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Social–ecological system's resilience analysis using MIMES model: a case study in Ubatuba (SP)

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Corrected Version

Thesis submitted to the Energy and Environment Institute at the University of São Paulo as partial fulfillment of the requirements for the degree of Doctor of Sciences, program of Environmental Sciences.

Supervisor:

Dr. Joseph Harari

São Paulo

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To see a World in a Grain of Sand
And a Heaven in a Wild Flower
Hold Infinity in the palm of your hand
And Eternity in an hour
(Willian Blake, Auguries of Innocence)

Principles for the Development of a Complete Mind:
Study the science of art.
Study the art of science.
Develop your senses– especially learn how to see.
Realize that everything connects to everything else.
(Leonardo da Vinci)

RESUMO

Com a publicação dos grandes estudos globais a respeito da saúde dos ecossistemas e da sua importância para sociedade, muita atenção vem sendo atraída para a área dos serviços ecossistêmicos (SE). Quando drivers indesejados como as mudanças climáticas são associados aos conceitos de SE, a questão mais pungente é se os sistemas socioecológicos (SES) que proporcionam esses serviços conseguirão suportar as pressões a que estão expostos e continuarão fornecendo os benefícios que permitem à sociedade humana habitar o planeta. Este trabalho teve os objetivos de verificar *in silico* como os SE costeiros de Ubatuba se comportarão no futuro e em diversos cenários; avaliar essa provisão de SE de forma a encontrar o valor total desses serviços (valores econômicos, sociais e culturais); construir um protótipo de índice de resiliência e finalmente analisar seu comportamento perante choques e no longo prazo. As simulações foram feitas para Ubatuba, uma cidade costeira do Estado de São Paulo, Brasil, altamente dependente e influenciada pelo turismo, e foi realizada usando o MIMES (Multiscale Integrated Model of Ecosystem Services) um framework capaz de produzir modelos integrados e dinâmicos dos SES. Os resultados trazem a caracterização das variações de dez SE (produção de crustáceos, moluscos, peixes cartilaginosos e peixes ósseos; sequestro de carbono, produção de oxigênio, mineralização, ciclagem de nitrogênio, depuração de esgotos e qualidade da água através da percepção) em condições normais e em função dos cenários, e apontam que os 8 primeiros sofrerão redução em sua provisão nos cenários climáticos; as perdas econômicas associadas estarão entre USD10.5 a USD21 milhões até o fim do século; as perdas materiais são grandes e variam de acordo com o SE estudado; o teste de sustentabilidade sugere que haverá escassez de SE per capita no futuro e sua exploração será insustentável nos níveis atuais; a avaliação de justiça mostrou grandes assimetrias na distribuição dos bens e serviços ambientais assim como nos custos decorrentes das mudanças climáticas; a análise de resiliência mostrou que esse atributo é dependente dos valores e crenças compartilhados pelas coalizões sociais locais. O comportamento do índice de resiliência em função das racionalidades foram caracterizados ao longo do século e dez reflexões são apontadas e discutidas com a literatura. Conclui–se que a provisão de SE está ameaçada devido aos cenários estudados; os prejuízos serão grandes e provavelmente serão injustamente compartilhados com parte da comunidade que não é reconhecida e respeitada nos processos de decisão locais; a resiliência de Ubatuba na provisão desses SE varia em função das conflitantes racionalidades locais e sua trajetória depende das interações entre essas coalizões. Individualistas são mais resilientes nos primeiros cinco anos (contados a partir de 2010), hierarquias são mais adequadas no período seguinte até meados de fim do século onde os igualitários são mais resilientes. Considerando os conflitos entre as racionalidades a possibilidade de uma solução desajeitada é considerada.

Palavras chave: 1 – sistema socioecológico. 2 – resiliência. 3 – modelo. 4 – MIMES – Multiscale Integrated Model of Ecosystem Services. 5 – Serviços Ecossistêmicos. 6 – Cenários de mudanças climáticas

ABSTRACT

Since the publication of major global studies about the ecosystem's health and their importance to society the understandings about ecosystem services (ES) have been gaining attention. When undesired drivers as climate change are linked to ES concepts, the most urgent question is that the social–ecological systems (SES) that create those services will hold the pressure they have been exposed to and will continue providing the benefits that allow human societies to thrive. This work had the objectives of verifying through simulation how the coastal ES from Ubatuba will behave in the future and according to scenarios; assess this ES provision to evaluate its total value (the integration of economic, social, and cultural values) and with the help of a prototype resilience index evaluate the capacity of keeping the provision against shocks and on the long–range. Results bring the simulation of the SES of Ubatuba, a coastal city from São Paulo State, Brazil, highly dependent and influenced by tourism. The simulation was made using MIMES (Multiscale Integrated Model of Ecosystem Services) a framework that creates integrated and dynamic models of SES; Simulation results show the characterization of ten ES (production of Crustaceans, Mollusks, cartilaginous and bone fishes, carbon sequestration, oxygen production, mineralization, nitrogen cycling, sewage depuration and water quality through perception) in normal conditions and compared to scenarios and also pointed that the 8 first ES will have their provision reduced due to climate change. Associated economic losses will be between USD10.5 and 21 million by the end of the century. Material losses are big and vary according to each ES. The sustainability test suggests that ES provision will be scarce in the future and its exploitation will be unsustainable on the current per capita levels. Environmental justice assessment revealed big asymmetries on the distributions of goods and services and so did for the losses caused by climate change. Resilience analysis showed this attribute to be dependent on shared values and beliefs from advocacy coalitions acting on the governance system. Resilience behavior was characterized and described throughout the century. Seven insights are pointed and discussed with literature. Conclusions show the city to be very dependent on ES provision; that these ES are threatened due to the studied scenarios and the losses will be big and with an unfair distribution considering part of the community are not recognized on the decision making process. The resilience on the provision of ES varies accordingly to conflicting rationalities and the trajectory depends on the interaction of those coalitions. Individualists are more resilient in the first 5 years (from 2010), hierarchies are more adequate along the century and egalitarians are more resilient at the end of the century. Considering the conflicts among these rationalities a clumsy solution is listed as a possible future.

Keywords: 1 – social–ecological systems. 2 – resilience. 3 – model. 4 – MIMES – Multiscale Integrated Model of Ecosystem Services. 5 – Ecosystem Services. 6 – Climate change scenarios.

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SUMMARY

1 GENERAL INTRODUCTION

Weaver (1948) classifies 20th–century science and its future development concerning its functions, despite the philosophical quest about its origins, to focus on its uses. To this author science is a way of solving some types of problems:

> Science clearly is a way of solving problems – not all problems, but a large class of important and practical ones. The problems with which science can deal are those in which the predominant factors are subject to the basic laws of logic, and are for the most part measurable. Science is a way of organizing reproducible knowledge about such problems; of focusing and disciplining imagination; of weighing evidence; of deciding what is relevant and what is not; of impartially testing hypotheses; of ruthlessly discarding data that prove to be inaccurate or inadequate; of finding, interpreting, and facing facts, and of making the facts of nature the servants of man. (WEAVER, 1948, p. 8)

The finalist and utilitarian view of the author can be questioned but it brings attention to the desired object: the problem. To Weaver (1948) there are three classes of science problems: problems of simplicity, problems of complexity, and problems of organized complexity.

Problems of simplicity are those made of one or two variables occurring in a controlled environment, dominant in 17th to 19th–century science. The solution to those problems brought great discoveries to society as radio, engines, airplanes, etc.

Disorganized complexity problems are those who embrace a huge number of variables that cannot be treated individually. Although every variable has its behavior, the system itself can be understood by some properties. This analysis, statistical, shows the state of the system independent of every variable's behavior. Temperature for instance is a measure of the average state of agitation of the molecules, although this variable cannot say about the individual state of every molecule in the system.

Between simplicity problems and disorganized complexity problems, one can find the class of problems formed by an intermediate state with a great number of variables but this time also with organization. This group though is formed by a considerable number of interrelated factors forming an organic whole (WEAVER, 1948). To this holistic problems statistic brings discrete collaborations and considering only one or two variables, the answers are extremely limited. For the author considering organized complexity means searching for the answers to questions like: In what depends on the price of wheat? Which is the pattern of behavior of a group of people, like a racial minority or a syndicate? Which sacrifices of actual society can bring more collaboration for the development of a decent and peaceful society in the future?

Weaver considered the problem as the basis from which a related research field is attached: to disorganized complexity it is statistics and for organized complexity the interdisciplinary approach. In a similar conclusion, but starting in the opposite direction, Overmars et al. (2007) compared statistical (Inductive) modeling with a causal type model (Deductive) to see if there were significant differences in these approaches. The authors conclude that both statistical and causal models can perform equally well but they have different explanation capacities because deductive models are based on causal inference, not correlation as statistical models do, and therefore its connection to the subjacent theory is broader.

Those complex problems can be better studied when different knowledge fields are used. Weaver (1948) uses the term "mixed teams" referring to the multiplicity of disciplines desirably applicable to complex problems. Skyttner (2005) agrees with multidisciplinary approaches and also considers that complex problems must be treated by interacting parts systems, and those interactions must be studied by several different perspectives, holistically. More important than different perspectives, to the author, systems perspective represents the approach that links them together in a coherent interdisciplinary communication. According to Boulding (1956):

> General Systems Theory is the skeleton of science in the sense that it aims to provide a framework or structure of systems on which to hang the flesh and blood of particular disciplines and particular subject matters in an orderly and coherent corpus of knowledge (BOULDING, 1956 p.108).

Systems Theory, or general systems theory, represents the tool to deal with systems (SKYTTNER, 2005) and had its origins with the research of Bertalanffy (1950) and Boulding (1956). Both authors created the *International Society for General Systems Theory* in 1954, an interdisciplinary research group that, according to Skyttner (ibid.) had the following goals: Integrate similarities and relations between sciences; promote communication through disciplinary boundaries; establish the theoretical basis for general scientific education.

General Systems theory (GST) has been built as the field responsible to study general systems properties. As applied science GST has become systems science (SKYTTNER, 2005) and represents the science of synthesis and integration.

1.1 COMPLEX SYSTEMS

Some authors use the term complex adaptive systems (e.g. . BIGGS, et al., 2015) to differentiate between an ecosystem and a hurricane (showing the differences between complexities). This work has accepted the suggestion of Mitchell (2009) and no distinction is made between those, considering all complex systems as complex adaptive systems. The definition of complex systems is different depending on the author:

> As used here a “system” means a grouping of parts that operate together for a common purpose. (FORRESTER, 1968 p. 1–1)
>
> A system is a set of things – people, cells, molecules, or whatever – interconnected in such a way that they produce their own pattern of behavior over time. (MEADOWS, 2008 p.2).
>
> a system in which large networks of components with no central control and simple rules of operation give rise to complex collective behavior, sophisticated information processing, and adaptation via learning or evolution. (MITCHELL, 2009 p.13)

Sterman (2000) made a list of complex systems attributes that can be used to understand it:

- Dynamic: attributes of systems change in time and frequently in time scales;
- Strongly coupled: everything is connected to everything else;
- Ruled by Feedbacks: considering that most elements are connected, feedbacks are the links that connect the system;
- Non–Linear: the effect is rarely proportional to the cause. Relations between variables are rarely proportional;
- Path dependence: several actions are not reversible and will determine the overall behavior from that point then on;
- Self–organizing: the dynamics of the system emerges from the interactions between inner structures;
- Adaptive: decision rules and values that reign the overall behavior change over time;
- Counter–intuitive: causes and effects can be separated in space and time, making the task of uniting them difficult;
- Policy resistant: systems complexities overwhelm our understanding capacity and sometimes problem resolutions can create adversities;

- Trade–offs: delays are frequent in feedbacks, and thus systems responses to an intervention can be different in short and long–range.

The scientific and managerial approach that complex systems provide to societies problems emerge with the understanding that their parts are interrelated; that solutions from today's problem frequently become tomorrow's problems; that relations between components are frequently non–linear; and the vision that the system is bigger than the sum of its parts. Those attributes do not mean in value judgment in favor of systems approach, but instead that this one can be complimentary to simpler, or statistical ones and can bring collaborations to social wellbeing. Deal with environmental problems using systems approach can reveal to be more adequate:

> I don't think the system's way of seeing is better than the reductionist way of thinking. I think it's complimentary, and therefore revealing. You can see some things through the lens of the human eye, other things through the lens of a microscope, others through the lens of a telescope, and still others through the lens of systems theory. (MEADOWS, 2009 p. 6.)

The case studied here is in Ubatuba municipality, considered as a socio–ecological system. Considered complex, dynamic and adaptive (WALKER et al., 2002; LIU et al., 2007; ANDERIES, JANSSEN & OSTROM, 2004; WALKER & SALT, 2012; LIU et al., 2015) its features include emergent behavior, path dependence, and several feedbacks linking different nature and social attributes. Social–ecological systems are considered "systems where people interact with natural components" (LIU et al., 2007). This system view applied to the social–ecological system is the vanguard of integrative studies regarding human–nature (DEARING et al., 2005).

1.2 THESIS STRUCTURE

This thesis was organized into three chapters and five appendices. The first chapter is the introduction to complex systems studies, considered to be the common ground of all other chapters. Each chapter brings its introduction, problems, and results. This chapter also brings the structure of the thesis.

Chapter two brings the development of MIMES (*Multiscale Integrated Model of Ecosystem Services*). This model intensely uses the system's perspective, with simulation *in silico* of Ubatuba social–ecological system, and formalizing the dynamic interactions between environment and society. From this simulation, ten Ecosystem Services were assessed in daily valuations along the century and interacting with three systems scenarios. The results of this simulation were then discussed in economic, material, and in terms of justice.

Chapter three is the development of the Dynamic Resilience Index (DRI), the main goal of this thesis. The chapter brings a short review of resilience concepts and develops its application into an index, with a discussion of seven insights that resulted from the in silico experience of modeling.

Appendix A shows the published paper of self–organizing maps study; Appendix B is an example of how the food web interacts on the simulation; Appendix C brought an exercise questionnaire (STERMAN, 2000) that modelers should reflect on when making models; Appendix D is the population distribution on the land polygons of Ubatuba and finally, appendix E is the whole code modeled in Simile for the sake of transparency and reproducibility.

1.3 GOALS AND OBJECTIVES:

The main goal of this thesis is to analyze the Ubatuba municipality, and the coastal area around it, under the perspective of a social–ecological system; to model its dynamics and complexities, and also to build the structure of resilience analysis and its dynamics to understand how the provision of ES is, how it is going to be depending on scenarios and finally to simulate the resilience of this social–ecological system.

Specific objectives:

- Chapter 2 – The objectives of this chapter are to integrate available information for the city in a dynamic comprehensive model that allows enhancing the knowledge and understanding about the region and their social–ecological challenges; to formalize the causal premises assumed for the system, the ecological attributes behavior and their interactions with human sphere; simulate these interactions in time and space; simulate the ES provision on the long–range, understanding how this ES provision would vary in function of different scenarios, to finally discuss the problems society can face due to the scarcity of ES.
- Chapter 3 – this chapter has the objective to take the resilience concept “from metaphor to measurement” (CARPENTER et al., 2001), and to integrate several systems features into a Dynamic Resilience Index (DRI) while

understanding this social–ecological system as an adaptive system (CARPENTER et al., 2001; GUNDERSON and HOLLING, 2002; GUNDERSON, ALLEN, and HOLLING, 2010; LEVIN, 2013; BOUMANS et al., 2002; BOUMANS et al., 2015). This simulation is embedded in the theory of resilience and system sciences for several reasons and understands resilience as an emerging property of a complex system, with non–linearity behavior, feedbacks, and several scales; it also represents the integration of the social and ecological components through the coupling, multiple dimensions, and path dependencies.

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2 COASTAL ECOSYSTEM SERVICES AND CLIMATE CHANGE – CASE STUDY FOR INTEGRATED MODELING AND VALUE ANALYSIS

2.1 INTRODUCTION

Ecosystem services (ES) gained much international attention as an academic research agenda and also as an applied body of knowledge for consultants, agencies, and practitioners after broad global reviews of their state (MEA, 2005) and the assessments of the economic value they represent to mankind (COSTANZA et al., 1997; De GROOT et al., 2012). The relevance of the field has been growing since and the corollary is the creation of the International Platform on Biodiversity and Ecosystem Services (IPBES) as an international institution "with the goal of strengthening the science–policy interface for biodiversity and ecosystem services, for the conservation and sustainable use of biodiversity, long–term human well–being and sustainable development" (Diaz et al., 2015).

Coastal ecosystem services are of main interest once they directly serve more than 2 billion people (MARTINEZ et al., 2007) and indirectly affecting the whole planet by controlling the climate, producing oxygen, etc. Historically it provided several resources to human endeavor (like fish, plants), allowing the transportation of goods and people, leisure and tourism and more recently providing energy from fossil fuels or waves. Marine and coastal areas are responsible for 60% of all economic value of the ecosystem services provided by the Biosphere (COSTANZA et al., 1997). Yet, with human population growth in the 20th century, associated impacts like the increase in the resource harvest, negative effects of resource extractions and coastal cities pollution, the uncertainties on the reliability of the provision of coastal ecosystem services at the long and short–range have been increasing (GARRISON, 2012). Thus, managing the marine environment and especially the coastal zones are crucial for mankind's wellbeing.

During the last decades of the 20th century, the majority of planning and policies regarding oceans and coastal areas were built by governments (BURROUGHS, 2011). These policies were mainly built under "command and control" perspectives, usually associated with some quality standard for water quality or pollution control methods and the environmental permitting processes were dependent on those actions. Currently, different perspectives consider resource management in a plural context, formed by distinct but complementary forces, habits, and behaviors, with formal and informal institutions acting at the same time, inside the government but also spread throughout communities. This new perspective assumes that to change human behavior, opportunities and problems must be assessed, institutions and agreements must be established and acceptable behavior regarding resources and the environment must be encouraged or sanctioned (JUDA, 1999).

Applying this new perspective of ecosystem–based management (BURROUGHS, 2011), requires a governance system that adapts itself to changes in the environment. Thus, knowing how the ecosystem works and to what extent it varies is fundamental. Nonetheless, considering the perspective of different scenarios (e.g. climate change or frequency of tourists) can make the whole difference when the future of coastal social–ecological systems is being planned.

MIMES (BOUMANS et al., 2015) is a very interesting tool for planning and management. The MIMES model is built on causalities, with complex adaptive systems background, embodying feedbacks, path dependences, and nonlinearities from the environment in a highly interdisciplinary and integrated simulation.

From the modeling, the presented work organizes insights and economic analysis of the marine ecosystem services provided by the coastal zone of a Brazilian city. According to Liquete et al. (2013) "Ideally, an ecosystem service analysis starts with the biophysical quantification and social assessment of the selected services; it leads to a valuation (monetary or another type) and, eventually, to the analysis of trade–offs, trends and scenarios". The work done here then follows properly those recommendations and intends to provide subsidies for informed decision making.

The objectives of this work were to integrate available information for the city in a dynamic comprehensive model that allows enhancing the knowledge and understanding about the region and their social–ecological challenges; to formalize the causal premises assumed for the system, the ecological attributes behavior and their interactions with human sphere; simulate these interactions in time and space; simulate the ES provision on the long–range, understanding how this ES provision would vary in function of different scenarios, to finally discuss the problems society can face due to climate change effects.

This study has one hypothesis: that the ecosystem services provision will be different in the future due to climate change and possible change in tourist behavior regarding local water quality.

Finally, this paper presents the Integrated MIMES model for Ubatuba, a Brazilian coastal city, with ten ecosystem services simulated dynamically from 2010-2100, showing their ecological and economic values regarding normal behavior and variations due to three scenarios (reacting tourists, climate change RCP2.6 and RCP8.5).

2.2 METHODS

MIMES is the acronym of *Multiscale Integrated Model of Ecosystem Services* (BOUMANS et al., 2002; ALTMANN, 2014; BOUMANS et al., 2015). This model is based on system dynamics and has been used in several cases (BOUMANS et al., 2002; KERCHER et al. 2008; BATKER et al., 2010; ALTMAN et al., 2014; BOUMANS et al., 2015).

System dynamics started in the ’60s with the seminal work from Forrester at MIT (Industrial Dynamics, 1961). Since then the science around system dynamics has expanded worldwide and reached a high degree of development. One of the main advantages of these models is the capacity to integrate systems complexity in the simulation, as described by Forrester (1994) “It can accept the complexity, nonlinearity, and feedback loop structures that are inherent in social and physical systems”. The method is responsible to enhance learning about complex systems (STERMAN, 2000).

MIMES is slightly different concerning regular system dynamics studies. Remarks should include the interaction with GIS systems, the use of arrays, and the great complexity of these models. The main objectives are to build integrated models of social–ecological systems to guide the process of decision making. Other objectives are (BOUMANS et al., 2015):

Build ecological economics models focused on integration of knowledge regarding ecosystem functioning and the provision of ecosystem services, under the human wellbeing perspective;

Create computer infrastructure as a modeling tool that can incorporate stakeholder input and biophysical dynamics for valuation of ecosystem services and decision–making: Simulate ecosystems and Socio–Economic systems in space; Simulate these systems over time, and Simulate the interactions between these systems through the coupling.

SES modeling represents one frontier in science development, to which spatially explicit and dynamic modeling is one vanguard “this represents the cutting edge of research in this field” (COSTANZA et al., 2014). For being a recent issue, SES modeling still lacks standardized methods (SCHLUETER et al., 2012).

2.2.1 Area description and spatial definition

Ubatuba is a coastal city on the northern São Paulo State coast, Brazil (Figure 2). The city is formed by 200km of beaches that cover all west frontiers. East limits are Serra do Mar mountain range, with altitudes of more than 1300m. The northern limit is Paraty (RJ state), and south Caraguatatuba (SP state), also two touristic cities but with different profiles. Ubatuba had its origins during the XVI century with the Portuguese arrival and making conflict with the Tupinambás natives that lived in the region. Around XVIII century the city was producing cachaça (a sugarcane strong alcohol beverage) and sugar to fuel the national market, but this production was about to decline due to the development of commerce in Santos region (the main Brazilian harbor since then), and also the faster development of other productive areas like the Paraíba river valley (FONTANELLI, 2019). After the sugarcane, started the coffee cycle, allowing the construction of the main buildings in the city (counselors chamber and the main church)[1]. At the end of the coffee cycle, Ubatuba didn't have great economic development from the end of the 19th century to the first decades of the 20th century. The economy started to grow significantly again during the '50s and '70s when roads connected the city and tourism activity started to push economic activity locally (DIEGUES, 1974).

Nowadays the city has 80% of its land covered by tropical forests, protected by the biggest protected area in São Paulo State, the State Park of Serra do Mar, which overlaps a national park (National Park of Serra da Bocaina), in the extreme north of the city. The marine area has other protected areas like the APAMLN protected area and the Anchieta Island State Park (PEIA).

Model boundaries follow the political limits of the city. The focus of this study is the marine ecosystem services, thus the modeling was developed to embrace the structure and processes that happen in the water. For the space limits, it embraces the continental area of the city, two main islands (Mar Virado and Anchieta), and also the marine area (Figure 1) until 50m depth, with limits following the northern sector (Cunhambebe) of the APAMLN protected area.

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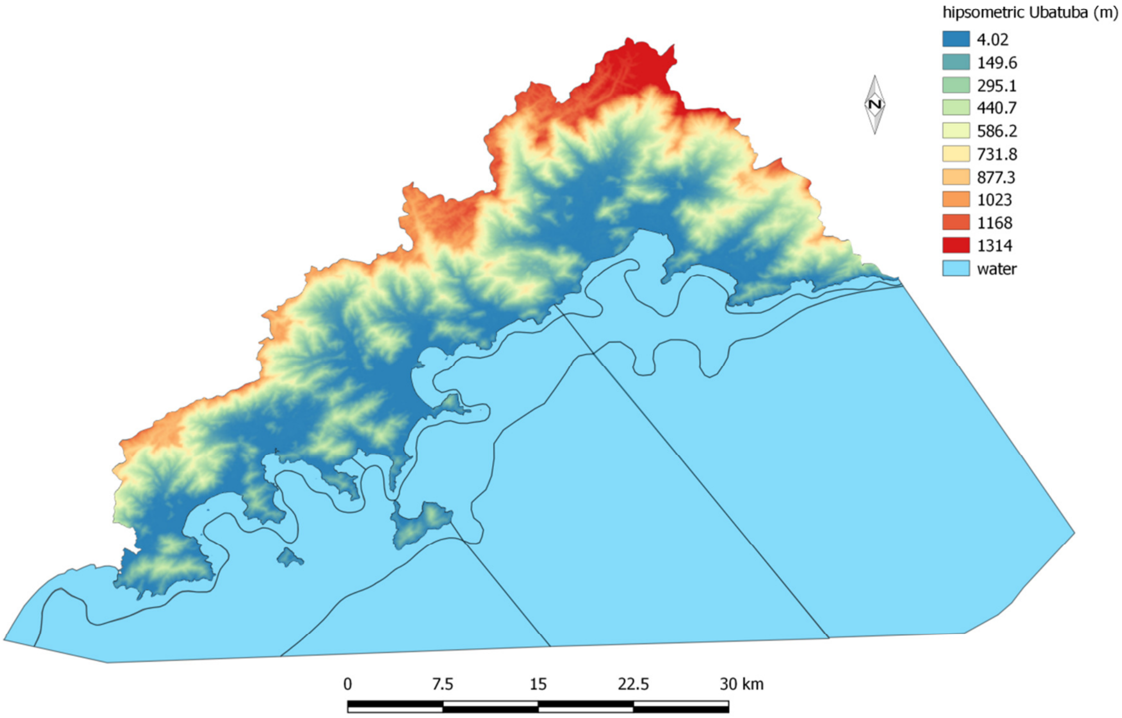
[1] https://www.ubatuba.sp.gov.br/a-cidade/ Acessado em 29/07/2020

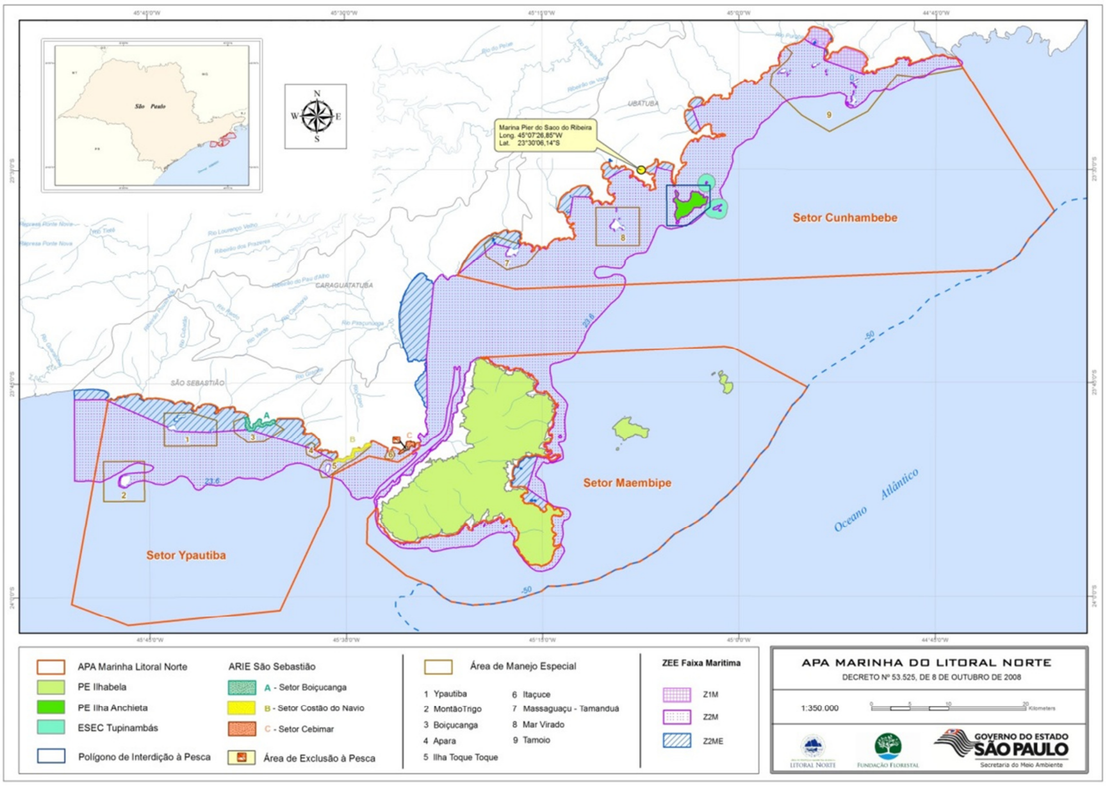
Figure 1: Spatial definition of the city and coast



Elevation curves of Ubatuba and the marine portion of the model. The ocean is based in polygons representing different depths (bathymetry lines in 10, 25, and 50m depth). Land is based in raster file. Source: the authors

Considering the possible future uses of the model for this protected area policymaking, the area embodied in the model was delimited to match the north sector of the main marine protected area in the region (APAMLN). This marine protected area also occurs in two other regions of São Paulo coast (Figure 2). The idea is that future developments of the model could be created to embrace the other regions.

Figure 2: APAMLN and its limits.



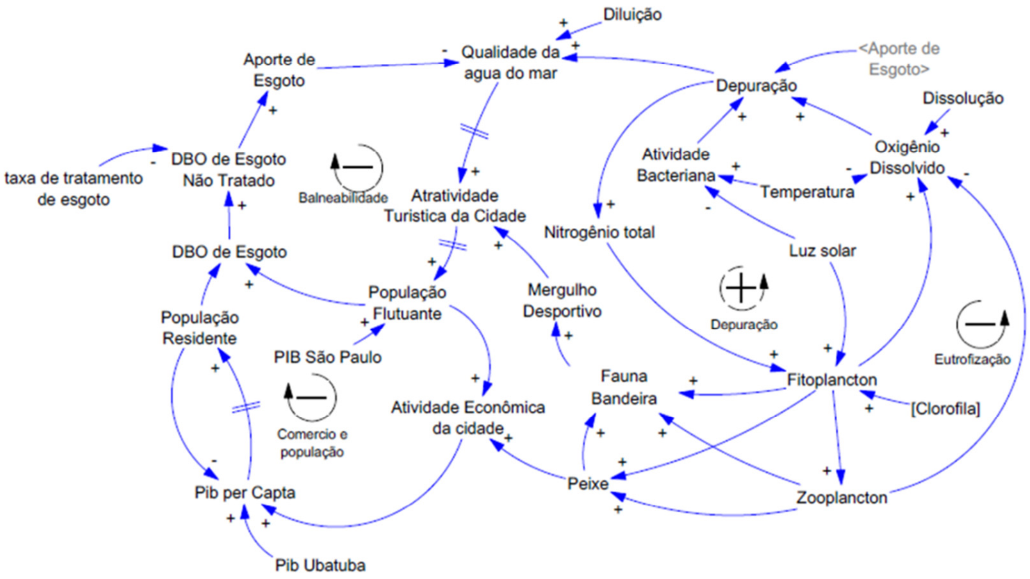
The marine portion of the model uses the spatial definition of the northern portion of APAMLN protected area. Source: the authors

2.2.2 Causal Loop Diagram – CLD

The causal loop diagram (Figure 3) is a representation of the main aspects that we wish to integrate into the model. This CLD was built and validated inside the research group in Brazil, so we kept the original CLD written in Portuguese. Starting from water quality (qualidade da água do mar), it is influenced positively by some ocean ecosystem services like waste depuration and dilution. The main attributes of these services are on the right side of the model, represented by variables like depuration, bacteria activity, and dissolved nitrogen (DIN). Some of these variables are influenced by temperature and sunlight and then influence phytoplankton growth, dissolved oxygen, consequently influencing zooplankton population, fish, and flag fauna (animals that can be attractive for scuba diving).

The left side of the CLD shows the main variables of the social sphere, represented by resident and visiting population (tourists), influenced positively by affluence (State GDP) and negatively by water quality decrease (due to sewage disposal).

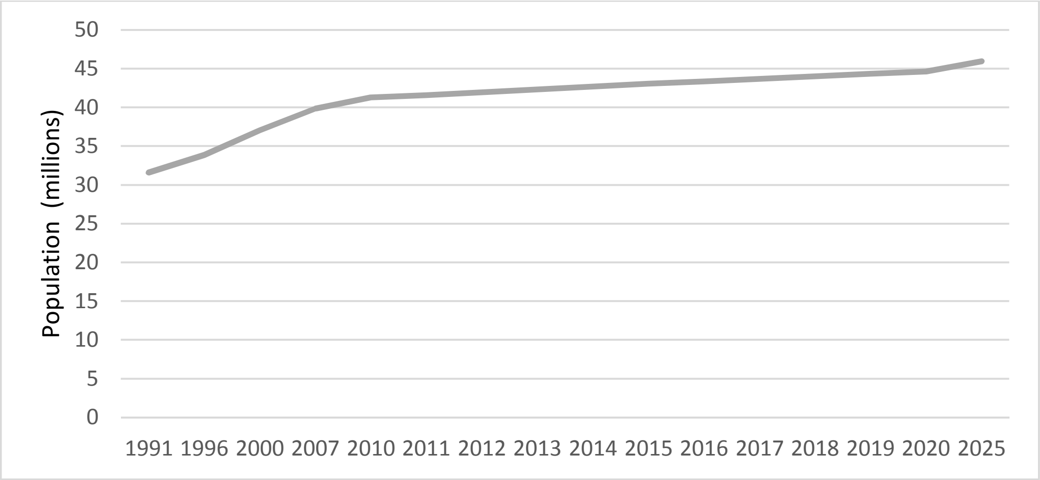
Figure 3: Causal Loop Diagram for the relations among society and nature in Ubatuba



This CLD was built with participation of the research group in 2017. The idea was to show assumed causality between water quality and economic and population variables. This is representative of some boundaries the model adopted, as considering the ecosystem provision of the coastal area being provided only to this city. Source: The Authors

Secondary data used as parameters for calibrating the model were obtained in the literature review (see calibration section), to include estimates of tourism and population growth (Figures 4 and 5; CETESB, 2014). The model follows the average visiting expectative investigated until the moment as a constant rate to the end of the simulation, except when a specific scenario (reacting tourists) is active. The time horizon of the model starts in 2010 because this represented the majority of data available. São Paulo state population growth (Figure 4) showed rapid growth in the ’90s, most of it due to migration from other states, and stabilizing on the 21st century (2010-2025) possibly signaling a demographic transition.

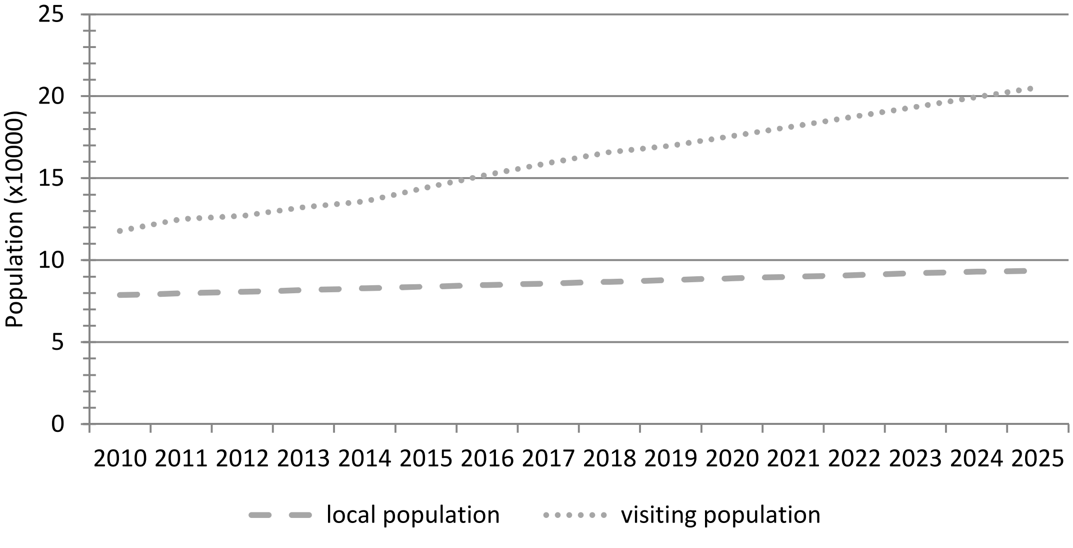
Figure 4: São Paulo Estate Population estimate



With the increase in the state population, more people are prone to visit Ubatuba during vacations of holidays. Source: Data from CETESB, 2014.

Visiting and resident population estimates (Figure 5) were obtained until 2025. This is most important for the model and local management once the city is dependent on tourism for the economy and this activity is the most related to environmental impacts on coasts.

Figure 5: Resident and visiting population estimate for Ubatuba for each year.



Comparative trends for local population and the expected number of tourists in the city. Source: made by the author with data from City’s plan for basic sanitation – Ubatuba 2013 / Water and sewage– SABESP – 2011

Data from sewage treatment (CETESB, 2014) considered the city collects 100% of sewage but only 50% is treated. The same estimates consider Biological Oxygen Demand in 0.045g/l per person per day.

2.2.3 Considerations about the model structure

The stock and flow structure (Figure 6) present all environmental attributes captured by the model and is the first result of the MIMES model. The model embraces causalities by drawing arrows connecting variables, however, the visual clarity is decreased by the number of variables and arrows connecting them. There is an initiative to make these models more visual and user friendly (MIDAS) [2] from Boston University, where professor Suchi Gopal transforms this modeling structure into a suitable interface where people can make their scenarios and learn with the model without specific training in system dynamics. At the moment, the presentation is divided into each sub–model to make the comprehension easier. The idea of Figure 6 is to understand that each sub–model is connected forming a coherent whole, that represents the SES modeled.

The light blue sub model contains the weather data; the dark blue shows everything modeled inside water, with fish (orange) and microscopic organisms and particles (green). Brown box is a sewage depuration sub model to simulate the bacteria death rate and dilution. The yellow box shows that everything inside it happens in geographic space and can be showed spatially explicitly by the model. Outside the yellow box, has scenarios sub–model; the red economic sub–model, other auxiliary sub–models with data and outputs from the main model, and finally the output for each ecosystem service and their economic value.

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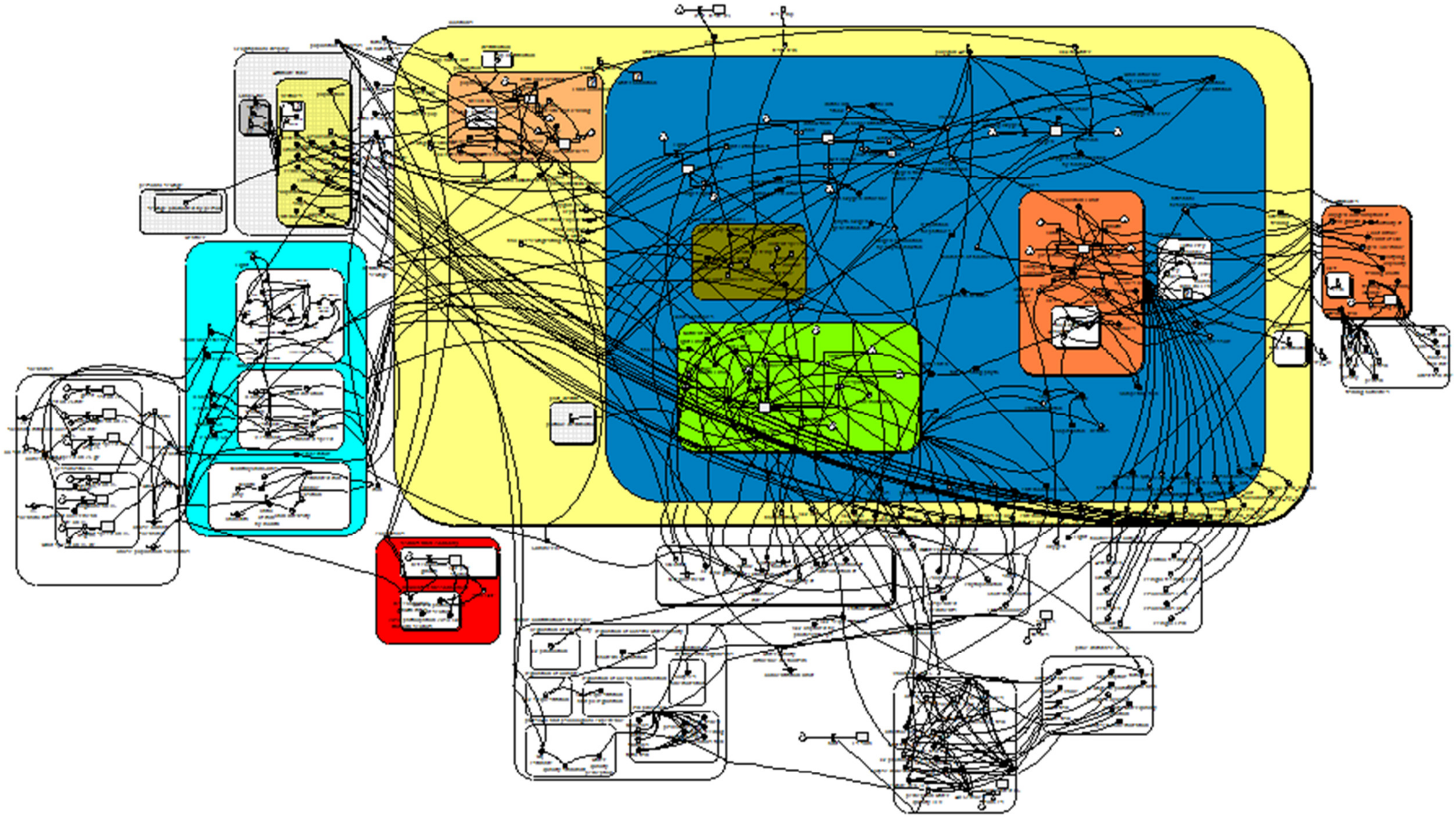
[2] http://chansmodels.org/

Figure 6: MIMES model for Ubatuba

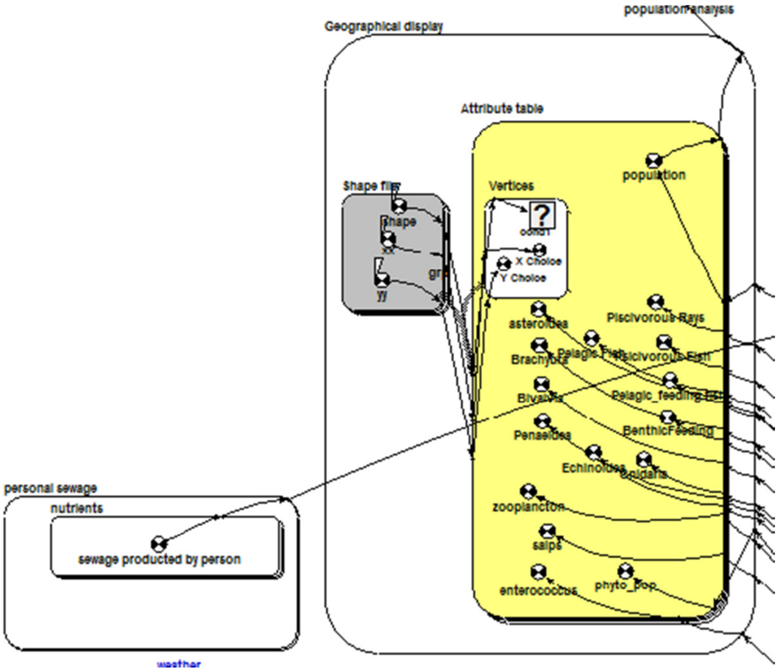


Visual of MIMES as specified within the Simile Software (Muetzelfeldt & Massheder, 2003). There is a limit of definition on this picture that does not allow seeing the individual variables. The idea is to understand the whole model being made of sub–groups. Notice the presence of big colored boxes and the interactions between them. Source: the authors

2.2.4 Sub model description

Spinning against the clock and starting from the upper left corner sub–model, we find the GIS interface sub–model (Figure 7). This part is responsible for the mechanism that plots other sub–models information into a map. The gray box is where the information about the map vertices is (the polygons) and the yellow box is where we plot the desired information to be mapped (attributes). In this case, all populations (human, fish, bacteria, plankton, etc.) can be presented spatially once they were modeled inside the yellow box (Figure 6), and thus all information is already modeled spatially. The state variables are measured with one square meter resolution, but the visual presentation (like Figure 19) they are presented in polygons as if the whole polygon behave as one, and therefore the definition in this case is the size of the polygon.

Figure 7: GIS interface of the simulation

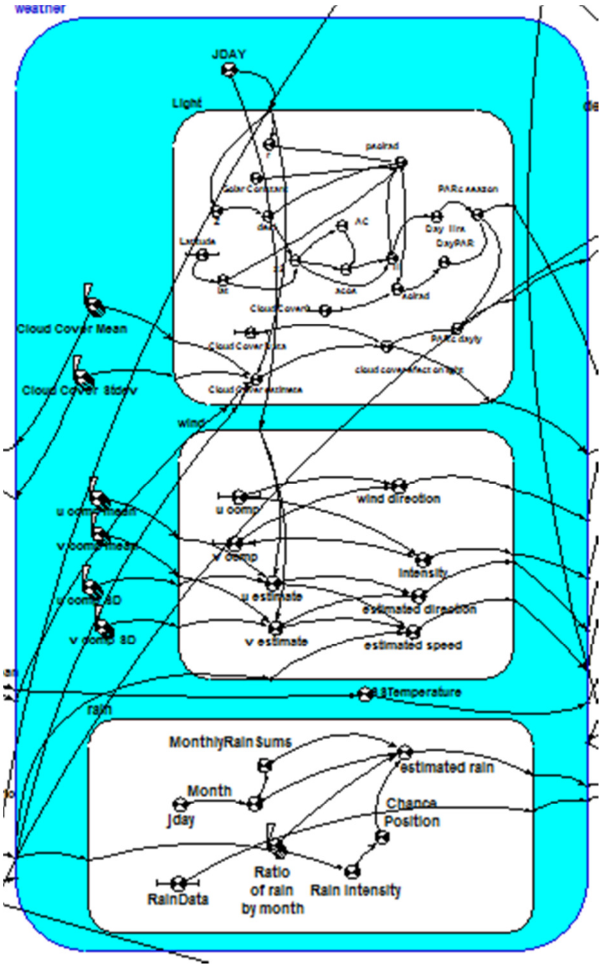


This is how Simile interact with GIS mapping. Source: the authors

The left box in figure 7 is shown here by convenience once this sub–model is related to sewage production and bring data about individual sewage generation for tourists and locals. Sewage is understood by its components as BOD, Nitrogen, Enterococcus (most common bacteria), and detritus that will be deposited in the water after partial treatment. Phosphorus was not included for simplicity but would make sense to implement this mineral and see its contributions to water quality and algae blooms.

The light blue model (Figure 8) represents weather data. It embraces sea surface temperature (SST), photosynthetic active radiance (light), wind (speed and direction), cloud cover, and rain pattern. SST was treated as a stochastic variable because it was simpler to use the data this way. These data were obtained in personal communication with Milton Kampel from National Institute for Space Research (INPE). Our simulation thus asks for Simile to use stochastic data between the average and standard deviation daily. Using this proxy works because the data will always be inside the spectral parameter for that variable.

Figure 8: weather sub model



This sub–model brings some climate variables as inputs for the model. Source: the authors

The light sub–model is more complex. To simulate the real light available for phytoplankton to use (Photosynthetic active radiance – PAR), it started with a standardized Simile light sub–model (as in ALTMAN et al., 2014 e BOUMANS et al., 2015) that defines the amount of solar radiation is available in that region of the planet (so it was calibrated for Ubatuba Latitude using one point only). That light then is filtered through local data of cloud cover, the more clouds less light available. For cloud cover, we used daily data from

"European Centre for Medium–Range Weather Forecasts (ECMWF)" with time series from 2010–2017. For future periods (ahead of July 2017), the model stops using data and starts to simulate data the same way it did for SST, that is, choosing stochastic numbers that happen between the average and standard deviation for cloud cover every day.

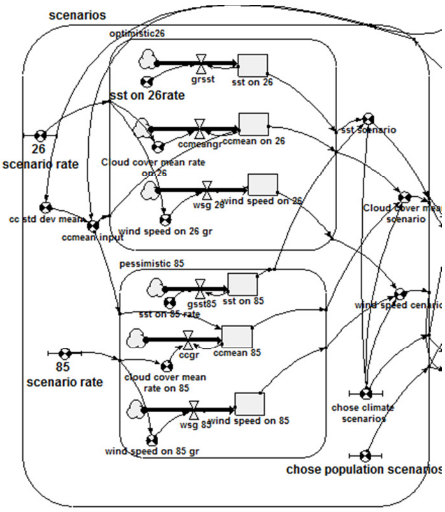
Wind sub–model used the same strategy as that for cloud cover. Data start in 2010 and goes to July 2017, and was collected in the same source (European Centre for Medium–Range Weather Forecasts (ECMWF). The same calculation happens when the model simulates ahead of July 2017, with a stochastic number being chosen between the average and SD for that variable.

The rain sub–model is more complex. First, we used data from Ciiagro[3] (http://www.ciiagro.sp.gov.br/dados/entrada.htm) for the same period of other weather variables with daily data of rain. The model uses this data until July 2017 and then starts to simulate its data.

To simulate precipitation, the model uses a stochastic generator to determine if it's raining or not (which is based on historical monthly profiles of rain). Then, if the model decides that is raining, it makes an estimation of the intensity (also based on historical monthly data).

Close to the weather sub–model is the scenarios sub–model (Figure 9) that will be described later. In short, this sub–model changes the weather data (SST, wind speed, and rain and cloud cover patterns) according to climate scenarios determined in the simulation. This sub–model also can change the number of tourists visiting the city in a scenario called reacting tourist (see ahead).

Figure 9: scenarios sub model



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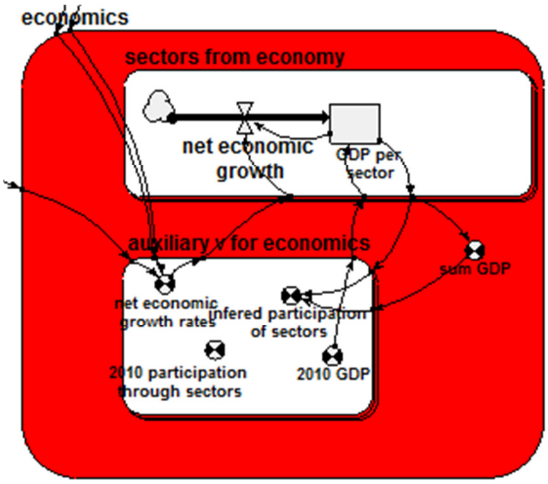
[3] http://www.ciiagro.sp.gov.br/dados/entrada.htm l Visited in 10 August 2017

This scenario sub–model brings the stocks that are changing along time and forcing the model to change accordingly. Source: the authors

Beneath the whole model, the small red economic sub–model is found (Figure 10). It is a brief simulation of the city GDP and the sectors that create that GDP (Industry, Services, or Agriculture). The growth rates were obtained for the period from 2000–2010 and considered constant for the whole period the simulation runs (2010–2100). GDP growth rate is altered only when the reacting tourists' scenario is active (to be described).

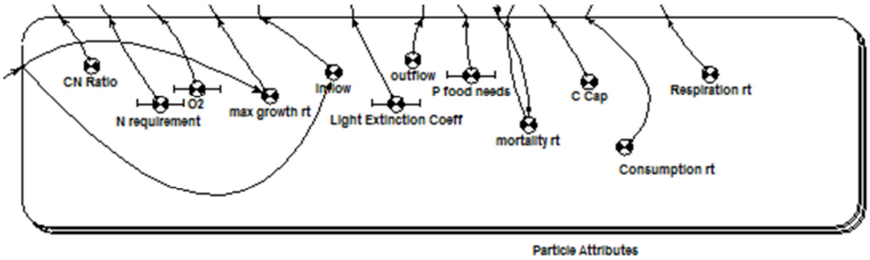
Figure 10: economic sub–model



The small structure presents GDP forecast in reais and USD and the participation of each main economic sector (agriculture, services and industry). Source: the authors

Close to the economic sub–model, there are three colorless sub–models (Figures 11, 12 and 13). Particle attributes sub–model (Figure 11) present auxiliary variables used for determining the dynamic of water particles sub–model (Carbon nitrogen ratio, nitrogen requirements, oxygen produced, maximum growth rate per species, inflow rates, light extinction coefficient, outflow rates, food need per species, mortality rates, carrying capacity, consumption rate, and respiration rate). Some data (max growth rate, respiration rate) came from Rocha et al. (2003), other variables are unknown (e.g. carrying capacity). To these variables, some values were arbitrarily assumed and then calibrated until obtaining the dynamic simulation that was coherent with data (population size in summer and winter) (Table 2).

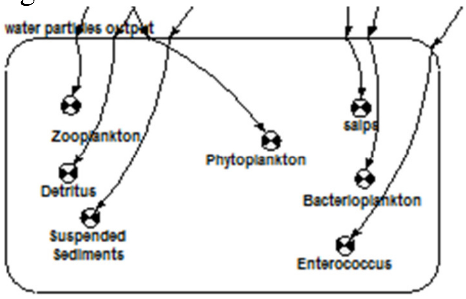
Figure 11: Particle attributes output sub model



This is one way to show output variables. Source: the authors

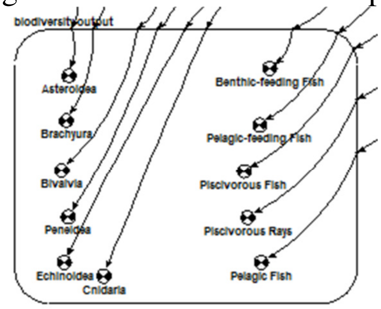
Some outputs numbers (without spatial information) can be seen in the outputs sub–models (Figures 12 and 13).

Figure 12: Water Particles attributes



Output from the water particles. Source: the authors

Figure 13: Fish sub–model output



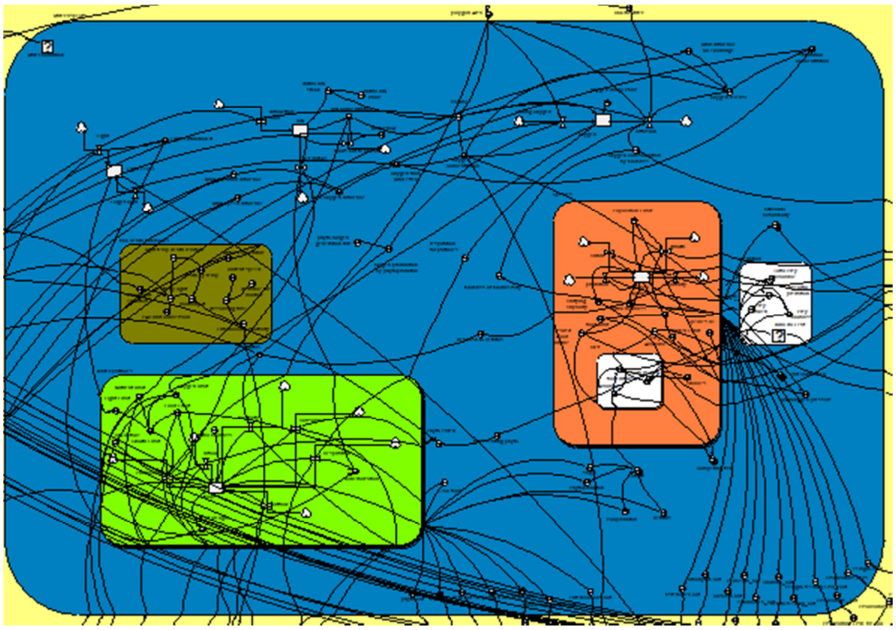
Output from the fish sub–model. Source: the authors

The big blue box shows what is simulated in the marine environment (Figure 14). It starts with isolated stocks that represent water extinction (due to particles dissolved in the water column), organic dissolved Nitrogen (DIN), and Dissolved Oxygen. Those variables are strongly influenced by sewage deposition and can contribute to eutrophication processes. The more Nitrogen in the water, the closer the Phytoplankton is to the maximum production rate. Oxygen is a limiting factor to all species in the water. For the sake of simplicity, we assumed the same oxygen tolerance level for every organism in the water (5 mg/L). Beneath this level populations start to die.

Oxygen insertion in the water happens through photosynthesis and also from dissolution from the atmosphere, a process that is determined by wind direction and speed. Oxygen consumption happens from all biodiversity in the water and the surplus of Oxygen is released when the saturation point is reached (this point varies according to SST).

Three other sub–models are embedded in the water sub–model: water particles, fish, and bacterial mortality.

Figure 14: water sub–model



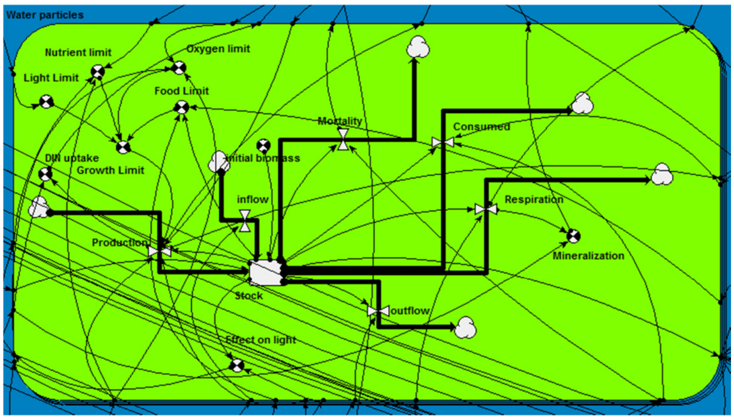
Note the green (water particle sub–model),brown (sewage depuration sub–model) and the orange (fish sub–model) boxes. Source: the authors

The water particle sub–model (Figure 15) shows the simulation of seven microscopic “particles” that occur in the water (Phytoplankton, Zooplankton, Detritus, Suspended Sediments, Salps, Enterococcus and Bacterioplankton). First, they are not just particles as part of them are organisms; second, they are not all microscopic because some salps can lengths in centimeters. Embedded in this model are the most representatives groups of the region (ROCHA et al., 2003; ROCHA et al., 2007, MESQUITA et al., 1993; GAETA et al., 1999). Their population dynamics (or weight for detritus) are controlled by the drivers presented in figure 14: production, migration (in and out), mortality, consumption, and respiration. It is also present in the same box the effect of light (the more particles in the water, less transparent it is to light), nitrogen uptake from biodiversity, and mineralization through biodiversity metabolism (that gives nitrogen back to the water).

Growth limits are defined by left side variables in the model. It considers as growth limiting factors: light (for phytoplankton and bacterioplankton), nitrogen concentration (for phytoplankton and bacterioplankton), food (for zooplankton, salps, Enterococcus), and oxygen for all. Detritus growth depending on the sewage production and the amount of suspended material is a detritus function.

The green box is an example of a matrix (array). There is only one visible green box, but actually, there are seven in the overlap. Arrays then are overlap of sub–models that have the same structure (but different numbers) determining their behavior.

Figure 15: water particles sub–model



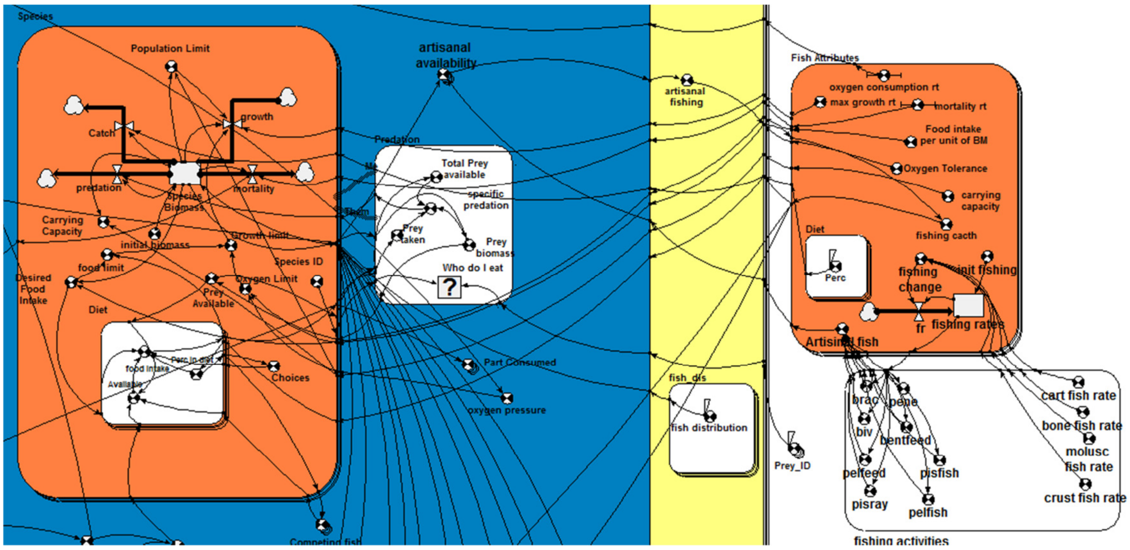
Water particles are represented by the central box from where all rates reach of start. Source: the authors

The fish sub–model (Figure 16) was built using three sub–models, left orang is a matrix of eleven biodiversity groups (vertebrate and invertebrate macrofauna), generically called fish. It was used the groups that are more representative of local biodiversity (ROCHA et al., 2003; ROCHA et al., 2007): Asteroidean (stars), Brachyuran (crabs), Bivalve (shellfishes), Penaeidae (shrimps), Echinoid (sea urchins), Cnidarian (jellyfishes), Benthic Feeding Fish, Pelagic Feeding Fish, Piscivorous fish, Piscivorous Rays and Pelagic Fish.

To simulate their growth, mortality, and predation an auxiliary sub–model was built (the right of Figure 16), which embraces fish rates. Data from fisheries were obtained from the Fishery Institute of São Paulo Estate (Instituto de Pesca do Estado de São Paulo) from 2010 to 2017 with monthly data. All debarkation (landings) were assumed to have been fishing in the area of the model. Growth and decay rates were calibrated to make the population curves follow the population data (ROCHA et al., 2003; ROCHA et al., 2007). Predation then is the simulation of the feeding behavior of those groups. The model can simulate from which group each group feeds.

The last sum model (fish_dis) is the spatial distribution of each group in the polygons of the area. Each population thus is spatially distributed and predation occurs only in polygons where pray and predator meet. Some groups occur where rocky shores are present (Brachyuran) thus they are modeled in polygons that have a coast or an island (Figures 34, 35, 36). The opposite happens with some fish (Pelagic fishes) that occur in the open sea and will not be found in a depth of 10m.

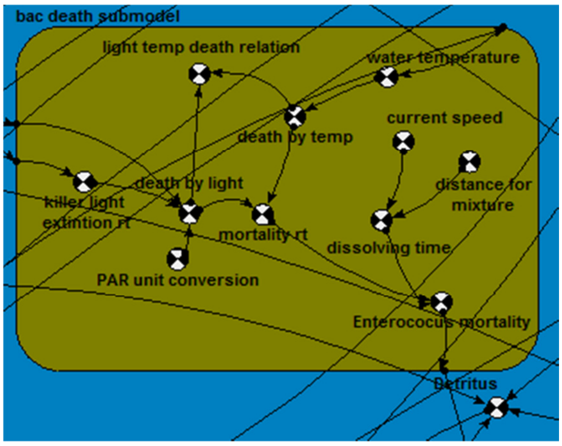
Figure 16: Fish sub–model



The model simulates 11 groups of vertebrates and invertebrates represented by the state variable in the left orange sub–model. Fisheries are represented by the state variable in the right orange box. Source: the authors

The last sub–model on the water (Figure 17) embraces the variables determining sewage depuration. Sewage is a relevant issue regarding Ubatuba (CETESB 2014; BATISTA e HARARI, 2017). The model then simulates two forms that determine the death rates of the sewage bacteria (represented by Enterococcus population): light and temperature. The death rate was simulated accordingly to a preexistent general bacterial death model (MANCINI, 1978) and that was applied for the same region (BATISTA e HARARI, 2017). The model also simulates the dissolution of the remaining bacteria being dragged by currents.

Figure 17: Bacterial mortality and dissolution rates

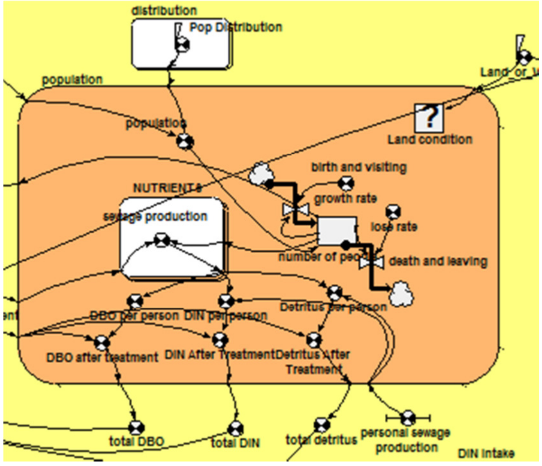


This sub–model is representative of bacteria mortality. See the light and temperature variables interacting to form the mortality variable. Source: the authors

The last sub–model represents the human population (Figure 18). Simulation of resident and the visiting population was calibrated using the most accepted data for the region

(CETESB, 2016). The exact number of tourists are unknown, and there are variations on the number of São Paulo State statistics department (Fundação SEADE) and São Paulo State Environmental Agency (CETESB). The simulation uses a higher concentration of tourists distributed in summer when compared to winter. Sewage deposition follows the same distribution.

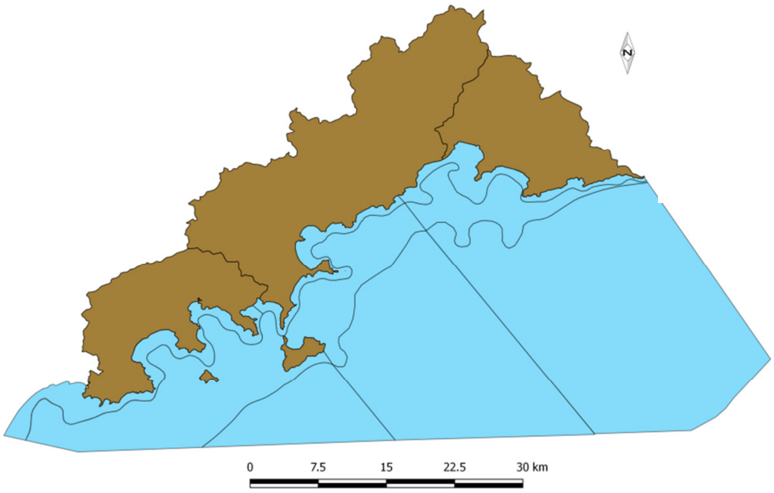
Figure 18: Human population sub–model



Population submodel shows the distribution, growth and decay rates and some sewage attributes that are directly dependent on the number of people. Source: the authors

The resident population is distributed along the 200km of shores. But the northern part of the city is less densely occupied (CETESB, 2016). The central part of the city is occupied with high–density houses and small buildings. The southern part is an intermediary density. We arbitrarily distributed the population to fill this pattern. The land part of the model (Figure 19) considers then 3 land basins determined by population density.

Figure 19: Land basins and population distribution



Brown polygons shows three land basins where the municipality population is divided. The center part is with high density habitation. The east part is low density habitation and the west is intermediary. Source: the authors

2.2.5 Scenarios description

The model works with two systems type scenarios (climate and reacting tourists) representing the biggest menaces to Ubatuba's SES (SÃO PAULO, 2019) and also with tree economic scenarios when dealing with economic valuation of ecosystem services (utopian, selfish, and balanced).

2.2.5.1 SES scenarios

2.2.5.1.1 Climate scenarios:

Climate scenarios were developed using two contrasting scenarios described by IPCC (2014): RCP 2.6 and RCP 8.5. Data used here sometimes are different than that found in IPCC once some variables were not found at a satisfactory scale for the municipality level even in downscaling works (CHOU et al., 2014a; CHOU et al., 2014b; BRASIL, 2013). For example, some sources (SÃO PAULO, 2019a) projects SST alterations between 4° and 8° C due to climate change scenarios. Despite the values used for SST in the model had their origin in IPCC reports (IPCC, 2014, page 61), the values used here are approximations (Table 1). The name RCP 2.6 and RCP 8.5 are references to the better and worse scenarios and must be understood as "RCP like" scenarios.

These climate scenarios bring variations in SST, wind speed, the amount of cloud cover, and the frequency and intensity of rain (Table 1). Values represented are the final state of each variable and are numerically modeled to use a daily crescent curve that reaches table values in 2050 and surpassing these values in 2100. Alterations in precipitation were made instantly once this model is already very complex and start to act with full intensity once the model is active (July 2017 or day 2738).

Table 1 – Climate attributes change due to climate scenarios

Year	2050		2100	
Attribute	RCP2.6	RCP8.5	RCP2.6	RCP8.5

SST (ºC)	0.5	1.5	1	3
cloud cover	7%	15%	18%	34%
wind speed	7%	15%	21%	50%
precipitation	15%	30%	15%	30%

Source: the authors

2.2.5.1.2 Reacting tourist's scenario:

The second system scenario used in the model came from previous research[4] made in the same city that remarked the great concern from tourists regarding the water quality. When asked about which factor was more important to tourist activities on the beach, 61% of tourists considered the water quality (followed by 33% on weather and 23% of sand cleanliness). This semi–structured interview reached 387 tourists during 2016 Summer also revealed that 83% of interviewees state they wouldn't come to the beach if it wasn't proper (meaning with good water quality) for batheability; 52% said they wouldn't come if the water present a different color and 74% said they wouldn't come if the water has mud or excess sediment. These results are corroborated by other authors for the same region (e.g. GHILARDI–LOPES et al., 2015).

It was considered then that water and sand cleanliness is relevant to tourists when choosing the beach they will visit. The way tourists perceive this cleanliness and act accordingly is harder to tell. The model arbitrarily uses a microorganism (*Enterococcus*) concentration as a proxy for water quality. The idea is that the São Paulo State agency for batheability management (CETESB) uses this indicator to monitor water quality. And their communication program has been using this same proxy to raise awareness about water quality for decades. Tourists cannot see the microorganisms on the water, but if the water quality is not adequate for usage, the environmental agency will put red signs on the beach and will make public announcements about the quality on their website, social media, and also in great circulation newspapers. So, it was considered a good proxy for reactive scenarios once the communication of the problem is most likely to reach tourists and it was expected they act accordingly.

It was considered that beyond a certain limit concentration tourists start to become reactive to water quality and start to move to a different location. Arbitrarily the concentration limit was established in 1.6 mgww/m2 of Enterococcus, which means twice the worst value found in the first year of simulation.

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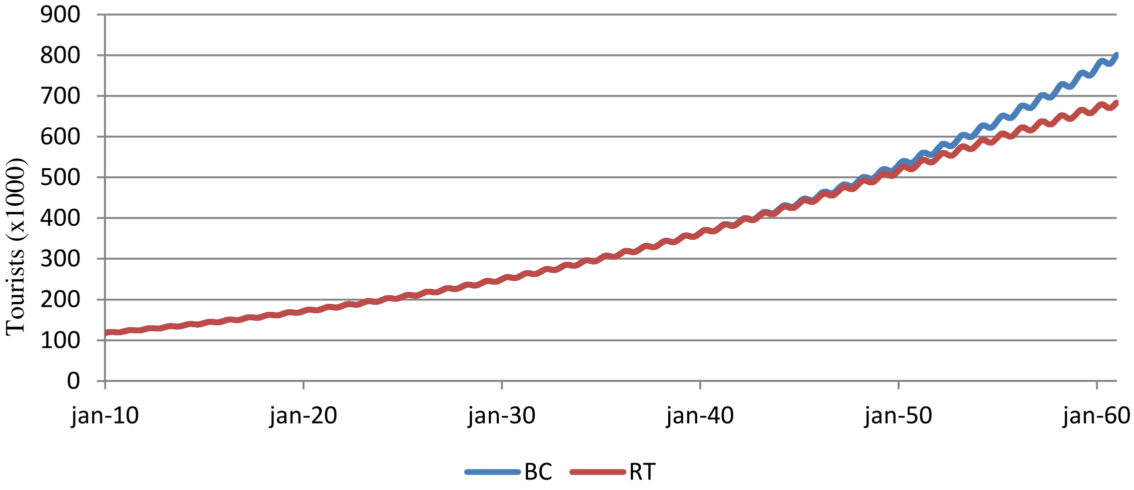
[4] "TOURISTS' PERSPECTIVES OF COASTAL/MARINE ECOSYSTEM SERVICES AS THE FIRST STAGE OF PARTICIPATORY MODELING." Accepted in the journal Anais Brasileiros de Estudos Turísticos, 2020

Due to the reactivity against environmental conditions, it was arbitrarily considered that up to 15% of the visiting rate could be affected if water conditions weren't proper.

Consequently, the curve that represents the number of tourist growth, due to this scenario, presents a lower growth rate compared to the normal curve (Figure 20), reaching their maximum at 85% of the previous rate.

Figure 20: Simulation of tourist growth from 2010 to 2060



Showing yearly visitations. Blue – normal case (base case), red means growth limited by reactive tourist's (RT) scenario. Source: the authors.

2.2.5.2 Economic Scenarios:

The future economic value of ecosystem services is unknown. Imagining what would be the price of one kilogram of shrimp in 2100 is an important theoretical exercise that brings several relevant learning and some knowledge to local management. Yet it must be seen as an exercise once this SES is opened and it is likely impossible to forecast precisely the price of this good in 90 years. Actually, in 90 years we cannot be certain about the existence either of shrimp nor dollars. Nonetheless, the possibility of making previsions of different possibilities of future prices can be interesting to build strategies for long term management.

The model uses three economic scenarios for dealing with prices (utopian, selfish, and balanced) that will depend on the discount rate used in each case for the future economic value of the goods.

The utopian scenario uses a discount rate of zero, meaning the money doesn't change its value over time. This scenario is called utopian because, like economists like to say, money changes its value over time. The idea here is to present one perspective that the flows of ecosystem services today, must have the same value for future generations.

The selfish economic scenario is the opposite. It considers a discount rate of 12% each year, meaning that all economic value of the goods must be explored in the shorter range possible, preferably during this generation lifespan (40 years) and nothing must be left after that. There is no concern about living resources available for the future, once on this perspective, the decision–maker will not be alive in the future.

The balanced scenario then is in the middle. It uses a discount rate of 6% and with that, it tries to balance price and conservation once it claims the resource will last more than one generation.

2.2.5.3 Equations description:

The model has something around 80 pages of code what raises some issues regarding the difficulty in documenting and therefore the reproducibility of the results. Copying the whole code in this thesis is not the answer to provide reproducibility or replicability (MILKOWSKI et al., 2018). This model will be hosted in the internet allowing users to come and use it to se the results by themselves or choosing different parameters to learn possible alterations on the results and mostly, to see the consequences of these parameters variations. Until that point, this work follows the lead of the reference papers in the field (BOUMANS et al., 2002; BOUMANS et al., 2015) and present some of the representative equations description, pointing where the data came from and how the model did to use the data and integrate it in the analysis.

a) Cloud cover simulation (as an example of climate data):

This equation is representative because it uses data acces and scenario condition at the same sintax.

(i) gaussian_var(element((if chose_climate__scenarios==0 then [Cloud_Cover_Mean] else Cloud_cover_mean__scenario),JDAY), *element([Cloud_Cover_Stdev],JDAY))

where:

- [Cloud_Cover_Mean] is an array of cloud cover data mean daily values (mean between 2010 to 2017);

- Cloud_cover_mean__scenario: is the same data on [Cloud_Cover_Mean] but with the daily increase of a rate forcing the average cloud cover to follow what is expected in climate scenarios (Table 1).
- gaussian_var: is the statistical function in Simile that makes the simulation chose a random number, disposed in a gaussian variation, around the mean data and using the [Cloud_Cover_Stdev] standard deviation calculated for each day along the mean values.
- Element: this part of the equation is the coding to Simile that for each mean value there is one standard deviation value in order (from 0 to 365).
- if chose_climate__scenarios==0 then … else… is the language Simile understand to run the base case data or the scenario simulation based on a second binary variable (chose_climate__scenarios).

b) Phytoplankton population (as an example of water particle sub–model)

In general all populations of the model will work as a state variable with rates enabling their growth (like migration or reproduction) and rates decreasing the population (as death, migration, predation, catching, etc.).

Phytoplanton growth is determined by the simplified equation:

(ii) Stock*element([growth_rt],index(1))*Growth_Limit*(1-Stock/element ([C_Cap], index(1))

Where:

- the growth rate ([growth_rt]) and the carrying capacity ([C_Cap]) are unknown and determined in the model in a non–exclusive pair of numbers that allows the phytoplankton population to reach values close to the calibration values considering the growth rates variations along time;
- growth rates are calculated with another equation:

(iii) least([(if index(1)==1 then Light_Limit elseif index(1)==7 then Light_Limit else 1),Food_Limit,Nutrient_limit,Oxygen_limit])

Where:

- equation iii shows that the maximum growth rates for every water particle (in this case an exception will be made on growth rates of zero for Suspsnded Sediments and Detritus, allowing only living things to be reached by this equation) is determined by the least of four possible environmental resources: Light, Nutrient, Oxygen and Food. For the producers (phytoplankton and bacteriolankton) light is usually the least factor. For the consumers (Salps, Enterococcus and Zooplankton) food, oxygen and nutrients are the only determinants of the growth limit. All this values are determined in the model and vary daily.

Light Limit is determined by the availability of Light at body of water considered as one depth only. The PAR is calculated by simile depending on the latitude programed in the model. The model then reduces PAR considering the influence onf cloud cover (from 0 to 17% (ANTHONY et al., 2004). Another light reducing influence comes from the amount of particles dissolved in the water. The influence of particles in water transparency data came from Lorenzen (1972).

c) Enteroccocus mortality rate (as an example of integrative rates)

This rate is the result of the mortality submodel. It embraces the logic that light and temperature are the responsibles for the Enterococcus mortality. The model assumes, for simplicity, that all bacteria that came from sewage, start dying only when they reach the salt water. Then light in wave length between 370nm to 400 nm are responsible for 75% of the death rates (Mancini, 1978; Batista e Harari, 2017). Considering the wave lengths change according to depth, the model considers that maximum death rate happens on the layer until 15m depth.

The other factor, temperature death rates, follows Mancini (1978) in which the formula for death rate is:

(iv) $k=[0.8+0.006(\% \text{ of sea water})]x1.07^{(t-20)}$

Where % of sea water was considered 100% (complete dissolution) and the temperature comes from SST data and simulation. The final Enterococcus death rate was built using an average death rate with the mean values between light and temperature.

d) Bivalves population (as an example for the fish sub–model)

These organisms population is treated as a state variable and is determined by growth, mortality, catch and predation (as all the organisms in the fish sub–model). Growth is dependent of max growth rate and carrying capacity the same way as in phytoplankton (determined in the model in the amount necessary to balance catch and predation). In this case cath is very interesting because catching rates are determined by the amount of moluscs landed in the city (obtained by historical landed data divided by the area of the ocean covered by the model) but also has a trend (decreasing in this case) that shows the fishing catch is changing along time.

The initial catching rate is based on landing data divided by the model area. The trend of catching is the angular coefficient of the trend line obtained by the graph analysis of the landing data. The trend line is described by the equation

(v) $y = -17.427x + 4580.3$

The trend is the coeficient of the x variable (-17.427). The same procedure was applyied to the rest of the groups where catch influences their population (for crabs and shrimps the crustaceans trend was 1.6542; for cartilaginous fish -98.928 and for bone fishes 694.7).

2.2.5.4 Data bases and Uncertainties assessment:

To increase the transparency and the possibility of reproducibility of the results in this thesis, a small session is dedicated to show some data used in this work and how it was used. The majority of data variables come from field assessments and therefore they are followed by an uncertainty in their values (standard deviation values). To embody that in simile, the syntax used is usually:

(v) Gaussian_var(mean,SD)

Where:

- Gaussian_var means Simile must chose a number between the mean and the SD every time step, and considers the number to follow a Gaussian distribution.

Considering this type of syntax to be stochastic, the simulation will always produce some different result every time the model runs. To counterbalance these variations in presenting the results, the model is simulated for five times creating a pool of results for each stochastic variable and others that are derivate from the stochastic variables. The final result is the average of these runs (followed by its standard deviation) and then presented in the descriptive graphs and accounting, when pertinent.

2.3 RESULTS

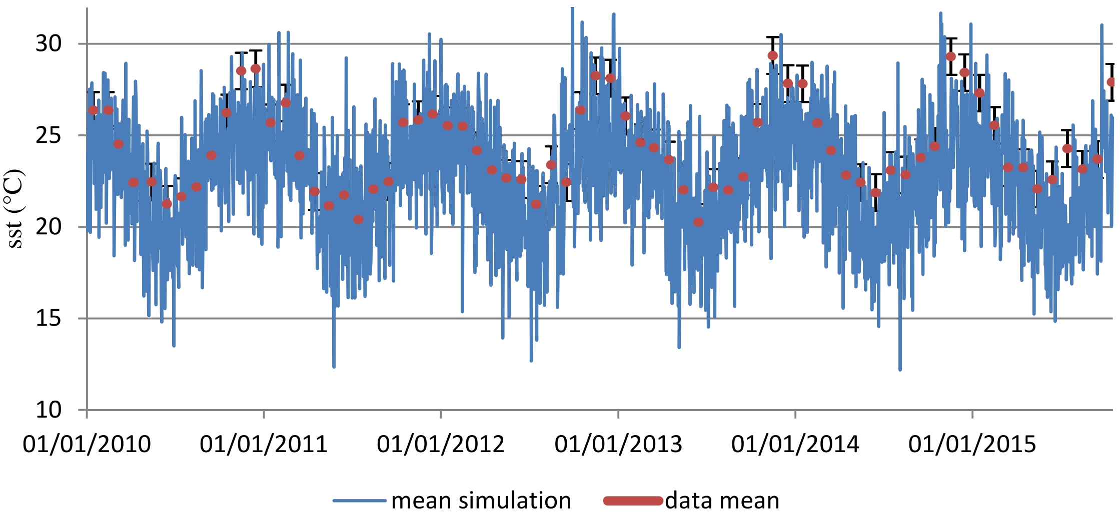
2.3.1 Considerations about calibration

Results show information calculated for each day of simulation but presented in a time scale that is relevant for each variable: the human population has small variations daily, then it is simulated along the century so their variations are understandable; rain, cloud cover, SST, etc. are important to see daily once they vary significantly every day.

To understand the scenario effect on ecosystem services provision we simulate them till 2100 and then variations on ES provision could be seen.

All input variables in the model were calibrated according to data. For sea surface temperature (Figure 21) data were presented in monthly averages and the model results are in daily data, but they follow the same seasonality and oscillations with a reasonable standard deviation (r=0.31).

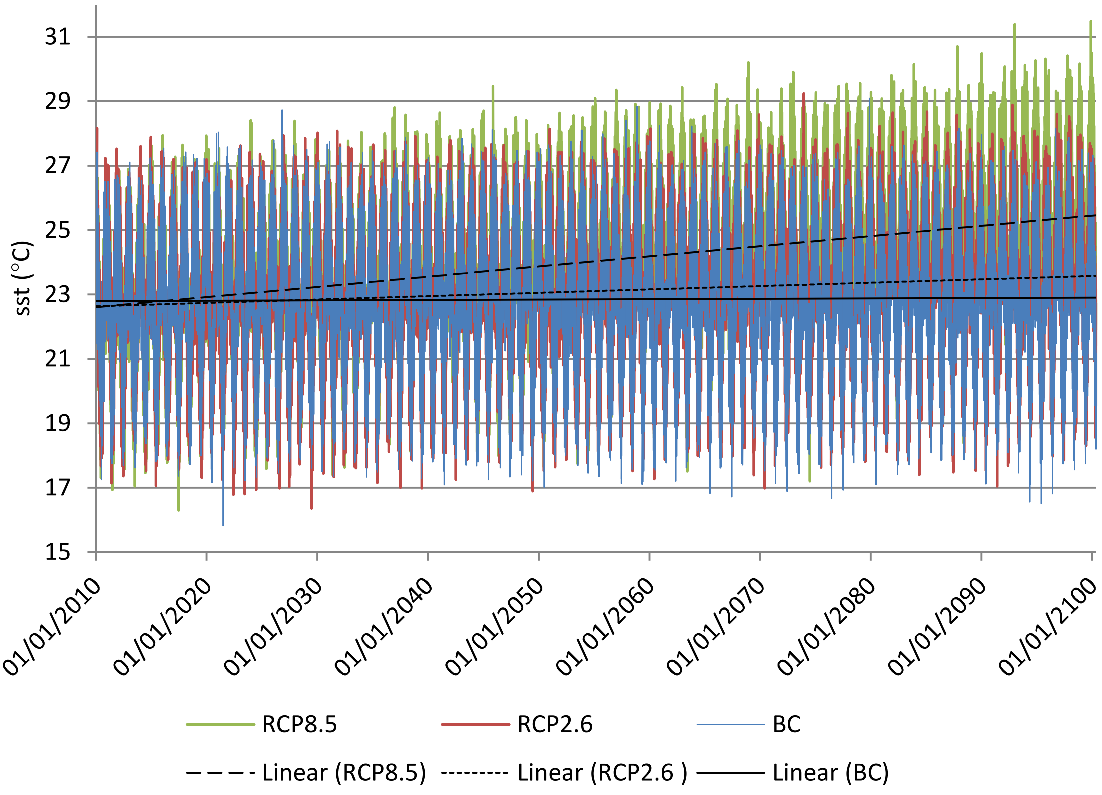
Figure 21: Sea surface temperature



Sea surface temperature from 2010–2017 showing the results of the simulation in comparison with data. Source: the author.

The sea surface temperature varies along the century depending on the climate scenarios (Figure 22). The graph in figure 22 shows daily variations of sst along the century. The trend of each scenario is different, each one being described by different linear equations (BC: $y = 3E\text{-}06x + 22.658$; RCP2.6: $y = 3E\text{-}05x + 21.481$ and RCP8.5: $y = 9E\text{-}05x + 19.139$).

Figure 22: Sea surface temperature and scenarios



Sea surface daily simulations from 2010 to 2100 in three different scenarios (Base case – blue, RCP2.6 – red and RCP8.5 – green). Source: the author

Trend lines (Figure 22) show the increase (linear) in the mean values for each scenario. The lower trend is BC, intermediate is RCP2.6 and the upper line is RCP8.5

Wind data are formed by two types of components (u and v) that are integrated in the model using the formulas:

(vi) 180-atan2(-u_estimate,-v_estimate)*57.29578

(vii) sqrt((u_estimate^2)+(v_estimate^2))*wind_speed_scenario

where:

- Equation vi is for main direction estimate and equation vii is for the wind speed.
- That syntax of each equation came from ECMWF[5] and represent the usual equations to calculate wind speed and direction modified by variables representing scenarios interfering in speed.

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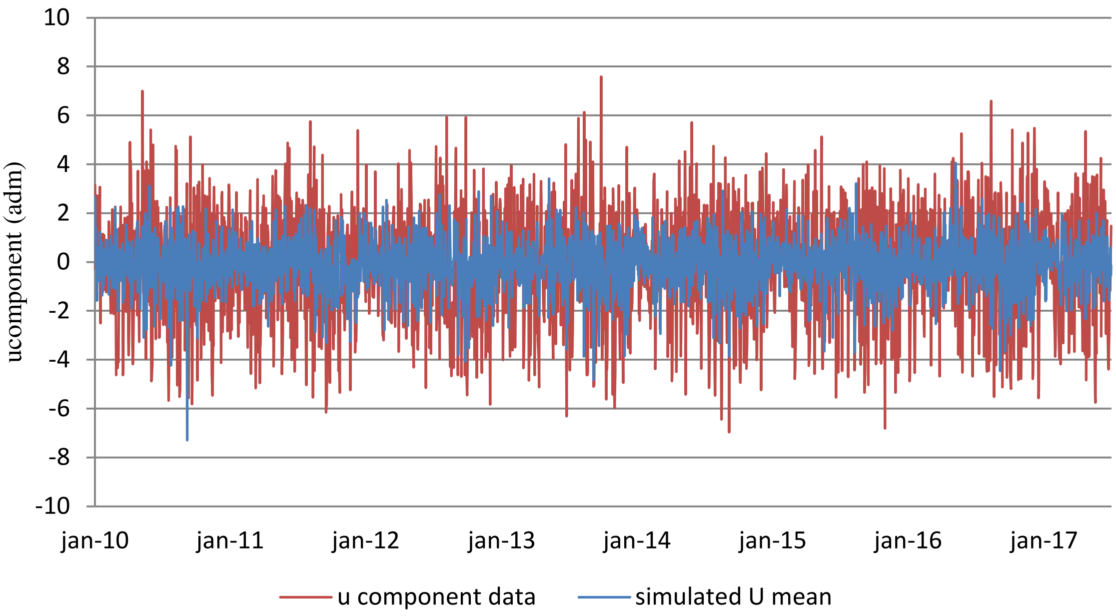
[5] https://confluence.ecmwf.int/pages/viewpage.action?pageId=133262398 Accessed in 20/03/2021

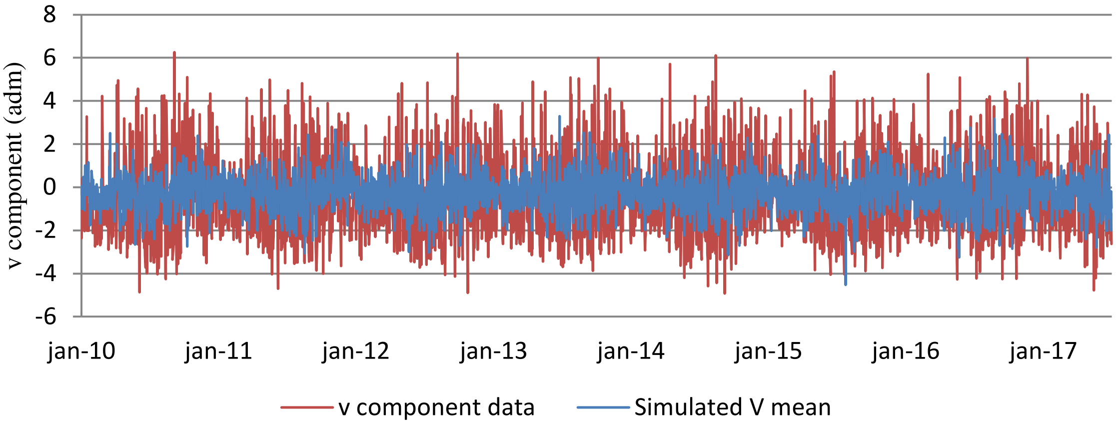
Considering these two components of wind separately (Figures 23 and 24) the simulation presents less variations when compared to data. This is an indicative that the simulation is conservative in relation to the variations of wind speed and direction (u component r = 0.15; v component r = 0.15).

Figure 23: wind u component



U component from 2010–2017 showing the simulation results against data

Figure 24:wind v component

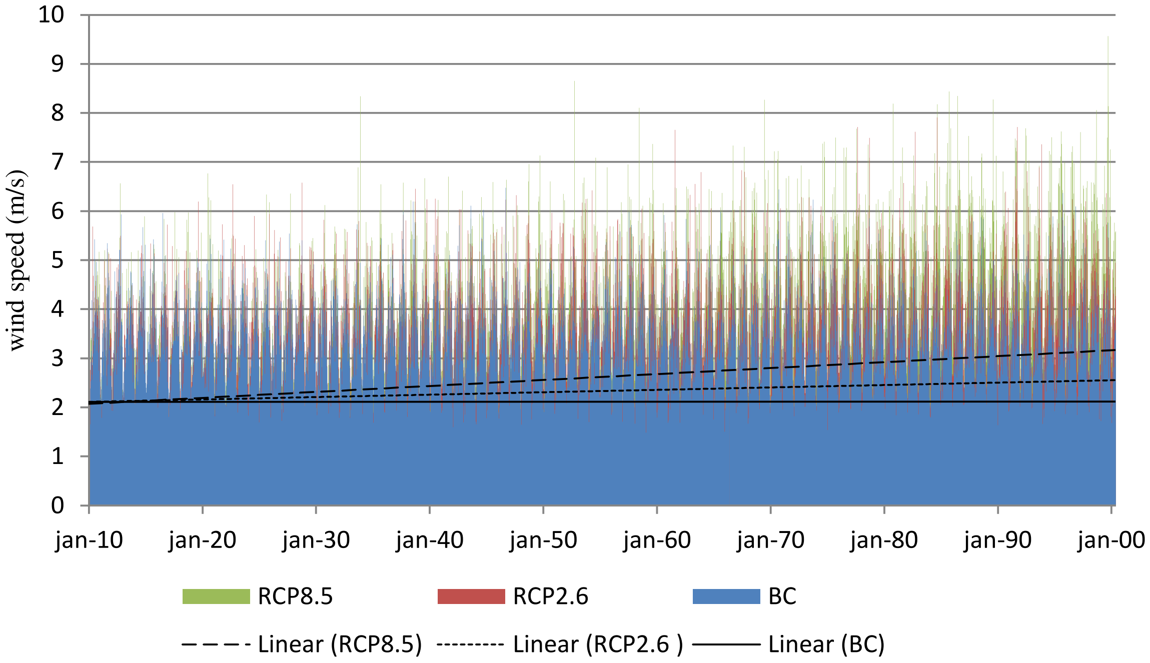


V component from 2010–2017 showing the simulation results against data

Wind simulation along the century shows the variations determined by both climate scenarios. The trends (Figure 25) represent the increase in speed determined by linear equations (BC: y = 3E-07x + 2.0946; RCP2.6: y = 1E-05x + 1.5631; and RCP8.5: y = 3E-05x

+ 0.7402). Directions were simulated as not varying with scenarios and were obtained using mean and standard variation from the seven years of data.

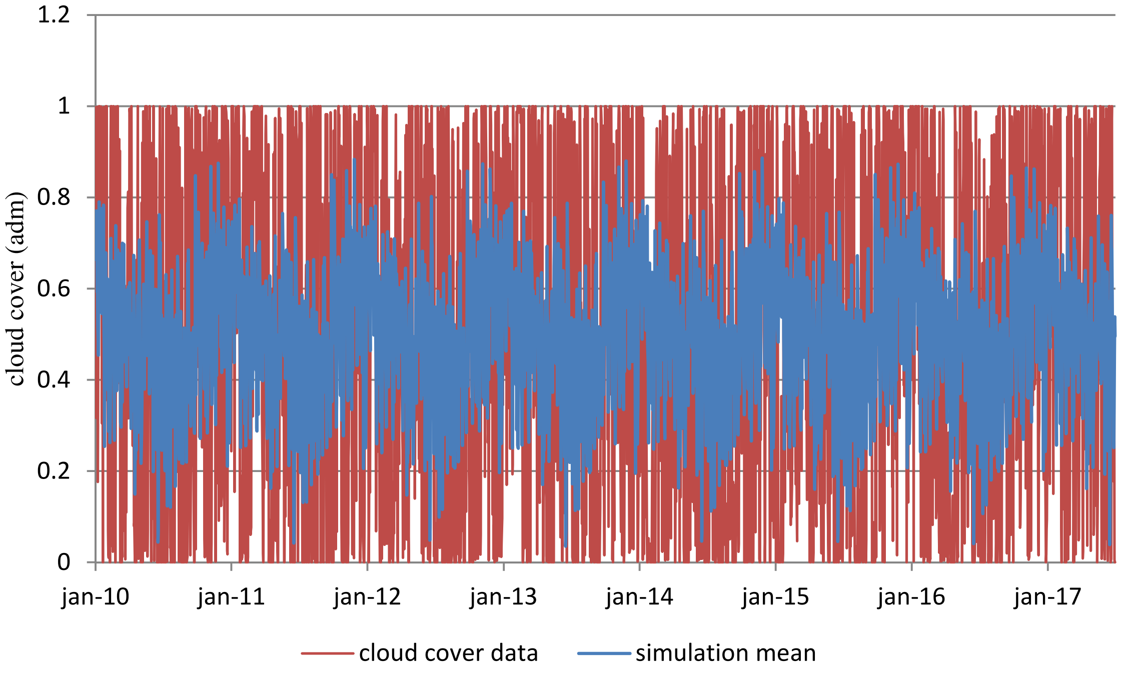
Figure 25: wind speed



Simulated daily from 2010–2017 showing the variations of scenarios (BC – blue, RCP2.6 red, and RCP8.5 – green). Source: the author.

Cloud cover is compared to data (Figure 26 and 27) and presented a positive correlation (r=0.26) again showing that the model is conservative when compared with the variations on data. Values vary from 0 (sunny day) to 1 (very cloudy day).

Figure 26: Cloud cover

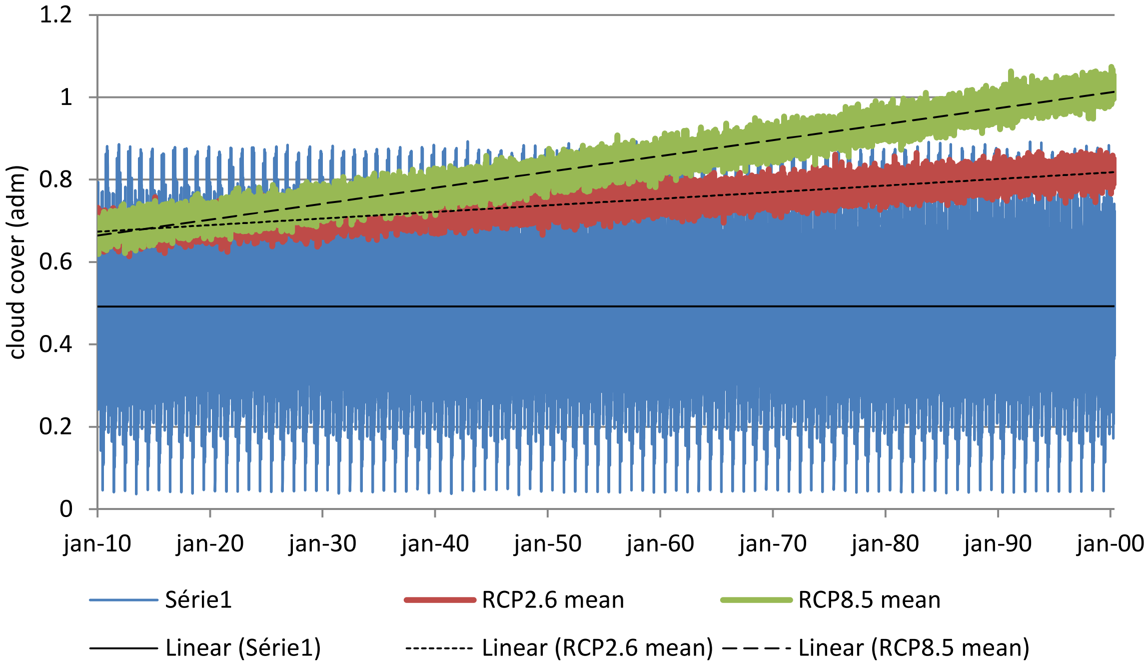


Cloud cover data and simulation from 2010–2017. (data – red, simulation – blue). Source: the author.

Cloud cover varies according to scenarios (Table 1). The linear equations (BC: y = 1E-08x + 0.4915; RCP2.6: y = 4E-06x + 0.4973; and RCP8.5: y = 1E-05x + 0.24) shows distinct trends on this variable and the forecast along the century.

Figure 28: Cloud cover and scenarios

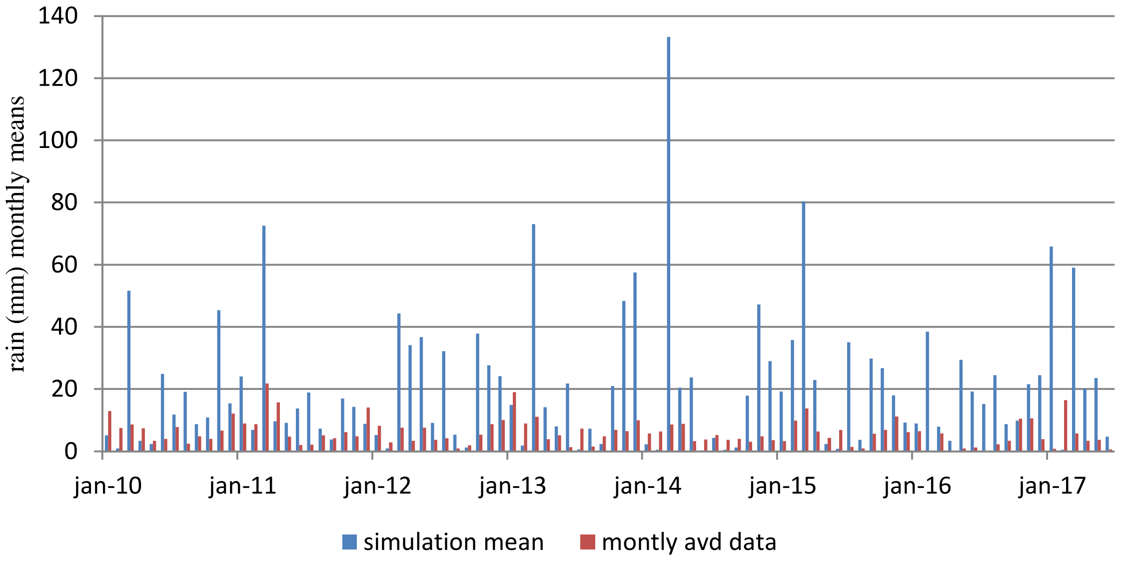
Figure 27: Cloud cover and scenarios



Cloud cover simulation from 2010–2100 (BC – blue, RCP2.6 red, and RCP8.5 – green). Trends show distinct path for each scenario. Source: the author.

Rain (Figure 28) is compared to rain data in monthly means (mm of rain) and presented a suitable correlation (r=0.21).

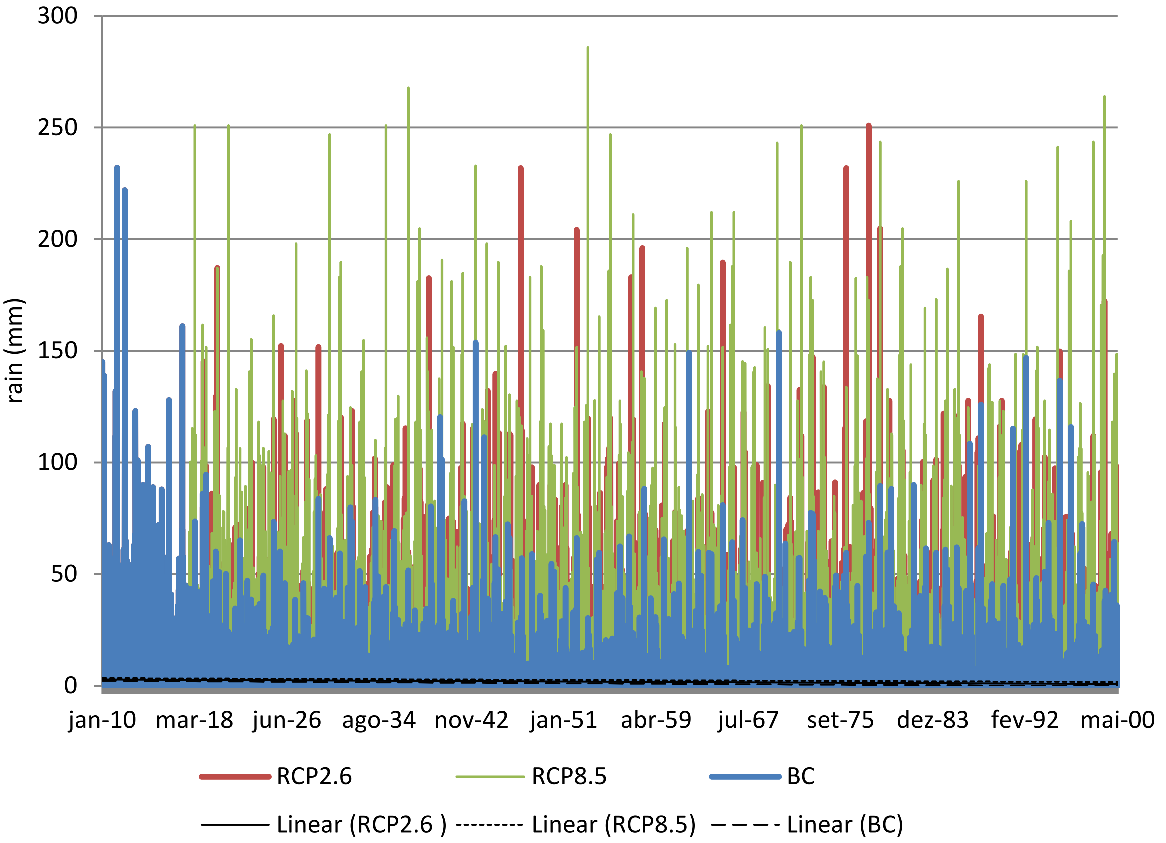
Figure 28: Rain simulation



Rain (mm) simulation in monthly means compared to data from 2010–2017 (data – red, simulation – blue). Source the author.

Rain simulations from 2010–2100 (Figure 29) present different trends for each scenario (linear equations BC: y = -7E-05x + 2.2619; RCP2.6: y = -6E-05x + 2.7564; and RCP8.5: y = -5E-05x + 3.4214) that will influence the system along the century, despite being very close one to each other.

Figure 29: Rain simulation and scenarios



Rain (mm) simulation from 2010–2100 in three scenarios (BC – blue, RCP2.6 red, and RCP8.5 – green). Trends are visually inseparable, but show distinct path for each scenario. Source: the author.

Water particle simulation shows the population patterns for each organism simulated. All populations were calibrated accordingly to data (table 2). For some groups the values in table 2 were used as max and min for seasonal oscillations (e.g. Phytoplankton, Bacterioplankton, and Salps). Some groups (Zooplankton, Brachyuran, and Penaeidae) the population is higher in winter when compared in summer. This model couldn't capture this inverse dynamics and then those groups are diminishing their population in winter like the other organisms.

Table 2: Calibration value for marine organisms

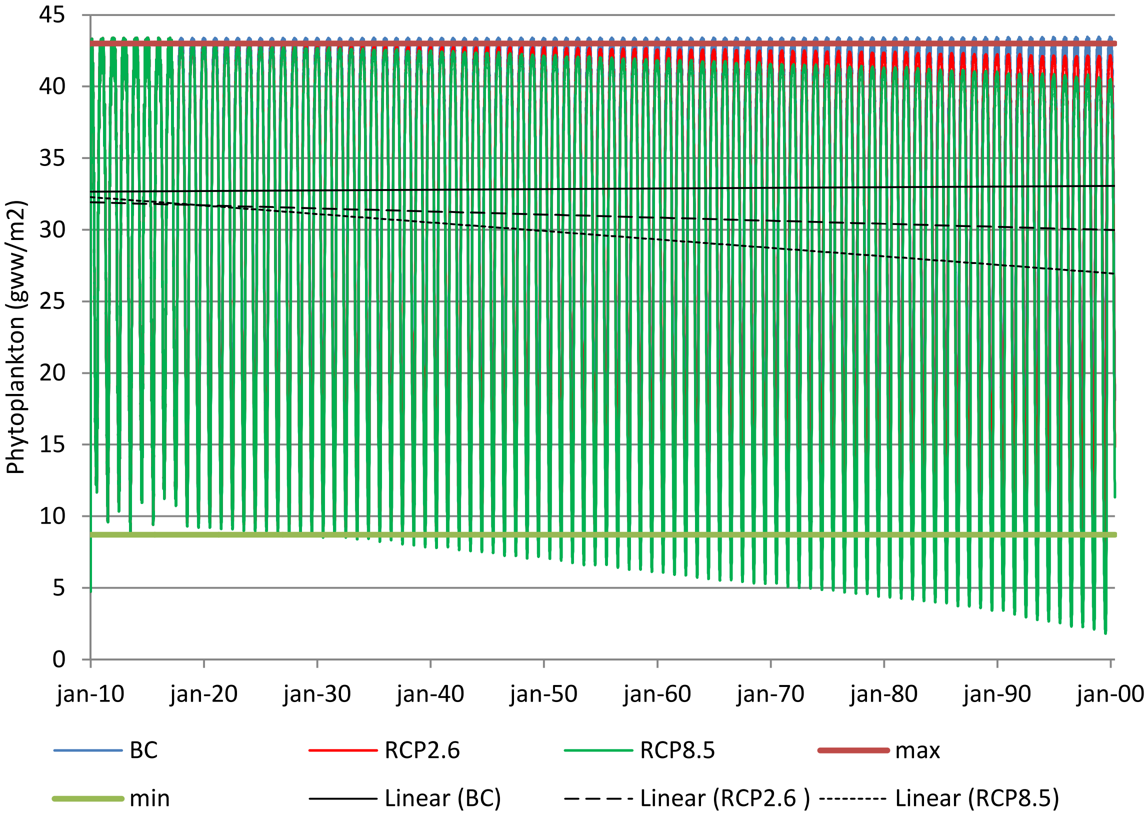
Organism	Summer	Winter	Source

	Weight in gww/m2		
Phytoplankton	43	8.7	Rocha (2003 p. 492)
Zooplankton	6	10	Rocha (2003 p. 492)
Detritus	Dependent on tourists number		Obtained in the model.
Suspended Sediments	Dependent on tourists number		Obtained in the model.
Salps	52.4	0	Rocha (2003 p. 492)
Enterococcus	Dependent on tourists number		Obtained in the model.
Bacterioplankton	6.2	2	Rocha (2003 p. 492)

	Summer	Winter	
Organism	Weight in gww/m2		
Asteroidean	6.3	8.9	Rocha (2003 p. 491)
Brachyuran	22.6	93.1	Rocha (2003 p. 491)
Bivalve	0.283	0.145	Rocha (2003 p. 491)
Penaeidae	3.3	4.7	Rocha (2003 p. 491)
Echinoid	56	46	Rocha (2003 p. 491)
Cnidarian	11	0.5	Rocha (2003 p. 492)
Benthic–feeding Fish	1.351		Rocha (2007 p. 153)
Pelagic–feeding Fish	0.304		Rocha (2007 p. 153)
Piscivorous Fish	0.254		Rocha (2007 p. 153)
Piscivorous Rays	0.322		Rocha (2007 p. 153)
Pelagic Fish	2.035		Rocha (2007 p. 153)

Phytoplankton population (Figure 30) is regulated according to growth factors (light and nitrogen). It is observable a seasonal pattern in its population but also some stochastic daily variations due to clouds and nitrogen variations. The model managed to follow the seasonal pattern found in Rocha (2003) when they are available. As the influence of scenarios change phytoplankton population, the trends in all three cases are described by equations (BC: y = 1E-05x + 32.157; RCP2.6: y = -6E-05x + 34.293; and RCP8.5: y = -0.0002x + 38.767).

Figure 30: Phytoplankton population



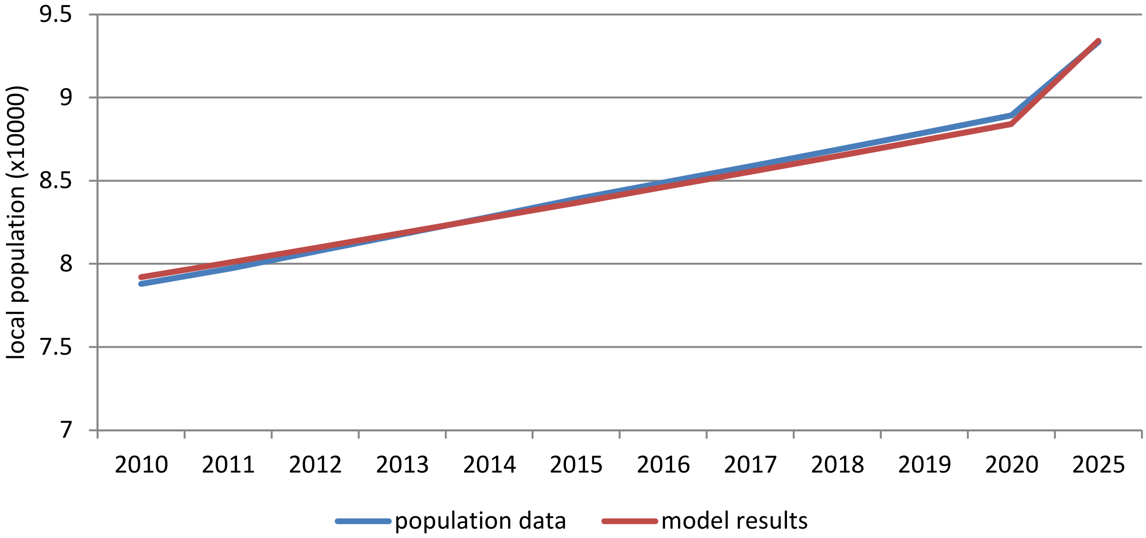
Phytoplankton population (gww/m2). From 2010–2100 showing the max and min values used for calibration and the variations according to the influence of scenarios. Source: the author.

The multi–decadal simulation will show the same patterns repeating along with the simulation period (until the year 2100) unless scenarios alter the factors that determine the viability of these particles.

Fish sub–model present distinct behavior for each group. Asteroidean present regular growth without reaching their carrying capacity. Brachyuran presents the same growth but shows a seasonal variation. Bivalve shows season variation following what happens to phytoplankton and zooplankton. Penaeidae present seasonal variation probably due to predation and fisheries. Echinoid, Cnidarian, and the vertebrate groups do not show great dynamism, showing growth curves that reach carrying capacities and remain in stable population size along with the simulation. All these populations will change accordingly to the scenarios.

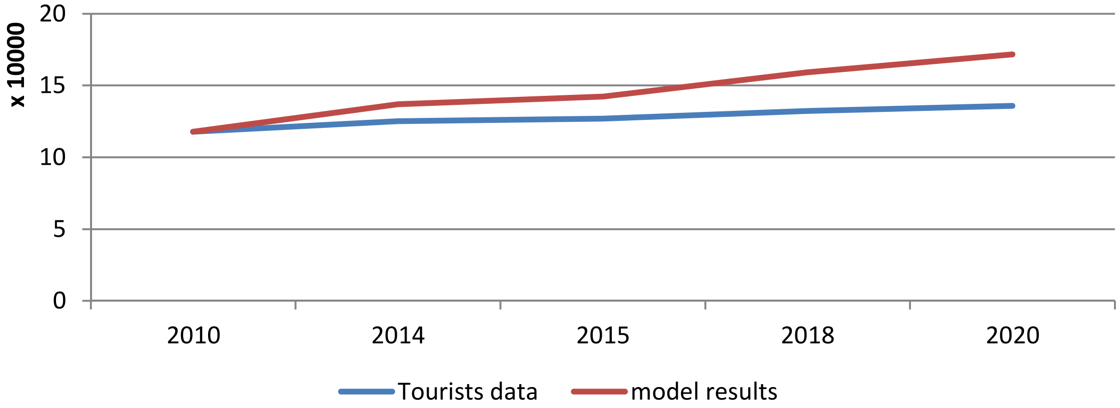
Human population grow at a very low rate (Figure 31 and 32). This simulation was calibrated to follow data (CETESB, 2016; FUNDAÇÃO SEADE, 2016 person. comm.) until 2040 (the maximum value were the official consulted forecast reach) and following the same trend until 2100. For local population the correlation (r=0.99) was higher than that for tourists population (r=0.98).

Figure 31: local population



Local population from 2010–2025. Data and simulation results for comparison. Source: the author.

Figure 32: Local and tourists populations

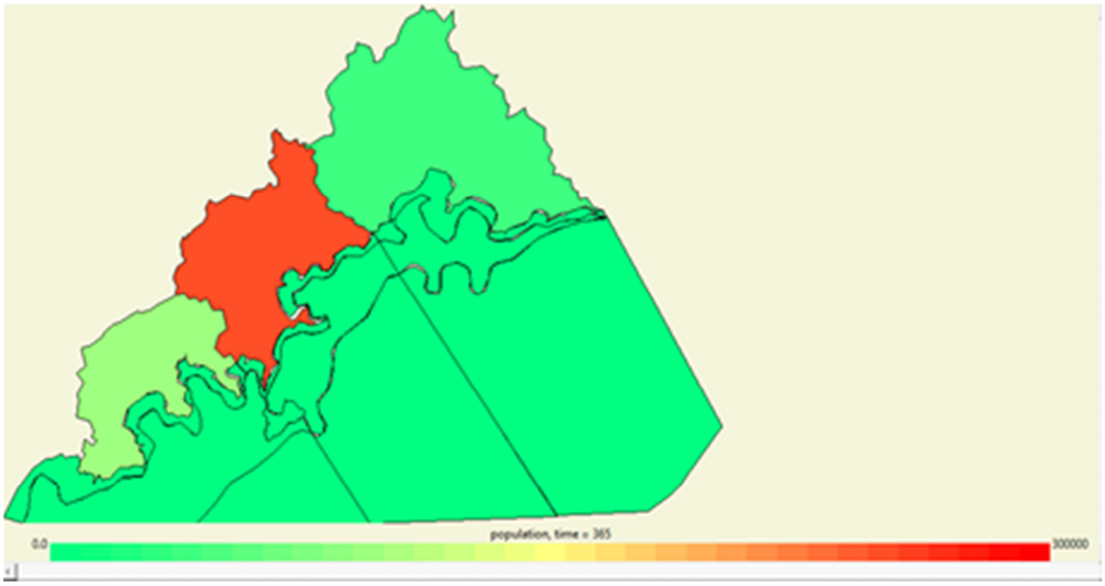


Local and tourists populations keeping similar growth rates until 2100. Blue for residents and red for tourists. Source: the author.

2.3.2 Spatial results of the model

The variables modeled can be shown spatially using the GIS interface of Simile (Figures 33 to 36). Human population density (Figure 48) represents the three land basins adopted and results show higher density in the center of the city, lower density on the northern part, and the intermediary state in the south.

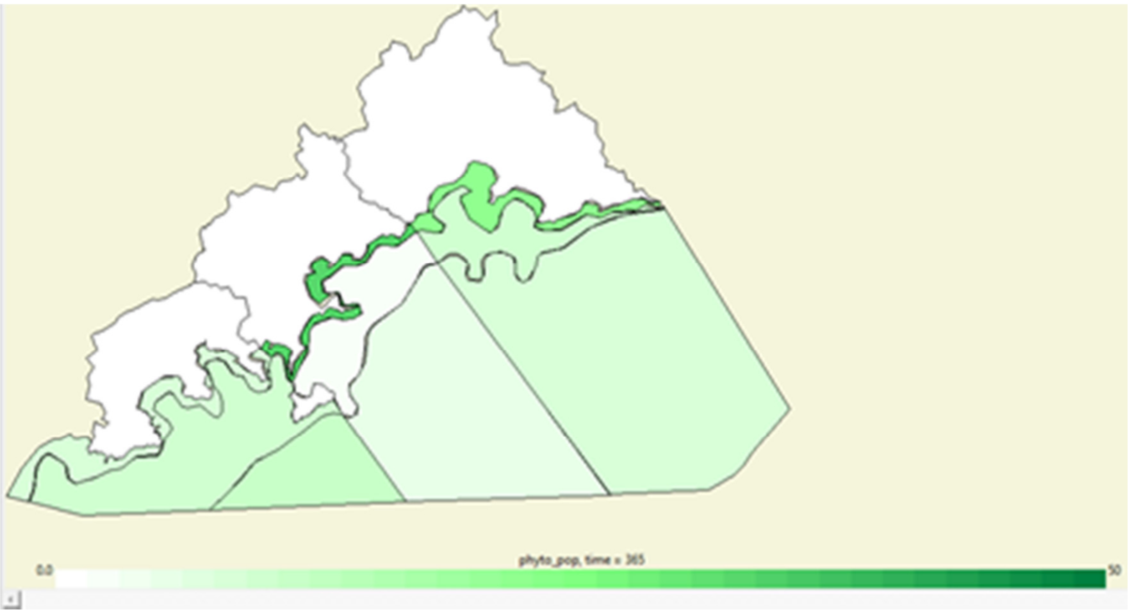
Figure 33: human population density



Population occupies the three land basins on the day 365 (1st of January, 2011). Source: the authors.

Phytoplankton simulation (Figure 35) show different patterns in different polygons. That distribution shows the model can simulate populations varying according to independent limiting factors (nitrogen concentration or light).

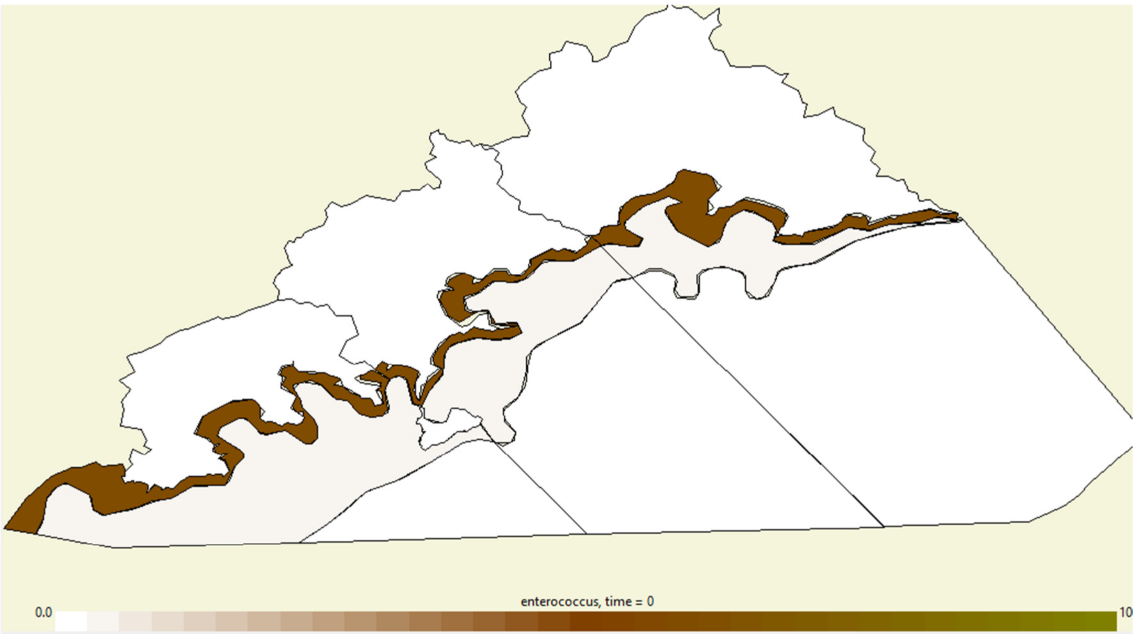
Figure 34: Phytoplankton population



Phytoplankton population on coastal polygons on the day 365 (1st of January, 2011). Source: the authors.

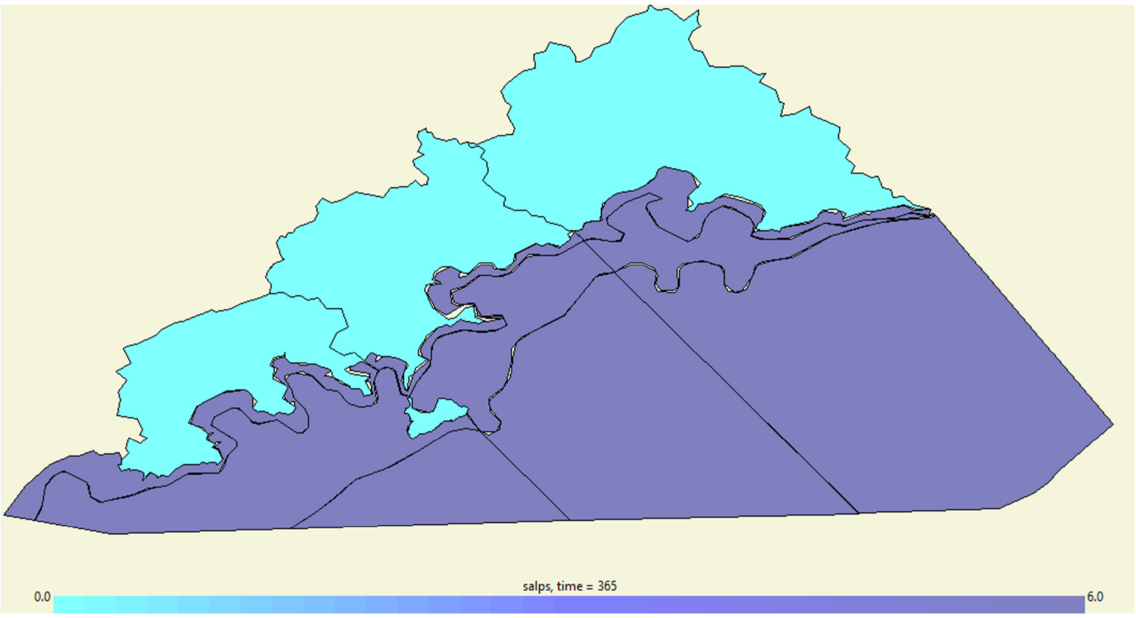
Coliforms (Enterococcus population) are represented only in the polygons that are close to the coast where they were dumped in the water (Figure 36). The model assumes the higher concentrations occur in low depth (<10m) waters and only a small portion of these organisms reach the second polygon line (>10m and < 25m) before they die.

Figure 35:Enterococcus Distribution



Population of Enterococcus deployed by sewage. As the die their population will not reach deeper polygons. Source: the authors.

Figure 36: Salps distribution



Salps are considered to live in all coastal polygons at the same density. Source: the authors.

Salps distribution is unknown, and then the model considers that these organisms can be living in every polygon (Figure 37). During winter all polygons became light blue once these organisms occur only during summer (not represented).

2.3.3 Ecosystem services provision

Each ecosystem service studied is shortly described in the appropriate time scale: (multi–decadal from 2010–2100) showing the base case behavior in the long–range and the effect of the scenarios.

Ten ecosystem services are present:

1. Food production – Crustaceans
2. Food production – Mollusk
3. Food production – Cartilaginous Fish
4. Food production – Bone Fish
5. Carbon sequestration
6. Oxygen production
7. Mineralization
8. Nitrogen cycling
9. Sewage Depuration
10. Water Quality – perception

Each production was calculated directly for those ES that is a simple provision of goods (e.g. fisheries) where the model informs us the amount of each population and the amount that was collected from them: some kilograms of each fish. The economic valuation of these goods thus is the multiplication of the amount harvested for the average price per kilo (using data from Instituto de Pesca – table 3).

The groups from the institution that makes price surveys (Instituto de Pesca) and the groups from the Ecopath model (Rocha et al., 2003) adopted here as well are different. Prices are available for four groups of organisms (Mollusks, Crustaceans, Cartilaginous Fishes and Bone Fishes) while the Ecopath model has eleven groups, 8 used here in provided fisheries (Bivalves – considered as mollusks; Brachyuran and Penaeidae – considered Crustaceans; Piscivorous rays and piscivorous fish – considered cartilaginous fishes; and Pelagic–feeding fish, benthic–feeding fish and pelagic fish – considered as bone fishes).

Oxygen production and carbon sequestration demand different forms to obtain their value, once there is no direct market to sell them. It was considered that the population of phytoplankton produces oxygen at a maximum rate of 0.06 $g/gww/m^2$ each hour and carbon dioxide intake happens at the same rate (TEIXEIRA, 1979; FALKOWSKI, 1994). Economic valuation of these ecosystem services happen using benefit transfer and uses values obtained usually from the TEEB database or a specific database when relevant (Table 3).

Sewage depuration is calculated using a proxy of Enterococcus mortality simulated in the appropriate sub–model and applied to the volume of sewage that is, in turn, dependent on the number of people in the city discounted the amount that is treated (50% of treatment according to CETESB, 2016). We considered that sewage treatment plants can deal only with 50% of regular production, meaning resident people, and when the surplus of sewage overwhelms the treatment capacity (meaning tourists in the city), this excess is deposited in rivers reaching the shores. Economic valuation of this service uses values maximum values (Table 3) that are adjusted to the variations of mortality.

Nitrogen cycling regards the assimilation of this element by aquatic biota. This service is one part of the nitrogen cycle that appears in the model (mineralization is the other). It was considered then nutrient cycling happens in the polygons adjacent to the beach, where sewage deposition happens and then Mineralization is the nitrogen cycle part that happens in the other polygons, where nitrogen from organism metabolism is deposited in the water and cycled through biota. That distinction is useful to avoid double counting, and the maximum value (Table 3) is therefore divided by two, once this maximum value applies to nitrogen cycling. Both maximum values are adjusted to ES seasonal variability.

Water quality – perception is an ES that showed relevant for the region in previous research. This service regards the perception of the water quality by tourists and therefore it is applied only to polygons adjacent to the beach. When the volume of detritus surpasses a determined threshold (arbitrarily defined as the worst value of the first year of the simulation), an event that can happen due to a strong rain or with a peak of tourists visiting the city, the water gets turbid. This increase in turbidity is considered perceptible to tourists and then the water quality is diminished. For the economic valuation, it was used the maximum reference value (table 3) adjusted to the quality losses that detritus produce.

Each ecosystem service has its metric unit (usually mass of a certain organism or material) and associated economic values. It was adopted the maximum values from the

Ecosystem Services Valuation Database[6], the platform that is kept and updated from the Ecosystem Services Partnership, probably the best one in this field. Each value is followed by an ID that can be used to verify its origin and value of each data. For each economic valuation that was not already in dollar, it was assumed an average price for dollar using daily data from 2010–2017

Table 3 – Data and sources for economic valuation of Ecosystem Services

Service	Avg. price	Unit	Value for model	unit.	Reference	Source
Crustaceans production	17.24	Reais 2017*	5.18	Average dollar from 2010– 2017	kilogram	1
Mollusk production	10.23	Reais 2017*	3.07		kilogram	1
Cart. Fish production	7.6	Reais 2017*	2.28		kilogram	1
Bone Fish production	2.6	Reais 2017*	0.78		kilogram	1
Carbon Sequestration	5.85	Euros 2017*	6.38		ton	2
Sewage Depuration	58	Dollars 1990**	70.84		Hectare per year	3, ID 837
Nutrient Cycling	118	dollars 1997****	70.82		Hectare per year	3, ID1040
Oxygen production	38.3	dollars 1997***	2.29		Hectare per year	3, ID1039
Mineralization	118	dollars 1997****	7.08		Hectare per year	3, ID1040
Water quality perception	0.22	dollars 1990*	0.27		Hectare per year	3, ID837

*average dollar price from 2010–2017 (USD 1 = R$3,33) (https://www3.bcb.gov.br/expectativas/publico/?wicket:interface=:0:6:::). Euro in 2017 = R$3,60

** Monetary update used discount rate of 6% each year

*** Total value for gas regulation by oceans. It was considered 10% of that for oxygen production

**** Nutrient cycling and mineralization are 50% of total nutrient cycling ID1040. Mineralization is only 10% of the final value to balance its disproportionality.

1 – Fisheries Institute report (Report obtained in 16/08/2017 at 10h44min Filter: period (01/2000 – 02/2017); City (Ubatuba);

2 – https://br.investing.com/commodities/carbon–emissions–historical–data

3 – De Groot, R.S., B. Fisher, M. Christie, J. Aronson, L. Braat, R. Haines–Young, J. Gowdy, E. Maltby, A. Neuville, S. Polasky, R. Portela, and I. Ring (2010b). Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. Chapter 1 in: Kumar, P. (editor) (2010) The Economics of Ecosystems and Biodiversity: Ecological

All the economic analysis are slightly presented separately with graphs (Figure 38–47) showing the ecosystem services production and its variations due to climate scenarios (RCP2.6 and 8.5). The reactive tourist scenario is shown in almost all ecosystem services, but it is suppressed from the graph representation when its results are indistinguishable from the BC (e.g. CO2, O2).

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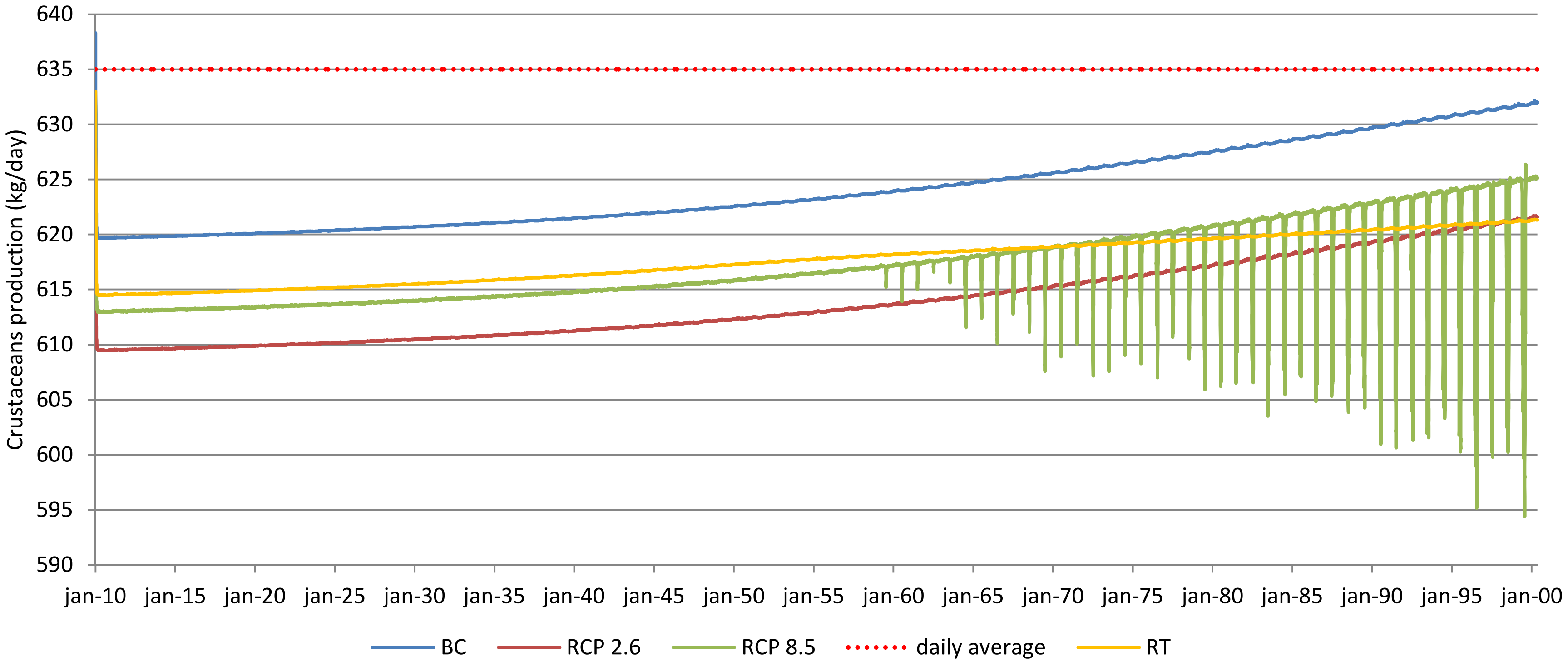
[6] Van der Ploeg, S. and R.S. de Groot (2010) The TEEB Valuation Database – a searchable database of 1310 estimates of monetary values of ecosystem services. Foundation for Sustainable Development, Wageningen, the Netherlands

2.3.4 Economic valuation of ecosystem services

2.3.4.1 Food production – Crustaceans

Crustaceans are represented by two organism groups (Brachyurans and Penaeidae). Each group had its dynamic independently modeled, with individual population data. Fish landing data has monthly frequency, and the data also has some gaps between 2010–2017, thus we calculated a daily average for these organisms and this average is represented by the mean line (Figure 37).

Figure 37: Crustaceans production and scenarios

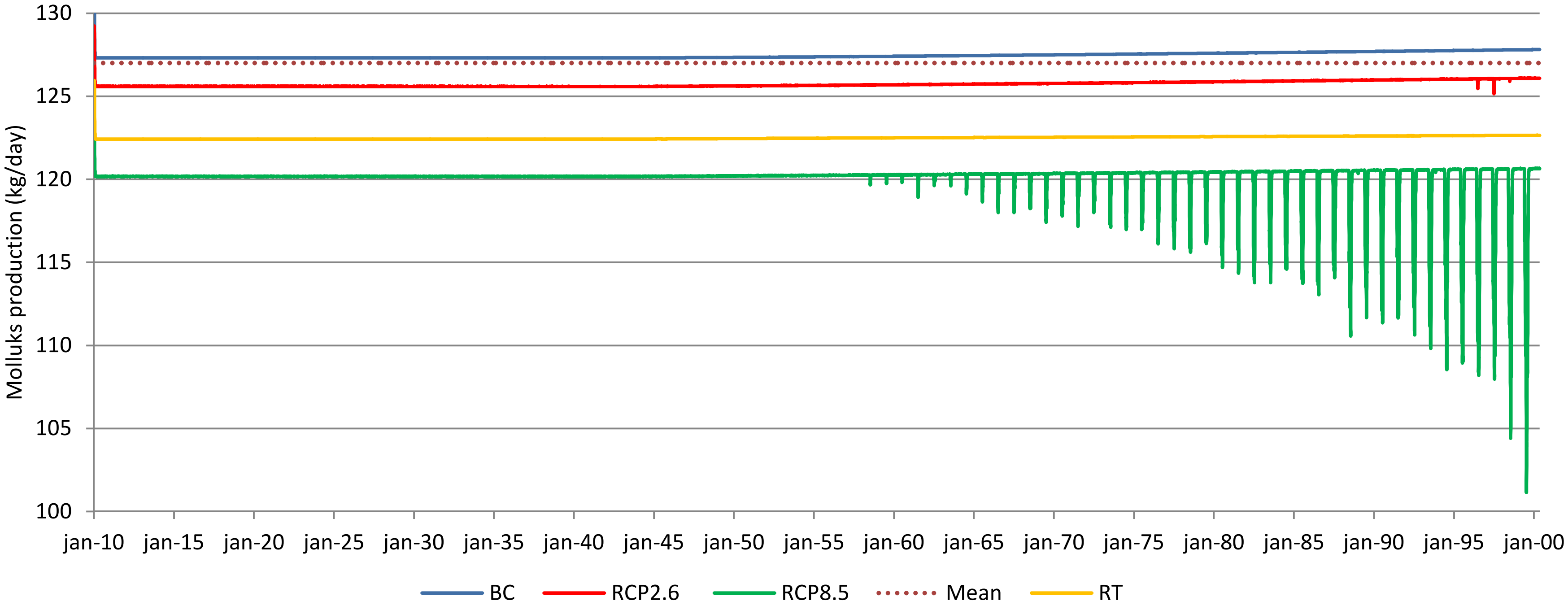


Crustaceans' production (kg/day) from 2010–2100 showing the mean values used for calibration (red dotted line) and the variations according to the influence of scenarios. Seasonal influence is made clear starting in 2060 where winter has very low productivity. Source: the author.

2.3.4.2 Food production – Mollusks

Mollusks are represented by several groups in the region. For this model, it was considered only Bivalve because its population is more representative (ROCHA, 2003). Again, landing data have some gaps on the time horizon researched. The daily average landing was 127kg from 2010–2017, and it is represented by the mean line (Figure 38).

Figure 38: Mollusks production and scenarios



Mollusks production (kg/day) from 2010–2100 showing the mean values used for calibration (dotted line) and the variations according to the influence of scenarios. Seasonal influence is made clear starting in 2060 where winter has very low productivity. Source: the author.

2.3.4.3 Food production – Cartilaginous Fishes

Cartilaginous fishes are represented by several species in the region but the model considered Piscivorous rays and Piscivorous fishes (ROCHA, 2003) to be cartilaginous. For this fishes, a daily landing average was calculated as a mean value (Figure 39). The daily average landing for cart. fishes are 236kg with a strong decreasing trend.

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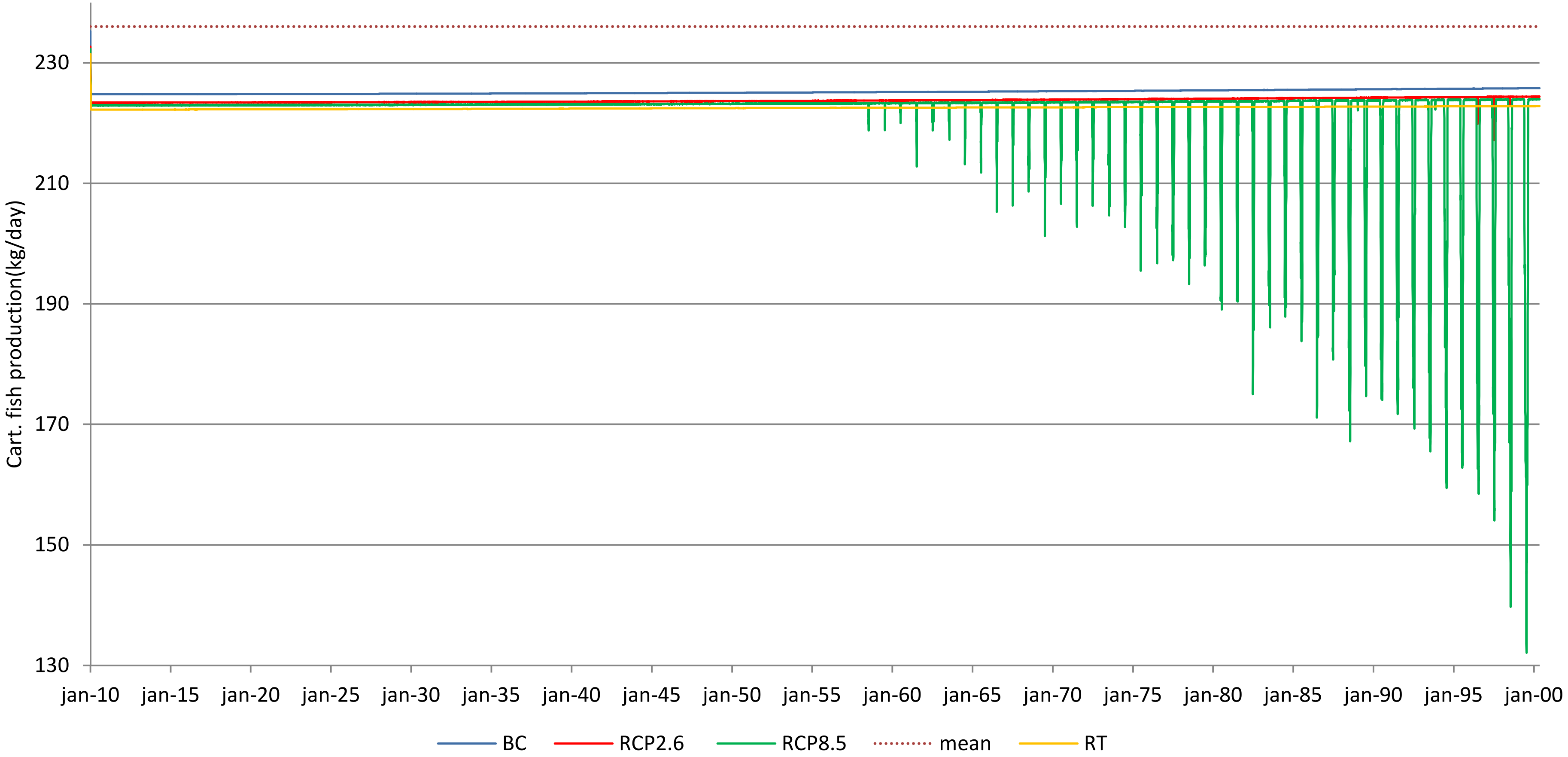
Figure 39: Cartilaginous fish and scenarios



Cart. fish production (kg/day) from 2010–2100 showing the mean values used for calibration and the variations according to the influence of scenarios Seasonal influence is made clear starting in 2060 where winter has very low productivity. Source: the author.

2.3.4.4 Food production – bone fishes

Bone fishes production is responsible for the bigger amount of landings in Ubatuba. To represent the great diversity of species in this group, three distinct groups of Rocha (2003) were added (benthic–feeding fishes, pelagic–feeding fishes, and pelagic fishes). Daily average landings for this group were 6200kg, represented by a mean line, with an increasing trend (Figure 40).

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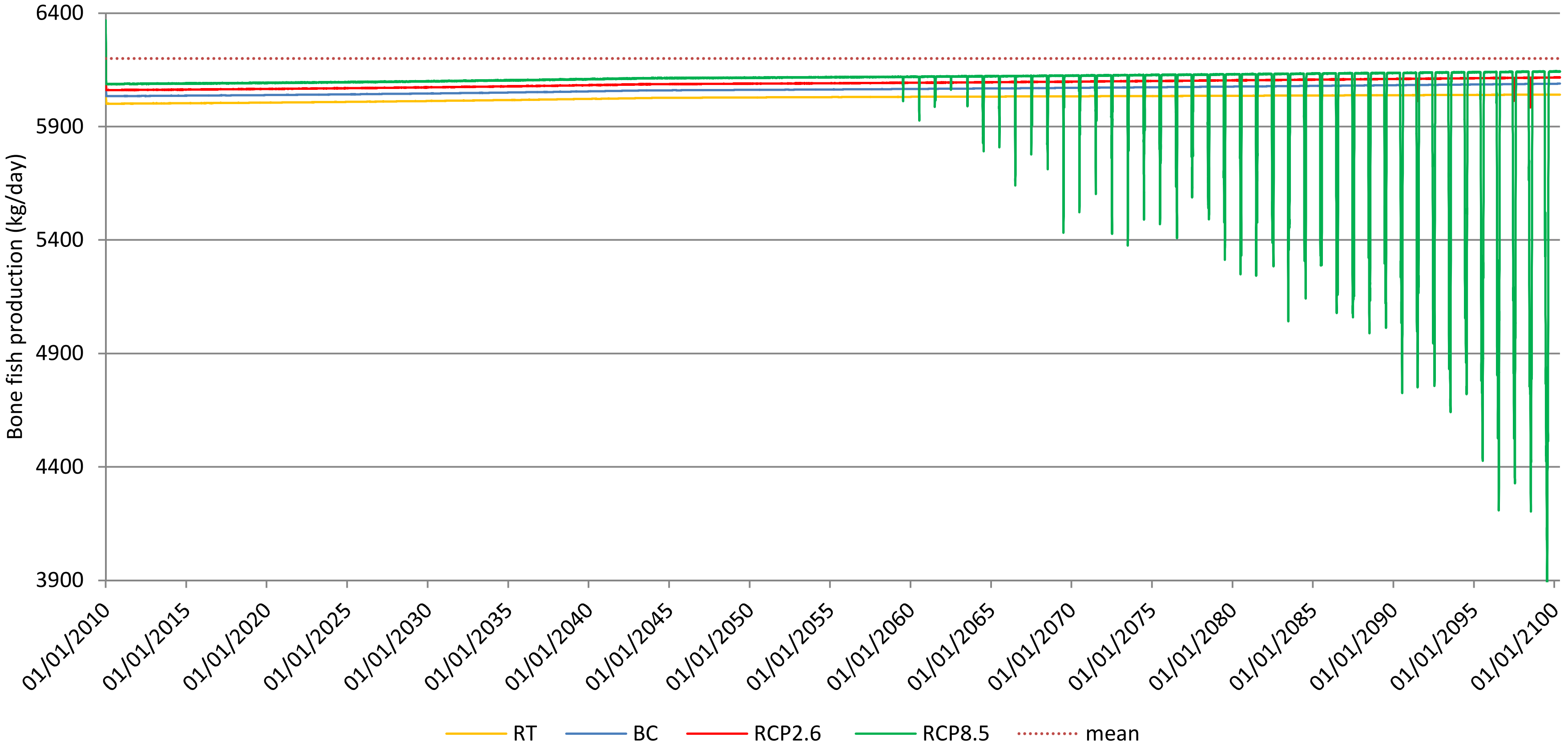
Figure 40: Bone fish production and scenarios



Bone fish production (kg/day) from 2010–2100 showing the mean values used for calibration and the variations according to the influence of scenarios. Source: the author.

2.3.4.5 Carbon Sequestration

The capture of CO2 by the oceans happens by the dissolution of this gas through interaction with the atmosphere (WILLIAMS e FOLLOWS, 2011) and this component is presented in three forms (CO_2^{aq}, HCO_3^- e CO_3^{-2}) but usually known as dissolved Inorganic Carbon (DIC). From this dissolution, a great part of the carbon is transformed into carbonate and bicarbonate, which in turn is responsible to make the ocean the greater reservoir of carbon when compared to the atmosphere. This DIC increases with depth showing the carbon removed from the atmosphere is being deposited in the deeper regions of the ocean. The other part of this DIC is absorbed by producers and transformed into organic compounds through photosynthesis.

The model uses producers' population data (ROCHA, 2003) and standard carbon absorption data (FALKOWSI, 1994 e TEIXEIRA, 1979) to infer the amount of carbon absorbed in the area. Falkowski (1994) considers between 1 and 10 mg of C fixed by m^3, depending on chlorophyll concentration and with light in saturation. Teixeira (1979) found values for Ubatuba that are compatible with those from Falkoski (between 0.87 and 10.7 mg of C by m^3 per hour).

Those values were incorporated in the model adopting an arbitrary value of 6mg de C (21.6 mg de CO_2) by hour when chlorophyll concentration (meaning phytoplankton and bacterioplankton population) is at the maximum. When the producers' population diminish, carbon capture diminish proportionally.

As this service is directly proportional to producers' population, oscillations are blatant (Figure 41). Reactive tourist scenario is not represented because it was graphically indistinguishable from the BC.

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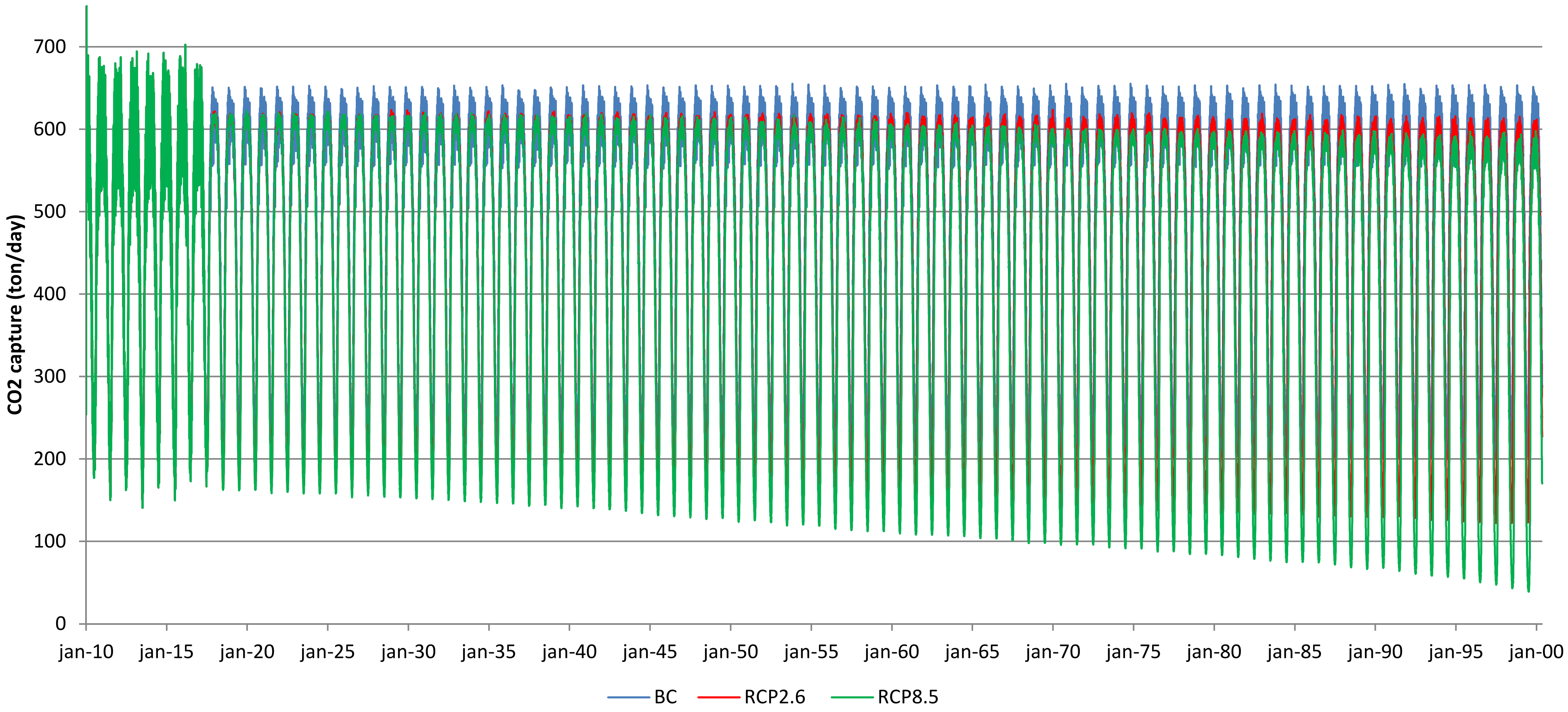
Figure 41: CO2 capture and scenarios



CO2 capture (ton/day) from 2010–2100 showing year seasonality's and long term the variations according to the influence of scenarios. Along the century RCP8.5 present a clear decreasing trend. RCP2.6 has a smaller tendency do decrease as well. Source: the author.

2.3.4.6 Oxygen production

The model associates oxygen production to the primary productivity and thus it happens due to the metabolism of phytoplankton and bacterioplankton. The great majority of this production happens due to phytoplankton activity because of its bigger population. These populations oscillate seasonally and therefore the oxygen production follows these oscillations.

Oxygen production in the ocean depends on temperature, nutrients concentration, and also in function of depth once the light became a limiting factor (EMERSON et al., 2008).

The model uses these three limiting factors to control producers' population growth. The most evident is light that presents the seasonal variation but also varies stochastically due to the presence of suspended particles in the water and cloud cover, hindering the light penetration. Thus phytoplankton and bacterioplankton present a seasonal curve with several stochastic variations and therefore the oxygen production (Figure 42) will follow the same patterns. The reactive tourist was not represented because it was indistinguishable from the base case.

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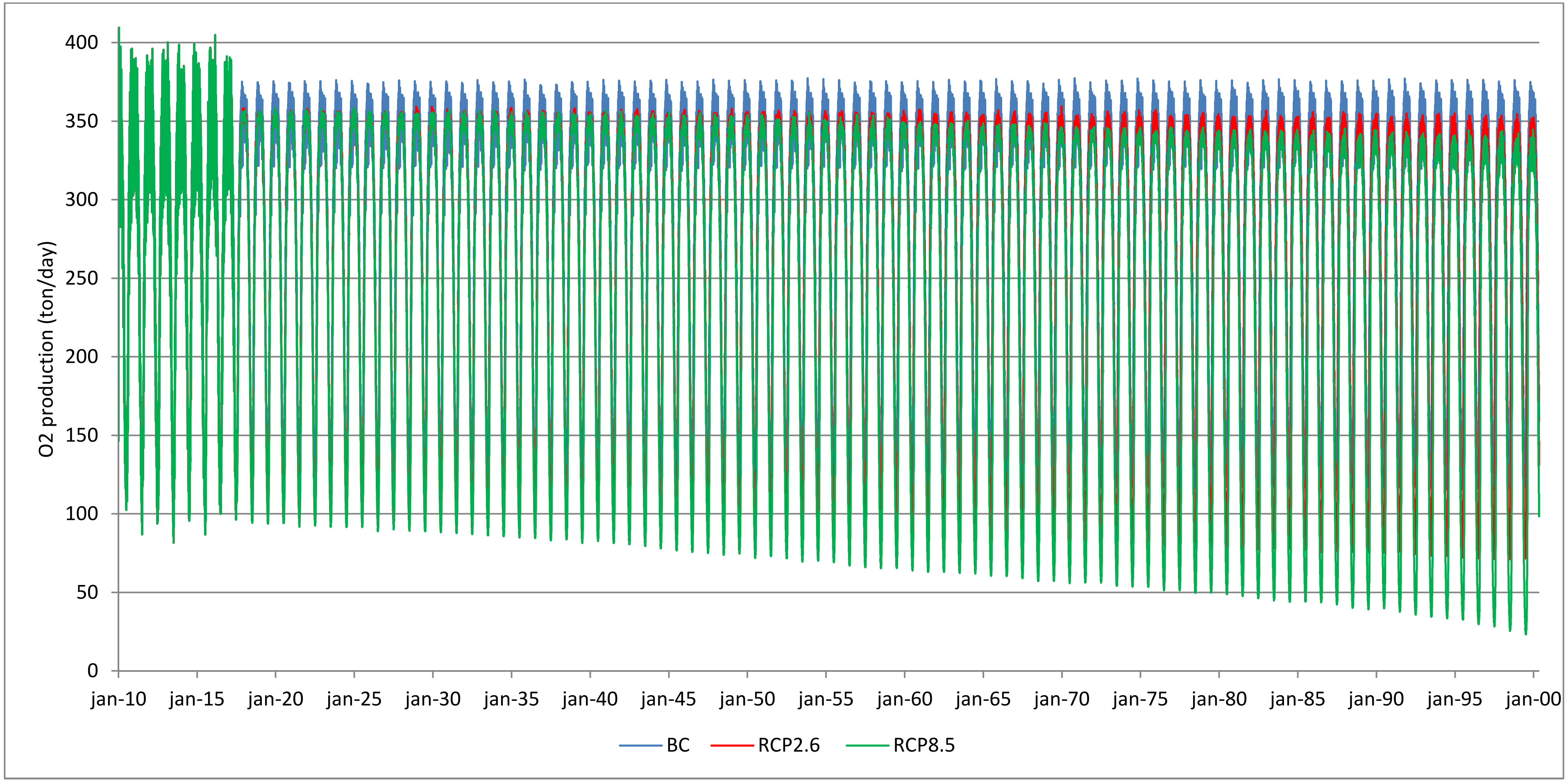
Figure 42: O2 production and scenarios



Oxygen production (ton/day) from 2010–2100 showing the year seasonality and long term variations according to the influence of scenarios. RCP2,6 presents a slightly decrease trend and RCP8.5 has a stronger one. Source: the author.

2.3.4.7 Mineralization

Mineralization is the way the model embraces the ecosystem services of nitrogen cycling in which the origin of the nitrogen is the local organisms. The organic compounds from the metabolism of the biota are released in the water and became available for new organisms to grow (Figure 43). In regions of scarcity, this can be an important source of minerals. In Ubatuba, they have limited importance due to the rich deposit of minerals that come from sewage.

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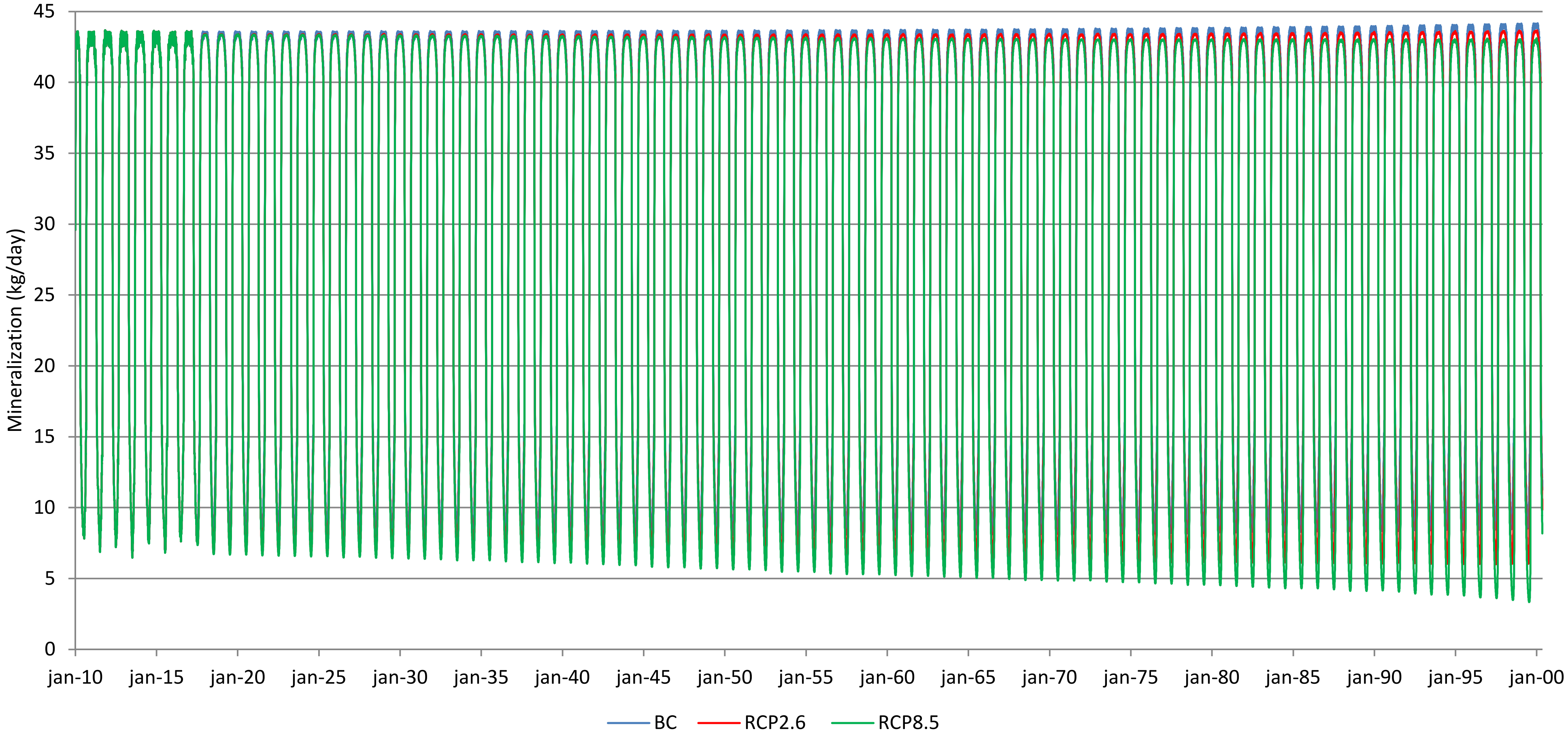
Figure 43: Mineralization and scenarios



Mineralization (kg/day) from 2010–2100 showing yearly seasonality and long term variations according to the influence of scenarios. Source: the Author.

2.3.4.8 Nitrogen cycling

Nitrogen cycling is about the absorption (Figure 44), depuration, and incorporation or final destiny of the nitrogen dumped in the seawater by land and rivers and also those carried by rain or wind. This nitrogen comes from human activities, sewage in special, and then it is different from mineralization.

The model considers each person in the area produces 180 liters of sewage and in which nitrogen concentration is an average of 55mg/l (LIN e LEE, 2001). Part of this sewage is treated and then this amount of nitrogen is not considered in the account. It is considered that 50% of sewage is treated (CETESB, 2014) on the polygon with higher population density, the remaining sewage is considered to be dumped in the sea directly or following the rivers.

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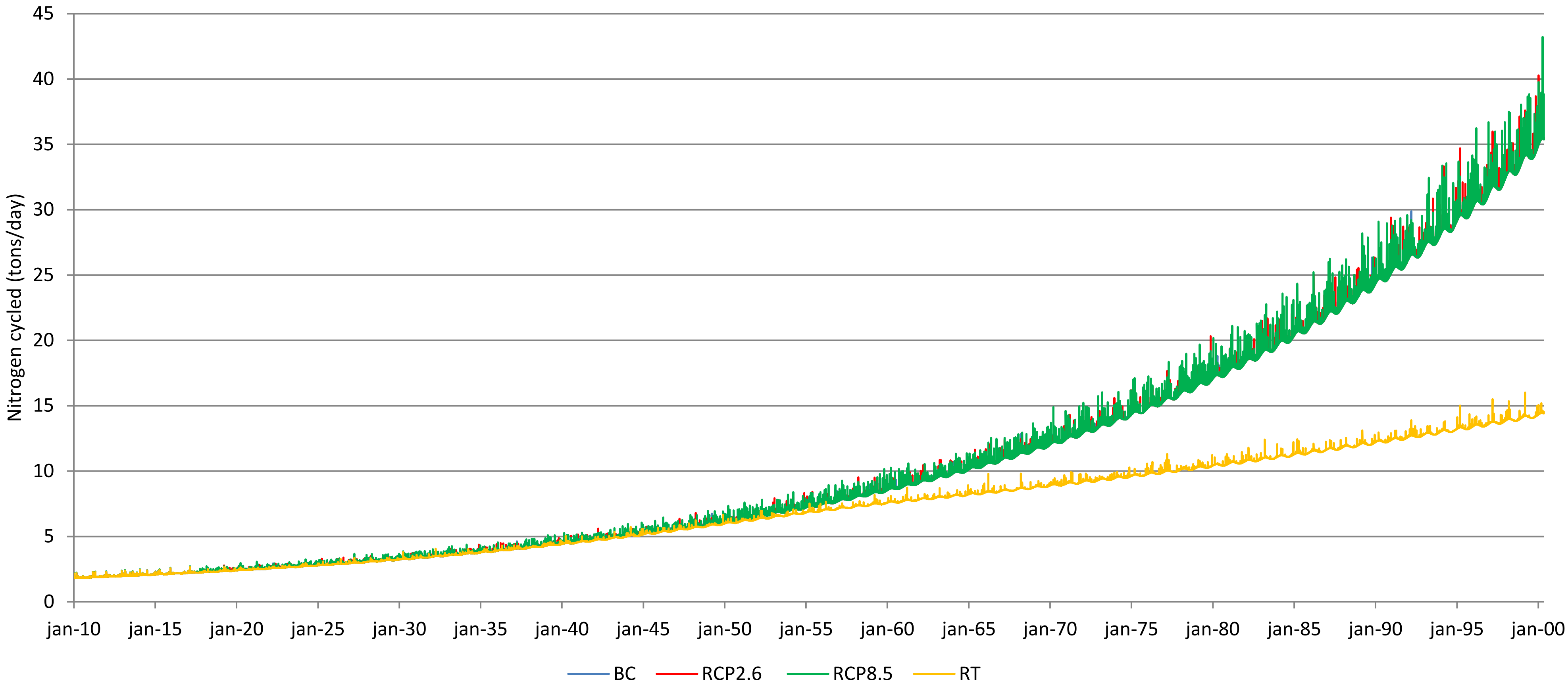
Figure 44: Nitrogen cycling and scenarios



Nitrogen cycling (ton/day) from 2010–2100 showing the year oscillations spikes from rain and long term variations according to the influence of scenarios. Source: the author.

2.3.4.9 Sewage depuration

Sewage depuration service (Figure 45) shows the relevance of coastal areas to receive and destroy a load of microorganisms, organic matter, and other solids society dump on the rivers or directly on the coast. The most frequent organism used in the control of batheability by CETESB (estate environmental agency) is Enterococcus once they act as an indicator of the amount of organic matter from sewage and therefore the risk of the presence of a pathogenic organism, like a virus, infectious bacteria or other diseases that come from water can be inferred.

The model considers these organisms come in great quantities with the dump of sewage in rivers but also with the rain, once accumulated material in gardens and streets are deployed in the coast, carried by the rainwater. It is considered that each person in the city produces 180 liters of sewage every day. It is also considered that 1% of this is solid (detritus) and from this detritus 50% are feces. For each ml of feces, the amount of bacteria was calculated using the formula I (Rocha, 2003)

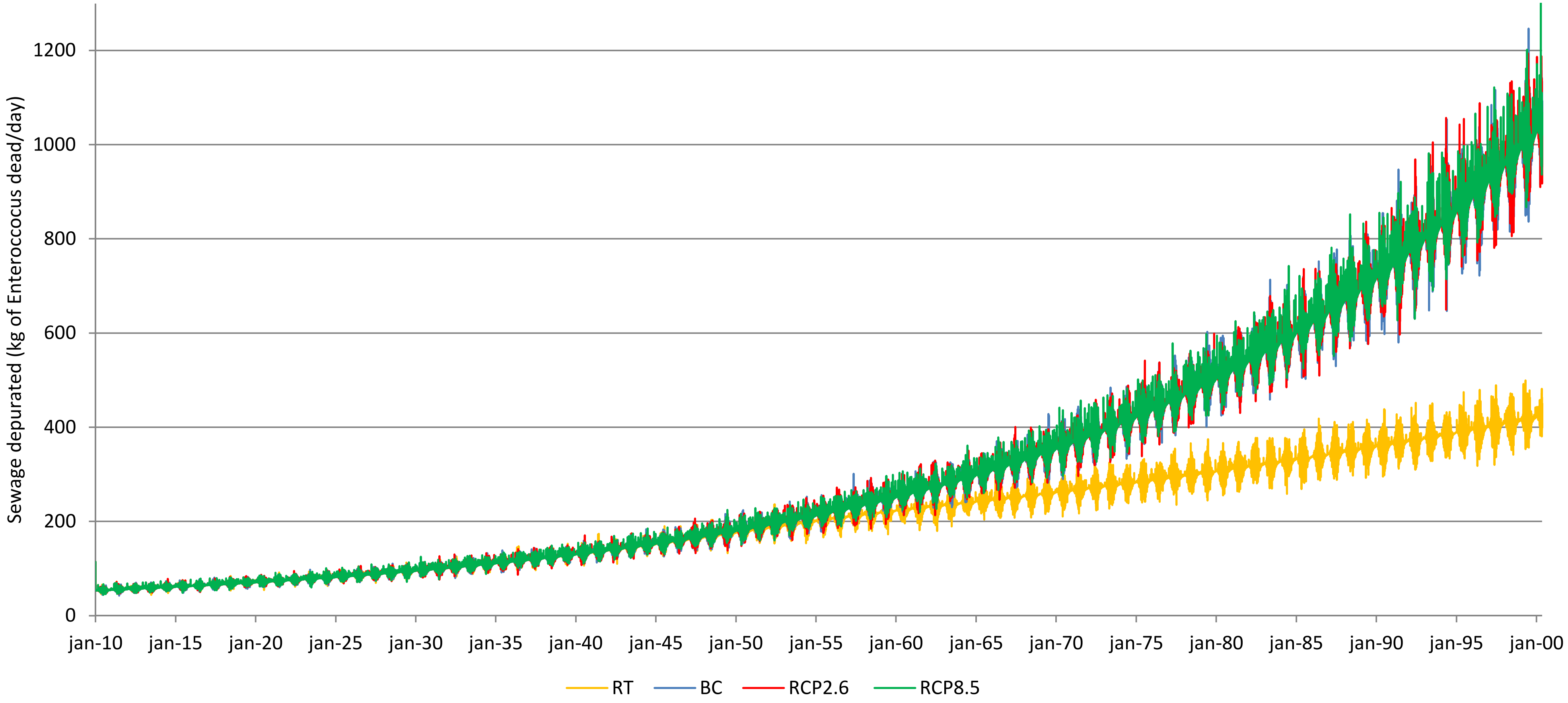
$$\text{Wet weight} = N \cdot V \cdot SG \cdot 10^{-6}\ \text{mg l}^{-1}$$

Where: N = number of cells. (10E06 according to LIN e LEE, 2001)
V = average volume of each cell (0.06 µm3)
SG = specific gravity (1.1 according to ROCHA, 2003)

Considering that 50% of sewage is treated (CETESB, 2014) on the polygon with higher population density, the rest follows untreated until reaching the coast. With this, the model adopts a death rate of Enterococcus based on the light and temperature of the coast water (BATISTA e HARARI, 2017 e MANCINI, 1978) when these bacteria reach the water.

The curve of the Enterococcus population is growing along with the simulation once it is directly dependent on the increasing number of tourists but also presents some stochastic character due to the influence of heavy rain on the deposit rate of these bacteria on the water.

Figure 45: Sewage depuration and scenarios



Sewage depuration (kg of Enterococcus/day) from 2010–2100 showing the seasonal oscillations and long term variations according to the influence of scenarios. Source: the author.

2.3.4.10 Water quality – perception

Surveys for environmental perception research have been common (GHILARDI–LOPES et al., 2015; OTRACHSHENKO & BOSELLO, 2015; KADRY et al., 2017; QUIANG et al., 2020). Usually, the objective is to understand which factors are most relevant to explain tourists' behavior and then use this new knowledge to improve local policies.

When dealing with beaches, the scenic beauty, the wellbeing, and other cultural values associated with the contemplation of the coastal environment are what the model tries to capture with water quality – perception (Figure 46).

The idea is that people attribute maximum value to a coastal ecosystem when the quality of the place matches their expectative. When the water is dirty, for what the model considers the amount of detritus dumped in the water as a proxy, the cultural value of this environment is diminished once it cannot fully satisfy what tourist were expecting (we are assuming tourist go to Ubatuba due to the high environmental quality).

Therefore, the model starts with the maximum value of water quality– perception and every event that diminishes the water quality (meaning detritus surpassing an arbitrary threshold) part of the quality is lost, and the economic value associated with this service (table 3) as well. The threshold was arbitrarily established as the worst case of the first year of the simulation.

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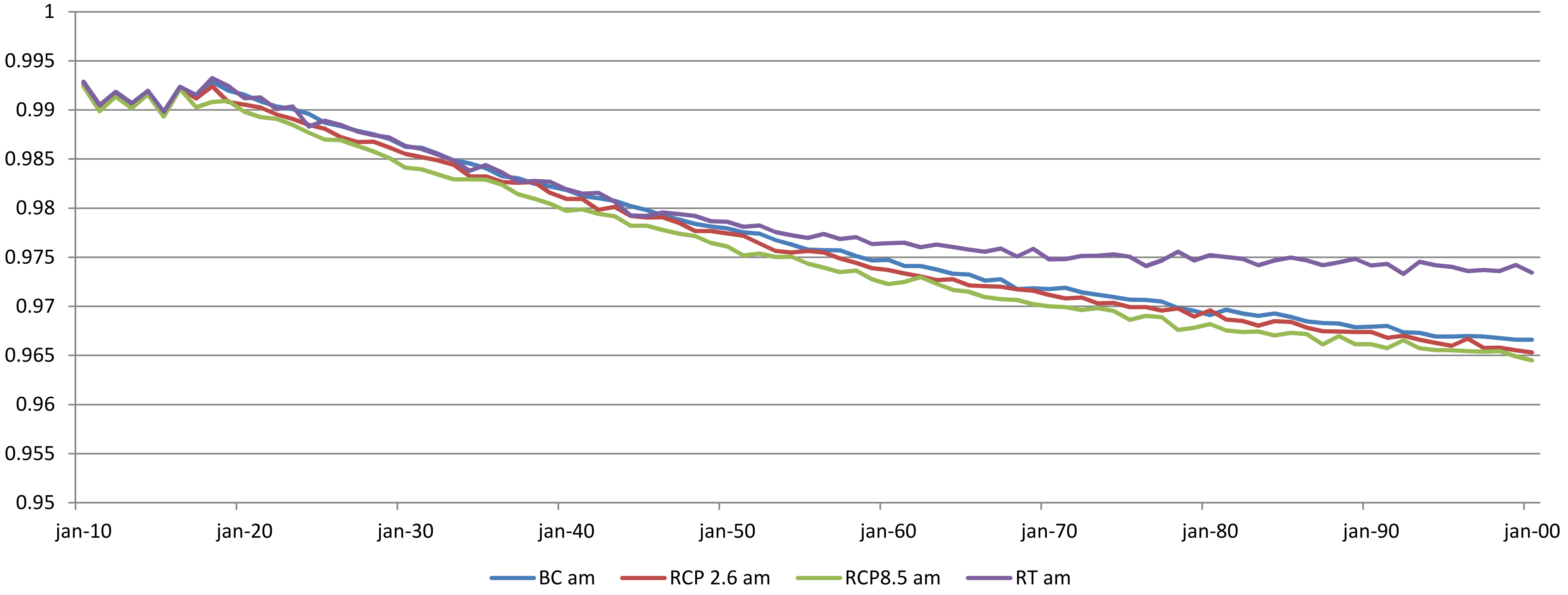
Figure 46: Water quality perception and scenarios

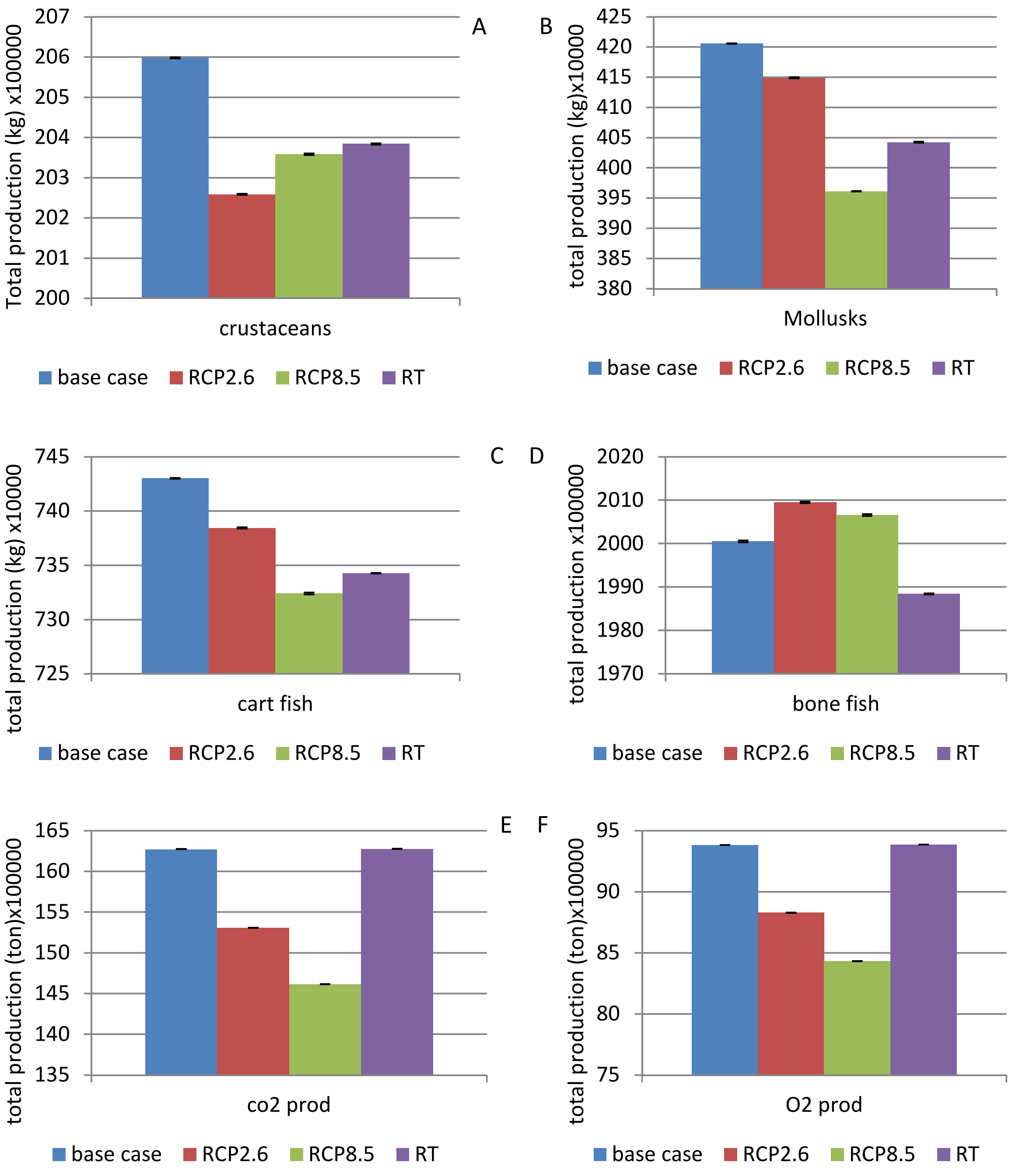


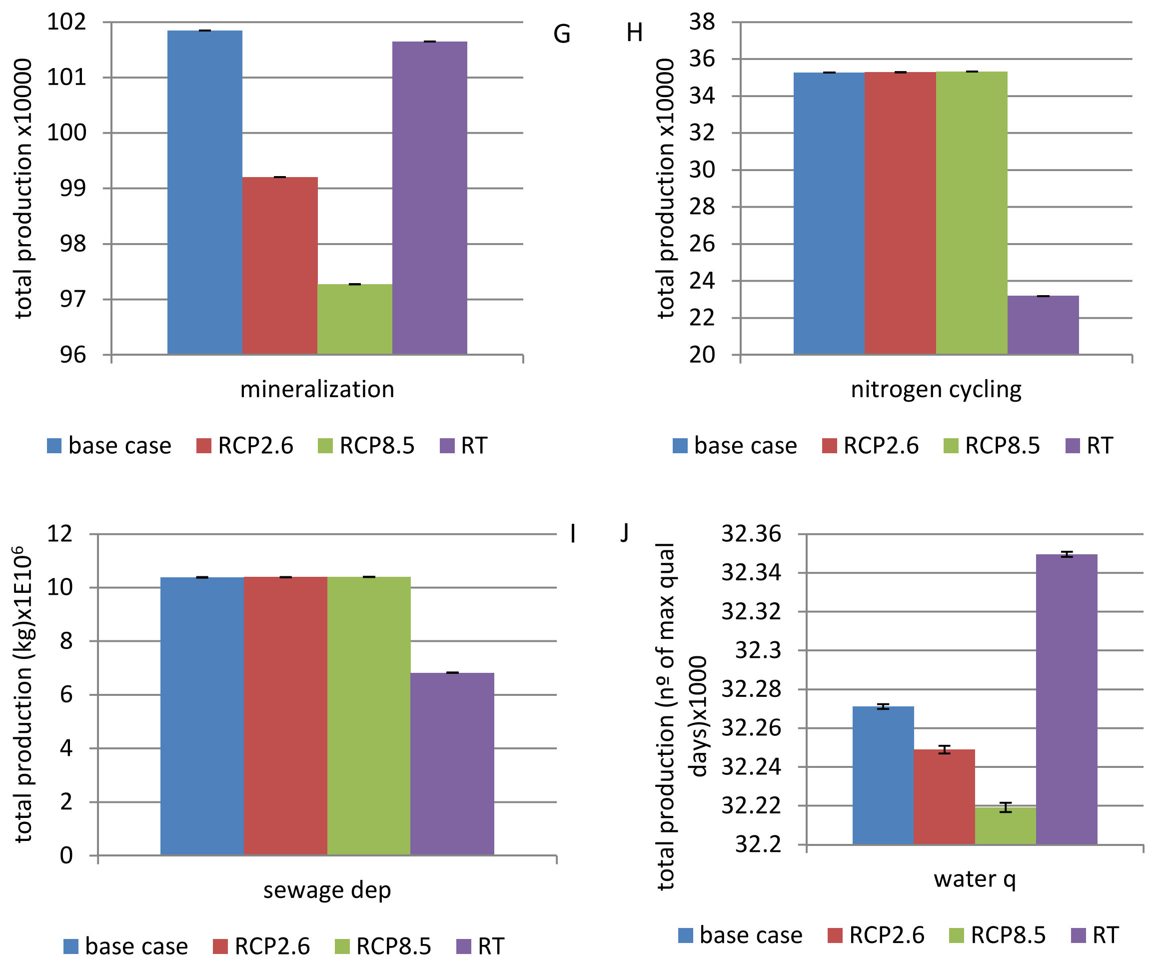
Water quality perception (as fraction of the maximum water quality possible/day) from 2010–2100 in annual mean values, showing the variations according to the influence of scenarios. Source: the author.

2.3.4.11 Effects of scenarios in ES provision

Plotting the effects of scenarios on the provision on ES (Figure 47a–j) is relevant to understand the variations each ecosystem service can suffer until the end of the century if the conditions embedded in the model were kept constant. The sum of all production of each ecosystem service is presented (Figure 47a–j)

Figure 47: total production of each ecosystem service and their scenario led variations





Source: the author

Notes: a) Crustaceans productivity show the maximum effect of climate change in RCP2.6, not on RCP8.5 as expected; b) Mollusks present the overall expected behavior for fisheries, with more severe effect of climate change in RCP8.5; c) cart. fish follows the same expected behavior; d) bonefish had its production increased by both scenarios of climate change; the four fishery groups are slightly being influenced by the RT scenario in their production; e and f) CO_2 and O_2 productions follow the same pattern since they are product of the same biological activity; g) mineralization has strong influence of RCP8.5 as expected; h) nitrogen cycling is almost immune to the effect of climate change but it is highly influenced by RT; i) sewage depuration is greatly influenced by RT; J) water quality has the higher influence of RT scenario.

2.3.4.12 – Ecosystem services aggregated

An exclusive economic evaluation is considered poor once sustainability and socio–cultural values are not embedded in the economic analysis. On the other hand, one of the advantages of economic valuation is that all ecosystem services are measured on the same currency, and therefore a globally integrated dimension of what has been evaluated is possible (Table 4).

Table 4: Economic losses due to different economic scenarios for ecosystem services (aggregated) from 2010–2100

n	Ecosystem Services	Scenario	Daily sum (Mil. dollars)	SD (10K USD)	Daily sum (Mil. dollars) with 12% discount rate	SD (1K USD)	Daily sum (Mil. dollars) at 6% discount rate	SD (1K USD)
1	Crustaceans	Base case	104.4	19.0	9.7	181.1	19.3	361.0
2	Mollusks	Base case	12.6	27.0	1.1	25.4	2.3	50.6
3	Cart. Fish	Base case	16.7	3.3	1.5	3.1	3.0	6.2
4	Bone fish	Base case	157.0	30.0	14.5	286.1	28.9	569.6
5	Carbon	Base case	103.8	0.3	9.6	0.6	19.0	0.5
6	Oxygen	Base case	19.8	0.07	1.8	0.1	3.6	0.1
7	Mineralization	Base case	64.8	0.1	6.0	0.3	11.9	0.4
8	Nitro. Cycling	Base case	78.9	0.3	7.3	0.5	4.6	0.7
9	Sewage dep.	Base case	63.8	0.3	5.9	0.7	11.8	1.0
10	Water quality	Base case	345.0	0.001	0.003	0.003	0.006	0.005
	Total		**622.0**	**366.00**	**57.7**	**340.0**	**114.8**	**676.00**
	Total of losses				- 564.5		- 507.3	
	Percentage				-90.73%	0.59%	-81.55%	0.59%

Ubatuba coastal zone will provide ecosystem services with an economic value of 622 M USD (±3.6 M USD) for the city from 2010–2100. This value is equivalent to something around 7 M USD every year, or even 19 thousand USD every day for the whole area.

The possibility of extracting all ecosystem services in the short–range or its substitution for a different activity would bring great losses. In the worst economic scenario, selfish, the ES provision is reduced to less than 10% if nature was kept healthy. Economic loss (-564 M USD) would represent 90.73% (±0.59%). Even when the balanced economic scenario is considered, 81.55 % (±0.59%) of ES are lost with values around -507 M USD.

If management was only an economic issue, the conservation effort costs *vs.* economic benefits of nature conservation it would mean that the city could spend 7 M USD each year on environmental conservation and still profit. This value is correspondent to 6% of the brute income of the city (R$402 millions) (UBATUBA, 2018). The annual budget for 2019 (UBATUBA, 2018) show big expenses in the environmental management area (around R$ 25 million), but most of this money is spent to remove solid wastes from the coast to landfills up the mountains in Vale do Paraíba[7] and therefore this resource spend in environmental management, despite being indispensable, is not focused exclusively in coastal ecosystem services conservation.

When climate change scenarios (Tables 5 and 6) are considered, the situation gets worse. In the best scenario (RCP2.6) economic losses are -1.23% (±2.96%) with values of -7.5 M USD (±3.8 M USD) for the utopic scenario. If the selfish scenario is considered, losses grow for -1.94% (±2.95%) adding – 1.1 M USD (± 0.35 M USD) to the previous losses of – 564.5 M USD. On the balanced scenario losses are -1.79% adding – 2.0 M USD (±0.7 M USD) to the -507.3 M USD previously lost.

For RCP8.5 the situation is more serious (Table 6) with losses of -2.34% (±3.88%) that correspond to values of -14 M USD (±USD 6.3 M USD) for the utopic scenario. To different economic scenarios, losses reach -5.29% (±3.81%) for the selfish scenario (adding – 2.9 M USD ± 0.5 M USD to the – 564.5 M USD previously lost). For balanced scenario losses are -4.42% (±3.84%) (adding – 4.8 M USD ± 1.1 M USD to the -507.3 M USD already lost).

For the reactive tourists' scenario (table 7) the situation is less worsening in all economic scenarios. For the utopic scenario, losses are -0.14% corresponding to -0.9 M USD. For the selfish scenario, losses are -0.40% with an additional value of -0.2 M USD to be

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[7] https://www.ovale.com.br/_conteudo/_conteudo/nossa_regiao/2019/08/86140-transporte-de-lixo-custa-r--60-milhoes-para-os-cofres-do-litoral-norte.html Acesso em 31/05/2020

added to those -591.3 M USD lost for this economic scenario. For the balanced economic scenario, losses are -0.33%, corresponding to -0.4 M USD to be added to the already lost – 530.7 M USD of the adoption of this economic scenario.

Table 5:Economic losses due to different economic scenarios for RCP2.6 on aggregated ES provision from 2010–2100

n	Ecosystem Service	Scenario	Daily sum (M dollars)	SD (1K dollars)	Losses(1K dollars)	SD (1K dollars)	Losses rate	SD	Daily sum with 12% discount rate (M dollars)	SD (1K dollars)	losses (1K dollars)	SD (1K dollars)	losses rate	SD	Daily Sum with 6% discount rate (M dollars)	SD (1K dollars)	losses (1K dollars)	SD	losses rate	SD
1	Crustaceans	RCP 2.6	106.10	1895.80	1710.30	473.00	1.64%	0.45%	9.80	176.50	159.10	43.90	1.64%	0.45%	19.60	350.00	316.30	87.40	1.64%	0.45%
2	Mollusks	RCP 2.6	12.50	408.60	-83.90	301.90	-0.67%	2.40%	1.10	37.70	-7.70	27.80	-0.67%	2.39%	2.30	75.10	15.40	55.50	-0.67%	2.39%
3	Cart. Fish	RCP 2.6	16.90	259.40	153.20	257.20	0.91%	1.53%	1.50	23.90	14.00	23.70	0.91%	1.53%	3.10	47.70	28.00	47.30	0.91%	1.53%
4	Bone fish	RCP 2.6	156.50	3266.60	-459.40	1055.30	-0.29%	0.67%	14.50	301.40	-43.70	94.60	-0.30%	0.65%	28.80	600.60	-86.10	190.50	-0.30%	0.66%
5	Carbon	RCP 2.6	97.60	9.30	-6158.90	8.90	-5.93%	0.01%	8.70	2.60	-843.80	2.60	-8.81%	0.03%	17.50	3.30	-1561.10	3.20	-8.18%	0.02%
6	Oxygen	RCP 2.6	18.60	1.60	-1167.60	1.40	-5.90%	0.01%	1.60	0.40	-159.70	0.40	-8.76%	0.02%	3.30	0.50	-295.80	0.50	-8.14%	0.02%
7	Mineralization	RCP 2.6	63.10	2.00	-1680.80	1.70	-2.59%	0.00%	5.70	1.00	-230.80	1.00	-3.83%	0.02%	11.50	0.90	-426.70	0.90	-3.56%	0.01%
8	Nitro. Cycling	RCP 2.6	78.90	9.00	72.30	8.50	0.09%	0.01%	7.30	1.70	6.20	1.60	0.08%	0.02%	14.60	2.80	13.20	2.60	0.09%	0.02%
9	Sewage dep.	RCP 2.6	63.90	6.30	59.70	5.10	0.09%	0.01%	5.90	1.00	6.50	0.70	0.11%	0.01%	11.80	1.40	12.40	1.00	0.11%	0.01%
10	Water quality	RCP 2.6	0.30	0.01	-0.30	0.01	-0.08%	0.00%	0.03	0.01	-0.03	0.01	-0.10%	0.02%	0.06	0.01	-0.05	0.01	-0.09%	0.01%
		Total	**614.40**	**3.80**	**7.50**	**3807.80**	**1.22%**	**2.96%**	**56.13**	**352.13**	**-1099.93**	**352.15**	**-1.96%**	**2.95%**	**112.56**	**700.83**	**-1984.45**	**701.26**	**-1.76%**	**2.95%**

Source: the author

Table 6: Economic losses due to different economic scenarios for RCP8.5 on aggregated ES provision from 2010–2100

n	Ecosystem Service	Scenario	Daily sum (M dollars)	SD (1k dollars)	Losses (1k dollars)	SD (1k dollars)	Losses rate	SD	Daily sum with 12% discount rate (M dollars)	SD (1k dollars)	losses (1k dollars)	SD (1k dollars)	losses rate	SD	Daily Sum with 6% discount rate (M dollars)	SD (1k dollars)	losses (1k dollars)	SD (1k dollars)	losses rate	SD
1	Crustaceans	RCP 8.5	104.60	2282.50	239.60	1179.90	0.23%	1.13%	9.70	211.40	5.70	107.70	-0.06%	1.11%	19.30	420.90	8.20	215.60	0.04%	1.12%
2	Mollusks	RCP 8.5	12.60	246.10	58.00	123.40	0.46%	0.98%	1.10	22.60	4.90	11.50	-0.43%	0.99%	2.30	45.10	2.00	22.90	-0.09%	0.99%
3	Cart. Fish	RCP 8.5	16.60	270.90	-122.40	268.80	-0.73%	1.60%	1.40	24.70	49.30	24.50	-3.19%	1.58%	3.00	49.10	69.10	49.00	-2.24%	1.59%
4	Bone fish	RCP 8.5	157.70	5901.50	808.20	5026.90	0.51%	3.20%	14.20	536.80	278.10	545.10	-1.92%	3.13%	28.60	1075.00	-281.30	912.40	-0.97%	3.16%
5	Carbon	RCP 8.5	93.20	11.40	-10592.90	11.00	-10.20%	0.01%	7.80	10.60	-1766.90	10.60	-18.45%	0.11%	15.90	9.80	-3116.80	9.80	-16.33%	0.05%
6	Oxygen	RCP 8.5	17.70	2.40	-2004.20	2.30	-10.13%	0.01%	1.50	1.80	-333.10	1.80	-18.27%	0.10%	3.00	2.10	-588.50	2.10	-16.19%	0.06%
7	Mineralization	RCP 8.5	61.80	3.70	-2912.90	3.60	-4.50%	0.01%	5.50	2.30	-489.90	2.20	-8.13%	0.04%	11.10	2.70	-862.20	2.70	-7.20%	0.02%
8	Nitro. Cycling	RCP 8.5	79.00	7.90	157.60	7.40	0.20%	0.01%	7.30	1.20	14.30	1.00	0.20%	0.01%	14.60	1.50	29.70	1.40	0.20%	0.01%
9	Sewage dep.	RCP 8.5	63.90	5.00	124.80	3.40	0.20%	0.01%	5.90	1.70	13.10	1.50	0.22%	0.03%	11.80	2.70	24.90	2.50	0.21%	0.02%
10	Water quality	RCP 8.5	0.30	0.00	-0.50	0.00	-0.16%	0.01%	0.03	0.00	0.01	0.00	-0.16%	0.01%	0.06	0.00	-104.83	0.00	-0.17%	0.01%
		Total	**607.40**	**6338.11**	**-14244.70**	**6338.16**	**-2.35%**	**3.88%**	**54.43**	**578.01**	**-2900.00**	**578.02**	**-5.33%**	**3.81%**	**109.66**	**1156.44**	**-4819.73**	**1157.05**	**-4.40%**	**3.84%**

Source: the author

Table 7: Economic losses due to different economic scenarios for Reactive Tourists on aggregated ES provision from 2010–2100

n	Ecosystem Service	Scenario	Daily sum (M dollars)	SD (1K dollars)	Losses (1K dollars)	SD (1K dollars)	Losses rate	SD	Daily sum with 12% discount rate (M dollars)	SD (1K dollars)	losses (1K dollars)	SD (1K dollars)	losses rate	SD	Daily Sum with 6% discount rate (M dollars)	SD (1K dollars)	losses (1K dollars)	SD(1K dollars)	losses rate	SD
1	Crustaceans	Turistas reativos	103.90	1154.30	-433.00	1576.50	-0.41%	1.51%	9.60	106.90	-86.70	147.10	-0.89%	1.51%	19.10	212.80	-145.20	292.20	-0.75%	1.51%
2	Mollusks	Turistas reativos	12.30	708.50	-263.40	652.80	-2.09%	5.18%	1.10	65.30	-25.60	60.20	-2.21%	5.17%	2.20	130.20	-50.30	119.90	-2.17%	5.17%
3	Cart. Fish	Turistas reativos	16.80	156.20	56.30	152.50	0.34%	0.91%	1.50	14.40	3.50	14.00	0.23%	0.91%	3.00	28.70	7.90	28.00	0.26%	0.91%
4	Bone fish	Turistas reativos	159.00	4141.40	2081.80	2755.70	1.33%	1.76%	14.60	382.50	172.70	253.90	1.19%	1.75%	29.20	761.90	355.60	506.00	1.23%	1.75%
5	Carbon	Turistas reativos	103.80	3.50	17.80	1.90	0.02%	0.00%	9.50	0.70	6.10	0.20	0.06%	0.00%	19.00	0.90	9.40	0.70	0.05%	0.00%
6	Oxygen	Turistas reativos	19.70	0.90	2.90	0.50	0.01%	0.00%	1.80	0.10	1.00	0.00	0.06%	0.01%	3.60	0.20	1.60	0.20	0.04%	0.01%
7	Mineralization	Turistas reativos	64.60	0.70	-128.00	0.70	-0.20%	0.00%	5.90	0.20	-46.30	0.10	-0.77%	0.00%	11.90	0.40	-68.90	0.00	-0.58%	0.00%
8	Nitro. Cycling	Turistas reativos	78.60	2.60	-198.90	1.50	-0.25%	0.00%	7.20	0.60	-50.70	0.40	-0.69%	0.01%	14.50	1.00	-85.50	0.70	-0.59%	0.00%
9	Sewage dep.	Turistas reativos	63.70	3.30	-155.50	1.60	-0.24%	0.00%	5.90	0.40	-40.00	0.60	-0.67%	0.01%	11.70	0.70	-67.40	0.80	-0.57%	0.01%
10	Water quality	Turistas reativos	0.30	0.00	0.80	0.00	0.24%	0.00%	0.03	0.00	0.20	0.00	0.67%	0.01%	0.06	0.00	0.30	0.00	0.57%	0.01%
	Total		**622.70**	**4360.05**	**980.80**	**4360.12**	**0.16%**	**5.75%**	**57.13**	**402.75**	**-65.80**	**402.85**	**-0.12%**	**5.74%**	**114.26**	**802.22**	**-42.50**	**802.29**	**-0.04%**	**5.74%**

Source: the authors

2.3.5 Ecosystem services material assessment

The material assessment will tell us how the structure and functions of the ecosystem will behave along with the simulation in the material analysis confronted with scenarios. These material losses will be also discussed later in terms of the co–production nature of part of these services and the impact the scenarios can have in terms of labor and income.

Material analysis against scenarios will show the behavior of each ecosystem service along with the simulation (from 2010–2100) and its variations according to climate change scenarios and reactive tourists' scenario. An abstract (Table 8) of the data presented for each case show climate scenarios causing gains and losses on the ecosystem services studied but most of these gains are dependent on the error margin of the simulation.

As expected, losses and gains in RCP8.5 are usually bigger than those in RCP2.6, The losses vary from very small values (+0.09% ±0.01%) as in Nutrient Cycling in RCP2.6 to more significant values (-10.20% ±0.01%) for carbon sequestration at RCP8.5. For reactive tourists' scenario, results show gains in five ES (cart. fish, bone fish, carbon sequestration, oxygen production, and water quality) and losses on the other five. It is important to understand that material losses in services like sewage depuration and nitrogen cycling are actually desirable because that means the ocean is dealing with less sewage to depurate and therefore less nitrogen from sewage, which can in turn indicate better sanitary conditions.

2.3.5.1 Food production – Crustaceans

Recapturing values presented before the average daily production of Crustaceans is 635kg with oscillations. The model shows this production roughly constant along the year without the oscillations shown before, following the trend, not the oscillations, and slightly influenced by stochastic variations, but with an average of 620 kg of Crustaceans for the first year. The estimated production to 2100 shows slight growth from 620kg to 634kg per diem, reaching average value expected for this variable.

The variation on Crustaceans production simulated for climate change influence show the influence of stochastic events with short duration, with small variances in the trend of the curve and the overall production. Changes in RCP2.6 start to happen on at the beginning of the simulation and present a lower trend when compared to the base case scenario. Changes in RCP8.5 are smaller in the trend, but starting around 2060 strong seasonal negative oscillations mark the graph for these organisms showing the influence of lower productivities in winter.

With this last climate scenario, minimum values of production can reach 595kg on winter peaks, with small trend variations when compared to the base case. For reactive tourists, the crustaceans graph shows a different trajectory for when compared with the base case, but with a very small numerical variance (0.078%) on the daily values when compared to the base case.

Finally the material losses of these ecosystem services show small gains in RCP2.6 of 1.64% (±0.45%) corresponding to values of 330 000 kg to the end of the century. For RCP 8.5 the average runs point to a small gain as well. In this case, the average gain was 0.23% (±1.13%) what configures a situation where losses in this service are also possible considering the standard deviation is bigger than the mean value. For the reactive tourists scenario the losses were -0.41% (±1.5%) again presenting a situation where gains are possible due to the difference of mean value and SD.

2.3.5.2 Food production – Mollusks

The average data for daily production for the period 2010–2017 was 127kg. Despite the oscillations presented in landings data, the seasonality is not clear because in some years (e.g. 2010) the peak of production couldn't be found and in the other years, the peak seems to be shortening the distance between them.

Oscillations on the data curve plummet from the average 127kg to zero during periods that fishery is deaccelerating. The model cannot reproduce these oscillations because the limiting factors of Mollusks growth (oxygen and food) don't exhibit this seasonal pattern and also the fishermen's behavior was not part of the simulation. Modeled curves put the maximum value for Mollusks fisheries in 126kg.

Under climate change scenarios Mollusks fishery will be slightly affected by stochastic events I winter but also by changing its trend showing days when this fishery will be around very low (close to 100kg). Trend changes start on the beginning of the model but more acute winter effects start from 2060 ahead for RCP8.5. For RCP2.6 just a small decrease in the trend was observed. For reactive tourists, changes are very small and seem related change in the trend. The reduction on the provision of these organisms is very small, with material percentage losses of -0.67 (±2.4%) for RCP2.6, pointing to the possibility of having small gains as well; small gain of 0.46% (±0.98%) showing the that small gains and losses are possible in RCP8.5; and losses of -2.09% (±5.18%) presenting more solid losses for reactive tourist but with the possibility of small gains as well due to the variations of data.

2.3.5.3 Food production – Cartilaginous Fishes

The average production of cart. fishes on data from 2010–2017 period were 236kg every day. The base case starts simulation this production on average around 225kg and the production goes with slightly increase until the end of the period getting closer to this average value. Average simulation of trends shows very small variances in the climate and reactive tourist scenario when compared to the base case.

For RCP2.6 average run has the mean of 0.91% (±1.53%) pointing to the possibility of gains and losses in this scenario. For RCP8.5 the losses are -0.73% (±1.60%) reinforcing the possibility of small gains despite the small losses found on the average run. For reactive tourists the small gains (0.34% ±0.91%) are also followed by bigger SDs what point to both losses and gains.

2.3.5.4 Food production – Bone Fishes

The average production of bone fishes on data presented a value of 6200kg from 2010–2017 period every day. The curve of bonefish fisheries shows several oscillations that can be related to seasonality being more present in RCP8.5 starting in 2060 as in the others ES.

The trend in this fishery is slightly increasing and it is being reproduced in the model along the simulation period.

The production of this ecosystem service is affected by climate change, eventually reducing daily production to 3900kg. Material losses in RCP2.6 are of 0.29% (0.67%). For RCP8.5 gains of 0.51 (±3.20%) repeat the tendency of having losses and gains in ES provisions. For reactive tourists gains of 1.33% (±1.76%) reinforce that this service will most probably be enhanced by some absence of tourism.

2.3.5.5 Carbon Sequestration

The marine area simulated by this model absorbs during 2010–2017 from 680 tons. in summer to 200 tons. in winter of carbon every day. These data were calculated from the activity of primary producers and their daily variance reflects on the amount of this service, including seasonal variations.

The trend of this ecosystem service is to keep roughly constant over the years, being affected only by stochastic events and the climate seasonality. Due to climate change, losses on this service for RCP2.6 are -5.93% (±0.01%). For RCP8.5 losses are much bigger -10.20% (±0.01%) pointing to a clear conclusion on this ES that climate change will affect negatively carbon sequestration. For reactive tourists a very small gain 0.02% (±0.00%) is probably occurring due to gains in water transparency.

2.3.5.6 Oxygen production

Oxygen production service has produced from 388 tons in summer to 100 tons in winter of this gas from 2010–2017 every day. The trend in this service is to remain roughly constant along the century showing slight stochastic variations but keeping the overall seasonality. Due to climate change scenarios the simulation presented losses for RCP2.6 of -5.9% (±0.01%). For RCP8.5 losses were bigger, with values of -10.13% (±0.01%) along the century. For reactive tourists there were small gains (0.01%±0.00%) probably related to water transparency increase.

2.3.5.7 Mineralization

Nitrogen cycling from local organisms produces from 44kg of nitrogen in summer to 8kgs in winter per day. Mineralization was calculated from the respiration rate (an indicator of the speed of the metabolism) for each organism. For the sake of simplicity, it was considered the same for everyone (6mmol de O2/m3/day) (ROBINSON, 2000). This metabolism was then multiplied for the Redfield coefficient (WILLIAMS e FOLLOWS, 2011) to know the amount of nitrogen excreted daily according to the carbon used in respiration. We adopted a coefficient of 6.5.

The trend here is to keep reasonably constant along the century as the simulated populations of fishes and particles do. Stochastic variations are present but do not affect the trend.

Material variations show losses -2.59% (±0.00%) for RCP2.6; losses of -4.50% (0.00%) for RCP8.5 and losses of 0.20% (±0.00%) for reactive tourists.

2.3.5.8 Nitrogen cycling

The nitrogen cycling tendency shows a growth pattern that is directly proportional to population growth but has a strong stochastic influence from the rain (because rain brings a lot of detritus from land). Therefore the cycling of 1.8 tons per diem in the first year is marked by the peaks of nitrogen deposited on the beaches that can reach 2.2 tons. The trend in this service is to grow following the population number but also to present seasonal oscillations.

Climate change influences the rain patterns causes this service to increase its capacity. Reactive tourist scenario, by reducing the presence of tourism, diminishes its intensity.

Due to climate change then, gains in this service are 0.09% (±0.01%) for RCP2.6 and 0.2% (±0.01%) for RCP8.5. For reactive tourists a -34.25% (±0.01%) variation was present due to the diminishing of tourist's presence.

2.3.5.9 Sewage depuration

The curve for sewage depuration starts with 55kg of enterococcus killed in the water every day, with strong stochastic influence concentrated in winter when these values can reach between 36 and 80kg by day. Light and water temperature are responsible for bacterial death (BATISTA e HARARI, 2017 e MANCINI, 1978), therefore in the period with less light intensity, SST becomes the dominant factor responsible to kill these organisms. During summer, the light is so intense that the bacteria die at the maximum rate determined by the sewage depuration sub–model. The oscillation in mortality due to light exposure comes from 1 during high summer to 0.65 in winter (when SST assumes).

The trend in this service is of exponential growth once it is directly proportional to population. Climate change affects positively this service, enhancing the effect of temperature on the bacterial death rate. Therefore percentages show positive gains for climate change scenarios in this service for RCP2.6 0.10% (±0.01%) and for RCP8.5 0.21% (±0.01%). Reactive tourist scenario in its turn present a big decrease in the materiality of this service due to the decrease of tourists -34.24% (±0.01%).

2.3.5.10 Water quality – perception

Water quality – perception is a cultural ES (COSTANZA et al., 1997; de GROOT et al., 2002) and thus the objective was to evaluate the spiritual satisfaction of the tourists with the quality of the beach they were visiting. Therefore the material component of this service was arbitrarily established as “the number of days with maximum quality”, determined by the maximum transparency in the water.

The perfect scenario would be the maximum water quality every day, which would correspond for 32850 days (rounded to 33000 days) (from 2010–2100). This is not possible once the city dumps sewage and the rivers and wind put other detritus on the water.

The trend in this service is to lose water quality along with the simulation due to the population growth and consequent increase in sewage dumping in the water. Climate change can worsen the situation by increasing the rain intensity and therefore bringing more detritus to the coast. The reactive tourist’s scenario, on the other hand, removes detritus from the city and thus the water quality improves.

Considering the percentage gains and losses of the material realm results show that climate change influences this service negatively (bringing more detritus to the water with averages of -0.08% (±0.00%) for RCP2.6 and -0.16% (±0.01%) for RCP8.5. For reactive tourists the results point to small gains 0.24% (±0.00%) in water quality.

Table 8: Material variations for ES due to scenarios from 2010–2100

ES	Scenario	Base case	SD	RCP 2.6	SD	RCP 8.5	SD	Reactive Tourists	SD
Crustaceans	Production (kg)	20153207.23	377204.55	20483388.31	365983.88	20199472.42	440644.73	20069614.44	222849.44
	Losses (kg)	0	0	330181.08	91318.51	46265.18	227781.72	-83592.79	304337.64
	Loss rate	0	0	1.64%	0.45%	0.23%	1.13%	-0.41%	1.51%
Mollusks	Production (kg)	4106556.45	89677.64	4079197.11	133102.50	4125474.97	80164.20	4020748.52	230782.48
	Losses (kg)	0	0	-27359.34	98357.49	18918.52	40196.78	-85807.92	212646.35
	Loss rate	0	0	-0.67%	2.40%	0.46%	0.98%	-2.09%	5.18%
Cart. Fish	Production (kg)	7350043.93	14848.52	7417263.45	113785.54	7296353.45	118855.36	7374765.67	68544.30
	Losses (kg)	0	0	67219.52	112812.55	-53690.48	117924.21	24721.74	66916.68
	Loss rate	0	0	0.91%	1.53%	-0.73%	1.60%	0.34%	0.91%
Bone Fish	Production (kg)	201215818.58	3963466.31	200626793.20	4188027.00	202252002.72	7566063.83	203884899.32	5309555.96
	Losses (kg)	0	0	-589025.38	1352961.54	1036184.15	6444862.81	2669080.75	3533032.58
	Loss rate	0	0	-0.29%	0.67%	0.51%	3.20%	1.33%	1.76%
Carbon	Production (ton.)	16272702.49	460.39	15307352.06	1471.74	14612358.33	1793.00	16275502.04	551.65
	Losses (ton.)	0	0	-965350.43	1397.87	-1660344.16	1732.89	2799.55	303.90
	Loss rate	0	0	-5.93%	0.01%	-10.20%	0.01%	0.02%	0.00%
Oxygen	Production (ton.)	9382692.73	351.40	8828747.83	757.12	8431830.35	1165.12	9384070.13	424.33
	Losses (ton.)	0	0	-553944.90	670.64	-950862.38	1110.87	1377.40	237.86
	Loss rate	0	0	-5.90%	0.01%	-10.13%	0.01%	0.01%	0.00%
Mineralization	Production (kg)	1018468.68	16.37	992045.53	32.23	972675.89	59.13	1016456.01	12.31
	Losses (kg)	0	0	-26423.16	27.76	-45792.80	56.82	-2012.67	10.80
	Loss rate	0	0	-2.59%	0.00%	-4.50%	0.01%	-0.20%	0.00%
Nutrient Cycling	Production (ton.)	352531.66	19.51	352857.30	59.21	353253.20	34.81	231801.29	52.68
	Losses (ton.)	0	0	325.64	55.91	721.54	28.84	-120730.37	48.94
	Loss rate	0	0	0.09%	0.01%	0.20%	0.01%	-34.25%	0.01%
Sewage depuration	Production (kg)	10382235.22	697.71	10392815.62	1491.36	10403681.92	1761.79	6827657.24	1409.57
	Losses (kg)	0	0	10580.40	1318.09	21446.70	1617.75	-3554577.98	1224.78
	Loss rate	0	0	0.10%	0.01%	0.21%	0.01%	-34.24%	0.01%
Water Quality	days of max qual.	32271.95	1.10	32245.33	1.59	32220.15	2.94	32349.57	0.85
	Losses (days of max qual.)	0	0	-26.63	1.15	-51.81	2.72	77.61	0.71
	Loss rate	0	0	-0.08%	0.00%	-0.16%	0.01%	0.24%	0.00%

Source: the author

2.4 DISCUSSION

2.4.1 Models tests

"*All models are wrong but some models are useful*" (George Box)

How can we know that what is being presented in the model corresponds to reality? How can the results be trusted with a level of confidence that allows us to base public policies and spend eventually great sums of people's money? Even more, what makes a good model? Those questions are fundamental for the decision–makers to trust and use these tools.

2.4.1.1 Verification and Validation

Oreskes et al. (1994) claim that verifies or validate numerical models of natural systems is impossible. That happens for two reasons: first, these systems are open, which implies that there are variabilities in the system that weren't captured by the model; second, some results, the more verisimilar they appear can be originated in different models, and therefore it is not possible to know for sure which represents the reality (which one is true).

Verify means showing that the truth was demonstrated through the model and then the model can be trusted to the point that is considered useful for decision making. The problem is that it is impossible to determine if the results of the model are true with exception of those from closed systems (ORESKES et al., 1994; STERMAN, 2000). The authors (Op.cit.) show an example of a closed system logic operating in an open system to justify this verification impossibility:

> For example, I say, "If it rains tomorrow, I will stay home and revise this paper." The next day it rains, but you find that I am not home. Your verification has failed. You conclude that my original statement was false. But in fact, it was my intention to stay home and work on my paper. The formulation was a true statement of my intent. Later, you find that I left the house because my mother died, and you realize that my original formulation was not false, but incomplete. It did not allow for the possibility of extenuating circumstances. Your attempt at verification failed because the system was not closed. Oreskes et al. (1994, p. 641)

The second problem happens when the model is confronted with the systems' data. If the results of the model and the data from the system are incompatible, usually the modeler enhances the resolution in the model, enhances the calibration, or adopt more adequate data to make results to become the closest possible to the reality that it is simulating.

But when results are coherent with data, there are no reasons to believe the model to be true because it is possible that a different model, with a different structure, also achieved the same results, and then which one is true is a question without an answer.

This characteristic of models, known as indetermination (ORESKES et al., 1994) does not allow a choice between two different but equally verisimilar models using only criteria like data and model's structure; it is necessary in this case to adopt some arbitrary criteria to adopt one model or the other. Usually, these criteria are simplicity, symmetry, elegance, or even personal or political trust. But these choices *per se* state that it wasn't possible to determine which model was the truest. In the absence of the truest model, an arbitrarily choice goes for the most suitable one.

Verifying, thus, can only happen in closed systems, when all data are known and known to be correct.

Validation, therefore, seems to be more adequate for open system models. Validation means the establishment of legitimacy, typically in terms of contracts, arguments, and methods (ORESKES et al., 1994). A valid contract is one that hasn't been shown to be incorrect yet; a valid argument is that one that hasn't been refuted by peers to that finality.

It is a common practice among modelers to divide data into two parts, using the first part to calibrate the model and then certifying the results of the model are coherent with that time series, and posteriorly comparing the other results with the second part of the data, from which is usually inferred that if the results and the data were congruent, the model is valid, otherwise not. This practice is misleading (ORESKES et al., 1994; STERMAN, 2000) and does not ensure the validity of the model because being an open system, the congruence of data and results are occasional.

Even if the model is congruent with data from the present and satisfactorily fits data from the past, there is no guarantee that it will explain future events for which no data is available yet. Finally, the model can be tested and declared false, but its veracity cannot be determined because it is embracing an open system. This claim leads us to problems in science philosophy about falsifiability and veracity in scientific hypotheses (e.g. Popper and Polanyi works) that are beyond the scope of the present research.

In the end, what makes a good model is its capacity to test discrepancies in other models (mental models included). Good models are those that confirm or refute the hypothesis that has been created from other research methods and knowledge gathering. Good models can be used to answer "what if questions" and then make some forecasts, or even explore causal hypothesis in its past and future behavior. In short, good models are tools for learning (STERMAN, 2000) and heuristics[8] (ORESKES et al., 1994).

For decision–making, models are fundamental, even knowing that their veracity is impossible to prove. The decision–making process traditionally is based on information (data or problems to be managed) and in the intuitive capacity of the decision–maker in integrating these data in a coherent and prognostic fashion to then choose a way to go. This process is analogous to what happens in modeling. The advantage of formal mathematical models is that data can be tested with several hands, the hypothesis of a relation between elements are explicit to several eyes, and prognostics can be formally discussed and debated by different people, including testing for different scenarios. But as scientific it can get, models have their limitations.

2.4.1.2 Calibration

With the comments about validation/verification in mind, we reach the calibration phase. Climate data as wind, sea surface temperature, and cloud cover used data from ECMWF in daily time–series from 2010–2017. From July 2017 ahead, the simulation uses the average and standard deviation to forecast these data in a probabilistic fashion. The values obtained in this part of the simulation are different from those in reality but at this point are considered satisfactory for the model development because they are delimited inside the same sample size of the real data from the historical time–series, in other words, they have the same average and SD values. For sea surface temperature the correlation between data and the results of the model was (r=0.31) what is considered a satisfactory for MIMES models. For cloud cover the correlation was r=0.26, showing the model is running in the right direction with data.

The rain model is more complex and tries to reach a closer picture of reality because despite the same length in time–series, in its forecast, monthly averages are used, embracing seasonality in rain patterns. The correlation in this case between data and the simulation was 0.21, what is considered a good result for this kind of model. Both winds components had correlations of r=0.15 when compared to data.

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[8] Heuristics are strategies for decision making that reduces the complexity of the task of determining probabilities of forecasting some events to a simple and feasible judgment operation (TVERSKY & KAHNEMAN, 1974.)

Population data for Phytoplankton, zooplankton, detritus, suspended material, salps, Enterococcus, and Bacterioplankton didn’t present time series data against which the simulation could be compared. Thus the model focused delineating the maximum and minimum populations (when available) and tried to follow satisfactorily those limits Rocha (2003) and CETESB (2016). All values in water particles sub model present clear seasonal variability, the causal reason for Phytoplankton is the light availability (season); zooplankton varies due to phytoplankton variation that acts as food limit; salps varies according to zooplankton and phytoplankton but only occurs in summer; detritus, suspended material and Enterococcus are directly dependent on tourists, but they usually occur more frequently during the summer.

Zooplankton population simulation presented a different pattern when compared to literature (ROCHA, 2003). The author reported higher values for the zooplankton population during winter, probably where the absence of salps predation allowed these creatures to reproduce and reach these high values. The model hasn’t captured this movement and the main limitation to zooplankton growth is food availability (phytoplankton) and therefore their behavior follows its variation.

Enterococcus population, however, presented more values in winter when compared to supper. When compared directly with batheability data (CETESB–2010 to 2016) these seasonal fluctuations cannot be detected easily. Nevertheless, in other research (OLIVEIRA et al., 2020) using neural network analysis, this seasonality was detected in batheability data showing the difference between seasons in bacteria concentration along the whole coast of Ubatuba.

The vertebrate and invertebrate populations showed simulated values that are very close to the literature (ROCHA et al., 2003 and ROCHA et al. 2007). Invertebrates presented slight seasonal variability that follows their food source variations (detritus, suspended material, etc.). Superior food chain groups, like vertebrates, haven’t shown the same amplitude in their oscillations presented by water particles or even by invertebrates. Vertebrate’s oscillations are very discrete in the model and absent in literature (ROCHA et al., 2003 e ROCHA et al. 2007). Probably the literature models didn’t reach seasonal variations in their analysis and here this is mandatory because the simulation is daily based.

Ecosystem services, in general, were calibrated using a point of reference (e.g. landed fish, nitrogen concentration, etc.). For landed fish the biodiversity in the ocean is considered poorly represented by the groups in the model. Despite that being the best data available for this research, a difficulty in matching those groups with the fishing landing data was clear. One example was the crustaceans landing data which encompasses crabs and shrimps with no distinctions of weight between them (despite the obvious price distinctions). In this case our approximation of prices was useful for understanding the overall behavior but probably is an underestimate of the local total value for these groups.

Water quality perception wasn't calibrated because there is no reference to which the model can be compared. In this case, it is being assumed that once all the variables that determined the water quality index (detritus and suspended material) were calibrated, the result of their interaction therefore is.

When considering ES with a clear material basis, as fisheries, etc., the calibration was done by comparing the simulated population data with landings data. It was clear that applying the fishing rates calculated by landings data to the whole area was creating a discrepancy in fisheries results. That happens because fishermen don't use the whole area of the simulation to fish, and therefore an "adjustment factor" was used to diminish the fishing area for each group and therefore make the landing and fishery rate to be compatible.

The spatial limitation used in the model, embracing the north sector of APAMLN seems appropriate due to the importance of this area in providing ES for the city, but future development of the model could use smaller polygons to enhance the definition of the results and also embrace the types of substrate in the bottom of the sea for each of these polygons because that would allow the simulation of Benthic species distribution, and increase the overall approach of the model.

Land basins definition (Figures 4, 5, 36, 37) could also use an increase in polygon definition by reducing their areas and increasing the number of polygons. Maybe the use of IBGE's census sectors for delimiting the land basis can be an interesting approach to enhance the spatial resolution of data. It wasn't done in this work because of the need for a higher power computer.

About the time horizon used in the model it probably could be improved using longer time series to understand the data, and thus starting the simulation in a previous period. It is important to notice that the capacity of this model to compare a "normal" situation *vs.* climate change influence is biased because the time series used to understand the normal situation and therefore extrapolate scenarios was already embedded on the climate change effects or in a broader sense, in the great acceleration STEFFEN et al., 2005):

> During the last 100 years human population soared from little more than one to six billion and economic activity increased nearly 10–fold between 1950

> and 2000. The world's population is more tightly connected than ever before via globalization of economies and information flows. Half of Earth's land surface has been domesticated for direct human use. Most of the world's fisheries are fully or over–exploited. The composition of the atmosphere – greenhouse gases, reactive gases, aerosol particles – is now significantly different than it was a century ago. (STEFFEN et al., 2005 p.2)

Future temporal horizon is opened because the model is robust enough to simulate for more than 100 years. But then the limitation of the time series is relevant because the data time series used in this model is short to provide a long forecast.

The choice of the groups in the water particle sub–model and the fish sub–model were based on the best data available (ROCHA, 2003 and ROCHA et al., 2007) but some of them revealed useless for ES assessment as Echinoids or Asteroidean.

2.4.2 Discussion about the Ecosystem Services

2.4.2.1 The body of knowledge and the research frameworks

Despite not being the goal of this work to discuss what are ecosystem services and the frameworks available for research, adopting the usual definition that has been used since the seminal works of Costanza et al. (1997), corroborated and discussed in MEA (2004), de Groot et al. (2002, 2012), Boumans et al. (2002, 2015), Costanza et al., (2014) to make a short and far from an exhaustive list, some comments are made to bring to the reader at least part of the most recent discussions about the theme. The reason is their implications in the formation of the conceptual basis that has been used by the broadest intergovernmental institution that deals with ES globally and the consequences to implementation of this research and operational agenda.

Diaz et al. (2018) claims to bring a different definition of ES with a more appropriate focus on cultural services, and changing the name of ecosystem services to "*Nature contributions to People* (NCP)" and stating that the adoption of NCPs would represent a paradigm shift in nature and society researches. This new conception has based on the approach adopted by IPBES (Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services) the international platform responsible for global assessment of the ES provided to society and their relevance for policymaking.

In a manuscript sent to *Nature*, de Groot at al. (2019), disagrees that NCPs bring something new to the research field and call Diaz et al. (2018) work of a “political compromise and not a new scientific concept”.

The issue took the form of a political dispute between frameworks, definitions, and approaches that start to happen in letters to great journals’ editors as *Nature* and *Science*. Masood (2018) made a collection of the strife until October 2018 from which is understood that one of the main points in conflict is the economic valuation of ES, defended by one communication form by ES team, and criticized by NCP team to be an occidental (capitalist) form of measurement (MASOOD, 2018; KADYKALO et al., 2019) that is excluding when applied to small communities or other forms of valuation of nature benefits, for example, those from spiritual and cultural order.

Peterson et al. (2018) claim that IPBES doesn’t have the obligation to adopt only one perspective of the framework to deal with ES and to promote plurality in research, suggests the adoption of multiple perspectives even because ES deals with interdisciplinary issues in which the community of researches are highly heterogeneous but works with the common goal of understanding the multiplicity of forms that society and nature are connected and intertwined. The authors also list a couple of advances and deficits in the NCP perspective against ES.

As an advance, the authors (PETERSON et al., 2018) call attention to the higher weight of cultural factors as a transversal element in society which permeates the very perception of nature and quality of life. From that follows that the concepts of ES would be context–specific because their perception is biased by cultural processes that in other approaches would be homogenized in a broad basked of problems happening in multiple regions under multiple cultures. The new NCP perspective thus would bring more openness to embracing concepts and problems from minorities and less represented in the scientific mainstream.

The second advance would be with the notion (not a service) of “keeping the options”, or using the author's words “the capacity of ecosystems to keep options open in order to support a good quality of life” (DIAZ et al., 2018). Peterson et al. (2018) consider this notion of openness as a bridge to regional development to be integrated with the perspective of surprises and variations from ecosystems, which in their judgment would be currently static in ES perspective. This greater mobility from NCPs would put them closer to ideas of adaptive capacity, transformation, vulnerability, and resilience.

However, Faith (2019) responding to Peterson et al. (2018), uses MEA (2005) to show that the maintenance of open options has been already proposed in that work. The main point of the author is that the conceptual divergence (between NCP and ES) starts with conceptual mistakes and from that, a list is made to show that these conceptual mistakes – from Peterson et al., (2018) and Diaz et al., (2018) – cannot be used to create a new paradigm (or paradigm shift) as claimed by Diaz et al. (2018) but a paradigm drift. Faith concludes his analysis by showing that more progress can be made by observing what is old and was neglected than searching for something really new.

Back to Peterson et al, (2018) deficits, the authors point to the substitution of the word "ecosystem" for the word "nature" as a loss of communicative value once people, in general, understand nature as something out of their daily lives, external and distant as forests or isolated natural places. On the contrary, the use of the term "ecosystem" would put the focus on any ecosystem, which includes the work environment, residences, parks, etc. representing a conceptual and communicative gain against the social–ecological challenges faced in the Anthropocene.

The second deficit from NCPs would be while promoting particularities in nature–society research (as cultural aspects), completely ignore the frontiers in current research about ES. Following Peterson et al. (2018), these frontiers are 1) the dynamic character and the feedbacks between the ecosystems and their benefits; 2) co–creation of Ecosystem services and society; 3) the inclusion of society and nature relations in time and space, and 4) the central role of infrastructure and technology on the creation and access of ES. The very concept of NCP would emphasize a unidirectional flow from "nature" to "people" and therefore would counterproductive regarding the dynamism and feedbacks found in ecosystems.

Keller et al. (2018), contribute to the discussion pointing that to consider NCP as something at the same scientific construction level that ES is, at least three things are necessary: 1) that this concept is extensively validated for research and practices as the ES concepts were; 2) part of the current discussion follows the short and insufficient formulation of the concepts in NCP and their differences of ES; and 3) the NCP concept brings few operational directives beyond the indicators that are common to both approaches, what results in questioning if this NCP concept is really new regarding ES.

Kadykalo et al (2019) made a systematic review, despite being limited, to point the differences and similarities between both concepts. The authors compared both concepts in eleven aspects (conceptual claims) and found six aspects where NCP despite claiming to be different, wasn’t considered a real novelty by the authors (culture, social sciences, and humanities, ILK [indigenous and local knowledge], negative contributions of nature, generalizing perspective, non–instrumental values, and valuation) and five aspects that in their analysis, resulted in novelties (diverse worldviews, context–specific perspective, relational values, fuzzy and fluid reporting categories and groups, inclusive language and framing).

The discussion then assumes that the central aspects claim as a novel by NCP (e.g. culture) was already being treated by ES and could have been underestimated in Diaz et al. (2018). The authors (KADYKALO et al., 2019) claim that ES is an active and live science branch and the discussions about diverse concepts are still open and evolving (e.g. cultural services) and possibly some of the “conceptual failures” pointed by Diaz et al. (2018) have increasingly being analyzed and gaining momentum, what in turn could be what has originated the NCP perspective.

Ainscough et al. (2019) work is almost an opinion survey that tries to elucidate the points of agreement/dissatisfaction of the ES community and collaborate by identifying in which points the practical and theoretical perspectives of ES must be improved. This work has a serious limitation in representativeness because it was made in a European conference from *ecosystem services partnership*, which excludes a part of the researchers' universe that didn’t attend that particular conference. Nevertheless, the authors present several results that probably will base the development of the field for next years and also two new concepts to be added to the current conceptual body: 1) the boundary object, the idea that ES are opened to multiple interpretations; and 2) guided pluralism, referring to criteria or reference themes (cross–cutting themes) in relation to which the research and works in the field must refer to keep cohesion on the theoretical body.

Remarkably, the first reference theme from Ainscough et al. (2019) discusses the “purpose of the concept” of ES where the majority of respondents pointed the reason for ES assessments as “raising awareness about the relations of nature and society”. The second theme (*concerns with the use of economic valuation*) was discussing the economic valuation of ES where the major preoccupation wasn’t the valuation per se but in the possible misuses of this valuation. The third theme, which content follows the second, (*the importance of understanding social and cultural values in policy and decision–making*) shows the concern of researchers with the lack of non–economic valuation methods and the lack of interest (…) of non–economic valuation in the decision making process. The absence of social and cultural values was considered a bias on the method and that bias should be used to guide future research. The rest of the reference themes are focused on method plurality and interdisciplinarity (the need to further expand inter– and transdisciplinary approaches to ecosystem services assessments) and on the decision–making process that is not relevant to the present discussion.

It is not possible to know if Ainscough's et al. (2019) work represents a reaction to NCP emergence or it is purely following an old trend inside ES evolution. The data of this research were collected in ESP 2016, but some relevant works about NCP were already published (e.g. DIAZ et al., 2015a and 2015b) what can also be understood as reinforcing the questioning from Kadykalo et al. (2019) about the independence and originality on the origin of NCPs.

In an approach methodologically close to Ainscough et al. (2019), Pires et al., (2020) made a survey at the ESP conference in Latin America (2018) in Brazil and found a positive correlation between those who were using a quantitative approach and the use of the term ES and on the other hand, those more concerned with qualitative approaches were keener to use NCPs. As in Ainscough et al. (2019), the representative bias is repeated by the sampling choice.

Despite that sampling issues, results seem superficial once it is possible the existence of a common causality underneath the qualitative and quantitative works that wasn't identified in Pires et al. (2020) work. It is possible that the quantitative researches are applied and operation uses of the theory, where the body of knowledge is used to test the hypothesis, subsidize calibration or validation of tools and discussion of applied results and less frequently these works tend to discuss the conceptual and epistemological basis of the field. That happens because the quantitative tools are focused to develop and discuss other objectives for scientific progress, named the application of the theory. Qualitative works, on the other hand, search for interpretations and reinterpretations of concepts and approaches and more frequently put them closer to conceptual scientific advances.

Independent on the root of the concept, deficits on the theoretical and practical approaches were identified and are now clear. Those deficits found by several authors (e.g. KADYKALO et al., 2019) must be used to expand the limits and influence of this research field, guided by the idea of the creation of a holistic body of knowledge, which helps the science–policy interface of IPBES and its influence in making the ES agenda present in decision making.

Perhaps the major noise created by the publication of Diaz et al. (2018) was the tension inside the ES researcher's community (PETERSON et al., 2018) once this tension can lead to less commitment with IPBES and therefore impact negatively on the implementation of ES research and operational agenda, which has been developed for more than 40 years (PIRES et al., 2020).

In the present work, it is understood that plurality in concepts and frameworks is fundamental to scientific development and that conceptual breaks are necessary and desired steps in the evolutionary process. Therefore we echo the position of Peterson et al. (2018) on the theme reiterating the concern that an eventual polarization between people and institutions would generate losses for both sides on the implementation of the research agenda in the ecosystem services field:

> Although scientific debate is vital for testing ideas, polarization within scientific communities often impedes science and practice because it can lead to the silencing of less powerful voices and reducing the diversity of perspectives in divisive and unproductive discussion. (Peterson et al., 2018, p. 6).

2.4.2.2 Ecosystem Services Valuation Theory

Ecosystem Services concepts have some sort of co–production character embedded. The production of these services is therefore made part by nature, part by society, with differing proportions among them depending on the service, but forming an intertwined entity that can only make sense when analyzed in an integrated perspective like the SES. Thus it makes no sense to the discussion of ES considering the ocean producing fish if there is no society to consuming them. If the society were eliminated from the equation, there will be no ES, just nature operating and self–regulating (what some authors consider as an ecosystem function – see de GROOT et al., 2002). It also cannot make sense in talking about cultural ecosystem services if there is no culture, a distinctively human trait. Therefore it is understood that ES works inside SES and is the fruit of the interrelations between nature and society, or in other words, they are co–creation of nature and society (de GROOT et al., 2002; KREMER et al., 2015; COSTANZA et al., 2017).

Societies have been acting on ecosystems to select and amplify those ES that is convenient. Thus it is not only nature that provides services to society, but also society making services to nature, in a feedback loop on the relation that can be called *Services to Ecosystems* (COMBERTI et al., 2015). Examples of that are in the domestication of fauna and flora, artificial selection of species, agriculture in general, soil quality enhancement, species protection, and others that have been practiced for millennia.

Currently, due to the population growth and the increase in social relations complexity, the way society organizes the increasing exchange in mater and energy with nature (the social metabolism of MARTINEZ–ALIER et al., 2010, or the throughput of DALY and FARLEY, 2011), is usually mediated trough markets, property rights, governance structures and social networks (COSTANZA e FARBER, 2002). Due to the technological potential of making great alterations in ecosystems and also due to the magnitude of necessary interventions in ecosystems to keep the flow of goods and services to society, those markets claim the necessity in assessing the value of those resources and also of the effort necessary to obtain them. That happens because at least in theory, society will choose resources that can bring a greater return for the least effort.

Choices in general bring implicitly the idea of valuation. Imagining the idea of choosing without valuating refers to entertainment shows where one person is locked in an acoustically isolated cabin must answer yes or no to the exchange of objects without seeing them. In this case, it would be possible to trade a fancy car for a banana, because the person was forbidden to make value judgments about the items in its possession. Trades like this are very difficult to see in the real world.

There are many definitions of value (COSTANZA e FARBER, 2002). Economists have been trying to define it since Aristotle (FARBER et al., 2002). A good historical revision of economic thinking about the value (FARBER et al., 2002; DALY e FARLEY, 2011) would show a usual concept of value as “the contribution of an action or object to determined goals, objectives or conditions” (COSTANZA, 2000). Valuation then is the relative weights people attribute to diverse objects involved in decision making, depending on its contribution to a certain goal.

Some authors (e.g. FARBER et al., 2002) claim the distinction between intrinsic values, where biodiversity and ecosystems have their right of existence and being kept healthy, independent of human satisfaction; and instrumental values, which are fundamentally anthropocentric, and based on the idea of human preferences. Costanza (2000) states that it is necessary to abandon this dichotomy and to realize that it is impossible to put a value on something without establishing the overall goal to which this thing is contributing. And these objectives, the author claims, are socially constructed.

Farber et al. (2002) also bring the concept of “system of values” as being the group of norms and psychologic values that guide the actions and judgments of humans: “’*Value systems’ refer to intrapsychic constellations of norms and precepts that guide human judgment and action*”. Thus, inside a determined system of values, the distinction of intrinsic and instrumental values can be sustained, which makes the works of Farber et al. (2002) and Costanza (2000) coherent for that system of values.

Daly (1992) had identified at least three great objectives that should guide the global economic sector management and its interactions with the biosphere: efficient allocation, equitable distribution, and sustainable scale. Allocation is the division of the flow of resources in different uses, efficient implies respecting the next two restrictions and applying them to goods and services, through the market or not (ES included); Distribution is the division of the flow of goods and services between different persons or groups, and equitable implies a notion of justice between the current and future generations and with the different species that inhabit the planet; Scale refers to the volume of trades in mater in energy, the magnitude of the throughput, and must be of a limiting size that makes it sustainable, referring to the three sustainability criteria (DALY, 1990; FARLEY, 2012).

Costanza and Folke (1997) in a historic perspective state that societies that managed to integrate these three objectives from Daly (1992) probably made it in a coevolution pattern between social and natural systems through adaptation to a crisis, learning, and reconstruction (redesign). From this coevolution between nature and society follows three system values identified by the authors (COSTANZA e FOLKE, 1997, COSTANZA, 2000 e COSTANZA et al., 2017): *Efficiency value*, *Fairness Value* e *Sustainability Value*.

Efficiency value (or E–value) suggests that humans are individualists and rationally search for their own interests. To the group of individuals that adopt this system values (*Homo economicus*) value come from individual preferences; little scientific knowledge is used on the definition of these preferences and the value shows the “willingness to pay” for that good or service. Greater value has that product that collaborates more to the satisfaction of individual preferences. These preferences are not static, they slowly change according to education, institutional framework, propaganda, cultural assumptions, etc. (NORTH, 1994).

> That is, the beliefs that individuals, groups, and societies hold which determine choices are a consequence of learning through time – not just the span of an individual's life or of a generation of a society, but the learning embodied in individuals, groups, and societies that is cumulative through time and passed on intergenerationally by the culture of a society. (NORTH, 1994 page 360).

Justice based value (*Fairness–based* value or F–value) suggests that people vote in their preferences, not as individuals but as members of a community. This group of people (*Homo comunicus*) would define the value of goods and services in a fair and agreed fashion among with the present community but also taking future community into account (including other species). The greater value would have the goods that the community agreed to have, in a fair decision–making process.

Sustainability–based values (*Sustainable–based value or S–value)* requires an evaluation of the contribution of the good or service to ecological sustainability. As the S–value depends on its contribution in physical, chemical, and ecologic on the long–range, including different spatial and time scales, it is necessary great scientific knowledge to understand the roles of each good or service in a broad and complex SES. People with this system of values usually attribute values as if they represent the system as a whole. This perspective, claim the authors, makes the best attribution of value to ES in all its contributions to society, including at short and long–range, and also the maintenance of options for future generations (COSTANZA e FOLKE, 1997). More value would have those goods and services that collaborate more to long–range sustainability.

There is a strong affinity in this approach (COSTANZA e FOLKE, 1997, COSTANZA, 2000 e COSTANZA et al., 2017) of Efficiency value, Fairness value, and Sustainability value when compared to the typology of de Groot et al. (2002). Despite the fact they didn't use the same terms, the last authors suggest that total ecosystem services values can be obtained after three valuation forms: *Ecological value*, *Socio–cultural value* e *Economic value*.

Economic value is the measure of goods and services in monetary terms. It can be obtained using direct valuation from the market for those goods that have a market value, through evaluations of revealed or stated preferences[9] , or even with group valuations where the importance of the service is determined in a collective agreement and not using the sum of individual preferences. This group valuation can be done in degrees of importance, despite the economic value (e.g. LAU et al., 2019). Except for the group valuation, Economic value (de GROOT et al., 2002) is very similar to Efficiency value (COSTANZA e FOLKE, 1997, COSTANZA, 2000 e COSTANZA et al., 2017).

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[9] Stated or revealed preferences

Social–cultural values are relevant to show the importance of goods and services to society, in terms of equity and perception. They are related to services that come from the informational function of ecosystems (de GROOT et al., 2002) like recreation, and other values as artistic and cultural, spiritual and historic, aesthetic and finally scientific and educational. These equity–related services are compared to the *Fairness–based value* (COSTANZA e FOLKE, 1997, COSTANZA, 2000 e COSTANZA et al., 2017) and are representative in both authors of a universe of plural values that must be presented in ecosystem valuations.

Ecological value (de GROOT, 2002) is the measurement of value based on the capacity of the ecosystem in sustainably providing goods and services, in the sense that these services can be explored at compatible levels of natural regeneration and resilience of the SES. The ecological value, for the authors, comes from the integrity of regulation and habitat functions, associated with their rarity, complexity, and diversity (de GROOT et al., 2002). Ecological value is very close to the Sustainable–based value (COSTANZA e FOLKE, 1997, COSTANZA, 2000 e COSTANZA et al., 2017) and it is remarkable that in all these sources the concern of duration in long–range (including future generations) are present.

Both classification (de GROOT et al., 2002) of *Ecological value*, *Socio–cultural value* e *Economic value* and (COSTANZA e FOLKE, 1997, COSTANZA, 2000 e COSTANZA et al., 2017) for *Efficiency value*, *Fairness Value* e *Sustainability Value* are based on what Farber et al. (2002) named “systems of values”. Finally, considering that systems of values and sets of shared values and beliefs, both typologies can be rooted in an older and broader approach presented by the Culture Theory, or the Theory of Plural Rationalities (THOMPSON, 1997; SCHWARZ and THOMPSON, 1990; THOMPSON, ELLIS and WILDAVSKY, 1990). This theory will be presented in the next chapter.

Valuation of ES, at last, is relevant for decision making because it provides a comparison of importance (value) between two things. This comparison is the basis of decision making. Economic valuation then is important in a determined context, usually a capitalist society, where gains and losses are measured in monetary terms. But purely economic valuation has several problems, for example ignoring justice and sustainability values. And even the discount rates, a very common tool of economic valuation to deal with monetary variations through time, has its problems. When adopting a discount rate for the future [an economist]:

> assumes that all consequences of that action are known; also assumes that all consequences can be measured in economic terms; stablishes that this

> generation is the only responsible for the determination of the discount rate; assumes that some mistake from now can be repaired in the future paying a different tax. (MEADOWS, 2010)

The author concludes with the idea that all limitations pointed above, due to climate change effects, are fundamentally wrong (MEADOWS, 2010).

North (1994) follows Meadows (2010) lines when states that the framework of rational decision assumes the individuals act in self–interest because they know what is best for them and act accordingly. That alone is problematic. But in situations of increasing uncertainty (like climate change), this rational decision is fundamentally wrong because it is happening in an open system with a pervasive driver with unknown effects.

Temper and Martinez–Alier (2013) criticize the process of economic valuation and discount rates adoption because a) the process of determining prices deepens and reproduces structural inequalities with negative distributive effects; b) the current value encourages decision making processes that excludes other forms of participation; c) current values do not recognize or considers cultural differences or value pluralities.

Other approaches to valuation are still possible. Systems ecology for instance has its methods of value attribution. The most known is eMergy valuation (ODUM e ODUM, 2008; FISCUS e FATH, 2018; OLIVEIRA e SINISGALLI, 2018). In this kind of analysis, the true value of a good or service is the measurement in terms of emergy, or the investment made by nature and humans in its creation. Emergy valuation, therefore, states that the energy flows are the source of all wealth, presented in ores, plants, or services that nature provides. Despite being an interesting alternative, this approach is hermetic and of difficult communication (OLIVEIRA e SINISGALLI, 2018).

Farber (2002) concludes that value originates at last from the constellation of society’s shared values, the systems of values, as does from the technological availability, which transforms things to satisfy human needs.

Costanza (2000) final recommendation is to consider the three types of values when ES valuation is at hand: “In doing valuation of ecosystem services, we need to consider a broader set of goals that include ecological sustainability and social fairness, along with the traditional economic goal of efficiency.”

Despite these limitations of economic valuation, it was realized in this work due to their communication capacity in the context of a capitalist society. It is undeniable that people in general and particularly decision–makers know the language of economic capital. Therefore economic valuation with all its problems is one of the main forms of showing the importance of ES to be understood by the general public. Quoting Costanza et al. (2017) one last time "There is not one right way to assess and value ecosystem services. There is however a wrong way, that is, not to do it at all."

2.4.3 Economic valuation of Ecosystem Services from Ubatuba

In global terms, society is losing ecosystem services. Despite the classic assessments that show the value of ES are bigger than the global GDP (COSTANZA et al. 1997 e de GROOT et al., 2012) a more recent study (COSTANZA et al., 2014) shows that just considering land–use change, the planet loses between USD4.3 and USD20.2 trillion per year[10]. For the year 2011, it was calculated that nature provides between USD 125–145 trillion per year (COSTANZA et al., 2014)[11] for a global GDP of USD73.3 trillion[12].

The downscaling of these global assessments and is economic values to a regional or municipal level is not trivial. Nor is the comparison of different assessments. The differences of values can happen due to incomplete studies, or to researches that focused on different sets of ES, even in close or related biomes (COSTANZA et al., 2014; RAO et al., 2015; MEHVAR et al., 2018). According to the authors:

> These discrepancies might be in temporal scale of studies, the way that data has been collected, number of services valued, type of the estimated values, location of the case studies, probability of the hazard occurrence and importance of the hinterlands (relevant for the replacement, substitute and avoided damage cost method) and other factors that make the estimated results not easily comparable. (MEHVAR et al., 2018, p.10)

It is therefore understood that comparisons about economic assessments could be more effective if standardization of methods, time horizons, number of services (RAO et al., 2015) but despite that being impossible (and even undesirable under plural valuation perspectives) it would also have intrinsic differences in each study because some ES values (tourism and recreation; aesthetic values, etc.) are assessed by contingent valuation, where people are questioned about their willingness to pay for these ES. Value then is obtained due to individual declarations, which can change at any moment. RAO et al. (2015) also show that some ES are directly dependent on local GDP, which makes sense when for instance coastal protection against storms is applied in rich *vs.* poor areas.

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[10] Considering a 2007 dollar

[11] Idem

[12] https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?end=2011&start=1960&view=chart acessado em 26/06/2020

One of the highest impact papers in the field of ES valuation (COSTANZA et al., 1997) assesses coastal ES on a global scale by the use of a standard value per hectare and applying it in the whole area (this technique is called benefit transfer). Results show USD 4050 per hectare per year (1997 dollar) for coastal areas in general and USD252 for the open ocean. In 2012 these values were revised, through a broad literature review, where authors (de GROOT et al., 2012) searched for local scale valuations to reduce the effects of benefit transfer. The results for the same ecosystems are Int$[13] 28 917 /ha/year for coastal areas and Int$ 491/ha/year to open ocean. Rao et al., (2015) assessment still found values of USD 0.51 to 2 529.9/ha/year for a 2013 dollar, reinforcing that variations are the rule when talking about economic valuation of ES.

The average value found in the present work was USD43.70 (±USD 0.26)/ha/year[14] for Ubatuba coastal area. Despite being inside the range proposed by RAO et al. (2015), this value is far from those stated by Costanza et al (1997) and for de Groot et al (2012). There are several reasons for that: first, our values are the integration of different values and some of them were not considered in the whole area (e.g. sewage depuration and nutrient cycling) that were considered only on the polygons adjacent to the beach; second, the values from Costanza et al (1997) and for de Groot et al (2012) consider a different set of ecosystem services (e.g. regulation against perturbation, biologic control, habitat/refugee, raw materials) despite the exaggerated value of nutrient cycling that we have reduced to 10%[15] of the proposed (see table 3).

Climate change, depending on the model considered, tends to reduce the value of ecosystem services (SUMAILA et al., 2011; GRIMM et al., 2016). On the simulations presented in this work, climate change has altered in difference rates, all studied ES. These variations are reviewed here for discussion.

Results for **Crustaceans production** show a small gain in production for both climate change scenarios with a small loss for reactive tourists' scenario.

Metzger et al (2007) call attention to the synergic effect of the increase in CO_2 concentration on the water with an increase in water temperature to have negative effects on the survival of the crab (*Cancer pagurus*). Other niche variations are documented for crabs due to changes in environmental conditions as conquering new habitats due to change in

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[13] Values were expressed in terms of 2007 'International' $/ha/year, i.e. translated into US$ values on the basis of Purchasing Power Parity (PPP) and contains site-, study-, and context-specific information from the case studies. (de GROOT et al., 2014 p.155)

[14] In this work all dólar measures considers na average 2010-2017 dollar price (USD 1 = R$3.33)

[15] De Groot et al. (2002) also found discrepant values for this ES (between USD87 and 21,100 /ha/year).

water temperature (e.g. NABOUT, 2009; NEUMANN et al., 2013; VIANNA, 2019); change in feeding behavior due to changes in the rainy season (ALBERTI et al., 2007; VIANNA, 2019) with possible effects on local food web; change in reproductive rate due to increase in temperature (CELENTANO & DEFEO, 2016) for the crab *Emerita brasiliensis* in Uruguay.

For shrimps, Nguyen et al. (2020) reported the drastic effect that salinity alterations can bring to the reproduction and survival of these animals. Synergic effects of variations in salinity and temperature were reported for several physiological disturbances in shrimps (GONZÁLEZ–RUIZ et al., 2020); an increase in parasitism with higher mortality rates are also present when the water temperature is increasing (BYERS, 2020). And toxic effects of organochlorine are worse when salinity and temperature are varying; consequently increasing mortality rates (PAWAR et al., 2020).

All these synergistic effects and variations in feeding behavior, mortality rates, etc. were not captured by the model. It could be embraced by the model in a new iterative process that would certainly result in greater variations of ES provision due to climate change effects.

Therefore it can be pointed out that the overall results of this model are conservative because there are several deleterious effects of climate change that weren't modeled due to restrictions in time and resources.

What can be said from the modelling is that RCP2.6 will bring a slightly increase in production (1.64% ±0.45%) with positive impacts of 1.7 M dollars (±0.5 M dollars). For RCP8.5 the average of runs point to small positive result 0.23% (±1.13%) showing a possible gain in this ES but considering the standard deviation of this variable, a small loss is also possible. Those uncertainties are happening due to the presence of independent variables that determine the growth of crustaceans being affected positively and negatively by climate change. In one hand climate change increase the rain patterns (bringing more detritus and food for crustaceans), on the other hand climate change decrease the reproduction rates and therefore the whole population. If base case conditions were kept, reactive tourists' scenario would most probably bring economic losses -0.41 (±1.51%) again allowing the possibility of a slight increase. This loss is following the decrease in food for Crustaceans that come from organic matter dumped at the sea.

The best results are on the utopic economic scenario because nature would provide this ES indefinitely without losing value. Here the base case points to gains of USD 104 M dollars (± USD 1.9 M dollars) with small gains and losses as described above.

For the selfish scenario the percentage losses and gains are the same of the base case for RCP2.6 scenario (1.64% ±0.45%) despite the loss of USD 96 million in adopting this scenario. For RCP 8.5 the losses are very small with a chance of having small gains as well – 0.06% ±1.11%. For reactive tourist, the losses are -0.89% (±1.51%) which again point to an inconclusive path.

Balanced economic scenario for Crustaceans shows the same small gains for RCP2.6 (1.64% ±0.45%) despite the losses of USD 85million in adopting this scenario. RCP8.5 shows very small gains 0.04% (±1.12%) which again may represent small losses. For reactive tourists the loss is -0.75% (±1.51%) which is smaller than in the selfish scenario.

Mollusks production results from the model shows their population is slightly affected by climate change and reactive tourists' scenarios. In a global study, Narita et al. (2012) calculated the economic losses associated with variations on the production of Bivalves to be around USD100 billion globally until 2100. Climate change can influence the bivalve population because of the change in the patterns of rain, salinity and even in the frequency of extreme events (BRUGÈRE, *&* De YOUNG, 2015); it is also expected changes due to the increase in toxic algae blooms, diseases, increase in invasive species and decrease in primary productivity (KARVONEN et al., 2010).

In some cases, Mollusks production is being limited by nutrients in the water (GUYONDET et al., 2015) and therefore these populations are more vulnerable to environmental conditions changes because they seem to live close to a threshold. These are examples that can happen in a future situation in Ubatuba and affect Bivalve production. Probably lack of nutrients wouldn't happen due to the human influence on the water quality by dumping sewage on the water.

The results found in the multiple runs of the present work showed for the utopic scenario, losses being more probable in a RCP2.6 scenario, a small gain more probable in the RCP8.5 and greater losses in reactive tourists. For RCP2.6 the losses were -0.67 (±2.40%) pointing that despite being more probable, losses are not the only possible result. These losses represent values of -83K dollars (± 301 K dollars) along the century. For RCP8.5 the average results of five runs pointed to small gain of 0.46% (± 0.98%) with values of 58 K dollars (± 123 K dollars), probably because the amount of detritus dumped at the water increased the food availability for these organisms in more dominant way that the negative effect of climate change has in their reproductive cycle. For reactive tourists losses were greater -2.09% (± 5.18%) with values of -263 K dollars (± 652 K dollars) but the standard deviation also makes possible to have small gains in this scenario.

The selfish scenario present losses in all climate scenario with percentages (-0.67% ± 2.39 for RCP2.6, -0.43% ± 0.99% for RCP8.5 and -2.21% ± 5.18% for RT) and associated economic values (-7.7 K dollars ± 27K dollars, - 4.9 K dollars ± USD 11.5 K dollars e –25 K dollars ± 60 K dollars) for RCP2.6, RCP8.5 and RT respectively. The adoption of this economic scenario would represent losses of one order of magnitude (1.1 M dollars ± 25 K dollars) when compared to the utopic scenario (12.6 M dollars ± 275 K dollars).

Balanced economic scenario showed intermediate percentage (-0.67% ± 2.39%, -0.09% ± 0.99% and -2.17% ± 5.17) and associated values (-15 K dollars ± USD 55 K dollars, -2 K dollars ± 22.9 K dollars e - 50 K dollars ± 120 K dollars) losses. This scenario value (2 M dollars ± 50 K dollars) represents great losses when compared to utopic scenario (12 M dollars ± 275 K dollars), but it is better than the selfish situation (1.1 M dollars ± 25 K dollars) in the base case and in all scenarios.

Cartilaginous fish most evident result points to production reduction due to climate change RCP8.5 scenarios. Both RCP2.6 and reactive tourists' scenario presents small gains. Our model points to losses on RCP8.5 of -0.73% (± 1.60%) corresponding to -122 K dollars (±268 K dollars). For RCP2.6 and reactive tourists small gains of (0.91% ±1.53% and 0.34% ± 0.91%), corresponding to 153 K dollars (±257 K dollars) and 56 K dollars (±152 K dollars) showing that this service is being affected positively and negatively by these scenarios in a very narrow proportion.

Rosa et al. (2014) show the necessity of major researches to enlighten the synergies in temperature increase associated with pH decrease for the survival of cartilaginous fishes and also point to the low survival rate of one tropical shark (*Chiloscyllium punctatum*) due to water temperature increase. Each species will react to climate change in a particular way depending on its genetics, niche, etc. (O'BRIEN et al., 2013) but species with similar biology probably will behave in similar ways.

Selfish economic scenario again showed almost the same results but with bigger and certain losses for RCP 8.5 (0.91% ± 1.53%, -3.19% ± 1.58% and 0.23% ± 0.91%) with associated values (-14 K dollars ± 23.7 K dollars, -49 K dollars ± 24.5 K dollars and -3.5 K dollars ± 14 K dollars) for each scenario respectively despite the huge difference of value between this economic scenario (1.5 M dollars ± 3.1 K dollars) and the base case (16 M dollars ± 33.8 K dollars).

Balanced economic scenario has intermediate percentages but again confirm the unambiguous losses for this service in RCP8.5 (-2.24% ± 1.59%) and associated values (-69 K dollars ± 49 K dollars) despite the gains in RCP2.6 and reactive tourists in percentage

(0.91% ± 1.53% and 0.26% ± 0.91%) and value (28 K dollars ± 47 K dollars and 7.9 K dollars ± 28 K dollars). Adoption of this scenario (3 M dollars ± 6.2 K dollars) are also very small when compared to utopic situation (16.7 M dollars ± 33.8 K dollars), but is better when compared to selfish situation scenario (1.5 M dollars ± 3.1 K dollars).

Using predictive population models for cartilaginous fish in the great reef barrier in Australia, Chin et al. (2010) found that species that were closely related to coastal environment and land (in opposition to those that live in the open ocean) probably will suffer more the consequences of climate change (temperature and current changes). Our aggregation of information from the work of Rocha (2003) and the fisheries data does not allows us to take any conclusion regarding this habits. But in an Ubatuba's survey, Silvério (2010) identified four main species landed on the harbor (*Sphyrna lewini* – Tubarão Martelo, *Prionace glauca* – Tubarão azul, *Rhizoprionodon lalandii* – Tubarão–de–bico–fino–brasileiro e *Isurus oxyrinchus* – Tubarão–mako). If we consider that those species more related to the coast would be strongly affected by climate change (CHIN et al., 2010), probably that would be observed happening in hammer shark (Tubarão–martelo) and the Brazilian fine–billed shark (Tubarão–de–bico–fino–brasileiro).

Bonefish production is also reduced due to both scenarios of climate change and have gains with reactive tourists' scenarios.

For the base case RCP 2.6 is the only loss with percentage of -0.29% ± 0.67% and associated values of –459 K dollars ± 1 M dollars; RCP 8.5 being positive with percentages of 0.51% ± 3.20% and associated values of 808 K dollars ± 5 M dollars in this case is seen as probably being part of the long tail, a minor possibility of the mean of 5 runs, because it present negative values in both economic scenarios (see ahead). Reactive tourists brings positive results again 1.33% ± 1.76% with associated values of 2 M dollars ± 2.7 M dollars showing that controlling the number of tourists can actually bring positive results for this service.

For selfish economic scenario, climate brings losses in percentages (-0.30% ± 0.65% and -1.92% ± 3.13%) for RCP2.6 and RCP 8.5 respectively with associated values of –43 K dollars ± 94 K dollars and –278 K dollars ± 454 K dollars; Reactive tourists brings gains in percentage 1.19% ± 1.75% and associated values of 172 K dollars ± 253 K dollars. Once again the economic provision in the selfish (14.5 M dollars ± 286 K dollars) and utopic scenarios (156 M dollars ± 3 M dollars) are very different with more than ten times the other of difference.

Balanced economic scenario presented intermediate percentages (-0.30% ± 0.66%, -0.97% ± 3.16% and 1.23% ± 1.75%) and associated values (-86 K dollars ± 190 K dollars, -281 K dollars ± 912 K dollars and 355 K dollars ± 506 K dollars) of losses and gain. As in the other cases of fisheries, the amount provided by the balanced economic scenario (28 M dollars ± 569 K dollars) is much smaller than the utopic situation (156.9 M dollars ± 3 M dollars) but still better when compared to selfish situation (14.5 M dollars ± 286 K dollars).

The bonefish group is strongly diverse and probably climate change will have a different effect on each species of this group. In a broad perspective, one can imagine that climate change will affect movement speed (NOWELL et al., 2015), physiology, development rates, reproduction, behavior and survival rates (BRANDER, 2010), habitat degradation (SUMAILA et al., 2011) and increase in respiratory rates (ROESSIG et al., 2004). Consequently, all economies that depend on fisheries will be affected.

Countries with a high dependency on fisheries and with limited economic capacity for adaptation to climate change impacts on this sector are more vulnerable. In a global study, some African countries, tropical Asia countries, and two South American (Peru and Colombia) are among this vulnerable list (ALLISON et al., 2009). Another study made in 67 exclusive economic zones, responsible for 60% of global fisheries, presents an increase of productivity in higher latitudes and decrease of productivity in lower latitudes, with an average variance of 3.4% (BARANGE et al., 2014), which are coherent with the simulations of the present work.

Carbon sequestration service could be of high relevance for the city's budget if there was a market that pays for the removal of carbon made for this coastal area. This study did not consider the additionality principle, common in carbon markets, because the objectives here were different.

Every day in the oceans more than one hundred million tons of carbon in the form of CO2 are transformed into organic compounds by Phytoplankton (BEHRENFELD et al., 2006). The trend of decreasing the primary productivity has been observed since 1999 (Op. cit.); other authors in a multi–decadal study (1998–2018) claim that there is no decreasing trend (KULK et al., 2020); different authors (e.g. HENSON et al., 2010) also claim that observed variations cannot be certainly attributed to climate change because usually decadal variations happen naturally. The difference between natural variations and those created by climate change is difficult to discern particularly when dealing with primary productivity because the time series of remote sensing is not very long (ELSWORTH et al., 2020).

For Ubatuba, starting for the calibration, this service shows that the studied region removes aroung 680 (summer) and 200 (winter) tons of carbon every day. These values are compatible with those suggested by Falkoswski (1994) of 30–50E9 metric tons of carbon each year for the ocean as a whole. When considered the oceans occupy an area of 360 million square kilometers, an average value of 3.805E-07 ton. per square meter is removed every day. Considering the studied area of 158E+09 m2 the daily removal of carbon would be around 602.3 tons.

Our results show that carbon sequestration would be affected by climate change with percentages of -5.93% ±0.01% and -10.20% ± 0.01% for RCP 2.6 and so does the values RCP 8.5 respectively, with associated values of - 6 M dollars ± 8 K dollars and –10.5 M dollars ± 11 K dollars. For Reactive tourists scenario a very small gain 0.02% ± 0.00% were observed to which correspond values of 17 K dollars ± 1.9 K dollars. For the reactive tourists' scenario, a small gain is presented, probably following the decrease in water particles dumped on the coast and consequent increase in light intensity in the water.

In the selfish scenario the losses due to climate change percentages (-8.81% ± 0.03%, -18.45% ± 0.11% and +0.06% ±0.00%) and associated values (-843 K dollars ± 2.5 K dollars, -1.7 K dollars ± 10 K dollars and 6 K dollars ± 265 dollars) are the worst. The selfish scenario yield (9.5 M dollars ± 659 dollars) is very low when compared to the utopic scenario (103 M dollars ± 2.9 K dollars) showing several million dollars and an order of magnitude of difference.

Balanced economic situation have again intermediate percentage losses (-8.18% ± 0.02%, -16.33% ± 0.05% and +0.05% ±0.00%) and associated values (-1.5 M dollars ± 3 K dollars, - 3 M dollars ± 9 K dollars and 9 K dollars ± 759 dollars). This situation is worse (19 M dollars ± 595 dollars) than the utopic scenario (103 M dollars ± 2.9 K dollars). But is better when compared to selfish situation (9.5 M dollars ± 659 dollars).

Oxygen production service shows that the region produces between 100 and 450 tons of this gas every day. These values are compatible with those suggested by Emerson et al. (2008) of 0.4208 ± 0.2367 g/m^2/day that applied to the total study area (1.58E+09 m^2) would produce 665.08±374.5 tons per day.

The discussion about primary productivity on carbon sequestration is also pertinent to oxygen production once both services are the fruit of primary productivity. Joos et al. (2003) states a clear tendency in the decrease of the global dissolved ocean concentration and also raise the hypothesis that this diminishing in O_2 concentration is related to a rearrange in global maritime currents. Other authors agree with that decreasing trend and estimate losses between 4 and 7% of O_2 concentration in the oceans until the end of the 21st century (MATEAR & HIRST, 2003). Limburg et al. (2020) state that the oceans have already lost between 1 and 2% of its ocean since the middle of the 20th century and the numbers of locals that have registered worse conditions are growing.

The results in the present work show that oxygen production will be affected by climate change in percentages of -5.90% ± 0.01%, -10.13% ± 0.01% and +0.01% ± 0.00% for RCP2.5, RCP8.5 and reactive tourist respectively, with associated values of –1.1 M dollars ± 1.4 K dollars, -2 M dollars ± 2.3 K dollars and 2.9 K dollars ± 501 dollars.

For the selfish economic scenario percentage losses (-8.76% ± 0.02%, -18.27% ± 0.10% and +0.06% ± 0.01%) and correspondent values (-159 K dollars ± 401 dollars, -333 K dollars ± 1.8 K dollars and 1 K dollars ± 91 dollars) are the worst option for both climate and reactive tourists. The difference between the utopic (19.7 M dollars ± 740 dollars) and the selfish (1.8 M dollars ± 129 dollars) scenario is again of one order of magnitude and several million dollars.

The balanced economic scenario presented the usual intermediate percentage losses (-8.14% ± 0.02%, -16.19% ± 0.06% and +0.04% ± 0.01%) and correspondent values (–295 K dollars ± 572 dollars, -588 K dollars ± 2 K dollars and 1.6 K dollars ± 208 dollars) for RCP2.6, RCP8.5 and reactive tourists respectively. This scenario once more represents an intermediate situation (3.6 M dollars ± 141 dollars) when compared to the utopic scenario (19 M dollars ± 740 dollars) and a better option when compared to selfish (1.8 M dollars ± 129 dollars).

Oxygen production and carbon sequestration are showing decreasing in future production due to climate change in the present simulation. Sumaila et al. (2011) show two projections for primary productivity varying to climate change: the first shows growth of 0.7–8% until 2050 and the other a decrease from 2–20% until 2100. In this case, the results of our simulation are congruent with the second Sumaila's projection.

For **nitrogen cycling** and **mineralization** economic values come from Costanza et a. (1997) that attributed to nutrient cycling a value (118 dollars per hectare per year) that we considered to be astronomical. For their work a value like that made sense because they calculated it in a role of soil creation. In our work, this value would put mineralization values much above any other service (because it happens in a huge polygon area), biasing the analysis. Therefore the option taken was to arbitrarily reduce the economic value of mineralization by 90% in a way that this service occupies the same scale of nutrient cycling service, considered a related ES. Then mineralization has a small value but operates in a huge area and nitrogen cycling has more accentuated value but happens on small scale.

The dumping of sewage and solids on the ocean has been studied for several years, particularly from a project created by IGBP (International Geosphere–Biosphere Program)[16] in 1993 named "land–ocean interactions on the coastal zone" (LOICZ) (RAMESHA et al., 2015). The objectives of this program were to understand to which extent land–use changes could affect the coastal environment and the consequences of these changes. Currently, the program is part of Future Earth[17], an international scientist's network searching for sustainable solutions for nature–society interactions. One of the main products of LOICZ is the volume that shows a synthesis of global continental flows (LIU et al., 2010) where nitrogen load to the ocean is calculated in 1,350E09 mol/year which is a number three times bigger than the previous mainstream literature (MEYBECK, 1982).

Currently is a consensus that nitrogen dumping on oceans (so does Phosphate) happens much above tolerable limits. Agriculture, due to fertilizers and through legumes for fertilizing plantations, turns reactive a huge amount of nitrogen that was passively stocked on the atmosphere or in fossil fuels deposits.

This global mobilization of nitrogen is something of 120 million tons every year (ROCKSTROM et al., 2009) and considering that a good part of this nitrogen ends up in the ocean, makes this mineral a menace for global sustainability because (associated to phosphorus) it causes algae blooms, eutrophication and dead zones in the ocean. The same authors (Op. cit.) in their seminal study about planetary boundaries for human development showed that the nitrogen cycle must be reduced to 25% of current values to operate in a safe space.

This same work was updated (STEFFEN et al 2015) to include regional goals to previous global ones, focusing on the control of fertilizers production and distribution on the planet. The global production limit in this new work is 73Tg (73 million tons) of nitrogen, which is more than the previous goal from Rockstrom and yet a huge challenge for the current 120 million tons.

Mineralization in the present work happens on the scale of kilograms by day, when the whole area is considered. Our results show that between 10 and 44 kilograms of nitrogen are mineralized every day. Results also show that this service will be affected by climate

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[16] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/international-geosphere-biosphere-program

[17] https://futureearth.org/

change in percentages -2.59% ± 0.00%, -4.50% ± 0.01%, and -0.20% ± 0.00% for RCP2.6, RCP 8.5 and reactive tourists respectively, with associated values of –1.6 M dollars ± 1 K dollars, -2.9 M dollars ± 3.6 K dollars and -128 K dollars ± 686 dollars.

For selfish economic scenario percentage losses (-3.83% ± 0.02%, -8.13% ± 0.04%, and -0.77% ± 0.00%) and associated values (–230 K dollars ± 1 K dollars, -489 K dollars ± 2 K dollars and -46 K dollars ± 149 dollars) are the worst of the three.

The balanced economic scenario has intermediate percentage (-3.56% ± 0.01%, -7.20% ± 0.02%, and -0.58% ± 0.00%) and corresponding values (–426 K dollars ± 913 dollars, - 862 K dollars ± 2.7 K dollars and -68.9 K dollars ± 54 dollars) for climate change and reactive tourists scenarios. The economic value of mineralization under the utopic scenario (64.7 M dollars ± 1 K dollars) is ten times bigger than in the selfish scenario (6 M dollars ± 299 dollars), and five times bigger than the balanced (11 M dollars ± 390 dollars).

Nutrient cycling results show that the city dumps between 1 and 3 tons of nitrogen every day. With the expected population growth until the end of the century this value can grow to 35 tons dumped every day.

Results also show that this service will be slightly but positively affected by climate change with percentages of (0.09% ± 0.01% and 0.20% ± 0.01%) for RCP 2.6 and RCP 8.5 respectively and associated values of (72 K dollars ± 8.5 K dollars and 157 K dollars ± 7 .4 K dollars) with this service are positive in the case of climate change as if society was receiving an additional benefit. For reactive tourists the variations are diminishing the results in percentage (-0.25% ± 0.00%) and value (-198 K dollars ± 1.4 K dollars). This increase associated with climate change is no reason for celebration because it means that the ocean will be cycling more nitrogen than expected by population growth alone (carried by stronger rain pattern) but the overall limits for nitrogen on the ocean are the same (ROCKSTROM et al., 2009; STEFFEN et al., 2015) and this more service puts the city closer to an unknown threshold, not safer. It is also unknown the effects of these dumping in terms of harmful algae blooms (BERDALET et al., 2017) and consequent negative impacts on tourism and fisheries.

For the selfish scenario, the percentage rates (0.08% ± 0.02%, 0.20% ± 0.01% and -0.69% ± 0.01%) and associated values of (6.2 K dollars ± 1.6 K dollars, 14.3 K dollars ± 1 K dollars and -50 K dollars ± 413 dollars) are pretty much the same, despite the great loss in adopting this scenario (7.3 K dollars ± 499 dollars) when compared to the utopic (78.8 M dollars ± 2.9 K dollars).

The balanced economic scenario presents intermediate values with percentages (0.09% ± 0.02%, 0.20% ± 0.01% and -0.59% ± 0.00%) and associated values (13.2 K dollars ± .6 K dollars, 29.7 K dollars ± 1.4 K dollars and -85.5 K dollars ± 698 dollars) for each system's scenario respectively. This scenario (14.6 K dollars ± 782 dollars) brings a worse situation when compared to the utopic scenario (78.8 M dollars ± 2.9 K dollars) but brings a better solution when compared to the selfish (7.3 M dollars ± 499 dollars).

Sewage depuration service discussion can profit from the discussion of nitrogen cycling because they both represent problems with the same origin, the lack of treatment in water wastes. But despite the small overlap, this one is focused on the ecological processes responsible for the mortality of the biological part of the sewage.

Attempts to control the sewage deposition on the water happen worldwide since 1675 (LAHEY, 1982). São Paulo state, through its environmental agency (CETESB), has a program for periodic assessment of coastal batheability since 1968, and data started to be collected in Ubatuba in 1968 (CETESB, 1988). The evaluation at that time was intermittent and used to happen in places with a great concentration of people, without a systematic approach. A scheduled system was implemented in 1974. Since then, the methods for monitoring and laboratory analysis have evolved, the same happened with the communication of results to society and the health system. Nowadays they send bulletins of water quality to the health system; signs are fixed at beaches showing the result of the water quality assessment; and most importantly, the information about water quality is on social media and the internet at very simple access for those interested.

The city has three sewage treatment facilities and two pre–conditioning facilities planned to treat the maximum volume of 328 l per second[18]. The sewage system attendance index in 2010 was 33.5% of the population when all systems are summed (SABESP, the public system, and also alternatives systems that happen in the city) (UBATUBA, 2014). The sewage treatment plan is currently under revision to establish new goals for the enlargement of the services (UBATUBA, 2019).

Economic valuation of this service was made using values from Ecosystem Services Value Database as in the other cases. These values are biased once they present a measurement of value that is dependent on the area of ocean that is responsible for depuration of the sewage, and not on the amount of sewage. Therefore we assumed that the day with greater activity on the first year was that of the greater economic value, and then limited the economic growth to this cap.

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[18] http://site.sabesp.com.br/site/interna/Municipio.aspx?secaoId=18&id=623

Despite this limitation, climate change brings small gains to this ecosystem service. And reactive tourists' brings losses. On the utopic economic scenario percentage variations (0.09% ± 0.01%, 0.20% ± 0.01% and -0.24% ± 0.00%) and associated values (59 K dollars ± 5 K dollars, 124.8 K dollars ± 3.4 K dollars and -155.5 K dollars ± 1.6 K dollars) for each system's scenario respectively. Once again, these gains represent that more bacteria are dying on the water than expected and should not be celebrated as a real gain due to thresholds of sewage deposition on the water as discussed before. The bacterial death curve shows what happens to the bacterial population along the year, with values around 55kg of bacterial mortality every day. In winter due to less sunlight, the water temperature becomes responsible for mortality and therefore stochastic oscillations are present on the curve.

On the selfish economic scenario the percentage (0.11% ± 0.01%, 0.22% ± 0.03% and -0.67% ± 0.01%) and associated values (6.5 K dollars ± 759 dollars, 13.1 K dollars ± 1.5 K dollars and -40 K dollars ± 582 dollars) variations are the worst when comparing to utopic or balanced scenario, despite the great loss of adopting this scenario (5.9 M dollars ± 714 dollars) when compared to the utopic (63.8 M dollars ± 3.6 K dollars).

For the balanced economic scenario once again results in percentage (0.11% ± 0.01%, 0.21% ± 0.02% and -0.57% ± 0.01%) and associated values (12.4 K dollars ± 1 K dollars, 24.9 K dollars ± 2.4 K dollars and -67.4 K dollars ± 847 dollars) are intermediary despite some values to be similar with the selfish scenario. The adoption of this scenario (11.8 M dollars ± 1 M dollars) is better when compared to the selfish (5.9 M dollars ± 714 dollars) but much lower when compared to the utopic (63.8 K dollars ± 3.7 K dollars).

Water quality perception shows that the region loses quality due to climate change. Despite the economic values associated with this service being very small when compared to the rest of the ES analyzed, this is an indirect index for tourist satisfaction and therefore it can be used to understand tourists' behavior and plan for public policies (GHILARDI–LOPES et al., 2015).

Other authors already showed that environmental quality is as important as price policies for tourists to choose their destiny (OTRACHSHENKO & BOSELLO, 2015) and more recently Qiang et al. (2020) showed that tourists stay for short periods in beaches where the water quality (in their case measured through the amount of plastic at the beach) was not satisfactory, with consequent economic impacts of 28–32% compared to clean beaches.

Our results show that water quality will be slightly affected by climate change in percentage (-0.08% ± 0.00%, -0.16% ± 0.01% and 0.24% ± 0.00%) and so does with associated values (-284 dollars ± 12 dollars, -553 dollars ± 29 dollars and 829 ± 7 dollars).

The losses in the quality start as soon as the scenarios became active on the simulation because the rain variations start immediately; therefore it was impossible to make an estimative of when these variations would occur on the field.

The selfish scenario has the worst losses in terms of percentage (-0.10% ± 0.02%, -0.16% ± 0.01% and 0.67% ± 0.00%) and associated values (-31 dollars ± 6 dollars, -50 dollars ± 2 dollars and 211 dollars ± 3 dollars). The difference between what is provided in utopic (344 K dollars ± 11 dollars) and selfish scenarios (31.5 K dollars ± 3 dollars) is very big, one order of magnitude as usual.

The balanced economic scenario presented intermediary results with the best percentages (-0.09% ± 0.01%, -0.17% ± 0.01% and 0.57% ± 0.01%) and associated values (-58 dollars ± 7 dollars, -104 dollars ± 4 dollars and 359 dollars ± 5 dollars) for each scenario respectively. This scenario (62.8 K dollars ± 5 dollars) again occupies an intermediate position between the utopic (344K dollars ± 11 dollars) and the selfish (31 K dollars ± 3 dollars) economic scenarios.

The **aggregate of all ES** analysis shows that the best option for the city is to keep nature providing these services as long as possible. Any economic scenario that brings future values to the present is showing an average loss of one order of magnitude in the economic yield of ES. In the utopic scenario the yield is 622 M dollars ± 3.6 M dollars then when compared to the selfish scenario would be reduced to 57.6 M dollars ± 340 K dollars and for 114.8 M dollars ± 676.5 K dollars when compared to the balanced scenario.

The losses from climate change on ES provision varying from –7.5 M dollars (±3.8 M dollars) to –14.2 M dollars (± 6.3 M dollars) dollars in the best scenario (utopic) along the century for RCP2.6 and RCP 8.5 respectively. If more aggressive economic scenarios are applied, the situation gets worse because the simple adoption of one of these scenarios implies losses (-564.4 M dollars ± 340 K dollars for selfish and -507.3 M dollars ± 676 K dollars for balanced) of -81.55% (±0.59%) for balanced or -90.73% (±0.59%) for the selfish scenario. To these economic scenario losses, climate change still must be added, what would bring more losses for selfish (-1 M dollars ± 352 K dollars and -2.9 M dollars ± 578 M dollars) and balanced scenario (-2 M dollars ± 701 K dollars and -4.8 M dollars ± 1.1 M dollars) for RCP2.6 and RCP8.5 respectively.

The losses related to the reactive tourists' scenario are smaller (-980 K dollars ± 4 M dollars) for the utopic case. For the selfish and balanced, despite their small losses of (-65 K dollars ± 402 K dollars) for selfish and (-42 K dollars ± 802 K dollars) for balanced, an addition of losses must be made due to the adoption of these scenarios (-565 M dollars ± 402 K dollars and -508 M dollars ± 802 K dollars) respectively. This scenario in turn shows losses that have one order of magnitude of difference when compared to the effects of climate change.

2.4.4 Material assessment of Ecosystem Services

The material assessment of ES allowed us to analyze the variations expected on the ES in terms that were not purely economic, as suggested by many authors (COSTANZA e FOLKE, 1997; COSTANZA, 2000; de GROOT et al., 2002; FARBER, 2006 e COSTANZA et al., 2017). The losses of production in material terms, can profit from the same discussion made for the economic analysis because the effects of the losses in society and the overall limits of the ES to dumping are the same. Then, a discussion in terms of working days lost to scenarios is made here because it brings a new perspective about the material losses. The sustainability test is also discussed.

The analysis showed that climate change will bring variations in the provision, quantity, and quality of ES to the studied area. An abstract of these variations (Tables 6–9) shows losses in virtually all ES of food provision, carbon sequestration, oxygen production, mineralization, and water quality, but also presenting some gains, for some of them, and doubtable gains for sewage depuration and nutrient cycling due to the increase of dumping in the ocean.

One way to discuss the losses in food production is to make clear the number of working days that will be lost on the co–creation of these services due to climate change. The use of working days lost is useful to understand the impact of climate change on labor and productivity. For instance, in Singapore (KJESTROM et al., 2013) the number of days per year where the heat was beyond a secure threshold for work (>29ºC in the shade) changed from 10 days in the ’80s to 70 days in 2011. Thus, in our work, a ratio of lost productivity was obtained by dividing the total amount expected to be lost by daily productivity.

For instance, the Crustaceans production in RCP2.6 showed gains of 516 (±143) working days (330 181.08 kg for a daily average of 635kg). For RCP 8.5 gains were of 72 (± 258) working days and for reactive tourists, the losses were from -131 (± 479) working days. With the same construct, the integrated results (Table 9) show that losses and gains in working terms are big.

For RCP2.6 the sum of losses and gains means a positive gain of 494 (±946) working days (1–3 years). For RCP8.5 the gains are 161 (±1248) working days and for reactive tourists the losses are -272 (1854) working days.

Table 9: Productivity gains and losses

ES	RCP2.6	SD	RCP8.5	SD	RT	SD
Crustaceans	519.97	143.81	72.86	358.71	-131.64	479.27
Mollusks	-215.43	774.47	148.96	316.51	-675.65	1674.38
Cart. Fish	284.83	478.02	-227.50	499.68	104.75	283.55
Bone Fish	-95.00	218.22	167.13	1039.49	430.50	569.84
TOTAL	494.37	946.89	161.45	1248.63	-272.05	1854.28

Losses and gains in working days associated to the loss of productivity in fishery according to scenarios Source: the authors

The international Labor Association (ILO)[19] shows a list of reasons why climate change can impact negatively the business sector and the availability of work. In their list, job losses are attributed to an increase in extreme weather events in cities; heavy precipitation or extreme heat resulting in damage in crops in rural areas; impact in business assets like infrastructure, production sites, raw materials, and supply chains; impacts on working conditions and safety like heat stress and even migration due to uninhabitable environment.

The case presented here, losing or gaining fish for climate change, will be partially covered by ILO forecast when they point the damage to production sites and raw materials, but it didn't seem that ILO was concerned about fisheries and the working class of this sector when created this forecast. This is remarkable because fisheries worldwide employ more than 260 million people directly and indirectly from which 22 million are in small–scale fisheries (TEH & SUMAILA, 2013) which is the case of Ubatuba.

The other ES this kind of comparison is more difficult because the human element embedded in the co–production of these ES are not easily identified. For carbon sequestration (and oxygen production) for instance, the work is done by photosynthesis and does not require human participation. But the carbon sequestration becomes a service because human emissions became a problem.

In terms of carbon removal, the third national communication from Brazil to the United Nations Framework Convention on Climate Change (UNFCCC) (Brasil, 2016 pg.38) showed that in 2010 Brazilian emissions were of 740000Gg of CO2. When considered the

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[19] https://www.ilo.org/global/topics/green-jobs/WCMS_371589/lang--en/index.htm Accessed in 27/10/2020

population of 190 million inhabitants[20] the annual per capita emissions are an average of 3.89tons. An inventory from 2001 (HERTWICH & PETERS, 2009) pointed to 4.1 tons per capita for each Brazilian, probably because the main efforts to slow deforestation on the Amazon were not ready at that moment. Brazilian per capita emissions are not very big when compared to the USA (28.6 ton/year), Hong Kong (29 ton/year), or Luxemburg (33ton/year) for that same year (HERTWICH & PETERS, 2009). Therefore the yearly 190000 tons removed by Ubatuba coast could help to minimize at least locally these emissions, but as it was seen this mitigation capacity is being reduced.

Mineralization and nitrogen cycling also is independent of human labor. Due to the excess of nitrogen dumped in the ocean (ROCKSTROM et al., 2009; STEFFEN et al., 2015), society must increase the intensity in a service provided to the ecosystem of removing this element from dumping that would be easily done with sewage treatment facilities. Despite some positive results for these services the limits in the nitrogen cycling and their relation to harmful algae blooms are not to be overlooked.

The water quality measured in maximum quality days is interesting, despite measured in different indicators than working days, because being Ubatuba dependent on tourism, the water quality is crucial for the satisfaction of tourists. RCP 2.6 and RCP8.5 can reduce the number of days with max quality (-26 ±1.15 and -51 ± 2.72 respectively). On the other hand, a reduction of tourists would increase these numbers for 77.6 (± 0.71) more maximum quality days, meaning practically one more summer season along the century. These indicators can be useful in guiding local policies for control of the number of tourists.

2.4.5 Future Development of the model

The first bottleneck faced by the model is its spatial delimitation. The choice of working with few polygons for land and sea was made due to the computational capacity demanded by a more detailed delimitation. It proved the right decision due to the time necessary to run the whole model at the end of the research. Considering that better inferences can be made with more definition, this is a point to be improved.

Some traits of the city were not captured like mariculture, mangroves, bycatch of turtles, etc. This was an arbitrary choice for the sake of simplicity in the model. Now that it is ready, it’s clear that these traits can be implemented without the burden of a huge complexity

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[20] https://www.ibge.gov.br/estatisticas/sociais/populacao/9662-censo-demografico-2010.html?edicao=9754&t=downloads

increase that demands other computers to solve the problem and therefore can be done if time and resources are available.

There is a necessity for statistical analysis of the model results compared to the data to see to which extent they are matching. This wasn’t done at this moment due to lack of time.

2.5 CONCLUSIONS

The objective of this research was in the first place to build a broad and embracing simulation that was at the same time able to integrate some key elements of the SES of Ubatuba and model them in time and space to finally understand and forecast the ES provision along the century under different scenarios. This was done with MIMES, a very integrative and powerful modeling technique that allowed us to embrace the main portion of the marine biota and simulate the ES provision in different scenarios.

This MIMES model embraces data from atmospheric sciences mostly collected by satellites (cloud cover, light availability, wind speed and direction, precipitation and sea surface temperature) and through its causal structure integrated this information with the biological and oceanographic information about the physical state of the coast (nitrogen concentration, oxygen, particulates, currents) and the food web (from primary producers to top predators). Human society appears making an influence on the water quality through sewage dumping and on the other side as the beneficiaries of the ES provision. A very small economic sub–model was created to understand variations on the GDP related to one scenario.

The initial hypotheses of ES provision on the region of study would be different in the future due to climate change and due to the possibility of the tourists changing their behavior according to the water quality. This hypothesis was fully corroborated by the results.

All then studied ES (Crustaceans production, Mollusks production, Cartilaginous fish production, bonefish production, carbon sequestration, oxygen production, mineralization, nitrogen cycling, sewage depuration, and water quality) showed individual variations between the climate scenarios RCP2.6 or RCP8.5 or even due to the reactive tourists' scenario. These variations spectrum was from very small (-0.08 ± 0.00%) for water quality in RCP2.6 to very big (34% ±0.01% for sewage depuration material analysis in reactive tourist scenario) percentages compared to the base case (the variations from 2010–2017), and depending on the ES and the scenario.

Six of these services show a decrease in the offer due to climate change in RCP 2.6 scenario, four presented some gain. For RCP8.5 it was five and five. It is necessary to say that most of ES provisions forecast did not pointed to unidirectional result as loss or gain, because when uncertainties were associated to the evaluated mean value, these values present a Gaussian curve with legs on the positive and negative side. The conclusion is that most probably there will be losses in ES due to the majority of means occupying a negative position but some positive effects were also obtained.

These services are fundamental to the maintenance of fisheries and of the social structure traditionally relate to this activity, despite the climate regulation services that are of local and global interest. Two services showed a clear increase in productivity with climate change influence because the environment became less propitious to sewage bacterial life and also able to deal more quickly with nitrogen from the same source. These positive results must be seen with care because there are limits of deposition of minerals and sewage on the ocean and consequences if the system trespasses these limits.

The overall picture is that Ubatuba coastal zone will provide ecosystem services with an economic value of 622 M dollars (± 3.6 M dollars) for the city from 2010–2100. This value is equivalent to something around 7 M dollars every year, or even 19 K dollars every day for the whole area.

When climate change scenarios are considered, the situation gets worse. In the best scenario (RCP2.6) economic losses are -1.23% (±2.96%) with values of -7.5 M dollars (±3.8 M dollars) for the utopic scenario. If the selfish scenario is considered, losses grow for -1.94% (±2.95%) adding – 1.1 M dollars (± 352 K dollars) to the previous losses of -564 M dollars. On the balanced scenario losses are -1.79% adding -2 M dollars (±701 K dollars) to the -507 M dollars previously lost.

For RCP8.5 the situation is more serious (Table 6) with losses of -2.34% (±3.88%) that correspond to values of -14 M dollars (± 6.3 M dollars) for the utopic scenario. To different economic scenarios, losses reach -5.29% (±3.81%) for the selfish scenario (adding – 2.9 M dollars ± 578 K dollars to the -564 M dollars previously lost). For balanced scenario losses are -4.42% (±3.84%) (adding -4.8 M dollars ± 1.1 M dollars to the - 507 M dollars already lost).

For the reactive tourists' scenario (table 7) the situation is less worsening in all economic scenarios. For the utopic scenario, losses are -0.14% corresponding to -898 K dollars. For the selfish scenario, losses are -0.40% with an additional value of -249 K dollars to be added to those -591 M dollars lost for this economic scenario. For the balanced economic scenario, losses are -0.33%, corresponding to -407 K dollars to be added to the already lost -530 M dollars of the adoption of this economic scenario.

It is clear that controlling the population visiting the area can have a positive effect in the water quality, carbon sequestration and oxygen production, remove the pressure of services like sewage depuration and nitrogen cycling and also increase yield in some fisheries (cart. fish and bone fish) despite the losses in crustaceans and mollusk fisheries.

In this statement we are considering the quality and economic value of ES. Considering most of ES are not embraced in markets and consequently they are invisible to the GDP of the city (due to so called market failures), the economic impact of this improvement would not be reflected in the city's GDP. Therefore, reducing the amount of tourists would be most probably perceived by the city as a reducing in the GDP, despite the gains in Ecosystem Services because they are not measured appropriately and in the same frequency as GDP.

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3 PROTOTYPE OF SOCIAL ECOLOGICAL SYSTEM'S RESILIENCE ANALYSIS USING A DYNAMIC INDEX

Abstract

Resilience thinking is understood as a social–ecological system (SES) property and therefore embodies nature and society in a research perspective that is also important as a body of knowledge with high potential to be applied to reach sustainability goals. The main message is that SES work properly within certain limits. These system's limits are composed of ecological and social limits that work as boundaries that, if trespassed, result in system regime change with increasing uncertainties; thus, impacting the reliability of delivering a set of desired ecosystem services. Modeling a SES as complex and adaptive, with feedbacks, nonlinearities, and path–dependence becomes a crucial tool to inform building a responsible governance behavior that tackles SES management. This work built a prototype model of SES resilience to assess the extent to the understanding and application of the principles that underpin resilience (e.g., polycentricity, connectivity, etc.) could benefit from the formalization of their interdependences and dynamics and to learn about the benefits of making quantitative assessments of such socio–institutional principles. Multiscale Integrated Model of Ecosystem Services – MIMES (Boumans et al., 2015) is a SES modeling system using System Dynamics that embraces various complexities' attributes in an interdisciplinary and integrated model. Constructing a causal loop diagram embracing the social sphere represented by seven resilience principles proposed by Biggs (2015), revealed the necessity to include an overall social perspective in the model. In particular, a wide social perspective was captured using Cultural Theory, or plural rationalities (Thompson, 1990), an anthropological theory that considers bias as an unavoidable feature in decision making and proposes a typology of bias that is a possible proxy for transforming the behavior of those principles as an endogenous feature, numerically treatable. Ten different types of ecosystem services were extracted from the ecological part of the simulation (*Chapter 2*) and then combined with those seven resilience principles into the Dynamic Resilience Index (DRI) using a Cobb Douglas–type production function that captures substitutability among factors. The numerical simulation produced dynamic representations of this DRI index, considering three Cultural Theory perspectives. Seven insights about resilience emerged and are discussed: 1st insight: There is not one goal for resilience, but three; although the system has one resilience, not three; 2nd insight: Resilience presents seasonal variations; 3rd insight: the system is operating if it is in early stage of development (akin to r phase in the ecological succession); 4th insight: The system may be locked in a trap; 5th insight: resilience of what to what? Resilience of the whole system in providing a set of ES against changes in slow variables; 6th insight: not all resilience principles have the same weight in resilience; 7th insight: each solidarity make DRI react differently to climate change. Conclusions point that adopting the SES perspective for resilience and measuring it with DRI brings a message that the prevalent cultural solidarity (values and beliefs) of the governance process are highly influential to the resilience of the system. Also, the resilience of each solidarity reacts differently to climate change scenarios. Nonetheless, resilience also behaves seasonally; "diversity and connectivity" have more weight than other principles and the case study shows a system that can be locked in a trap.

Keywords: Social–Ecological Systems, Resilience, System Dynamics, Governance, Culture Theory.

3.1 INTRODUCTION

Ecosystem–Based Management (FOLKE et al., 2005; BURROUGHS, 2011; PARAMIO et al, 2015) is an approach that includes several distinct advances regarding environmental management. One thing is to consider economic activity (social) a human feature that occurs inside a larger and finite natural system (ecological). This research agenda has been increasingly taking into account after global diagnoses of the state of ecosystem services (LEEMANS & de GROOT, 2003) and the value they represent to society (COSTANZA et al., 1997; de Groot et al., 2012).

A broader perspective that includes economy and society inside the ecosystem and couples them in intricate networks of relations and dependencies is called social–ecological systems and considers that those subsystems are linked once they affect and are affected by each other in complex dynamic relations (feedbacks). Effective management of the ecosystem can be made by those who recognize these links as well as the limits of the combined social–ecological system (BURROUGHS, 2011).

The ecological subsystem of the Social–Ecological System must be managed sustainably to obtain a continued yield of ecosystem services in the short and long term (DAILY et al., 2000; BEAUMONT et al., 2007). The principles of sustainability proposed by Herman Daly are one path for this management:

> - Renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate.
> - Nonrenewable resources such as minerals and fossil fuels must be used no faster than renewable substitutes for them can be put into place.
> - Pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless. (DALY, 1990)

Governance, on the other hand, needs to be able to work properly under a system that changes across time due to internal variations and also external influences like climate change. Adaptive governance seems to be one way to connects individuals, organizations, agencies, and institutions at multiple organizational levels (FOLKE et al., 2005) and can be considered the way societies can manage themselves to change accordingly to the behavior of ecosystems. To be served by the desired set of ecosystem services, in the short and long–range, within a certain level of confidence, requires a social system able to adapt itself to nature’s regular behavior and changes (in other words: require a resilient SES). FIKSEL (2003) agree with that vision and concerning systems management, the author claims:

> Traditional systems engineering practices try to anticipate and resist disruptions but may be vulnerable to unforeseen factors. An alternative is to design systems with inherent “resilience” by taking advantage of fundamental properties such as diversity, efficiency, adaptability, and cohesion. FIKSEL (2003)

The resilience concept has been used in several disciplines from business to medicine. In a brief review (DOWNES et al., 2013) more than ten concepts were found for the resilience of social–ecological systems. The concept has turned into a prolific branch of science in the last few years with impressive numbers: less than 100 citations in 1995 turned into 20.000 citations in 2014 (FOLKE, 2016). Resilience thinking understood as the use of resilience concept by practitioners or scientists in the SES field, has started with Holling (1973) and recent information (FOLKE, 2016) shows that it has evolved, forming a developing field inside the academy but also as a movement outwards academic research being embedded in environmental and sustainability planning by several countries and institutions.

Despite the increasing adoption of this concept as an investigative agenda, Resilience seems to have an important message in this concept: social–ecological systems work properly under certain limits. These ecological and social limits (thresholds) are boundaries and if they are trespassed, the system will be operating under a different regime, in a new attract basin. This new regime is unknown and its capacity to provide ecosystem services that support human wellbeing is also unknown. Uncertainty is a keyword when Resilience is at stake because system tipping points (limits of the regime) are also commonly unknown.

Resilience is usually desired in a system when the provision of ecosystem services suits what society expects from that system. Sometimes resilience locks the system in a poor condition that is undesired by the community revealing a “duality of resilience” (KHARRAZI et al., 2016). In other words, resilience is not good or bad, is a feature of the social–ecological system regarding change and identity.

In a narrow view, Resilience is the capacity to return to a stable point after some perturbation. This view is narrow because underneath it it’s implicit the idea of stability of systems, and also the control over its behavior. Systems are not stable, they are dynamic, sometimes under gradual changes (slow variables), sometimes in abrupt changes; sometimes changes are predictable, and sometimes they are not. Therefore Resilience thinking, in a broad view, is the “capacity of people, communities, societies, cultures to adapt or even transform into new development pathways in the face of dynamic change” (FOLKE, 2016). Resilience thus is related to transformation, not stability. That transformation is cyclical in SES and is described by the adaptive cycle (GUNDERSON & HOLLING, 2002).

Several concepts are usually closely related to Resilience thinking, albeit being different. Transformability is about changing the development in new pathways, this means to cross a threshold and align the social–ecological system behavior in a new regime, under a different basin of attraction (FOLKE, 2016). Adaptability is the capacity of people "in a social–ecological system to learn, combine experience and knowledge, innovate, and adjust responses and institutions to changing external drivers and internal processes" (Op. cit.) and maintain the system operating at satisfactory levels in the same regime, under the same basin of attraction.

There is a distinction between Specific Resilience and General Resilience. The first one is the answer to the question "Resilience to what?" meaning specific resilience is considered concerning a specific menace. On the other hand, general resilience is a general feature of systems, not a reaction regarding some specific threat. It is the capacity to deal with uncertainty, complexity, and surprises (FOLKE, 2016).

Operationalizing Resilience is a field in fast development, although modeling and measuring resilience is not a trivial task. Specific Resilience is easier to handle and there are several experiences in the literature (e.g. Resilience Alliance) but operationalizing the concept at a higher level is an operational challenge. Béné et al. (2016) also claim that "none [analyses] provides an approach or a methodology that enables us to measure resilience simultaneously at several levels".

The author also shows another operational challenge that is to consider the multi–dimensional character of the system, meaning social dimension, ecological dimension, the economic dimension must be embedded in the analysis. According to the author (BÉNÉ et al, 2016): "This means that, in theory, the framework proposed to measure resilience should be designed in a way that allows for integrating this multi–dimensional nature (even if we are interested in one particular dimension e.g., food security)".

3.1.1 Modelling Resilience

Resilience is a theoretical concept that was originally envisioned using models (CARPENTER et al., 2001). Despite the usual claim that "resilience cannot be measured" (BROWN, 2016) or resilience is "difficult to model" (SCHIPPER & LANGSTON, 2015; ANGELER & ALLEN, 2016), several attempts of measuring and modeling resilience are currently in development. Some authors (CARPENTER et al., 2005; BENNET et al., 2005) discuss the possibility of measuring surrogates for resilience, considering the unattainable nature of the measurement of the last.

In the resilience index constructed by Alinovi et al. (2008), that is used by FAO (BROWN, 2016), the index was built using the scope of households, based on a framework and the integrative equation used the sum of each factor.

Our index is different from Alinovi et al. (2008) because our scope is the social–ecological system, with ecological boundary in the city, but the social attributes have no defined boundaries since governance is a multilayer feature and it was not possible to delimitate the arena in which decisions were made. Also, the index presented here is based on a numerical model, not a framework, and thus it is not static information about the resilience, but a simulation through time. Finally, the integration used here (Cobb–Douglas–like function) seems more appropriate once none of its components can be zero, otherwise, the whole resilience would be zero (non–substitutability of each component is important for strong sustainability).

The dynamic index proposed here is also different from Anderies et al. (2002) once that stylized model does not use dynamic feedbacks and the approach of resilience is measured like engineering resilience of the system against fire, not using the bottom–up approach used here to understand resilience attributes and its interactions. Our index is related to Walker et al. (2009), once it admits the system to be a complex adaptive system with feedbacks, but instead of a qualitative study, the present paper is a quantitative model and with stated causalities declared in the dynamic model.

Rasch et al. (2017) presented a dynamic model of two scales for resilience, at the system level and individual level. Despite the promising results, the model was built using agent–based models and thus differ from what is presented here in scope and technique.

A broad review of resilience modeling is presented by Angeler & Allen (2016). Despite several contributions of the authors to understand the state of the art in resilience modeling, the highlight is given to the very rare combination of social and ecological aspects of resilience and the virtual absence of this combination in quantitative analysis.

A broad review about resilience quantitative assessments (SCHIPPER & LANGSTON, 2015) shows three relevant thoughts: first that most numerical evaluations of resilience are based on the use of indicators from great themes (e.g. learning, food security, health, etc.), but they are independent indicators, not connected through causalities like what is presented in this work. Second, those indicators are very dependent on the conceptual basis on which they were built. This is intuitive but is important for this work because most of the indicators, and frameworks, were based on different assumptions of what is being used here (BIGGS et al., 2012, 2015). And third, those indicators are snapshots in time not allowing the analyst to understand the trend in time of each indicator.

To collaborate with the exposed, this work has the objective to take the resilience concept "from metaphor to measurement" (CARPENTER et al., 2001). The goal was to integrate several systems features into a Dynamic Resilience Index (DRI) while understanding this social–ecological system as an adaptive system (CARPENTER et al., 2001; GUNDERSON and HOLLING, 2002; GUNDERSON, ALLEN, and HOLLING, 2010; LEVIN, 2013; BOUMANS et al., 2002; BOUMANS et al., 2015). This simulation is embedded in the theory of resilience and system sciences for several reasons and understands resilience as an emerging property of a complex system, with non–linearity behavior, feedbacks, and several scales; it also represents the integration of the social and ecological components through the coupling, multiple dimensions, and path dependencies.

Regarding social–ecological systems, Schlueter et al. (2012) argue that modeling for SESs is a cross–cutting issue and still has lots of work to be done to establish a body of knowledge from which society can obtain the necessary answers to SES challenges met worldwide. SESs modeling still doesn't have a unique framework for analysis and its methods represent an interdisciplinary attempt to reach some aspects of these dynamic, complex, and adaptive systems (Op. Cit.). In this context, a causality model like MIMES, we claim, is an interesting tool in this task, once its capacities of integration enhance the usual techniques reach used in resilience models and extrapolates disciplinary knowledge. MIMES is the acronym of Multiscale Integrated Model of Ecosystem Services (BOUMANS et al., 2002; ALTMANN, 2014; BOUMANS et al., 2015). This model is based on system dynamics and recently have been used in several cases worldwide (BOUMANS et al., 2002; KERCHNER et al. 2008; BATKER et al., 2010; ALTMAN et al., 2014; BOUMANS et al., 2015).

3.1.2 Foundations for index development

Several authors have been studying what systems properties interact forming the substrate from which Resilience emerges. FIKSEL (2003) establish a list of four components of Resilience: Diversity – the existence of multiple forms and behaviors; Efficiency – performance with modest resource consumption; Adaptability – flexibility to change in response to new pressures; Cohesion – the existence of unifying forces or linkages.

Other authors (CALGARO et al., 2014 and VAN DER VEEKEN et al., 2016) build a framework for resilience analysis. Despite the fact it is focused on tourism activities, it is very comprehensive, brings the knowledge of complex adaptive systems to the core of the analysis, and shows that feedbacks and dependencies are crucial to understanding resilience.

A similar approach is presented by BIGGS et al. (2015) with a deeper analysis and more detailed features underneath the resilience concept. Their understanding focuses on the resilience of Ecosystem Services, meaning the “capacity of a social–ecological system to continue providing some desired set of ecosystem services in the face of unexpected shocks as well as more gradual ongoing change”. This comprehensive approach brings seven components of resilience:

(P1) Maintain diversity and redundancy – systems with high levels of biodiversity and redundancies tend to be more resilience in providing ecosystem services;

(P2) Manage connectivity – ecosystem recovers from disturbances using internal links of species and social actors. In social networks it can also provide new information and trust;

(P3) Manage slow variables – identify slow variables and their feedbacks is a challenging effort, but understanding these general system features enhance resilient behavior;

(P4) Foster Complex Adaptive Systems (CAS) thinking – comprehension of the need of integrated approaches, non–linearity and uncertainty regarding ecosystem services production in social–ecological system enhance the ability to deal with changes, and then increases resilience;

(P5) Encourage learning – studying how systems works reduces the uncertainties and enlighten non–linearity behavior, experimentation and monitoring thus can enhance knowledge and foster resilience;

(P6) Broaden participation – participation enhance relationships, can build trust, can facilitate learning, and make collective action possible. All these are directly related to governance and resilience;

(P7) Promote polycentric governance systems – provides a structure in governance that allows the other principles to develop and also enhances participation and social networks.

Principles 1 to 3 are general systems features and principles 4–7 are more related to the governance of social–ecological systems. All those principles have their issues regarding field measures, communication, and relation with ecosystem services production. Considering a social–ecological system as a complex adaptive system, and adopting resilience as an emergent behavior of this complexity means the understanding of the non–linearity of its components, the non–linearity of their combined influences, and the uncertainties associated with systems features. Thus measuring and validating the results of those principles remain as challenges to be pursued by scientific development. Probably this challenge starts even with the very definition of each of those principles and more, with the variables underneath each of them (e.g. trust, modularity, disturbance recovery).

What this paper offers is a prototype that used a shortcut to the results of an integrated analysis of those variables, assuming arbitrary values for each of those subcomponents based on their relative position on the causal network. Although we do not know the instant values each independent variable (trust, modularity, etc.) present on the system, we hypothesize the goals of the dependent variable (resilience principles) should pursue: the goals the society desires for them. And those goals will be better explained by culture theory (Thompson, 1990). With this arrangement, the causalities between variables and the final goals allowed us to build the numerical simulation of the DRI and test its behavior on the long–range and due to climate change.

The reason that justifies this work is that although all those components are still under scientific scrutiny, theoretical definition and measurement techniques are still under development, they form the actual state of the art in social–ecological resilience studies.

The main hypothesis is that it is possible to simulate resilience of this social–ecological system through time using a model of the social sphere component even without knowing each variable’s instant value (what ALINOVI et al., 2008 called “latent variables”), but knowing the causal relation between them and their final goals (assuming an arbitrary common start point).

Some may argue that the whole theoretical perspectives and numerical modeling assumptions presented in this paper are non–orthodox, attaining the obscurity regarding the step of translation of social attributes (e.g. trust, connectivity, brittleness, and others) to numbers and their simulation. For those, we may remember that first, this is a prototype, which means by Cambridge dictionary: the first example of something from which latter forms are developed. Second, we would like to remember this work is not alone; the practice of creating numerical models from sociological theory without real field data has been done before. Janssen & Carpenter (1999) did a very close simulation including numerical simulation and culture theory; Sterman (1985) did the system dynamics simulation of Kuhn’s “the structure of scientific revolution”, treating the absence of data in a very similar way we did here; Rahmandad et al. (2009) used system dynamics for a numerical simulation of “learning”, using the same level of abstraction. Robinson (2007) brings a great review of numerical simulation on sociology, rooting this practice since the ’40s. Third, we agree with Midgley (1992) that pluralism is much deeper than a way to “promote openness and conciliation while at the same time preserving theoretical coherence”: it is essential for system sciences.

3.2 METHODS

> It is a tempting and safe academic device to approach any problem from a traditional viewpoint. By so doing we assume that the twenty or so civilizations of man and the few thousand years of recorded history are sufficient to have faced all problems and devised all solutions (HOLLING & CHAMBERS, 1973).

The dynamic resilience index is composed of two types of models that embrace and connect ecosystem and society components in complex analysis (HUGHES et al., 2005). The first one (Figure 49), represents the translation of the theory about the resilience of ecosystem services provision in social–ecological systems as found in Biggs et al. (2012) to numerical MIMES type model. This is a slow specificity model, with arbitrary numbers described below. As this resilience approach regards ecosystem services provision, a second model is required showing the provision of the ecosystem services in the case study and its variance according to scenarios. This second model is presented in (chapter 2) and will not be discussed in detail once it is published. What is relevant is that this second model will provide us the local situation about ten ecosystem services (crab production, clam production, cartilaginous fish production, bonefish production, carbon sequestration, oxygen production, mineralization, sewage depuration, nutrients cycling, and water quality) all normalized to vary from 0 to 1. If the first part of the model is a generic and broad defined social sphere sub model, the second part is a specific case, full of data and with very low capacity for generalization once the very structure of the model was built considering this specific case.

The first step to translate the theory into a model was the construction of the causal loop diagram in which we could represent the most relevant objects that were simulated and the causalities that connect them (STERMAN, 2000). Considering this as a prototype model means that this translation of the theory in a causal loop diagram (for example the CLD in Figure 3 and 50) represents the author's understanding of the theory and validation occurred inside the research group only. To be transparent about our assumptions during translation, every causal relation pointed in the CLD is followed by the phrase or word on a specific page of the paper (BIGGS et al., 2012) used as a source of this interpretation.

The next step was translating the CLD into a numerical simulation. This part is experimental again because the computer simulation requires numbers for each variable. Despite the seven main principles of resilience (connectivity, diversity, management of slow variables, understanding of a system as a complex adaptive system, learning, participation, and policentricity), that we did not know their state in the system from a qualitative and from a quantitative perspective, there are all the other sociological attributes of the theory that we also didn’t know (e.g. trust, confusion, connectedness, all seven principles growth, and decay rates, etc.).

So, different from the ecosystem services part of the model, which came from data available in the literature review, this resilience social sphere is a conceptual model in which we assumed values for each variable to run it. Then, all variables had a spectrum of values, usually from zero to one, meaning that zero is the worst value possible and one represents the highest situation. A higher situation not necessarily means the best for society. Sometimes when a variable assumes a higher value it can bring some undesired consequences as well. For example, low diversity can lead to brittleness (and consequent lower resilience), but high diversity can lead to low redundancy and diminish resilience as well (BIGGS et al., 2012 page 6). To embrace these negative feedbacks of the highest values, the model was constructed with specific feedback that embraced this effect of diversity in reducing the overall resilience.

To simulate the participation of the other variables in the system, we assumed values for them regarding their proximity to the main seven principles. This way allows all variables to be relevant in the final result but also proportional to their relevance in the theory. Thereby all seven principles are considered tier 1 (varying from 0 to 1, starting with 0.5) and variables that influence directly one of them are tier 2 variables, whose highest value is 1E-3. Variables that influence tier 2 are considered tier 3 and have the highest value of 1E-4 and so on (Figure 164). Goals for each principle are dependent on theory as described below, but numerically (Table 31) they can assume values from 0.04 (a number meaning zero, but numerically feasible for the model to run), restricted position (0.4), a very limited position (0.6), acceptable limitation (0.9), high (1) and infinite (2). Those numbers are representative states of the importance each social solidarity puts on every principle of the resilience theory which will be described below.

The last step on the simulation methods was to run a sensitivity analysis to test the relations simulated made sense. The results of the sensitivity analysis are discussed with the results of the simulation. We simulate for 33000 days (from 2010 to 2100) to be congruent with the ecosystem services model.

3.2.1 Anthroposphere sub–model from GUMBO

There is a method used in system analysis to integrate several different components of the system into one meaningful indicator. It has been used in economic modeling and is exemplified by one sub–model of GUMBO (Boumans et al., 2002). GUMBO is similar to a MIMES model but it was applied on a planetary scale.

GUMBO (Global Unified Meta–model of the Biosphere) embraces under Anthroposphere sub–model, economic and social attributes. The general approach is an input–output view, meaning the social and economic sectors work upon materials and energy that enters the anthroposphere system and after that produce wastes that are released in the environment, producing along with the way economic and social welfare. This is the same approach called "throughput" from Daly and Farley (2011). To GUMBO, these energy and material flow rates are controlled by population, knowledge, and social institutions.

> The anthroposphere brings together the numerous elements within the other spheres that affect human well–being, links them to human activities that affect well–being, and assesses the impacts of human activity on those elements (BOUMANS et al., 2002)

The model focuses on two different variables to assess value: Gross World Product (GWP) and Sustainable Social Welfare (SSW). The first is a conventional economic valuation of goods and services; the second measure the contribution of system elements in the quality of life assessment, represented by SSW function.

In the model, both variables (GWP and SSW) are mathematically obtained using Cobb–Douglas-like equation, as follow:

i. $\mathrm{GWP} = \mathrm{HK}^{\alpha 1} \,.\, \mathrm{SK}^{\alpha 2} \,.\, \mathrm{BK}^{\alpha 3} \,.\, \mathrm{W}^{\alpha 4} \,.\, \Pi^{10}{}_{\mathrm{i}=1}\mathrm{NK}_{\mathrm{i}}{}^{\alpha}{}_{i}{}^{+4}$

And

ii. $\mathrm{SSW} = \mathrm{BK}^{\beta 1} \,.\, \mathrm{C}^{\beta 2} \,.\, \Pi^{7}{}_{\mathrm{i}=1}\mathrm{NK}^{\beta}{}_{i}{}^{+2} \,.\, \mathrm{HK}^{\beta 10} \,.\, \mathrm{SK}^{\beta 11} \,.\, \mathrm{W}^{\beta 12} \,.\, \mathrm{M}^{\beta 13}$

Where α and β are the percentage increase in levels of output (GWP or SSW) starting with a 1% increase in the corresponding input. HK is human capital (represented in the model by technology and labor); SK is social capital (measured by social networks and institutions); BK is for built capital; W is for waste (waste products of consumption and also from depreciated capitals); C is for consumption (measured as non–invested GWP); NK is for natural capital that considers 7 different ecosystem services in SSW and 10 different for GWP); M is for mortality. Coefficients for waste ($\alpha 4$ and $\beta 2$) and mortality are negative. All the others are positive. The values range from –0.2 to 2.

The differences between the two equations are that GWP includes ecosystem goods and services (including oil reserves for instance) and SSW includes only ecosystem services;

SSW also includes consumption C (measured as a portion of production) and mortality (a proxy for human health indicator) and both act like indicators of human well–being.

> Thus the welfare function includes the welfare derived from production (via consumption) plus the welfare derived directly from the non–marketed ecosystem services, social capital, built capital, and human capital, and the negative influences on welfare of waste and mortality. (BOUMANS et al., 2002)

In GUMBO authors calibrated all α exponents to create a curve that fit GWP data of the countries under study. The same thing could not be made with SSW once this indicator is not usually measured by nations. Thus β are arbitrary statements of the researchers and reflect their individual preferences, which will always be biased by their point of view about society. To deal with that bias they used two profiles of people (from COSTANZA, 2000) and adopt their choose preferences: one group is technological optimists and the other is formed by skeptics. The first one gives more importance (weight) to built capital, consumption, and individual knowledge, and less importance to natural capital and waste. Social capital and mortality are weighted equally among both. Energy is also present as an underlying attribute to calculate social, built, and human capitals. Waste reduces the value of GWP and SSW and Consumption increases SSW.

Mathematically, the Cobb–Douglas equation is used for three reasons (BOUMANS et al., 2002): 1) because of marginal product of new inputs are positive but decreasing (meaning additional units of the same attribute will enhance the overall index at a lower rate every time step); 2) Because the equation allows substitution between components; 3) it is mathematically treatable.

Cobb–Douglas's advantages are very relevant to dynamic modeling. The marginal product of new inputs increasing at a decreasing rate must occur to be consistent with the expected behavior of the index. If you have more biodiversity, is expected to have more SSW, but not as an exponential growth curve. Thus more biodiversity implies more SSW at lower growth rates.

Substitution among components must be seen with caution. Strong sustainability (NEUMAYER, 2003) is based on the assumption of non–substitutability among natural capital and built capital but in this function, it is possible (except if one variable assumes value zero). This is one limitation of Cobb–Douglas equations. Nevertheless, several arguments make the strong sustainability perspective feasible and corroborate this equation's adoption. Because this equation is based on a system model, the built capital cannot substitute natural capital if this last is almost depleted. For example, you cannot increase the number of fishing boats (built capital) and expect the same results for fishing if you don’t have enough fish stock (natural capital). Because of the system approach of the model, meaning there are feedbacks linking built capital, social capital, and human capital to natural capital, it is not possible to substitute them indefinitely because built (social and human) capitals came from natural capital and when natural capital stock is low, it controls other capitals growth. Additionally, if natural capital falls below a certain low level (pass some threshold), it cannot regenerate properly anymore, and that will lead all the system way down. If the natural capital fall to zero, production of all social, built and human capital also falls to zero and SSW as well. These behaviors are aligned with strong sustainability principles.

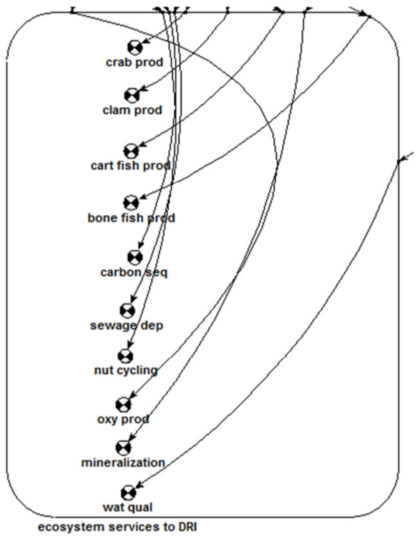
3.2.2 Dynamic Resilience Index formula

The index was built using the seven principles from Biggs et al. (2012, 2015) coupled to ecosystem services provision using Cobb–Douglas–like equation gives this formula:

$$DRI = P1^{\gamma 1}.P2^{\gamma 2}.P3^{\gamma 3}.P4^{\gamma 4}.P5^{\gamma 5}.P6^{\gamma 6}.P7^{\gamma 7}.\ ES^{\gamma 8\text{-}17} \qquad \text{(III)}$$

Where DRI is a Dynamic Resilience Index; P1 to P7 are the resilience principles (BIGGS et al., 2012, 2015). ES embraces all ten ecosystem services extracted from the ecosystem model (Figure 48).

Figure 48: Ecosystem services output from the model



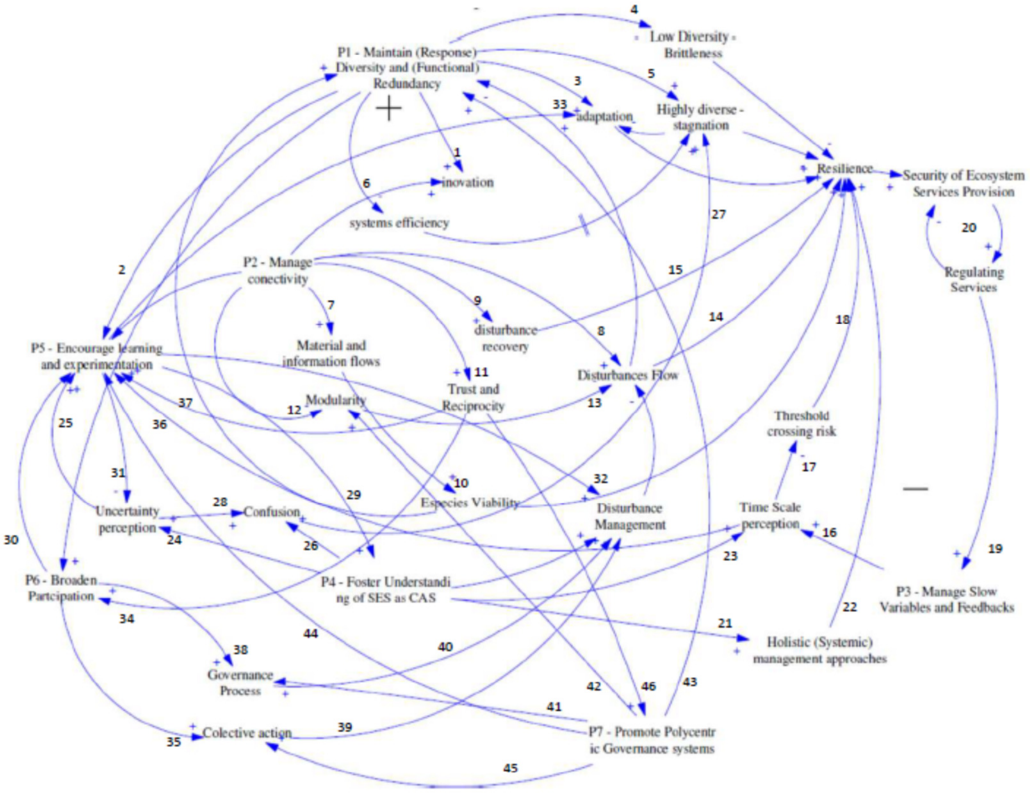
Source: the authors

3.3 RESULTS

3.3.1 Causal Loop Diagram (CLD) for Resilience attributes

Causalities were assumed connecting each variable underpinning resilience principles. Those causalities were extracted from the text (BIGGS et al., 2012). This section presents the CLD and a list showing the origin of each relation embedded in the model (Figure 50) during a process of reading and interpreting the resilience theory. They form the causal basis for the construction of the numerical model.

Figure 49: Causal loop diagram from the translation of Biggs et al. (2012) to a simulation perspective



Numbers means:

1 – The diversity of system elements, such as multiple species, management approaches, and institutions, provides the basis for innovation, Page 425;

2 – Learning, Page 425;

3 – Adaptation, Page 425;

4 – Low levels of either can lead to brittleness of the SES and compromise resilience, page 6;

5 – By contrast, very high levels of diversity and redundancy can undermine ES productivity and resilience in the longer term, page 426;

6 – Both diversity and redundancy are costly in the sense that they reduce system efficiency and…, Page 426;

7 – Connectivity in SES facilitates the exchange of material or information necessary for the functioning of ecological and social processes, page 428;

8 – Connectivity also affects the resilience of ES because it affects the spread of disturbances…, page 428;

9 – And facilitates recovery after a disturbance…, page 428;

10 – Connectivity between habitats enhances population viability…, page 428;

11 – High levels of connectivity between different social groups increases information sharing and develops the trust and reciprocity necessary for collective action…, page 428;

12 – Network theory suggests that it is not only the presence of links and their strength that determine the resilience of ES to disturbances, but also that differences in system structure— specifically modularity…, page 428;

13 – Modular ecosystems, e.g., lakes, are functionally independent locally and can prevent disturbances from spreading across…, page 428;

14 – Pest outbreaks, disease epidemics, invasion of alien species, and even financial crises, such as the global spread of the 2008 recession triggered by the collapse of the US housing market, confirm the high risk of propagation of disturbances in strongly connected systems…, page 429;

15 – Implicit in 9 (page 428);

16 – SES consist of variables that change and interact on a range of timescales…, page 429;

17 – In SES if certain thresholds are exceeded, with page 429;

18 – Changes in slow variables and feedbacks can lead to nonlinear changes or regime shifts page 429

19 – Limited. Maintaining regulating ES as a proxy for managing slow variables might be a practical way forward. Page 431

20 – An imprecise relation between ES and regulating services. Implicit in the whole text.

21 and 22 – Fostering an understanding of SES as CAS among actors involved in SES management is thought to enhance the resilience of ES by emphasizing holistic (rather than reductionist) approaches, the management of multiple ES and trade–offs in an integrated way… page 432

23 – And the importance of slow variables, lags, … page 432

24 – A CAS worldview also emphasizes the substantial uncertainties … page 432

25 – And therefore the need to continually learn and experiment … page 432

26 – Presenting the concept of complexity in ways that do not create a sense of bewilderment remains a key challenge in practical ecosystem management settings… page 433

27 – Lead to gridlock and stagnation…. Page 433

28 – When combined with more traditional views about the need for reducing uncertainty before taking action, such interpretations may lead managers to invest heavily in monitoring and data collection, rather than encourage the use of adaptive approaches that allow for uncertainty…page 433

29 – In practice, an understanding of SES as CAS is likely to co–emerge and be reinforced by learning–focused approaches such as adaptive management… page 433

30 – Participation (P6) is therefore a key enabler of social learning. page 433

31 – And dealing with uncertainty in SES… page 434

32 and 33 – Monitoring and experimentation are central to adaptive management and adaptive co–management, which typically involve a series of management experiments that support learning about SES responses to management actions or disturbances… page 434

34 and 35 – Others, which builds trust and relationships and facilitates social learning as well as collective action…page 434

36 – Long term as well as able to withstand the impact of short–term politics and objectives… page 434

37 – By its nature, experimentation in SES is risky and requires leadership, trust… page 435

38 – Active engagement of relevant stakeholders in the management and governance process… page 436

39 – Required to respond to disturbance and changes …page 436

40 – The participation of a diversity of stakeholders in SES management is suggested to improve legitimacy, facilitate monitoring and enforcement, promote understanding of system dynamics, and improve a management system's capacity to detect and interpret shocks and disturbances …page 436

41 – One of the key principles of policentricity is to match governance levels to the scale of the problem… page 437

42 and 43 – ES. Polycentric structures confer modularity and functional redundancy that can preserve key SES elements in the face of disturbance and change… page 438

44 – Polycentric systems also provide opportunities for enhanced learning and experimentation… page 438

45 – Governance at multiple smaller scales enhances opportunities for participation… page 438

46 – Evidence further suggests that polycentric governance structures are most effective in securing resilience of ES in cases where groups have open communication, accountability for actions, and time to work together to build trust and social capital… page 439

Source: the authors.

The idea is that the CLD is a translation of the text into a simulation of relationships. The most transparent it is, the more clear what kind of assumptions we used to build the numerical model.

3.3.2 A limit was required

The foundational principles from Biggs et al. (2012, 2015) were published as a consensus paper following a workshop of specialists (op. cit.). Rightfully, the paper is highly cited, but some limitations must be addressed to use the framework on the numerical model created here. First, the principles, as the word means, are high–level understandings about what should be underneath resilience. As principles, they are generic and broad, and thus the initiative of measuring, or applying them in an operational approach is difficult, as recognizes by the authors (BIGGS et al., 2012).

Second, the consideration of scenarios that lack resilience was probably pervasive, because they usually use terms with growth connotation as “enhancing, foster, broaden” when applied to those principles. Despite the semantics, in the logic structure of the paper, translated into a causal loop diagram (Figure 163) authors pointed out more feedbacks related to growth and enhancement that to balance or decrease of variables. This concern about enhancing principles is also demonstrated by the apparent lack of mechanisms to “direct” diminish principles 3 to 7, found absent in the text (although they can be diminished indirectly by feedbacks) (Figure 50).

The third point is the lack of a cap limit to all of the principles. Considering every SES is different and thus its resilience is not depending on the same generalized system’s state for all cases (*Panaceas* from Ostrom, 2007), it is comprehensible that no specific ceiling was pointed for each principle and resilience as a whole. Actually, in that paper the growth is unlimited, but as remarked by the authors and embraced in this model, with consequences. But in this case what is important to be remarked is that every limit for SES principles regarding resilience is, in the end, a social goal, determined and chosen by the society in that system with more or less interference from upper and lower level governance layers.

This is what Carpenter et al. (2001) meant by: "The best way to cope with surprise is resilience—that is a broad basin of attraction for the socially preferred ecosystem state[21] and the social flexibility to change and adapt whenever ecosystem services are altered in an unexpected way."

The simulation of resilience principles without limits means that those variables' curves are endless growth or decay and that is not possible. Kenneth Boulding would remind us that "anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist" (FARLEY, 2012). As Adger et al. (2009) claim: "limits to adaptation are endogenous to society and hence contingent on ethics, knowledge, attitudes to risk and culture". The authors understand limits for adaptation, and we are understanding resilience in a parallel, conceiving it as society's feature dependent on values and goals: something socially builds and politically supported by part of society's decisions, but at the same time contested in desirability, effectiveness, and feasibility by other parts of the same society (ADGER et al., 2009). Thus the dynamic equilibria of social forces would bring the adaptation (or resilience) to a point determined by goals, but influenced by those social interactions. In Adgers' words: "any limit to adaptation depends on the ultimate goals of adaptation underpinned by diverse values" (op. cit.).

The judgment about the standard value for a social principle (adaptation, resilience, and others) is then dependent on each society's, or part of the same society's, shared values and beliefs, in other words, culture.

3.3.2.1 Culture Theory and shared goals for social attributes

Holling et al. (2002) made clear that resilience is dependent on social goals and established some rationalities to understand categories of goals from society and their relevance to resilience. Although slightly different, there is a great overlap between Holling et al. (2002) and culture theory's (THOMPSON, 1997) categories that will be explored in a specific publication in the future. We chose the latter because it is clearer and closer to the application required in this paper.

Culture Theory or Plural Rationality is then the common ground for values and culture, which in turn are the cornerstone on goals setting for resilience principles considering the social–ecological perspective embedded in Biggs et al. (2012, 2015) papers. According to

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[21] Emphasis made by the authors

this theory (THOMPSON, 1997; SCHWARZ and THOMPSON, 1990; THOMPSON, ELLIS and WILDAVSKY, 1990; NEY, 2009; THOMPSON & VERWEIJ, 2004; SCOLOBIG et al., 2016; LINEROOTH–BAYER et al., 2015), there are five frames or rationalities that can be understood as the basis of human biases (values and beliefs) to understand nature and individual participation on social life. Two of them are not real active, and thus the other three are described briefly (mostly based on the description made by NEY (2009), THOMPSON & VERWEIJ (2004) and LINEROOTH–BAYER et al. (2015)):

Profligacy, an egalitarian tale: according to this frame, most environmental problems come from the disparities presented by societies concerning consumption and justice. They consider the world as a highly intricate place where everything is connected to everything else, an eco–centric world in which environmental degradation is not just environmental, but a reflex of asymmetries of power and richness of the society as a whole. Management is a moral issue and they ask for more holistic and naturalistic solutions.

The inequities of the capitalist societies and global markets are the villains, pushing society to desire unsustainable products, empty of what matters to humans (living in harmony with nature and others); the heroes are those institutions or people who managed to see through the veil of progress and technology to understand that to stop environmental degradation, a social transformation to equality is mandatory. Using the precautionary principle and spreading the decision–making power are ways to achieve an egalitarian goal.

Prices, an individualist story: to this frame, environmental problems come from relative prices of environmental resources, which are historically distorted and do not reflect their scarcity, allowing overconsumption and thus degradation. There is no need to appeal to complexities and social justice when dealing with social problems, once markets can make the proper allocation of resources. Environmental degradation is just a technical issue, for which a technical answer can be given.

Economic growth and markets are not the sources of the problems, but the solution to those problems once all management is cost–intensive and through economic growth, the bill of a technical solution can be paid. Misguided economic policies, barriers to international trade, and subsidies for inefficient sectors are the villains in this story. They ask for deregulation and freedom to innovate and take risks as a way towards solutions.

The heroes of this tale are those institutions who reinforce the market solution for problems, and there is no need for rebuilding them because the economic institutions are already in place: they just need to put the right prices on products and services like carbon taxes and tradable emission permits.

Proportion, a hierarchical tale: Here the environmental problems come from the disproportionate growth of society due to the lack of control. In the global south, rapid and uncontrolled growth of population leads to environmental pressure, increasing resource demand, and degradation. In the global north unregulated markets lead to environmentally imbalanced societies. They say that “wise guidance” and expert planning as a solution.

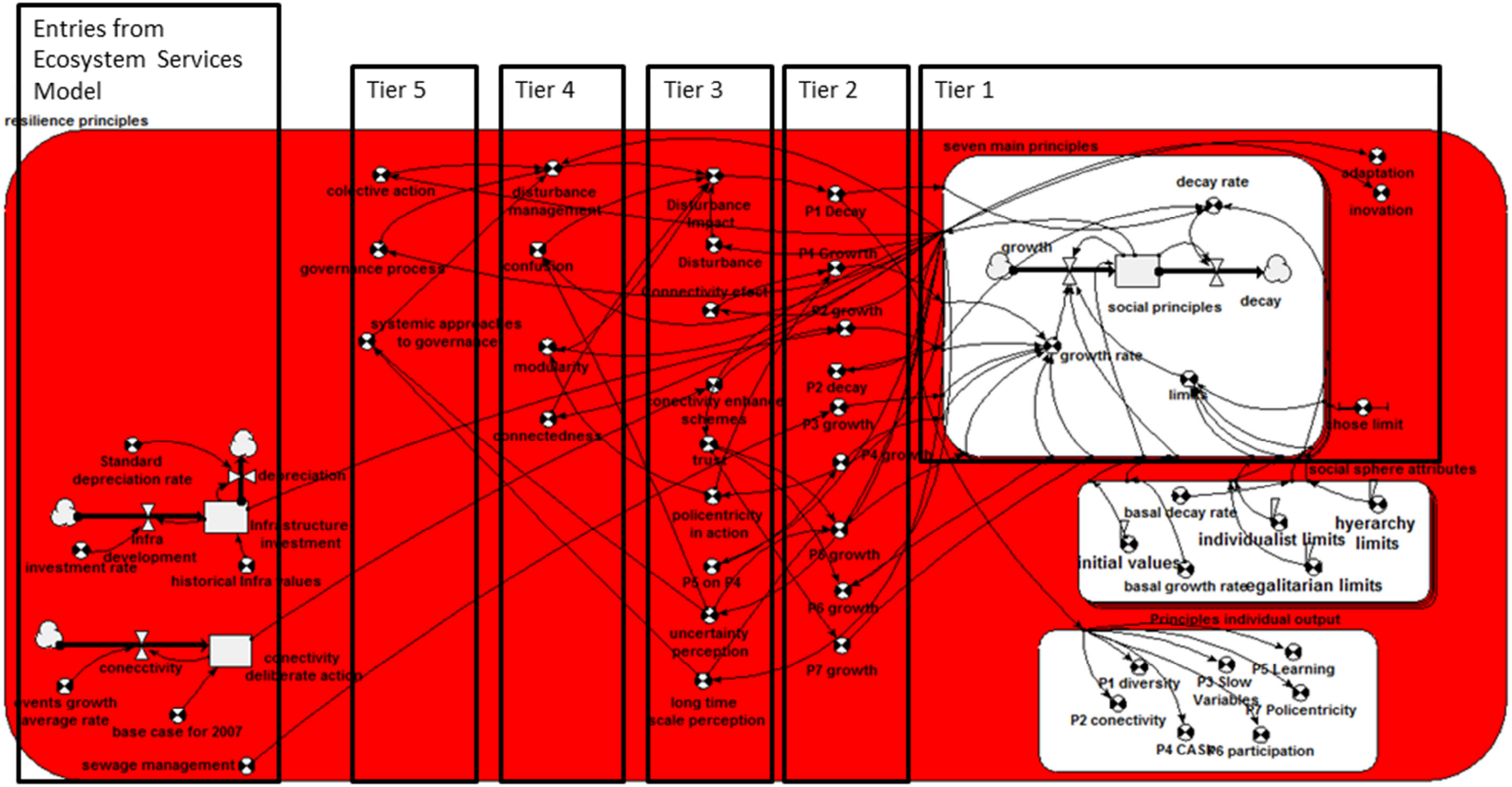
They agree with egalitarians that management is a moral issue, and since humans are the most developed species, it’s up to them the responsibility of the wise custody of the earth. On the other hand, they disagree on the point that humans have special status on nature, not being just a part of an interconnected whole.

They agree with individualists that human beings make rational informed decisions heading to fill their necessities (maximization of utility), but they disagree on the point that a collective decision, even taken by a group of rational beings, can be irrational, or undesired for the environment. So even with the moral necessity of managing the planet, a specialized group of technical managers is needed. Economic growth and the social–economic system underneath it are necessary to engage and manage environmental problems, only if they are conducted by the careful and expert application of knowledge and judgment.

The villain for this frame is the lack of control and thus the heroes are those institutions with the technical capacity and the “right” moral responsibility. Environmental problems, on every scale, should be left to appropriate expert institutions with power and resources to take the appropriate answer.

Culture theory perspectives (solidarities, or frames) vary through two axes: group (meaning the degree to which one individual choice is bounded by the group) and grid (or degree of regulations), the degree to which an individual life is circumscribed by externally imposed prescription, and thus the degree to which is open to individual negotiation (THOMPSON et al., 1990) (Figure 51). The exhibition of an Egalitarian worldview indicates strong group boundaries and weak prescriptive (grid) values. To this group the theory attributes the Ephemeral myth of nature, meaning they understand nature as a fragile thing that needs attention and caution when treated. Any mistake can lead the system to an undesired state or collapse.

Figure 50: Numerical Simulation of the resilience principles showing tiers of values of each variable



Source: the authors

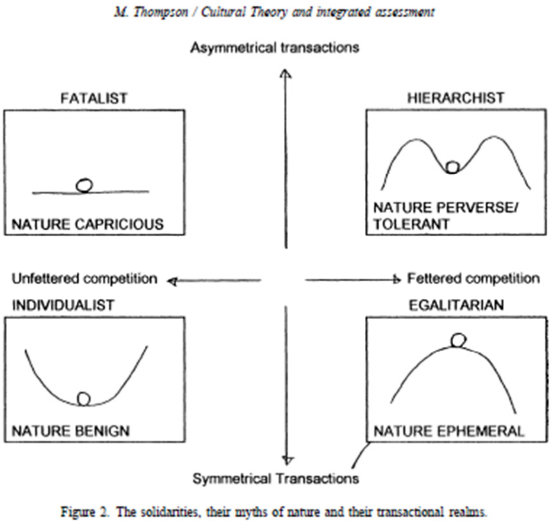
Individualist's worldview is presented in the group that is not bounded by group or grid. They are virtually free from control from others, but this does not mean they cannot control others. To this group, the theory attributes the myth of nature as being benign, meaning all boundaries are flexible and nature can always take care of her, independent of human use or abuse.

Hierarchies behavior in their turn has strong group boundaries and grid prescriptions, resulting in hierarchical relations. For this group, nature can be perverse or tolerant depending on thresholds that must be managed properly by qualified personal.

Fatalists worldview, indicating people strongly bounded by grid prescriptions, but excluded from group participation. To these people, nature cannot be managed or controlled, and thus the myth of Nature Capricious is attributed to them. They cope with nature and institutions did not learn or adapt.

The last worldview would be the Hermit which is not controlled by grid or group and left the participation of any decision. Fatalists and Hermit are not active frames once they are not participating in decision making, one by choice, the other by lack of opportunity.

Figure 51: Culture Theory's solidarities typology



Source: Thompson, 1997

The idea of using the typology from culture theory is that it provides the structure and help to understand the behavior of contending advocacy groups. Ney (2012, page 11) shows us that those coalitions will exhibit particular behavior that is predictable. Some coalitions will value:

> "order, harmony and process [Hierarchy]. In other coalitions, members will freely negotiate their relations with one another. These coalitions will emphasize individual liberties, competition and the primacy of the bottom–line [Individualists]. Other coalitions will be well–defined groups that shun internal distinctions; members of these coalitions will stress equality, holism and the ever–present need to speak out against injustice [Egalitarians]. Members of the last two forms of social relations do not take part in policy debates. Fatalists, isolated as they are, see no reason to participate in politics since whatever they do never seems to amount to much. Hermits, in turn, go out of their way to avoid any social interaction."

These three different active solidarities thus can determine the goals of the social attributes (principles) embedded in the resilience concept. Because MIMES runs a numerical simulation, we needed to transform those goals in numbers: a profile of the principle's values for each solidarity (Table 10). This kind of profiling of solidarities is similar to Janssen & Carpenter (1999) and Janssen (2002). The translation of each resilience principle's limit with a culture theory's solidarity interpretation and also the numerical profiling are new. To validate the table and values they were discussed internally by a group of specialists in cultural theory.

Table 10 – profiling of each solidarity's goal for resilience principles.

Principles	Individualist	Hierarchy	Egalitarian
Response diversity and Functional Redundancy	Almost zero (0.04)	Must be managed in acceptable limits (0.9)	narrow limits (0.6)
Connectivity	Must be high (1)	Must be managed in acceptable limits (0.9)	narrow limits (0.6)
Management of slow variables	Should be high (1)	Must be managed in acceptable limits (0.9)	narrow limits (0.6)
SES as CAsK	Almost Zero (0.04)	Almost Zero (0.04)	Higher the better (2)
Learning	Narrow limits (0.4)	Must be managed in acceptable limits (0.9)	Higher the better (2)
Broaden Participation	Desirably narrow limits (0.6)	Restricted (0.4)	Higher the better (2)
Policentricity	Desirably narrow limits (0.6)	Restricted (0.4)	Higher the better (2)

Source: the authors

The story that this table tells for individualists is that there is no need for response diversity and redundancy (P1=almost zero), the market is the answer to solve environmental problems. Thus the market must stay connected to every possible point in the system (P2=high) and slow variables as long economic cycles must be managed properly (P3=high) to avoid surprises or dissonances in the market equilibrium. The resource bases of the economic system are not complex (P4=near zero) and can be managed by the rational economic beings, that know the ways of the market, their preferences and with few more learning (P5=narrow) about the right prices, the management will be appropriate. There is no need for participation of others unless it is necessary to maintain the good competition of the markets (P6=very limited) and also there is no need to spread the government when centralized solutions can leave the markets free to work (P7= very limited).

Hierarchy understands the value of diversity and redundancy but limits them to a somewhat controllable fashion (P1= high but limited), the same happening with connectivity among this diversity (P2= high but limited). Slow variables like economic development or tax rates must be managed in high, but controlled standards (P3= high but limited). Understanding the system as a complex thing only muds the clear view experts have about the complicated, but not complex nature of things: there is no need for such uncertainty (P4= almost zero). Learning is high because being the management experts requires technical development and governance maturity: they know how to put things in order (P5= high but limited). Participation is tolerated under a controlled situation (P6= restricted) and policentricity is almost unnecessary (P7= restricted).

Egalitarians use the precautionary principle when nature is at stake, so diversity (P1 = narrow limits) and its connectivity (P2 = narrow limits) must be managed with caution. Slow variables as economy must be highly controlled (P3 = narrow limits) because they know it is part of an infinitely interconnected and non–linear system (P4= higher the better) that requires a lot of science development and understanding (P5= higher the better). And to manage this highly complex system all participation is required (P6= higher the better) and the most decentralized form of decision making is better (P7= higher the better).

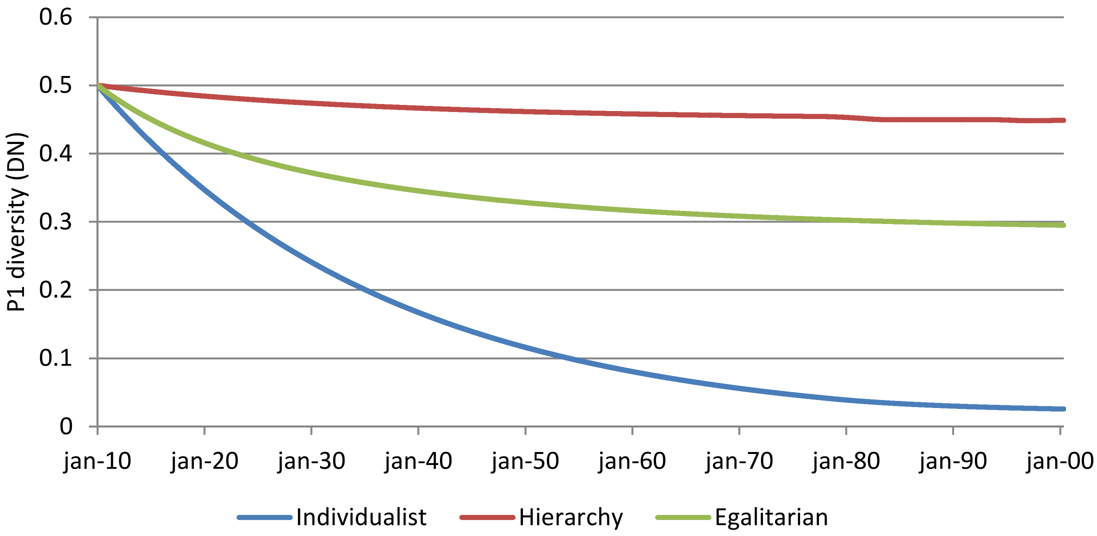
With goals in hand, the numerical model was constructed (Figure 50) and all the feedbacks identified in the causal loop diagram were embodied to simulate the behavior expected in the original text (Biggs et al., 2012).

3.3.3 Results and discussion of the simulation

3.3.3.1 Description of the principles behavior

This section presents the results of the resilience sub–model alone, to show the behavior each principle (Figures 52 to 59) presents in the function of each solidarity. It is important because it shows the manifest behavior of the causal structure built from the theory.

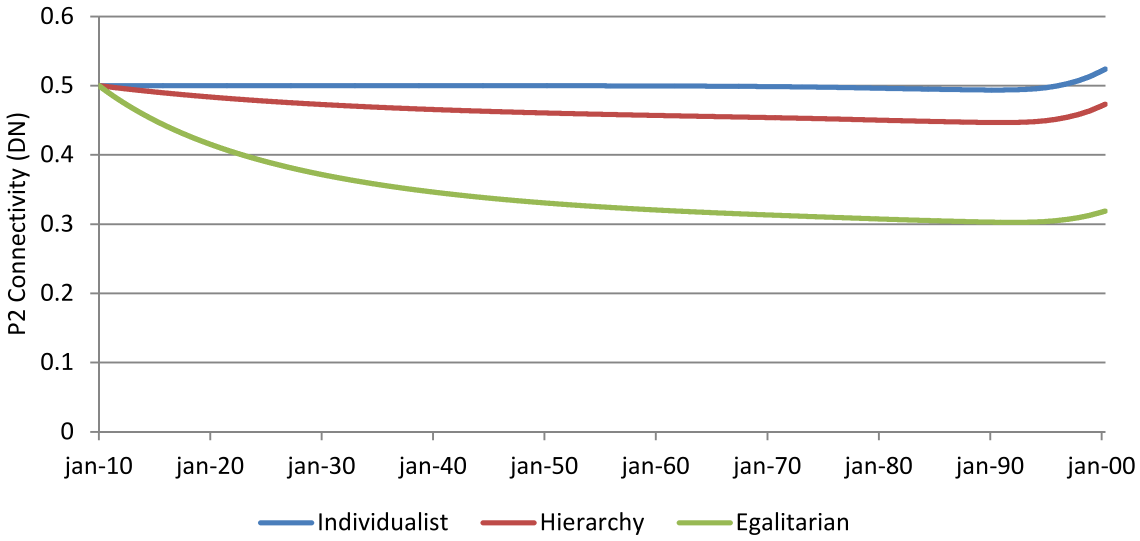
Figure 52: P1 diversity and redundancy



Simulation shows distinct paths according to the solidarity adopted. Source: the authors

Diversity and redundancy present an expected behavior once individualists have the lowest goal for this principle (Table 31). Hierarchy has the highest goal and thus occupies the higher position on the graph. Egalitarians have an intermediary state coherent to their goals. The curve shows all three solidarities having problems in keeping high diversity, despite their goals: for individualists, the lower goal explains the behavior; for hierarchy and egalitarians the growth comes from a "connectivity effect" which in turn is a function of principles P1 and P2 plus the effect of policentricity which is higher in egalitarians, justifying their disproportionate proximity to hierarchy in this principle behavior despite their different goals.

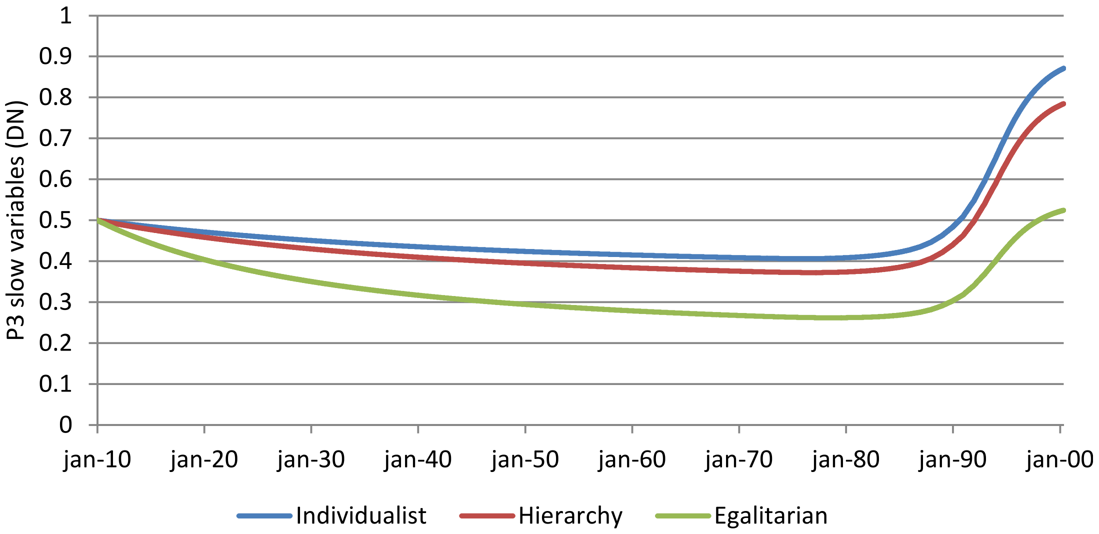
Figure 53: P2 connectivity



Simulation shows distinct paths according to the solidarity adopted. Source: the authors

All three solidarities show the same pattern of behavior (Figure 53) for connectivity varying the intensity due to the goal (Table 10). The overall behavior is a slight decay curve during the first 30000 days of simulation and then a slight turn in the curve, pointing to exponential growth. This behavior is dependent on the "investments in infrastructure" and "connectivity enhancing schemes" which are social activities that promote interaction of stakeholders regarding some collective action demand. We extrapolated the tendency of those connectivity meetings from the data (2010–2017) in a linear tendency, so it will achieve higher values at the end of the simulation. Considering "investments in infrastructure" a fraction of the city's GDP, it behaves like an exponential growth reaching a maximum value at the end of the simulation.

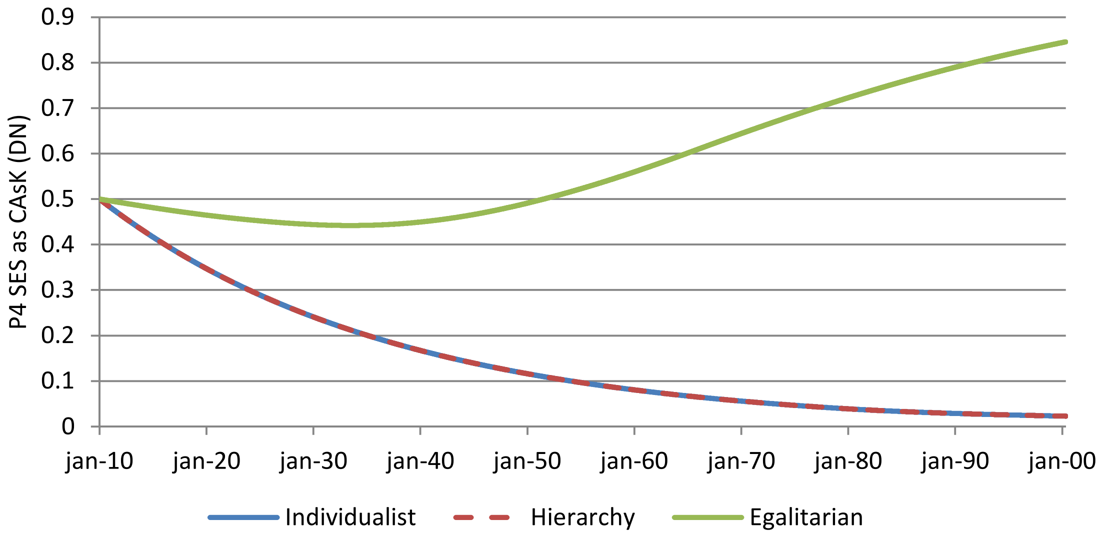
Figure 54: P3 slow variables



Simulation shows distinct paths according to the solidarity adopted. Source: the authors

Management of slow variables presents a decay curve (Figure 54) showing the goal seek behavior dependent on each goal with a turn upside occurring around day 28000. Since this simulation is based on the management of the effect of population growth (sewage depuration) all three curves come from the same city infrastructure, depending then only on their different goals. The change in the curve reflects the moment when finally the city invested so much in infrastructure that the sewage problems are resolved as well.

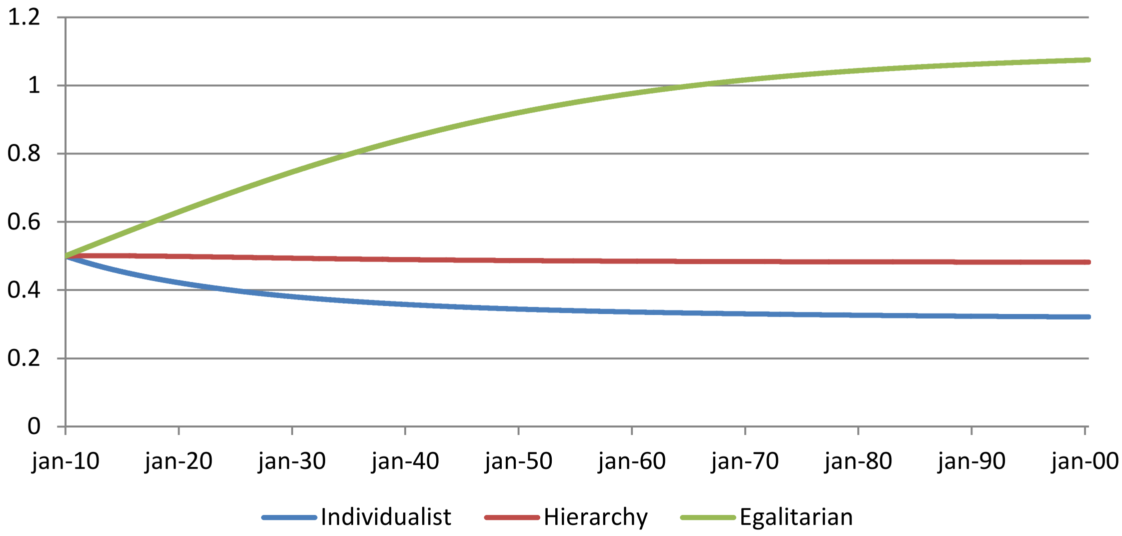
Figure 55: P4 SES as CAsK



Simulation shows distinct paths according to the solidarity adopted. Individualists are overlapped by hierarchy. Source: the authors

Understanding the Social–Ecological System as a Complex Adaptive System shows a decay curve for individualists and hierarchy (Figure 55). They are overlapped in the graph once they have the same goal (Table 10). For egalitarians, the curve starts with a decay similar to the others, but as they learn faster than others, the CAsK curve changes the behavior after the day 10000 and then starts to growth searching for its higher goal.

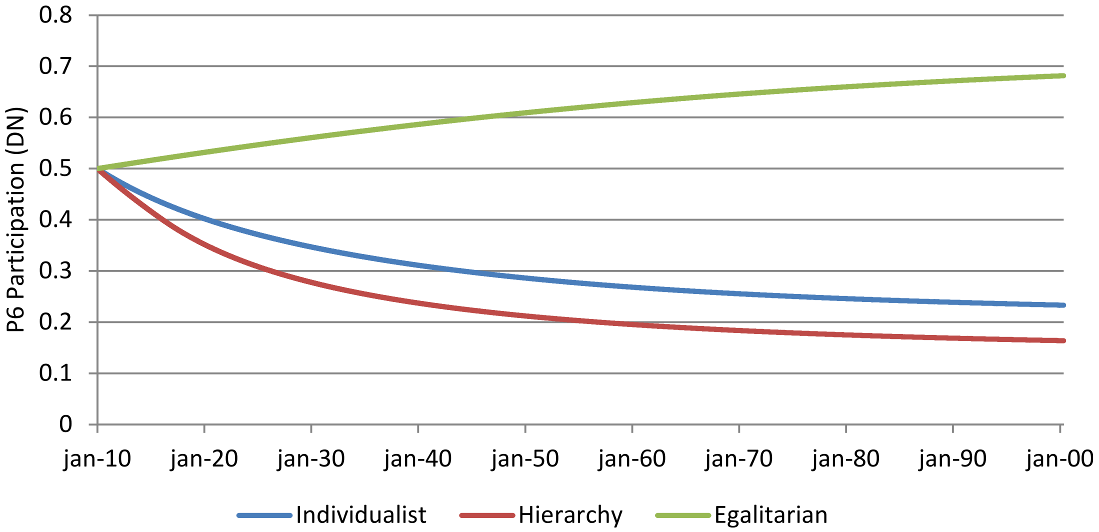
Figure 56: P5 Learning



In this case learning was the only attribute allowed to growth more than 1. Source: the authors

Learning (Figure 56) shows a goal seek growth behavior for egalitarians. The reaching of values higher than 1 on the curve is not seen as a problem once it was used infinite goals (actually limited by a number 2 on the model) for learning. Using the precautionary principle means they don't know the answers and need to learn how to manage their SES. For hierarchy, the goal is smaller and then its behavior almost doesn't change along with the simulation. Considering the already know the proper limits to manage, there is no need for great improvement regarding this attribute. Individualists present the lower curve due to their smaller goal for learning. Considering the market is the answer, they need to learn only the prices.

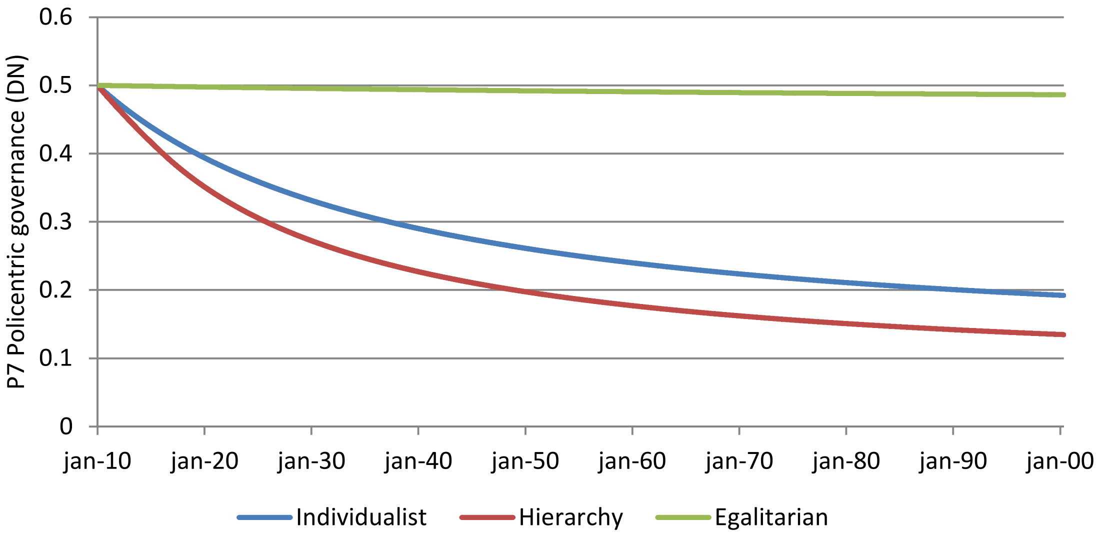
Figure 57: P6 participation



Source: the authors

The participation curve show decays for individualists and hierarchy following the expected on their low goals for this variable. Hierarchies are the opposite of participation by definition, and individualists can allow some participation to keep the market running with competition and then keeping the prices at the desired state. On the other hand, egalitarians present a growth goal–seeking curve that starts with the beginning of the simulation, as expected. They assume that everybody has the same right to be part of the decisions, then higher participation.

Figure 58: P7 polycentric governance



Source: the authors

For polycentric governance in the model is derivate from the trust, and trust came from connectivity. All three solidarities present a decaying curve on this principle, being hierarchy the lower curve, coherent with their restriction to relax the control of the hierarchy to more institutions, followed by individualists and their desire to keep the Government in a minimum level and then egalitarians that despite the high goal for this variable did not achieve a growth curve once connectivity and trust are not strong enough to make this slope acute and positive.

3.3.3.2 Sensitivity analysis

In the beginning, we can imagine that each principle has the same importance in the resilience of the SES. From Biggs et al. (2012) no principle is more important than the other and the authors state, and we eco, the multiplicity of meanings and processes embedded in each principle enhance the uncertainties about their participation in resilience. In this simulation, we tackle this problem with the numerical simulation followed by a sensitivity analysis. Our understanding of each principle is broader as possible, but we consider this the price to make a quantitative, not an extensive qualitative, analysis about the issue.

The analysis of a model’s sensitivity allows evaluating the variation of which of its inputs (independent variables) explains the most the variation of one of its outputs (dependent variable) (CARIBONI et al., 2007). As different inputs are considered together, the point usually is to compare them rather than getting an absolute measure of how their changes influence changes in the output, although this depends on the used method (here, we are in the first case).

The results of sensitivity analysis (SA) can serve different purposes depending on the stage of the model's life at which it is performed. During the development of the model, it serves to 1) understand its general behavior, identifying which input influences which output; 2) focus other types of analysis, such as calibration or uncertainty analysis, since it allows to select which inputs should be first studied (typically the most influential ones); 3) provide a sort of validation of the model (although incomplete), since the relationships that it highlights among variables should make sense when compared to the theory creating the possibility for the modeler to explain them.

In our SA, we assess the sensitivity of each resilience principle's output individually and in a preliminary integrative version of the integration between those principles (without the ecosystem services). This integrative variable was called preliminary DRI (preDRI) and it is different from the index itself once this one does not uses weighted exponents as demanded by Cobb Douglas equation (actually the exponents are there with value 1 for every variable) and also do not account for ecosystem services. PreDRI then was obtained by simple multiplication of every principle (equation IV):

$$\text{PreDRI} = P1*P2*P3*P4*P5*P6*P7 \qquad \text{(IV)}$$

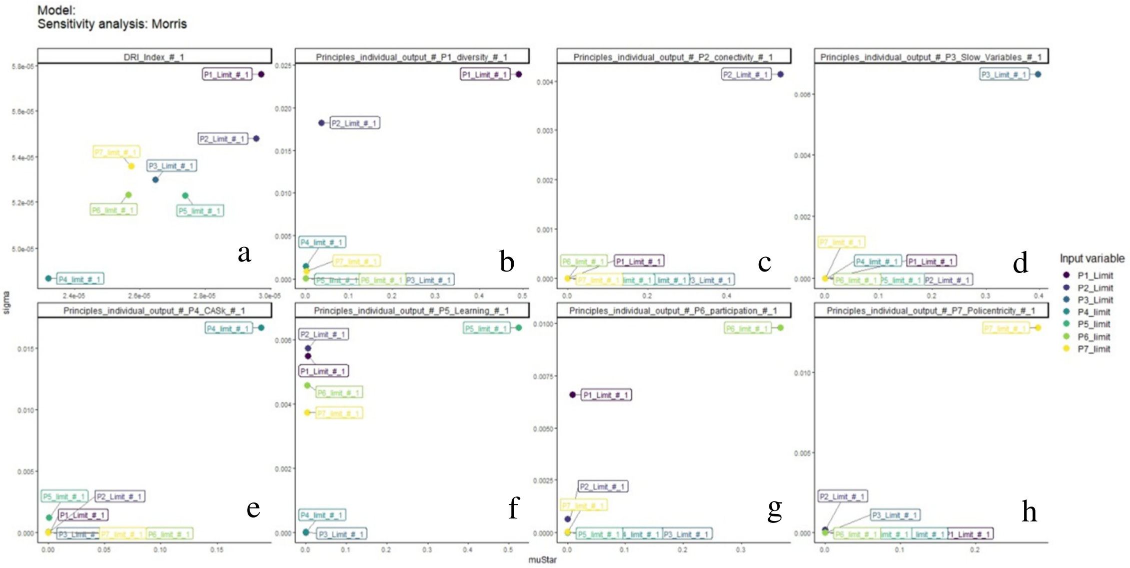
PreDRI was necessary because we could not test the whole ecosystem services model in our SA due to two technical unfeasibility: 1) the size of the whole model; 2) the fact that part of the ecosystem model uses some stochastic variables (e.g. wind speed and direction, cloud cover, rainy days, etc.) that our present version of the R package responsible for the SA cannot manage. A more comprehensive package is being built and further results will be published as soon as they are available.

We did the analysis using the Morris method (MORRIS, 1991). This method is global, meaning it looks at variations in all the inputs simultaneously, considering their whole possible value range. We chose this method because it is more computationally efficient than other SA methods, like the calculation of Sobol indices for instance (SALTELLI et al., 2008). Also, it doesn't require to set distributions for the input variables (unlike Sobol indices again), which we don't know in the case of the principle's limits of our model.

The results of the Morris method are best communicated in the form of a graph where the influence of each input on a chosen output is depicted by a point. For a given input (point), its coordinate on the x–axis (indicator μ^*) indicates the importance of its direct linear influence on the output. The higher is μ^*, the more sensitive the output is to this input. The coordinate of the point (input) on the y–axis (indicator σ) indicates either the indirect influence of the input (its interaction with other inputs causes the output's variation) or a non–linear effect on the output. The higher is σ, the more the input interacts with others or the more non–linear is its influence on the output. The absolute values of μ^* and σ are "meaningless" and are just meant to be compared among inputs (Figure 59 a–h).

Settings–wise, we run the model from 0 to 33000 days (representing the period from 2010 to 2100). Each input can take a value between 0 and 1 (possible range) with a step of 0.01. The value of the other model's inputs, i.e. the initial values of the principles, are set to 0.5. The Morris method has a single parameter (r) where the value of which defines the number of performed simulations of the model. While the Morris method is usually used for models with a large number of inputs, in which case r is set to a small value (below 100), we only considered 7 inputs (7 principles). Therefore, we could use larger values of r to obtain a more accurate result. To ensure the quality of our results, we repeat our SA with an increasing r (200k) until we observed a convergence in the results. In the main text, we present the results obtained with r = 200k. To conduct our SA, we used the *R* package *sensitivity* (R Core Team, 2018; IOOSS et al., 2018) that we nested in a package of our design (*similR*, soon published) that serves to manage, analyze and run Simile models in *R*.

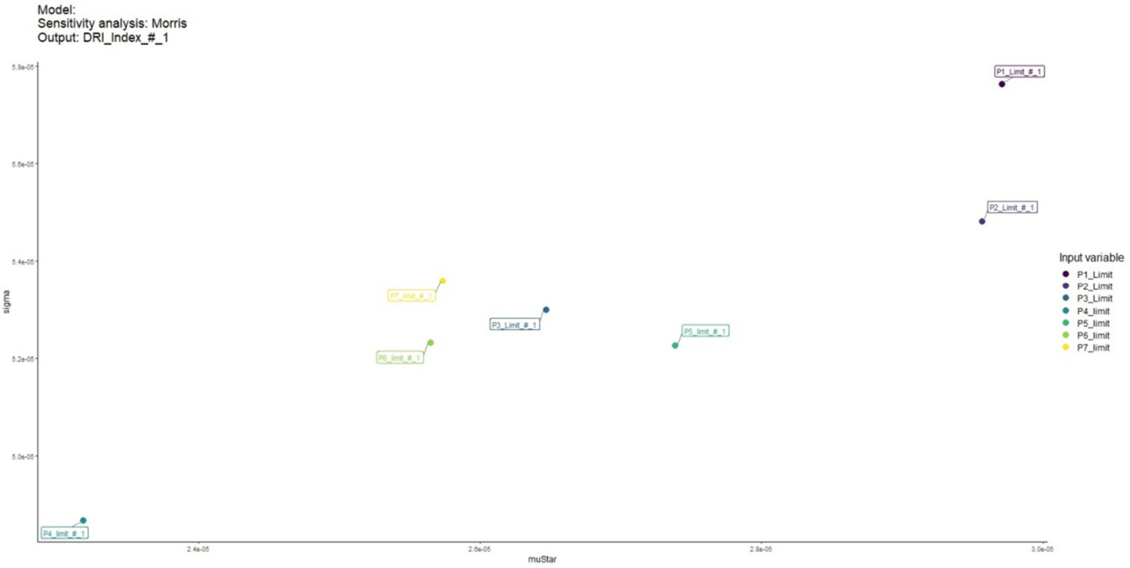
Figure 59: sensitivity analysis



The results of the resilience sub–model (pre-DRI): X–axis (μ^* - muStar) indicates the importance of its direct linear influence on the output. The higher is μ^*, the more sensitive is the output to this input. Y–axis (σ – sigma) indicates either the indirect influence. Source: the authors

Figure 59 “a” shows the participation of each principle on the overall PreDRI index. From that we can see the higher μ^* of P1 (diversity) which is the most relevant principle for determining the overall resilience behavior, followed close by P2 (connectivity). That is coherent with the model and the theory because as pointed before, some of the principles don’t have a variable direct influencing their decreasing rate, and usually, the feedbacks responsible for decreasing the resilience when those principles surpassed the desired point are embedded in P1 or P2. That fact is also corroborated by P1 and P2 having the higher σ, meaning they are more sensitive to an indirect influence of the input (principles values) than the others.

Figure 60: Main contributions to resilience.



X–axis (μ^* - muStar) indicates the importance of its direct linear influence on the output. The higher is μ^*, the more sensitive is the output to this input. Y–axis (σ – sigma) indicates either the indirect influence. Source: the author.

In the middle of the figure 60 it’s shown the participation of P3 (management od slow variables)(intermediate μ^* and intermediate σ); P5 (learning)(higher μ^* and intermediate σ); P6 (participation)(lower μ^* and lower σ) and P7 (policentricity)(intermediate μ^* and higher σ) showing that the participation of these variables in resilience occurs at the same scale, with small variances of direct (μ^*) and indirect (σ) influence in the overall result. Away from this central group, is P4 (SES as CAsK)(low μ^* and low σ) showing its influence in resilience is the smallest.

Figures 59 to “h” are individual analyses showing the influence each principle has from the others. Every principle is mostly influenced by its limits. That reinforces the necessity of understanding stakeholder’s goals and their influence in the resilience of the SES, for which cultural theory showed to be an interesting and feasible theoretical background. Some principles are not influenced by other principles, which does not mean they are not connected. Sometimes the links between them are variables common to both, in a lower level of the model, and thus they escape from the analysis which is focused only on principles.

Figure 59 “b” shows P2 (connectivity) limit as the higher σ to P1 (diversity), showing those variables are highly connected through feedbacks. P4 (SES as CAsK) and P7 (policentricity) showed a small influence on P1 as well; Figure 59 “c and d” showed none of the principles influences P2 or P3 (management of slow variables) (direct or indirect) which happens to occur only by variables influencing principles (P1 growth), not by principles themselves. Figure 59 “e” showed P4 being influenced indirectly by P5 (learning), pointing that learning is responsible for the understanding of SES as CAs; Figure 59 “f” showed P5 (learning) being indirectly influenced by almost all principles, but strongly by P2 (connectivity) followed by P1 (diversity). An intermediate influence is presented by P6 (participation) and P7 (policentricity) and the lower influence comes from P4 (SES as CAsK) and finally from P3 (management of slow variables). Figure 59 “g” shows that P6 (participation) depends on P1 (diversity) and P2 (connectivity); Figure 59 “h” showed P7 (policentricity) is slightly dependent on P2 (connectivity).

In an overall view, we consider these results highly corroborative of the model and the theory, pointing the relevance of the limits to every principle and showing part of the intricate network of feedbacks that connect them.

3.3.3.3 Weighting the Cobb Douglas Equation:

The method used for aggregation of ecosystem services and resilience attributes (equation III) as a Cobb–Douglas like function, demands to deal with exponents ($^{\gamma 1\text{-}17}$). The original authors of this function (COBB & DOUGLAS, 1928) only had to deal with two exponents, one for labor other for capital, and they reach a proportion between those exponents that fit their data ($P=1.01L^{3/4}C^{1/4}$). Those exponents represent the weight every variable has on the overall index (production, in their case).

More recent applications of this kind of aggregation by composite index deal with much more than two variables and the weight of each variable became a challenging task where the diversity of aggregation methods can lead to slightly different results (MACHADO & RATICK, 2018).

Boumans et al. (2002, 2015) claim that the weighting values are intrinsically unknown and reflect aggregated individual preferences. In our paper, it’s also remarkable that an index is being created with no correspondent in reality to which it can be compared and calibrated. Thus the arbitrary choice of weighting values became a deliberate choice of the authors. As we already clustered the stakeholders in three culture theory solidarities, we used the same profiling types to create three weighting profiles that reflect the individual preferences of each group (Table 11).

Table 11 – weights for each principle and ecosystem service according to each solidarity

		Individualist	Hierarchy	Egalitarians
Resilience Principles	P1 – Diversity	0.01	0.07	0.02
	P2 – Connectivity	0.1	0.07	0.02
	P3 – Slow Variables	0.1	0.07	0.02
	P4 – SES as CAsK	-0.01	-0.01	0.07
	P5 – Learning	0.05	0.07	0.07
	P6 – Participation	0.01	-0.01	0.05
	P7 – Policentricity	-0.01	-0.01	0.05
	subtotal	0.25	0.25	0.3
Ecosystem Services	Crab production	0.1	0.1	0.07
	Clam production	0.1	0.1	0.07
	Cartilaginous fish production	0.1	0.1	0.07
	Bone fish production	0.1	0.1	0.07
	Carbon sequestration	-0.01	0.05	0.07
	Sewage Depuration	0.1	0.1	0.07
	Nutrient Cycling	0.1	0.01	0.07
	Oxygen Production	-0.01	0.05	0.07
	Mineralization	0.07	0.04	0.07
	Water quality	0.1	0.1	0.07
	subtotal	0.75	0.75	0.7
	TOTAL	1	1	1

Source: the authors

The weights assumed values ranging from an undesired situation (-0.01) to positive weights representing grades of approval for each variable in function of each solidarity: very low (0.01), low (0.02), medium (0.05), high (0.07), and very high (0.1). Those values are arbitrary and represent variations around the medium value of 0.058 for each of the 17 components of DRI, which sum totalizes 1. The only exception is to mineralization for the hierarchy that should be 0.05 but this value makes the sum of their weights be more than 1, so it was arbitrarily limited to 0.04.

The story in table 11 for each solidarity is a complement of that goal attribution (Table 31). For individualists, there is no need for response diversity (P1=very low), the market is the answer to solve environmental problems. Thus the market must stay connected to every possible point in the system (P2= very high) and slow variables (e.g. economic cycles or water quality) must be managed properly (P3=very high) to avoid surprises or dissonances in the market equilibrium and also to avoid losing the source of economic income. The resource bases of the economic system are not complex, and the understanding of it as complex is undesired (P4=undesired); resource bases can be managed by the rational economic beings, that know and learn about their preferences (P5= medium). There is no need for participation of others unless it is necessary to maintain the good competition of the markets (P6=very low) and also there is no need to spread the government when centralized solutions can leave the markets free to work (P7= undesired).

Individualists focus their efforts on ecosystem services that provide an immediate economic return, maximizing the bottom line. Thus high value is given to production (crab, clam, cart. fish, bonefish = very high) and also to water quality and sewage depuration (very high) because they matter to tourism frequency. Nutrient cycling (very high) and Mineralization (high) are bonuses from nature that can help to ensure better water quality and thus tourism. Carbon sequestration and oxygen production are global problems that could lead stakeholders to choose a different management system for the environment, against that one provided by markets, and so they are not welcome (undesired).

The story for hierarchies reflect their understanding of the value of diversity and also the limits they skillfully put on this value (P1= high), the same happening with connectivity (P2= high). Slow variables (e.g. economic development, tax rates, or sewage depuration systems) must be managed in high, but controlled standards (P3= high) due to their costs to society. Understanding the system as a complex thing would bring confusion and uncertainty (P4= undesired). Learning is high but still limited once complexities must be avoided (P5=

high). Participation and policentricity preferably should be avoided because they make the decision making slow and reduce the efficiency of governance (P6 and P7= undesired).

Regarding ecosystem services, hierarchies value all kind of fisheries production (crab, clam, cart. fish, bonefish = very high), water quality, and sewage depuration (very high) because those are measurable and relevant variables to the proper management of the coastal area and thus assuring the revenue for city development. Carbon sequestration and oxygen production (medium) are relevant in a secondary position once climate change is supposed to be taken care of, in a higher governance hierarchy. Mineralization (medium) and nutrient cycling (very low) are important but they are already included when fish production and water quality are monitored and satisfactorily managed.

Egalitarians cherish management with precaution and thus diversity (P1 = low), connectivity (P2 = low) and slow variables (P3 = slow) must be managed with caution, preferably allowing the precautionary principle and noninterference make its part. Considering the system is infinitely interconnected and non–linear (P4= high), learning (P5= high) must also be enhanced. Considering there are no guardians of the truth, all have something to say about the governance and thus participation (P6= medium) and policentricity (P7= medium) can be a useful strategy. Egalitarians would like to weigh more learning, cask, participation, and policentricity but their understanding that nature is the best guide for herself limits the amount of governance this solidarity must–have.

Thus, for ecosystem services, egalitarians give the same value for each of them (high), with no advantage for those with economic return once all aspects of nature are equally relevant and deserve to be treated with the same caution and respect.

3.3.4 Dynamic Resilience Index Results and discussion

Applying equation III resulted in a DRI composed of seventeen components, seven principles for resilience plus ten ecosystem services, each of them with a respective exponent given in table 32 and for the resilience principles, a maximum value given in table 31.

Every ecosystem service (ES) simulated (chapter 2) was then normalized (MACHADO & RATICK, 2018) to vary between 0 and 1, to be at the same scale of resilience principles to be clear that zero mean no ecosystem services and 1 is the higher production the system can get under normal conditions. ES directionality was also checked but not inverted, meaning some ecosystem services have their production enhancing (e.g. bonefish), some are decreasing (e.g. clams). Every simulation is adopting one set of values for resilience goals and one set of exponents that match that solidarity.

None of the insights found in this paper are supposed to be understood as systems properties that would be presented in all SES like universal properties. Ostrom (2007) adverted about panaceas and we agree that insights that happened in this model are bounded in reach and data, with clear and discussed limitations.

3.3.4.1 1st insight: There is not one goal for resilience, but three; although the system has one resilience, not three.

Being resilience property of the social–ecological system means it is therefore dependent not only on the set of ecosystem services provided but also on goals and standards for what society envision as desirable for those principles supporting resilience (HOLLING, GUNDERSON & LUDWIG, 2002; GUNDERSON & HOLLING, 2002; ADGER, 2009, NEY, 2009). Being those goals socially determined, culture theory claims that three different active groups inside society have their own set of goals. The consequence is three different values for resilience (Figures 61 to 63). Which of these sets of values we see in reality, supposed they could be measured?

The answer is none of them and all of them at the same time. The type of problems that are strongly dependent on social perspectives (value dependent) and filled with uncertainties – or Rayner's (2006) contradictory certitudes – are called messy or wicked problems (NEY, 2009). Messy problems[22] emerge from the idea of none public good (or policy) are indisputable; that equity lacks an objective definition and there can be no optimal solution to social problems without the price of imposition (and thus lack of legitimacy), once optimal is always a partial solution (what is the best for the spider is chaos for the fly) (RITTEL and WEBBER, 1973; THOMPSON & VERVEIJ, 2004; NEY, 2009). These kind of problems bring ten distinguished characteristics that allow them to be recognized (RITTEL and WEBBER, 1973; RAINER, 2006; NEY, 2009):

a) "There is no definite formulation of a wicked problem". Any definition is uncertain and invariably contested;
b) "Wicked problems have no stopping rule". As the time horizon is not definitively formulated, it's impossible to know if the problem has been solved;

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[22] considered synonym of wicked problems (Rittel and Webber, 1973; Forrester et al., 2018)

c) “Solutions to wicked problems are not true–or–false, but good–or–bad”. Considering there is no absolute (only relative) criteria to judge the solution, it will always depend on judgment and interpretation;
d) “There is no immediate and no ultimate test for a solution to a wicked problem”. In complex systems, solutions create waves of consequences over an unknown period of time, so the evaluation criteria must change along the time;
e) “Every solution to a wicked problem is a ‘one–shot operation’, because there is no opportunity to learn by trial and error, every attempt counts significantly”. Even with *in silico* simulations reducing the uncertainty, there will always be unexpected consequences of implementation of the solutions and the whole solution cannot be undone;
f) “Wicked problems do not have an enumerable (or exhaustively describable) set of potential solutions, nor is there a well–described set of permissible operations that may be incorporated into the plan.” Considering the uncertainty regarding the causes of those problems, the set of solutions are always open to new inputs;
g) “Every wicked problem is essentially unique.” There will always be an amount of overlap between similar problems, but what distinguishes them will eventually prevail what makes the “one solution fits all problems” something impossible;
h) “Every wicked problem can be considered to be the symptom of another problem.” If we consider that in complex systems, solutions create waves of consequences some of them maybe good and some bad, which reinforces the creation of problems indefinitely;
i) “The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem’s resolution.” When wicked problems are at stake, the rationality behind the argument is richer than those in the scientific discourse. There will rarely be a policy problem formulated as an scientific hypothesis to be accepted or rejected and it is not possible to put the problem in a controlled test;
j) “The planner has the right to be wrong.” Policy making is different from science; there can be no controlled test and hypothesis refutation. The solution will also depend on valuation, which are value dependent, and thus change according to groups and time.

Messy problems can sometimes create what Rein and Schön (1993) called “Intractable Policy Controversy”. These types of conflicts, the authors claim, are weakly affected by scientific information, once the very formulation of the problem depends on point of views and values, not just data. Is not a lack of information that underlies those problems, but usually, the amount of scientific information available either surpasses the ability of the decision–makers to deal with or even the knowledge available do not address specifically the problem the policymaker needs at that moment (NEY, 2009). Yet, a diverse group of institutions and actors select, filter chose, and finally adopt a part of the total information available, the part they consider relevant to the problem.

The act of interpreting and selecting information requires a judgment of what is relevant, precise, important, true, valuable, etc., and this “judgment is guided by shared ideas, values and beliefs" (NEY, 2009), in other words: judgment is culture–dependent. That happens because with shared values and beliefs, data and scientific information gain significance in an intellectual shared context (culture), a broad view about the world, instead of forming an independent and disconnected body of knowledge. In terms of society, the consequence of shared culture is the formation of groups with common ideas and values: "Individuals tend to work together if they share a particular frame" (NEY, 2009), what has been called "advocacy coalitions or discourse coalitions" (NEY, 2009; MA et al., 2020).

In the end, messy problems can develop into intractable policy controversy exactly because they bring to discussion different frames (culture theory solidarities), set of shared world views (values and beliefs), not facts and data. Ney (2009, page 10) claims that if contending frames are in discussion, there is no (or small) room for negotiation:

> Neither is this type of conflict amenable to resolution by bargaining: since contending world–views are at issue, there is no basis for negotiation. Policy–making about messy challenges then is an inherently argumentative process in which contending advocacy coalitions pit arguments – plausible and convincing accounts of what is and what should be going on – against each other. This is why conflict about messy issues is inevitably about values and beliefs. And that is also why frame–based conflict about messy issues is inherently intractable. (NEY, 2009 page 10)

The way to deal with those opposite frames authors claim (NEY, 2009) is to understand the arguments they provide to justify their frames, moving the conflict away from "intractable policy controversy". Operationalization of this approach is made by dealing the contending as narratives contend (stories to mobilize or justify a particular course of action), navigating the body of arguments and unraveling the assumptions and background (settings), redefining the problem (villains) which may lead to a different solution (heroes) of that story: "[…] the loser may be more willing to accept the loss if losing does not mean that society will become callous to the values he or she held."(SHAPIRO, 1988).

Policy theory describes three possible scenarios for the result of this advocacy coalition's interaction: a) is the "dialogue–of–the–deaf" which independent of the plurality of ideas, basically, no one is listening to each other and just trying to impose their values and beliefs. This usually results in policy stagnation "as conflict becomes a way of preventing rival advocacy coalitions making any gains" (NEY, 2009 page 203).

In the case of resilience, if the discussion is a "dialogue of the deaf" the overall goals for each solidarity is continued biased, sabotaged, or substituted by some random individual goal, that makes sense for a particular coalition group that had the opportunity to claim its values in that particular moment of the decision–making process. But decision making happens in diverse arenas and multiple levels, it is not a moment when all problems are decided at once. On the contrary, it will happen in different moments, different locations, with different people representing different power balances in a continuum process. In the case of "dialogue of the deaf", resilience would be lost once the goals for each principle would be constantly being erased and sabotaged by other parts of the same society that created them, and then resilience would be virtually zero.

If some dialogue happens, which literature suggest must occur in a highly regulated space, with norms described below (Sabatier and Jenkins–Smith, 1993), the a) deafness can be reduced and substituted for a productive dialogue that will result in b) reinforce the power of a dominant advocacy group (leading to boom–and–bust) or c) lead to increase in empathy, interaction and responsiveness from advocacy groups (rough–and–tumble) (NEY, 2009). The norms allowing interactions are:

> H6: Policy–oriented learning across belief systems is most likely when there is an intermediate level of informed conflict between the two coalitions.
> H7: Problems for which accepted quantitative data and theory exist are more conducive to policy–oriented learning across belief systems than those in which data and theory are generally qualitative, quite subjective or altogether lacking.
> H8: Problems involving natural systems are more conducive to policy–oriented learning across belief systems than those involving purely social or political systems because, in the former, many of the critical variables are not themselves active strategies and because controlled experimentation is more feasible.
> H9: Policy–oriented learning across belief systems is most likely when there exists a forum that is: prestigious enough to force professionals from different coalitions to participate and dominated by professional norms. (Sabatier, and Jenkins–Smith, 1993 *apud* Ney, 2009 page 225)

It is not a good option to have strong and dominant solidarity whatsoever. First, because culture theory claims that there are no right or wrong worldviews because all of them were created using reason and logic (RAYNER, 2006). "None of them is wrong in the sense of being implausible or incredible" (NEY, 2009). All of them bring values and flaws, which first define them in opposition to each other, but mostly can provide creative and plausible goals for complex SES problems. Second because when the system is stiff on the same trajectory it can be in a system trap–like "the rigidity trap" (GUNDERSON & HOLLING, 2002; FATH et al., 2015; KHARRAZI et al., 2016) that will be discussed properly ahead.

Culture theorists claim the necessity of all those groups to exist once they are defined by opposition to each other – the requisite variety (THOMPSON, ELLIS and WILDAVSKY 1990; RAYNER, 2006; NEY, 2009). All of them are incomplete although all have something to say (HOLLING, GUNDERSON & LUDWIG, 2002; GUNDERSON & HOLLING, 2002). Legitimacy and social adherence to solutions gain power, the argument goes, when all solidarities are present and risks of lack of compliance and even sabotage increase if one or more active groups are expelled (THOMPSON, ELLIS and WILDAVSKY 1990). In Rayner's (2006) words "You don't want to push one particular value set – the hierarchical, egalitarian, or competitive – out of the picture because they all have something to bring to the table in terms of solutions".

In the end, the level of openness to listen to other perspectives and mostly responsiveness to contend position will define the learning process of the advocacies coalitions debate and eventually lead to the desired scenario which is the rough–and–tumble (NEY, 2009). The output of this process (the solution) is a policy filled with elements of all active advocacy groups, called clumsy solution (SHAPIRO, 1988; VERVEIJ et al., 2006; NEY, 2009; SCOLOBIG et al., 2016; LINNEROOTH–BAYER et al., 2016). The clumsy solution happens when the hierarchy's call for "rules and wise guidance", the individualist's call for "optimal technical solutions and entrepreneurship" and the egalitarian's call for a "whole new relationship with nature" coexists, cope and despite the volume of the discussion, manage to build a constructive solution. The whole idea is to answer SES problems by constructing solutions that are widely accepted, and democratically legitimated. The point is reaching not only effectiveness, which is obviously in the discussion, but also legitimacy:

> And, unlike many commentators would have us believe, the most effective way of embracing conflict without risking either a melt–down into an intractable cacophony or an implosion due to sustained policy failure is to adopt pluralist and democratic practices in policy subsystems. (Ney, 2009 page 202)

It means that society must dialogue and reach some consensus on which way to go, even if this answer is not exactly what each advocacy group desires. When the complexities and uncertainties from the ecological subsystem, which are not fully understood, are added to those from the social subsystem, which are also only partially known, we end up with a massive problem that surpasses the human mind intellectual capacity (FORRESTER, 1971; RITTEL and WEBBER, 1973; STERMAN, 2000; VAN DEN BELT., 2006). This is important because the idea of the perfect solution must be abandoned in the function of a negotiated suboptimal one. Even though because messy problems “tend to be persistent and insoluble” (RAYNER, 2006).

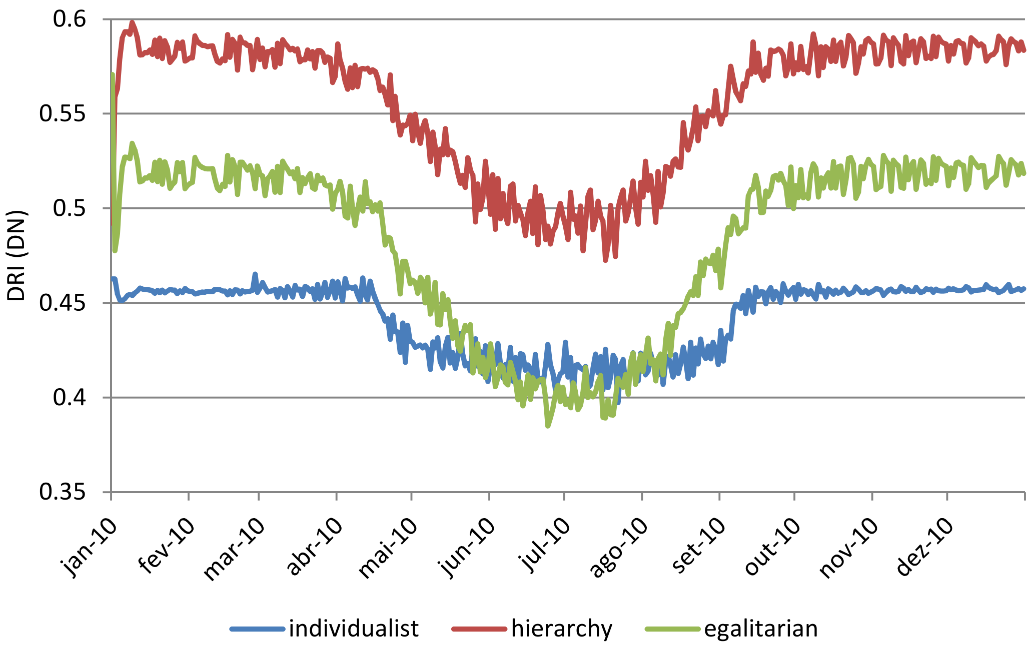
Then in opposition to the idea of rational policy–making, in which social problems can be solved by the application of rational scientific methods, using the relevant facts as support and finally imposing the optimal solution, emerges the pluralist politics (or plural rationality as a synonym of culture theory) in which solutions come from deliberation and argument: “The pre–requisite for a clumsy solution, it follows, are *accessibility* (each voice able to make itself heard) and *responsiveness* (each voice engaged with, rather than dismissive of the others)” (SCOLOBIG et al., 2016). This is a major change in the way planning is done. Several experiences corroborated this in the literature (e.g. NEY, 2009; SCOLOBIG et al., 2016; LINNEROOTH–BAYER et al., 2016). What may not bring the optimal scientific solution, brings the most democratic and legitimate answer (NEY, 2009).

To close this first insight, resilience will vary through these three possibilities of values determined by advocacy coalitions interactions, theorized by culture theory: a) it can be virtually zero if deafness reign; b) It can assume one of the values individually calculated (Figures 61–63) if the advocacy groups of each solidarity occur in a dominance level, or it can be inside the negotiated space formed by those three curves (Figures 61–63) if a legitimated and dialogued agreement had been reached.

3.3.4.2 2nd insight: Resilience presents seasonal variations

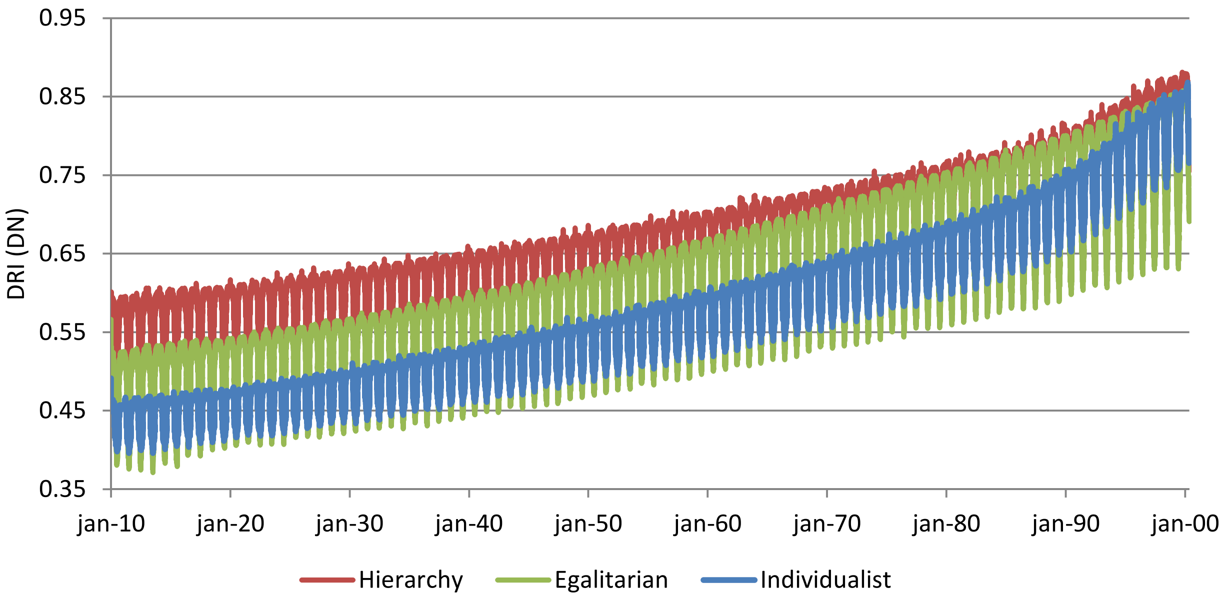
The fact that the index is proportional to some ecosystem services that have a strong seasonal pattern, makes the index seasonal (Figure 61 and 63). All fisheries in the model are seasonal as well, but their oscillation is small. Carbon sequestration, oxygen production, mineralization, and sewage depuration are strongly seasonal, and then their oscillation is reflected in the index as well.

Figure 61: Dynamic Resilience Index



DRI for three different rationalities simulated from January to December 2010, showing the marked seasonal oscillation in DRI. Source: the authors

Figure 62: Dynamic Resilience Index from 2010 to 2100



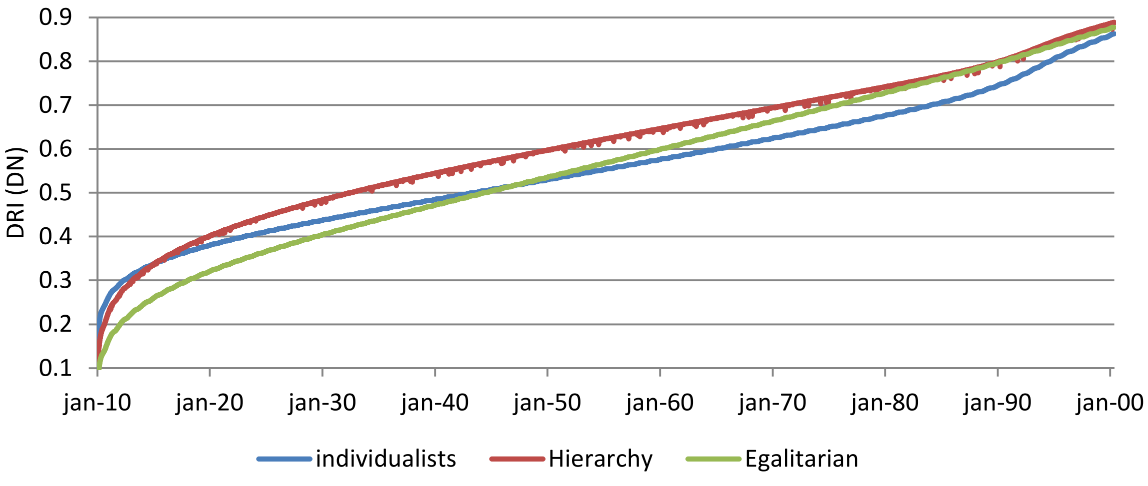
Simulated with seasonal oscillations for the three different rationalities Source: the authors

Oscillatory behavior has been shown before in r to k phases (described below) (BURKHARD, FATH & MÜLLER, 2011; FATH et al., 2015; KHARRAZI et al., 2016), but they were random oscillatory movements not related to seasons. In this sense, this observation can be valuable once it allows the interpretation that certain systems are more resilient in certain seasons, and thus if disturbances can be delayed to hit the system during high resilience season, maybe those disturbances unfold in smaller impacts.

To enhance visual clarity, it is possible to smooth those oscillations. In this case, the resilience index curves change position along the century (Figure 63). In the first 5 years, approximately (2010–2015) individualists have the higher DRI, followed close by hierarchy, and egalitarians are decoupled with the lower index. This happens probably influenced by the same starting point in the social sphere sub–model which didn't have the time to decrease due to slow standards of some social sphere goals of individualists (e.g. learning, connectivity, etc.). Hierarchies start with the same background but usually have higher standards for social limits (Table 31 and 32) and then grow with a higher slope when compared to individualists. Egalitarians are well below those two solidarities and growing with a gentle slope.

Then hierarchy crosses the individualist line in 2015 and continues to present the higher DRI along the century until 2082 when it virtually equals to the egalitarians until the end of the simulation. Egalitarians also cross the individualist line, but latter than hierarchy, only in 2045, but with a steep slope that will make them reach the hierarchy curve in 2082.

Figure 63: Dynamic Resilience Index normalized



In this simulation the oscillations of some ES were normalized. Source: the author.

3.3.4.3 3rd insight: the system is operating in r phase

Holling and Gunderson (2002) show that most ecosystems change along time in an evolutionary cycle called the adaptive cycle. The cycle is a metaphor for how changes in systems occur through time and what the role of resilience is. The cycle is usually represented by the infinity symbol, the lazy eight, displaced inside two axes (x for connectedness and y for potential) and divided into four phases: r for exploration – phase with the rapid growth of the system using available materials and low competition; k for conservation – slower growth rates and high competition meaning the system is becoming mature; α for reorganization – after a disturbing phase (Ω) reorganization is marked by slow nutrient loss, the opportunity for colonization and/or innovation; Ω for release – “creative destruction” occurs when resource accumulation from the previous cycle (k) becomes fragile and susceptible to an agent (drought, insects, fires, etc) (HOLLING and GUNDERSON, 2002; FOLKE, 2006).

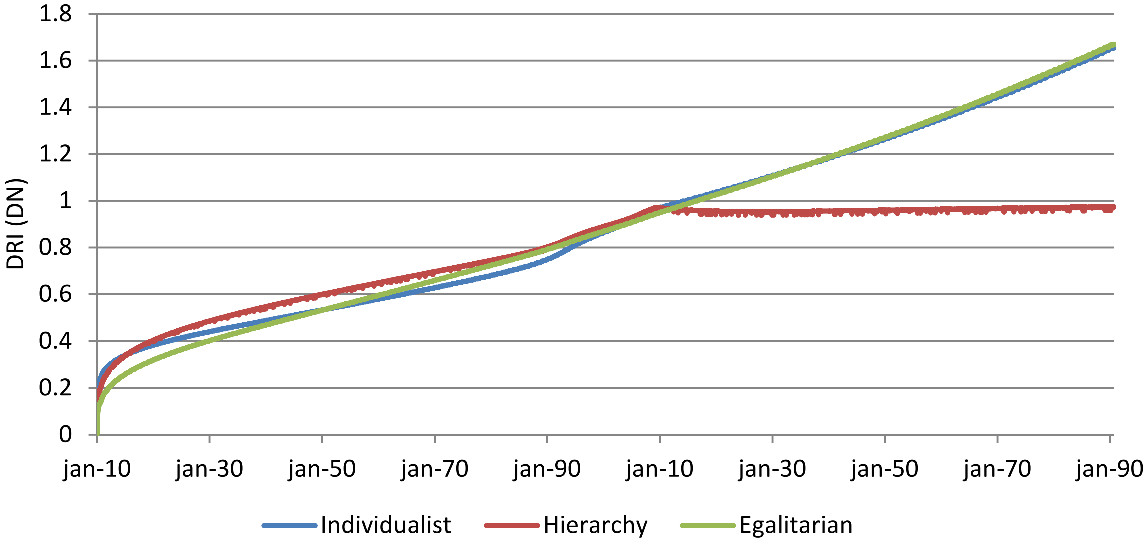
Through this cycle connectedness and stability increase from phase “r” to “k” forming some sort of capital of nutrients and biomass in natural systems or mutual trust, social relations, and partnerships in the social sphere. At the end of the “k” phase, few species or social groups become dominant and most of the diversity is residual, peripheral to the mainstream system. The increasing accumulated capital built from growing also represents the increasing potential for different uses or futures, and with Ω part of it becomes available to new arrangements and opportunities (α). Resilience in this framework appears as the z–axis. The lowest value occurs after the Ω phase and it starts to grow at the “r” phase. The highest value occurs in the late “r” or early “k” phases and then starts to decrease in the late k phase (due to the rigidity of this late phase).

Our results for DRI show that the system is in the r phase, with growing resilience until reaches the k phase which is not happening during the simulated time (2010–2100) (Figure 64).

3.3.4.4 4th insight: The system may be locked in a trap

It is also related to some cases that the system can be maladaptive and remain locked inside a system trap. This maladaptive system is also understood as resistant, instead of resilient (WALKER et al., 2002). Traps mean the system cannot “change or adapt to new conditions nor escape from a trajectory toward an undesired regime” (GUNDERSON, ALLEN and HOLLING, 2010). There are several system traps (GUNDERSON and HOLLING, 2002; GUNDERSON, ALLEN and HOLLING, 2010) but what seems to fit in our case is the rigidity trap: “The rigidity trap occurs when a system becomes so refined in its processes that there is little room for further innovation” (FATH et al., 2015). O traps are usually defined by combinations of three system elements: 1) potential (or capital); 2) connectivity 3) resilience.

Figure 64: Dynamic Resilience Index from 2010 to 2190



The three solidarities were simulated for an exceptionally long time showing different behavior that is compatible with a rigidity trap. Source: the author.

Thus the curve of very long simulation (Figure 64) shows that the system might be operating in a “rigidity trap” (GUNDERSON and HOLLING, 2002; GUNDERSON, ALLEN and HOLLING, 2010; FATH et al., 2015). The combination of the trap elements is high for resilience (Figure 64). It is high for capital (once the system is still growing in the r phase). Among the 16 elements modeled from the ecosystem (including phytoplankton, zooplankton, salps, detritus, bacterioplankton, clams, shrimps, crabs, starfish, jellyfish, five functional groups of bone and cartilaginous fishes), 13 are high showing that the overall picture of capital (or potential) is high on the system.

Connectivity (Figure 53) varies among solidarities. In the case of egalitarians, connectivity is decreasing along with the simulation, but it’s not reaching zero or a very low value. Its lowest value never reached 0.3 and also it starts growing again in 2090. Although in this case, it is not pointing to the rigidity trap demand (high connectivity) it is possible that connectivity is not very high, but simply high enough to keep the system in the trap. For Individualists and Hierarchy, on the other hand, connectivity is higher (minimum of 0.45) and presents the same curve pattern of growth after 2090 showing that in all cases there is feedback increasing this element and then the hypothesis of the trap can be more likely.

3.3.4.5 5th insight: resilience of what to what? Resilience of the whole system in providing a set of ES against changes in slow variables

It is very common in resilience literature the necessity to establish the resilience of what to what meaning the analysis must specify the state of the system and also to what this state is resilient against. This practice is usually grounded in Carpenter et al. (2001) and its metrics are based on the size of the basin of attraction. Folke et al (2010) called that specified resilience and in an opposing concept defined general resilience: "resilience to all kind of shocks, including completely novel ones". Also, the authors call the attention that reinforcing part of the system to be resilient against a determined perturbation can make the whole system lose resilience in other ways (FOLKE et al., 2010).

In this case, DRI probably occupies answers both questions from specific and general resilience because it has characteristics from both (like in WALKER et al., 2009): first, it is *a priori* unspecific about disturbances (and thus what happens is dependent on slow variables because they are the only thing varying through the long time series); second, when stressed with known shocks, it reacts accordingly in an expected way. SCHIPPER & LANGSTON (2015) call attention to the very rarity of general resilience quantitative approaches.

Being unspecific about disturbances is related to the fact that in DRI simulation there is no delimited basin of attraction in one variable to be tested against one specific disturbance. What DRI is showing is the overall behavior of the ES production system in a landscape with several basins of attraction (social goals) that change. And thus the whole system changes along concerning: a) social goals; b) time; c) season: d) climate change.

3.3.4.6 6th Insight: Not all resilience principles have the same weight in resilience

Resuming Figure 59 "a" (and Figure 60) where the results of the sensitivity analysis are presented, the participation of each principle on the overall PreDRI index and presumably in resilience is different. The higher μ^* of P1 (diversity), followed close by P2 (connectivity) shows that these two principles are mathematically more relevant for the objective.

In an intermediary position appears P3 (management of slow variables) with intermediate μ^* and intermediate σ; P5 (learning), with higher μ^* and intermediate σ; P6 (participation), with lower μ^* and lower σ and finally P7 (policentricity), with intermediate μ^* and higher σ. Those four principles (P3, P5, P6 and P7) for a distinct group of intermediary influence in resilience, with slight variances of direct (μ^*) and indirect (σ) intensity. The least influence is made by P4 (SES as CAsK) with low μ^* and low σ, that appear isolated in the left corner of figure 59 “a”.

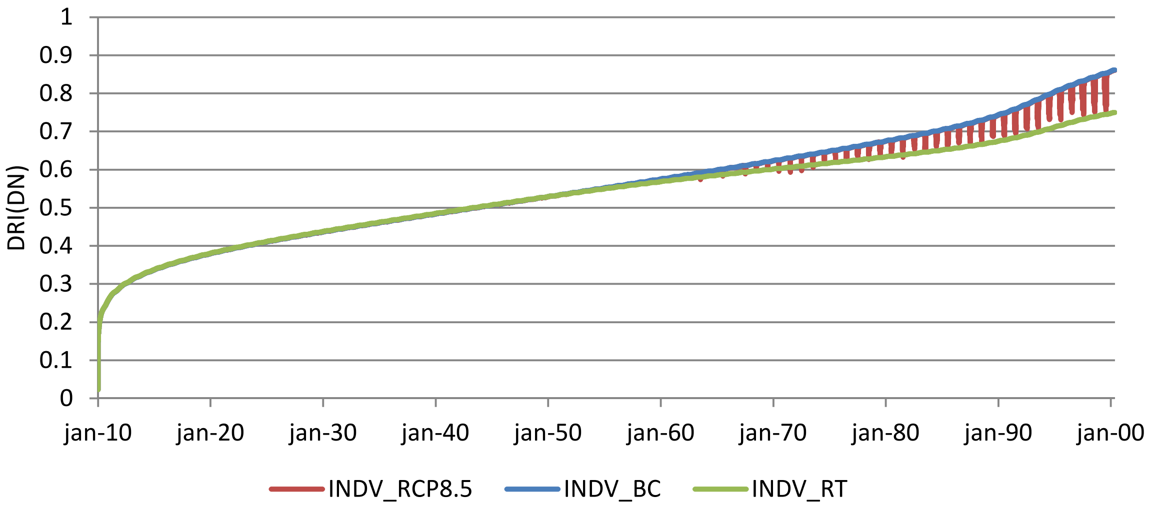
That result is coherent with the model and presumably with the theory (BIGGS et al., 2012). Some of the principles don’t have a variable directly influencing their decreasing rate (P3 to P7), and usually, the feedbacks responsible for decreasing the resilience when those principles surpassed the desired point are embedded in P1 or P2. That fact is also corroborated by P1 and P2 having the higher σ, meaning they are more sensitive to an indirect influence of the input (principles values) than the others.

Regarding the management of resilience, those principles seem to be the focal point to be managed because they have more effect on the result with the same input change. This make sense once this high leverage effect of response diversity and functional redundancy have been described by resilience theory (BIGGS et al., 2012, 2015; WALKER et al., 2002, 2009)

3.3.4.7 7th insight: each solidarity make DRI to reacts differently to climate change

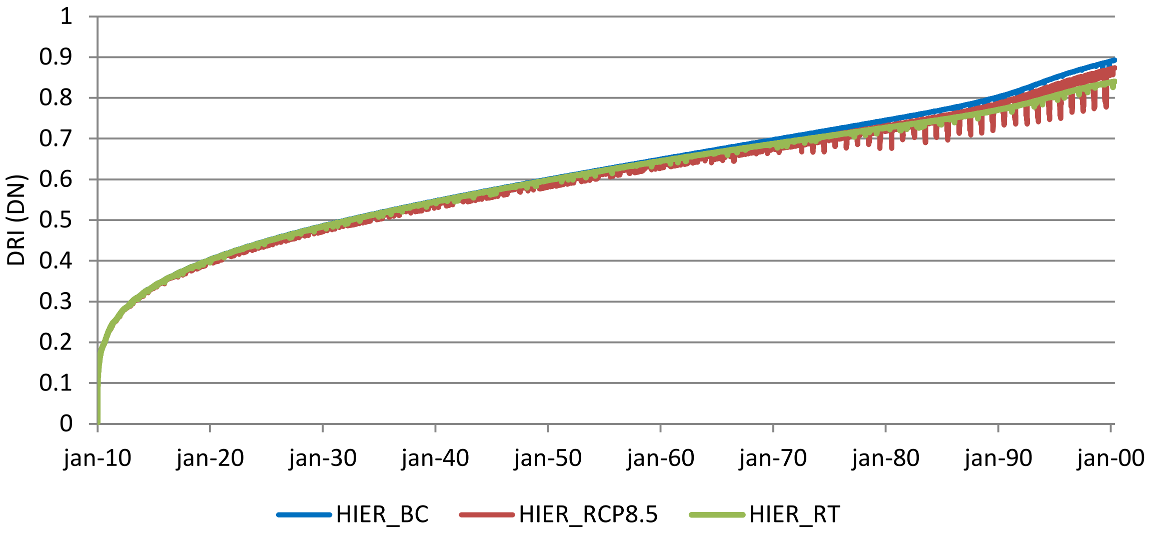
Each solidarity suffers from climate change in different ways (Figures 65–67). Individualists suffer less impact from climate change showing that resilience is affected only by stochastic variations due to extreme events like heavy rain, or strong winds, and unusual cloud cover. Hierarchy and egalitarians also show this stochastic variation but also present the overall behavior detached from the baseline (Figures 65 and 67) showing that not only extreme events affect the index but also the overall pathway is changing, pointing to behavior of losing resilience along the century.

Figure 65: DRI for individualists in CC and RT scenarios



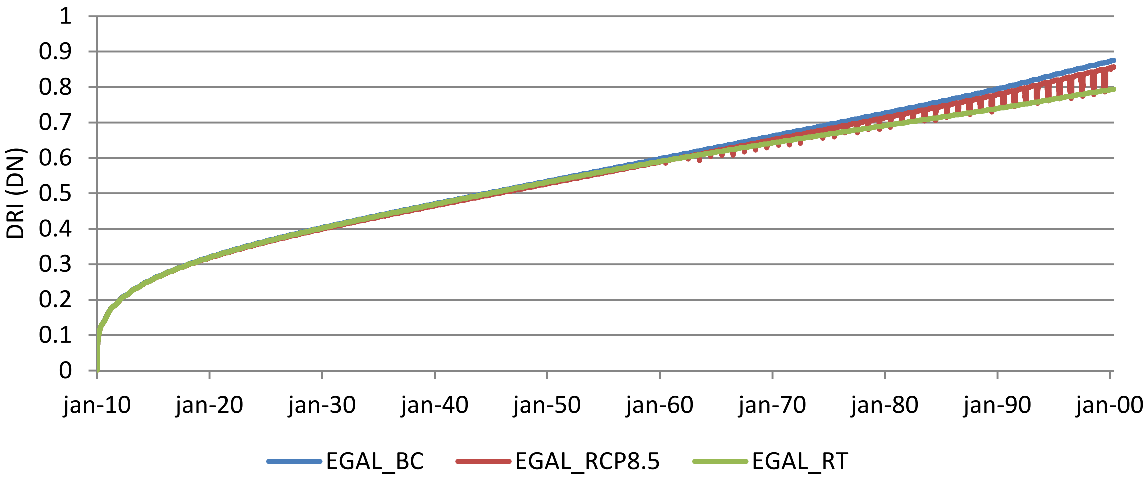
Simulation shows the index for individualists in RCP8.5 climate scenario and in Reactive tourists from 2010–2100. Source: the author.

Figure 66: DRI for hierarchy in CC and RT scenarios



DRI for hierarchy during normal, climate change and reactive tourists scenario from 2010–2100. Source: the author.

Figure 67: DRI for egalitarian in CC and RT scenarios



DRI for egalitarians during normal, climate change and reactive tourist scenario from 2010–2100. Source: the author.

The model assumes that the climate change scenario only changes ecosystem services provision and doesn’t change any governance attribute. So, ceteris paribus, the more ecosystem services change, the more their penetrance in DRI will be present. Individualists' base for resilience is ecosystem services that have small changes due to climate change like those from fisheries, nutrient cycling, and sewage depuration (table 11). Hierarchy and egalitarians weigh more a different set of ecosystem services (table 11) and those ES are more susceptible to climate change variations (e.g. carbon sequestration and oxygen production).

Different weights are determinants for resilience behavior in climate change scenarios. It shows that despite the individualist behavior present a higher value for DRI in the RCP8.5 scenario, presumably being more resilient, on the other hand being less responsive to CC means it is not perceiving the losses brought by this scenario, which can vary from US$27 to 46 million (reinforcing the idea that this system can be locked in a trap). Maybe that insensibility to these losses happens for two reasons: first, the distribution of the losses are not allocated in the main economic sector of the city (services derived from tourism), reaching only a part of the society that has been historically excluded from the decision making and the main economic activities (e.g. fishermen); second is that a good part of the ecosystem services losses is happening in ES that individualists almost don’t care about (table 32), like carbon sequestration or oxygen production.

On the other hand, hierarchy, and egalitarians, once they care more (put more weight) for ecosystem services that are prone to change due to climate change (e.g. carbon sequestration and oxygen production), present slightly less resilience in this scenario (Figures 191–192). Coherently this diminishing in resilience means also those solidarities are more sensitive to variations on those services and then losing the services (and all values associated: economic, material and sustainability and also those from justice) make the system less resilient.

3.3.5 About resilience

Although Resilience is undeniable growing in scientific research some oppose the adoption of the agenda (BROWN, 2014; CRETNEY, 2014; STONE–JOVICICH, 2015; OLSSON et al., 2015). All those authors agree that the social sphere is underrepresented in resilience studies. In a broad view, they argue, as social scientists, that social–ecological systems view (not only Resilience) lack of social perspective, being too ecological.

The use of the dynamical resilience index (DRI) was an attempt to contribute to enhancing social perspectives regarding SES analysis once it embraces part of the knowledge that is from social sciences as culture theory but obviously with limitations of adopting a numerical perspective for those social perspectives. This index therefore is not supposed to substitute all the discussion and the qualitative analysis that is done, on the contrary, it is an attempt to operationalize the concept and contribute to the discussion. And as a prototype, it is supposed to be enhanced in quality and depth of analysis in the future.

Brown (2014) is not properly against the use of Resilience. The author argues the idea of social and political features being underestimated in resilience practice and science. Cretney (2014) pursue a political criticism of the risk of adopting resilience thinking because it “justify projects informed by neoliberal ideologies that aim to decrease state involvement, increase community self–reliance and restructure social services” and also argues that the concept does not consider power, agency, and inequality in the use of the term. A deeper criticism is found in Stone–Jovicich (2015). The author draws attention to different perspectives (materio–spatial world systems analysis, critical realist political ecology, and actor–network theory) from social sciences regarding social–ecological systems and argues those to be more appropriate when compared to resilience.

World system analysis uses several approaches to investigate the “emergence and dynamics of the capitalist world political economy over the past 500 years” (STONE–

JOVICICH, 2015). The overall premise is that world system–level processes are important to understand human–nature relations in the long term and cross–scale. This approach also claims that considering only the internal dynamics of a small or local society are insufficient to explain its dynamic of change.

Critical realist political ecology has different characteristics in its evolving stages (from 70's structuralism, followed by 90's post–structuralism). In a wide view, this approach claims that environmental problems are independent of human understanding (STONE–JOVICICH, 2015), and adopts a perspective that "reality" problems can never be understood in its totality by societies. With that perspective, scientific explanations of environmental degradation are considered to be always limited, to be able to provide only limited insights of the unattainable complexity of the system, and therefore, can "exacerbate environmental crises and social injustices" (Op. cit.).

The actor–network theory perspective considers that the domain of the social relation is always mediated (even enabled) by non–human entities and thus, at least at the beginning of the analysis, humans, and non–humans have a similar potential role in the overall behavior of the system (what is called generalized symmetry). The focus is not on the structure of networks, but more on the "structure of networking" (STONE–JOVICICH, 2015), meaning the ways that actors interact and affect each other. This perspective also considers that change is always happening (this might justify the abandonment of pursuing stable networks) and thus dynamics is at the core of the analysis.

The criticism is pertinent to the understanding of system behavior. System dynamics has been dealing with limits on system problems since its foundation and the way to do that seems to be related to delimiting system boundaries. Building a system dynamic model is an iterative process of enhancing complexity (STERMAN. 2000). In this process, the modeler will deal with endogenous and exogenous variables relevant to the overall behavior of the system, but being a model an exercise of capturing the essence of a problem in a system, it is limited indeed. Political ecology's position seems correct and resumes the human condition towards a complex system, but the problem is that it is not applied. This argument overlooks that management is necessary, and currently being done, even with imperfect knowledge about systems. To do the challenging task of applying science to society's benefit, one must decrease the expectations of having all the answers and use the best available techniques and tools to make things better. In system dynamics, these limits of knowledge are called bounded rationality, and it is well known as a limit both to knowledge but also to be trespassed by scientific experimentation. Finally, the structure of networking is probably the major contribution of system dynamics models to collaborate with resilient thinking. The way that actors interact and affect each other is, in system dynamics terms, considered by causalities. Causalities are the expression that conditions the change in behavior of one variable in function of changes that already occur in another variable. That’s why the first step in translating the resilience theory (BIGGS et al., 2012) was to build a causal loop diagram (Figure 163).

Olsson et al. (2015) agree with Cretney (2014) about the absence of power, agency, conflict, and knowledge in resilience theory once they are precious for social sciences. Also, those authors (OLSSON et al., 2015) bring several arguments that put away the possibility of an integrated social sciences/ecology understanding of resilience: a) the ontology (resilience virtually demands system sciences); b) systems boundary (for them always an arbitrary cut in reality); c) equilibria, thresholds and feedbacks (in general taken as too simple to describe the complexity of human relationships); and d) self–organization (authors disagree with the idea that in social systems, people have the freedom to self–organize indefinitely and then prefer the use of power as a metaphor to understand the emergence of macro patterns in society); e) the idea of function and functionalism (where function in social systems imply necessarily cohesion, consensus, and order where conflicts, power imbalance, and social stratification should be instead).

The last point in Olsson’s argument (function and functionalism) seems to be a critic on an ecotopia more than to resilience itself:

> In essence, resilience theory is implicitly based on an understanding of society that resembles consensus theories in sociology, according to which shared norms and values are the foundation of a stable harmonious society in which social change is slow and orderly—and where, in analog, resilience thus becomes the equivalent of stability and harmony or the good norm. (OLSSON et al., 2015, page 5).

Social scientists, as the authors claim, are interested in understanding social changes and conflicts seem to be the norm. Ecologists in turn and they are mostly responsible for resilience theory, seem to look at a social sphere of SES with more distancing. It is not that they postulate a coherent harmonious planet within people, with a perfect balance between society and nature, an ecotopia of an egalitarian dream. But during the attempt to make the integrative proposition of resilience in SES, during the leap to reach the far distant social sphere, they used the skills and perspectives they have: natural sciences concepts and theories – what Downes et al. (2013) called different methodological and epistemological traditions.

That's why they try to understand social systems in terms of (systems…) feedbacks, self–organization, and else. Despite the strong arguments in their work (OLSSON et al., 2015) that point to an insurmountable abyss between resilience and social sciences, both knowledge fields still flirt (actually the interaction has never been so intense, SCHIPPER & LANGSTON, 2015; FOLKE, 2016) because the space to questions and collaborations remains open, serving a broader movement towards an integrative social–ecological perspective, through resilience or another broad concept. That is exactly what was named the first chapter in the *Panarchy* book: In quest of a theory of adaptive change (HOLLING, GUNDERSON & LUDWIG, 2002), and also what Downes et al. (2013) called "appreciation and reconciliation".

Despite the scientific vanguard represented by resilience in this integrative attempt, the arguments presented are legitimate and must be taken into account when pursuing the integrative approach:

> (i) the ontological presupposition to see reality as a system with equilibria, feedbacks, and thresholds; (ii) the principle of self–organization overshadowing agency, conflict, and power; and (iii) the notion of function as foundational to resilience theory while having lost its centrality in the social sciences (OLSSON et al., 2015, page 6)

There are also some criticisms in Olsson et al. (2015) that probably can be surpassed. First, they understood the phases in the adaptive cycle as strict functions of ecosystems, which seems incompatible with the current understanding in the environmental mainstream of the cycle being a metaphor to understand change (GUNDERSON and HOLLING, 2002; FOLKE, 2006).

Second, about the consensus vs conflicts in social theory, DRI could be a contribution when it understands that resilience is dependent on social goals: the possibility of three different resilience's values in the same system reflects that society is not homogeneous (there is no consensus). On the contrary, the presence of one resilience in systems is a product of interaction of irreconcilable conflicting rationalities (theorized by the plural rationalities theory or culture theory) – which would be a transversal approach to conflict and social stratification. It is important the remark that clumsy solutions do not come from consensus, but from compromise (SCOLOBIG et al., 2016) avoiding a utopian scenario of agreement between dissident perspectives to embrace a mediated conflict of irreconcilable opposition groups. Resilience, therefore, emerges in a place within the plural rationalities (theorized in culture theory), reflecting exactly the heterogeneity of social values and beliefs. If a somehow controlled space allows contrasting groups to dialogue productively (e.g. SABATIER and JENKINS–SMITH, 1993; SCOLOBIG et al., 2016) the clumsy solution can be reached, otherwise not. That is a limit of clumsy solutions: once it is a fruit of dialogue and democracy, it cannot happen in a monocratic decision environment (hegemony).

If Ney (2009) is right, the origin of messy problems, and then intractable policy controversy, is in part explained by a social transition from a "monolithic centralized state" to a "scattered in a network of power" state which includes different institutions in different levels and with specific interests with a "far wider range of actors and organizations". This is congruent with other authors (e.g. ADGER et al., 2008; FORRESTER et al., 2018) and probably could be the third point to remark against Olsson's et al. (2015) criticism.

Finally, the current resilience principle's theory (BIGGS et al., 2012, 2015) reinforces society's participation and policentricity as part of the main system's characteristics that form resilience. That is also an understanding that puts society closer to the center of the SES analysis. Maybe the next steps in developing the field would be to embrace power, agency, conflict, and knowledge in a more suitable way that enhances the political sphere in resilience theory and methods.

Now using an opposite view and trying to consider the possible overlap between social sciences and resilience theory, it is not clear where culture theory dialogues with the adaptive cycle. Despite the recognition of Holling that Culture Theory has something to say about resilience (GUNDERSON and HOLLING, 2002, page 13), and Thompson's knowledge about Holling's myths of nature (THOMPSON, ELLIS and WILDAVSKY, 1990), none of the authors proposed a common ground about their theories. It is evident, as Olsson et al. (2006) claim, that the solution – being clumsy or other – must occur in an appropriate window of opportunity because otherwise there is no meaning in solving a problem that has already been solved or substituted by a worse one.

3.3.5.1 About system's traps

In our simulation, it is possible to run the model for a very long period (2010–2180) to test that hypothesis. Even being aware that the length of the time series used to build the model is short (2010–2017), and thus extrapolations must be seen with limited confidence while uncertainties are growing through the simulation, we are keen to try once this is explorative research and a prototype that can be enhanced in precision and scope in the future.

Notwithstanding the uncertainty regarding the numbers, we have taken into account that numbers are not the most important thing in modeling complex adaptive systems. Many other features are more important than numbers in defining its behavior (e.g. causalities, feedbacks, goals, etc.) (STERMAN, 2000; MEADOWS, 1999; MEADOWS, 2009).

3.4 CONCLUSIONS

Social–ecological systems (SES) are complex, adaptive systems with feedbacks, uncertainties, and surprises that make the process of management far from trivial. Resilience appears though as a feature of this SES that encompass several distinct system aspects which embody uncertainties, feedbacks, and complexity and thus can be an interesting way of dealing with complex challenges and also increase society participation in the management process despite the whole and accurate criticism at the pretense integrative capacity of social and ecological sciences intended by resilience theory.

This work presented a prototype that embedded a system dynamics index for measure resilience: Dynamic Resilience Index (DRI). Far from exhausting the possibilities of calculations, the goal was to collaborate with the discussion regarding SES Resilience in at least two points: First is to bring resilience in a treatable mathematical index that should not substitute the mainly qualitative assessments presented in the literature, but enhance the application of the concept and the operationalization of the theory; Second, it provides a mathematical approach and a causal model that can be useful in establishing a comparative index after improvement.

From the DRI results, seven insights were discussed and they point to several properties of resilience, some of them new in literature. Considering this a prototype model, with clear and discussed limitations, these results must be corroborated with future studies to make stronger statements. Yet, as far as we know, this is the first report of resilience being seasonal (2nd insight); that climate change might influence in different forms the resilience of the system based on the rationality advocated to that group (7th insight), and finally that "diversity and connectivity" influence in resilience showed their higher weight in the final result (6th insight) compared to the other resilience principles.

Other insights are also relevant despite not being a novelty. Considering plural rationalities as social determinants for resilience (1st insight) is not novel (actually using it in a systems model to embed numerically these profiles is). Results can be understood as relevant for new perspectives about resilience, changing the idea of the system's resilience as an agreed SES pathway to embed three conflicting rationalities interacting to determine the (desirably clumsy) SES future. That is made clear where DRI demonstrated the distinctions between social goals and the path of resilience along with the simulation.

Other results seem to be more related to this case and probably have less potential for universalization as the phase which the system is (3rd insight), the possibility of being in a trap (4th insight) and the general or specific classification of the index (5th insight).

Enhancing the use and application of resilience concepts through the measurement of DRI, we argue, can enforce the awareness of society regarding complexities, uncertainties, and feedbacks of SES and promote the development of this scientific field. It could also, after some improvements, be used for developing a comparative standard for future simulations or land and coastal management comparisons.

Finally, the idea of simulating the SES with provisory numeric assumptions for unknown independent variables (e.g. trust) showed to be possible and profitable under a social theory umbrella (culture theory) that allowed transforming unknown and possibly unattainable social goals into something plausible and theoretically coherent, from which those insights emerged.

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