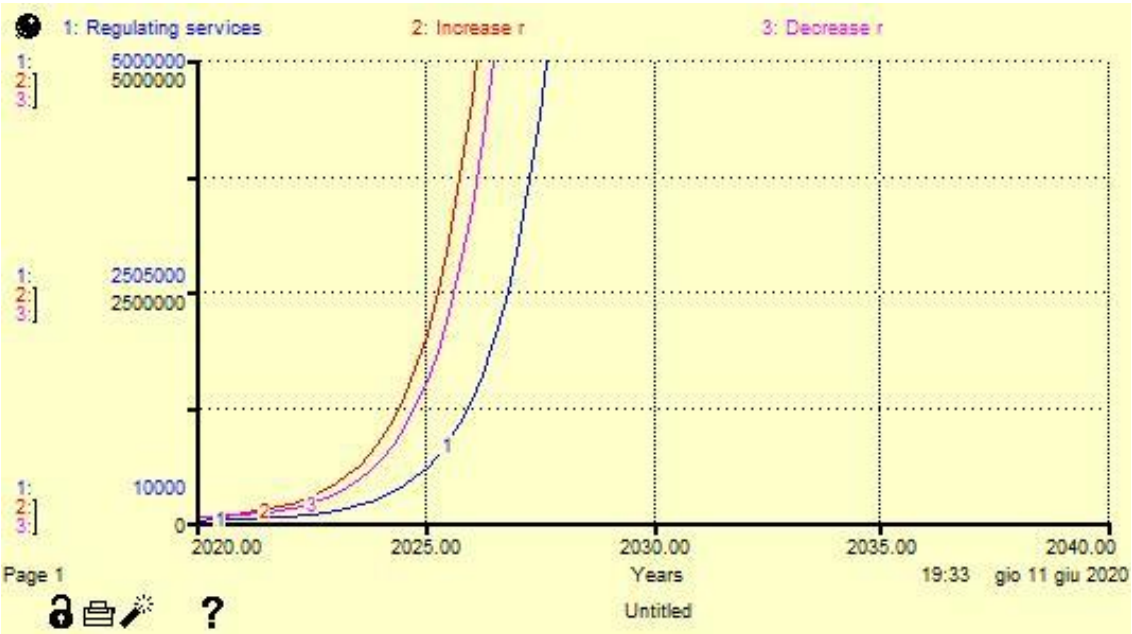

Fig. 7 Graph of regulating services

The graph illustrates a rapid increase of the amount of dollars that we invested in regulating services after 2025 years, according to the values added in the equations.

Cultural services

Cultural services are the nonmaterial benefits such as spiritual enrichment, cognitive development, meditation, recreation, and aesthetic experiences. Cultural services provided by reefs are various and mainly due to their aesthetic value attracting tourists.

The following figure shows the STELLA™ model for the cultural services:

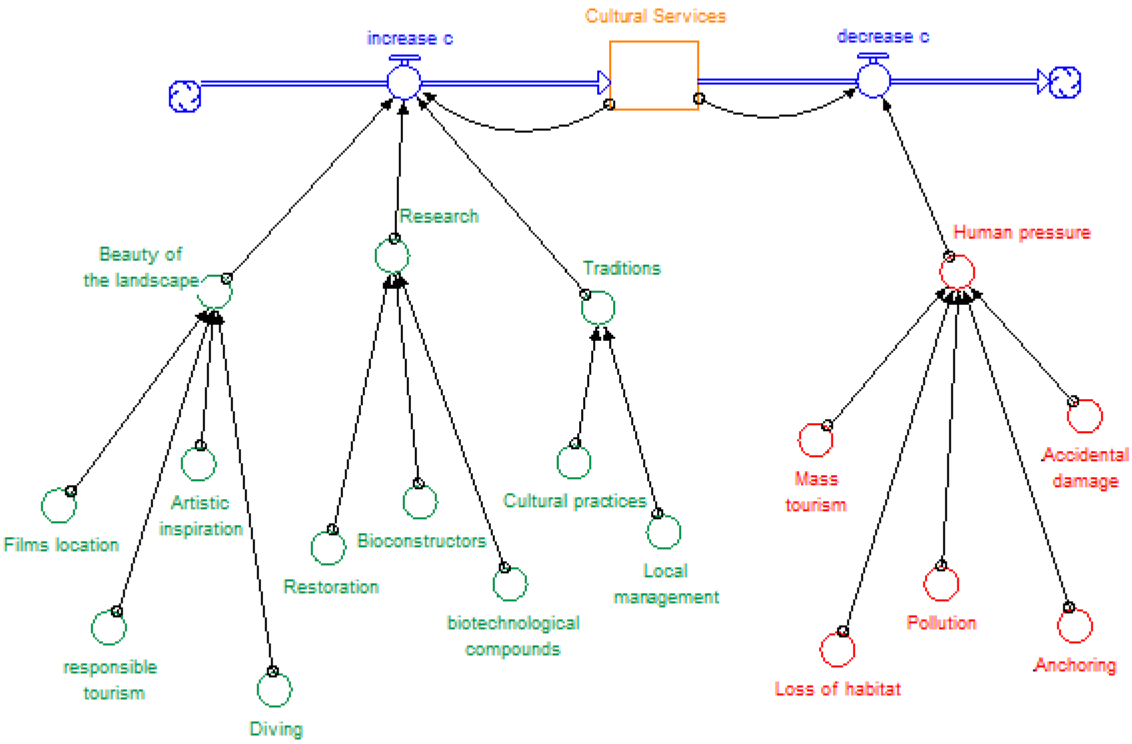

Fig. 8 STELLA™ model for cultural services

This figure shows the equations that describe our cultural services for the stock and the two flows:

Cultural_services(t) = Cultural_services(t - dt) + (Increase_c - Decrease_c) * dt
INIT Cultural _services = 10.000 dollars
INFLOWS:
Increase_c = (Beauty_of_the_landscape+Research+Traditions)*Cultural_services

OUTFLOWS:
Decrease_c = Human_pressure*Cultural_services

Fig. 9 Model equations for the cultural services related to the Great Barrier Reef.

The following tables show the cultural services' converters for the increase flow:

Beauty_of_the_landscape = Artistic_inspiration+Diving+Films_location+responsible_tourism	
Artistic__inspiration	0.1
Diving	0.4
Films_location	0.2

Responsible__tourism	0.5

Research = Bioconstructors+Biotechnological_compounds+Restoration	
Bioconstructors	0.3
Biotechnological_compounds	0.2
Restoration	0.2

Traditions = Cultural_practices+Local_management	
Cultural_practices	0.2
Local_management	0.4

The following table shows the converters for the decrease flow:

Human_pressure = Accidental_damage+Mass_tourism+Pollution+Anchoring+Loss_of_habitat	
Anchoring	0.2
Accidental_damage	0.2
Mass_tourism	0.4
Loss_of_habitat	0.3

Among the most important cultural services that increase the value of the ecosystem, can be found:

1. **The beauty of the landscape**
   Coral reefs and many organisms of coralligenous are a source of artistic inspiration, for example for photos and painting. This beautiful landscape is also used as films and publicities location. Corals create spectacular seascapes built by gorgonians that are among the preferred diving sites. Each year millions of scuba diving tourists visit coral reef. Responsible tourism pays particular attention to the relationship between tourist activity and nature, and which adopt operational strategies taking into account the relationship both in the name of harmony and respect.

2. **The research**
   Including restoration but also the discovery of new biotechnological compounds and the presence of important bio-constructors.

Bio-constructors act as climate records since the chemical composition of skeletons can be used to obtain information about sea surface, temperature and to track variations in salinity.
Sponges in recent years acquired importance due to their potential in providing new designs for fiber, optics, glass, civil engineering.

3. **Cultural traditions**
   Religious rituals and cultural traditions have been developed around coral reefs in many tropical areas. Many coastal communities have traditional practices linked to reefs. Some studies demonstrated a positive influence of traditional practices and local management.

Among the factors that can decrease the value of cultural services, we considered:

Human pressure

Tourism represents undoubtedly an economic resource, and it has been considered for a long time a low-impact option, for coral reef use, if compared with extractive practices such as fishing. Nonetheless, recently, studies began to demonstrate that reefs can be damaged and degraded because of uncontrolled tourism representing a considerable impact. Impacts related to tourism development include sedimentation, loss of habitat by land reclamation, dust, disposal of solid waste and sewage, anchoring, and direct damages. Mass tourism not only poses a threat to reefs' health but paradoxically even limits, in the long period, potential income from coral reefs and associated recreational activities to the local populations. For instance, scuba divers may even unintentionally damage reefs affecting their growing or reproductive capacity. The number of diving resorts is continuously increasing as well as the number of boats that drop their anchors on the reef. At present, the damage from these impacts seems to be relatively restrained but it begins to be perceived in some sites.

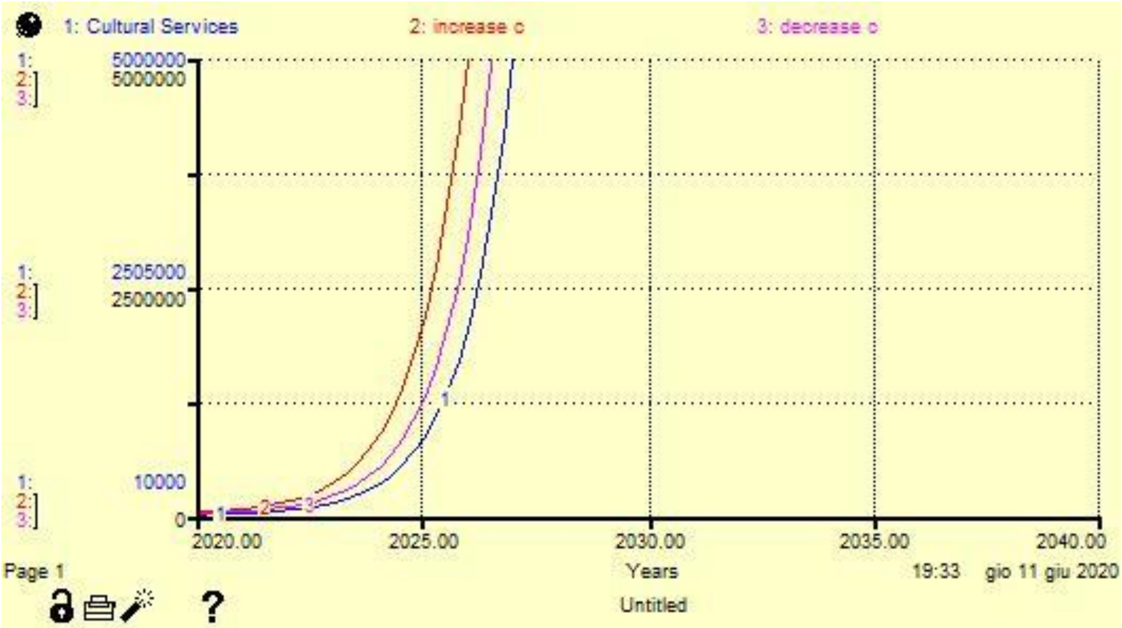

Fig. 10 Graph of cultural services

The trend of cultural services, increase and decrease are shown in the graph, where it is possible to observe their exponential trend. For example, starting from time 0 (2020) with a value of 10,000 dollars, it is possible to see that after only one year the cultural services reach the value of 24,414 dollars and after two years 59,605 dollars. Therefore, the annual increase is 24414 times compared to the previous year.

Supporting services

Supporting services are generally defined as those services necessary to produce all the other ecosystem services[1]. They include important habitat and biodiversity services for the Reef and adjoining ecosystems that indirectly contribute to human well-being, but are challenging to capture in terms of their independent service value[15]. Differently from the others, impacts of supporting services on people are either indirect or occur over a very long time[16]; for this reason their starting value has been set to 8,000 dollars.

Supporting_services(t) = Supporting_services(t - dt) + (Increase_s - Decrease_s) * dt

INIT Supporting_services = 8.000 dollars

INFLOWS:

Increase_s =

(Biodiversity_benefits +Habitat+Nutrient_cycling+Primary_productivity)*Supporting_services

OUTFLOWS:

Decrease_s =

(Biodiversity_loss+Increase_algal_cover+Invasive_species)*Supporting_services

Fig.11 Initial value assigned to supporting services, equations of inflows and outflows

Among the most important supporting services that increase the value of the ecosystem, can be found:

1. **Biodiversity Benefits**
   The term describes the services and benefits gained from having a diverse reef ecosystem that underpins other services and benefits[15]. It has been evaluated in terms of biomass production and genetic library. A value of 0,2 has been assigned to the first and a value of 0,3 to the latter; the biodiversity benefits' value is equal to the sum of these two.

2. **Habitats' Provisioning**
   Corals engineer the environment, interacting with and creating suitable conditions for other tropical nearshore ecosystems[15]. Bio-constructional activity plays a pivotal role in modifying the shape

and ecological characteristics of the transitional area between midlittoral and infralittoral flats, creates three-dimensional environments, and amplifies the available space for organisms[1]. Thanks to its structural complexity, the Reef constitutes a nursery for many species.

To "Structural complexity", "Nursery" and "Interaction with near ecosystems" have been respectively assigned values of 0,25; 0,15 and 0,20. The total value of "Habitats' Provisioning" is given by the sum of these values.

3. **Primary productivity**

   Primary productivity may be defined as the amount of organic material produced per unit area per unit time; or simply as the product of phytoplankton biomass times phytoplankton growth rate. Marine primary production plays an important role in food web dynamics, in biogeochemical cycles and in marine fisheries[17], for this reason a value of 0,4 has been set.
4. **Nutrient cycling**

   Nutrient cycling describes the movement within and between the various biotic or abiotic entities in which nutrients occur in the global environment; it is enabled by a great diversity of organisms and leads to creation of several physical structures and mechanisms that regulate the fluxes of nutrients among compartments[18].

Biodiversity_benefits = Biomass_production+Genetic_library	
Biomass_production	0,2
Genetic_library	0,3

Habitat = Interaction_with_near_ecosystem+Nursery+Structural_complexity	
Interaction_ with_near_ecosystem	0,2
Nursery	0,15
Structural_complexity	0,25

Primary_productivity	0,4

Nutrient_cycling	0,2

Figure 12 - Supporting services that increase the value of the GBR

Among the factors that can decrease the value of the ecosystem, can be found:

1. **Biodiversity loss**
   Biodiversity is fundamental to ecosystem functioning. The extinction of local populations, or their reduction to the point that they become functionally extinct, can have dramatic consequences, because of this, in the model the value has been fixed to 0,7.

2. **Increase in algal cover**
   Increases in algal cover reduce the structural complexity of the reef and generally decrease the availability of habitats for reef-associated species. Herbivorous species may benefit from increases in algal growth but will be negatively affected if algal stands are too dense[15]. In the STELLA™ model, the negative effect of the increasing algal cover has been set to 0,3.

3. **Invasive species**
   Invasions of species beyond their native range constitute a global driver of change of major concern for the conservation of natural and managed areas. Invasive species threaten biodiversity, change ecosystem functioning, and have economic costs. Empirical evidence suggests that areas of high species richness (such as hot-spots) are more susceptible to invasion than species-poor areas[19]. The impact that invasive species may have on the value of the ecosystem has been quantified and in the model it's equal to 0,3.

○ Biodiversity_loss	0,7
○ Increase_algal_cover	0,3
○ Invasive_species	0,3

Fig. 13 - Supporting services that decrease the value of the GBR

After estimating the effect of each modifiers on the value of the Great Barrier Reef, the graph for “Supporting Services” has been built.

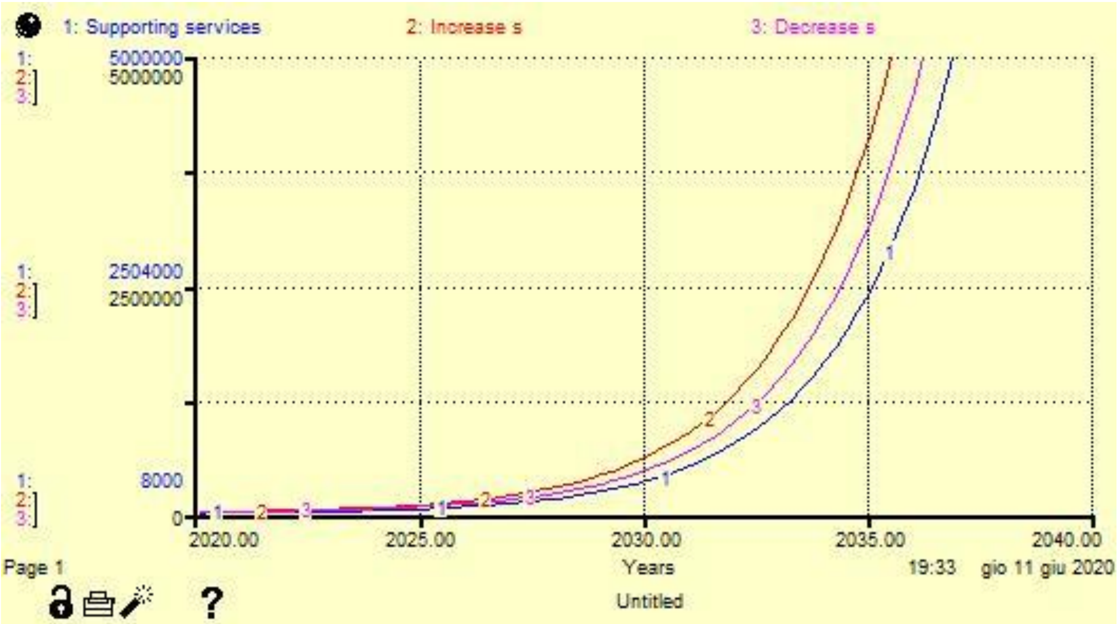

Fig.14 - Graph of supporting services

In the graphic representation it can be observed the gradual increase in the value of the supporting services. The growth is exponential, in according to the equations that have been included in the model. As stated above, the starting value assigned to the supporting services is 8,000 dollars, but after 15 years they will reach a value of 2,504,000 dollars.

By the end, the STELLA™ model concerning the supporting services will be represented as reported below.

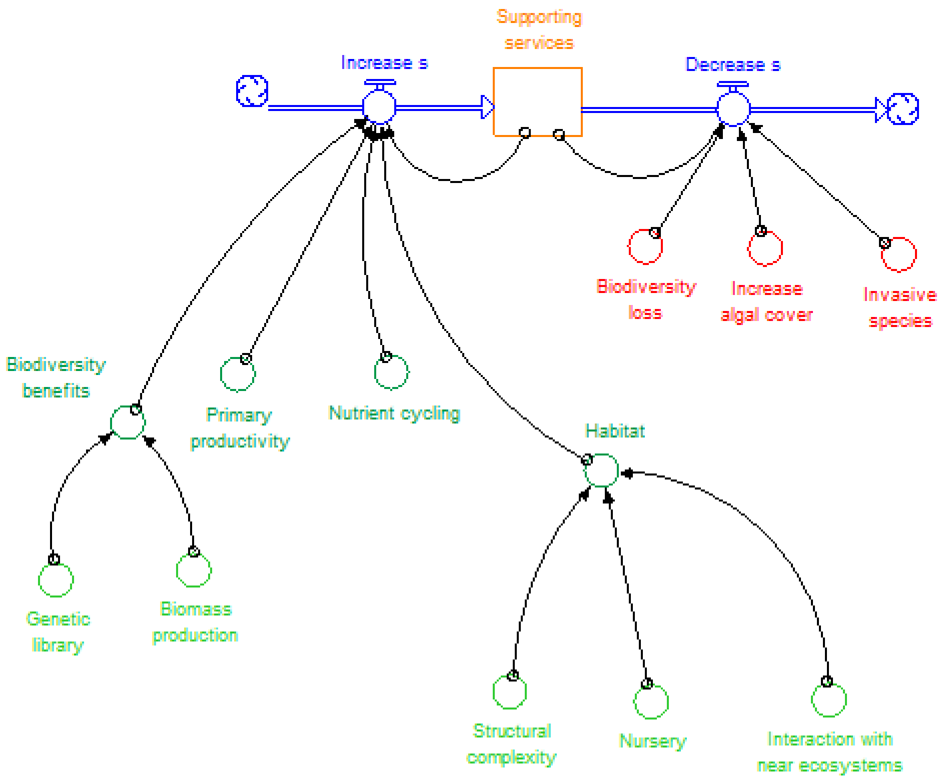

Fig. 15 - STELLA™ model for supporting services

Conclusions

In conclusion we have resumed in the graph below all the trends of the ecosystem services offered by the Great Barrier Reef.

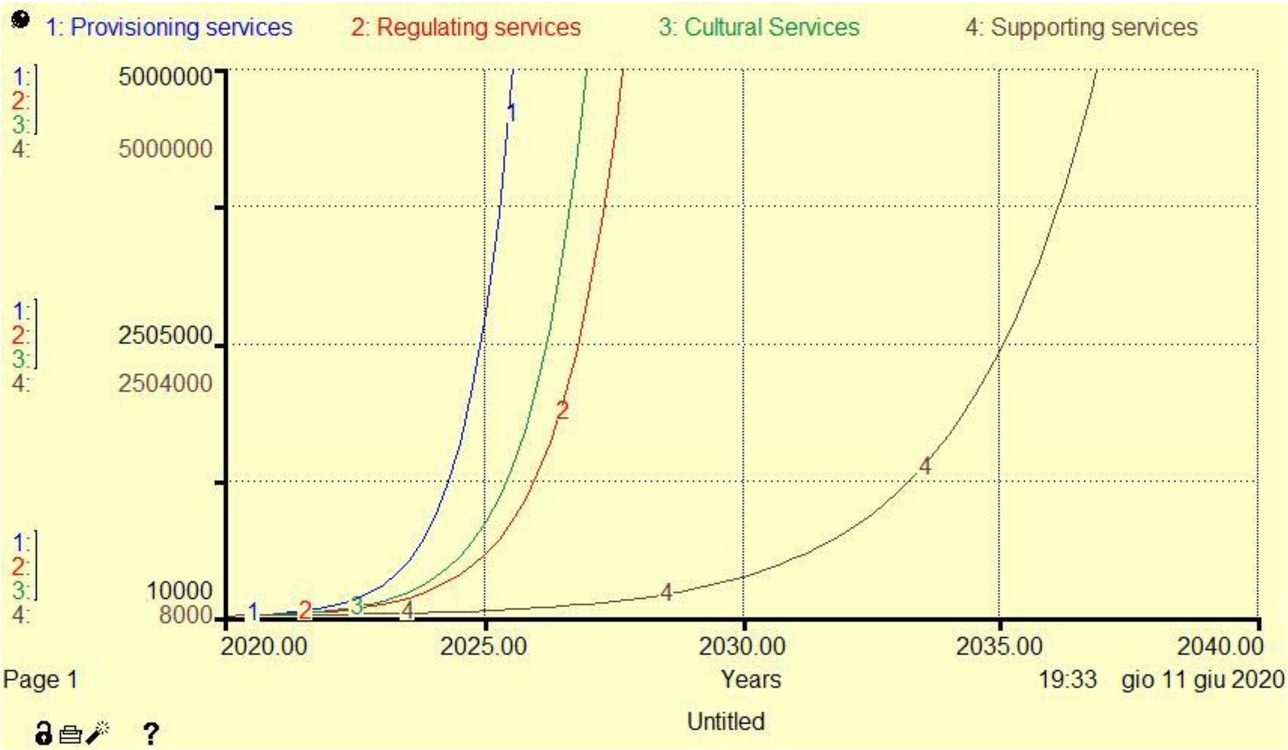

Fig. 16 STELLA™ model for all the ecosystem services

On the vertical axis we can see the initial values, that are equal to 10,000 dollars for each type of service apart from the supporting, to which a value of 8,000 has been assigned. Then, it's possible to compare the different growth rates. All the services have been represented with an exponential curve: the one of the provisioning has the fastest growth, while the one of the supporting is the last to reach the value of 5 million dollars.

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