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PILOT SYSTEM DYNAMICS MODEL FOR COASTAL RURAL INTERACTIONS – DANUBE'S MOUTHS - BLACK SEA CASE STUDY

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ABSTRACT

This study examines the methodology that was used to transfer the analysis from stakeholders meetings that led to causal loop diagrams (CLDs) into a pilot system dynamics (SD) for land-sea interactions in the Danube's Mouths - Black Sea region.
The model addresses the main problems raised by stakeholders, represented in the CLDs for which the SD structure is fully defined in Vensim software. The aim of the paper is to design an SD model for each CLD developed together with stakeholders and experts from the Danube's Mouths-Black Sea area.
For this study, the first three steps necessary for the full implementation of the SD model in the Danube Delta Biosphere Reserve and its marine area were considered: identify the main stock variables and their flows for each CLD sector, identify or add causal interactions between stock variables, design and combine causal loop diagrams for sectors, supported with dynamic hypotheses. In order to have a functional model, the work continues with collection of data, models equations and non-linear table functions, to quantify the CLD, design, implementation and testing of generic model archetypes and inspiring tutorial examples, implementation of stock-flow models, calibration, testing, and validation, policy design (identifying policy levers) and policy analyses.
Further, the model's objective is to explore alternative scenarios for improving the quality of life and sustainability within the Danube Delta Biosphere Reserve and its marine waters (Black Sea) as one of the most affected areas along the Romanian coast.
Key-words: land-sea, interactions, modelling, system dynamics, Vensim, Black Sea

AIMS AND BACKGROUND

Effective decision making and learning in a world of growing dynamic complexity requires us to become systems thinkers-to expand the boundaries of our mental models and develop tools to understand how the structure of complex systems creates their behaviour (Swanson, 2002). Systems Dynamics (SD) modelling is widely used since the 1950s for problem analysis in applications ranging from logistics, control management, engineering, and financial management to public policy. Stakeholders interacted to create mental models clarifying the problem at hand and defining the way the problem(s) are connected to specific policy or management indicators and potential solutions. The sector workshops were aimed at developing raw mind maps for specific sectors (agricultural, tourism, fisheries, rural development, and blue growth). Processing and polishing of the mind maps result in more refined conceptual models, which can be used to formulate CLDs showing the relevant feedback mechanisms explaining the problem.

These CLDs can be quantified in ‘stock-flow’ models which allow examining the combined impact of reinforcing and balancing feedback mechanisms on the dynamics of the system. Typical questions that can be answered are: What is the effect of implementing bioeconomy principles in the area? What is the dynamic of fish stock if illegal fishing ends? Although the human brain can provide part of the answer this becomes more difficult when multiple factors play a role. This is certainly true for complex social-environmental systems such as coastal regions which are densely used and rapidly developing, with economic activities competing for resources such space, water, skilled labour, and use of transport infrastructure.

Therefore, designing coherent actions requires acknowledging the corresponding system’s feedback structure. A feedback is a chain of causal relationships that leads back to its origin (Collste, Pedercini and Cornell, 2017). For example, if in the region investments in waste management are planned, this may over time, result in cleaner waters and villages which may in turn increase the region’s attractiveness for tourists. With an effective tax system and local empowerment, increased attractiveness could lead to higher local revenues which enable new investments that could be used to further improve the waste management in the area.

This example involves significant delays, which may need to be considered for successfully assessing the long-term effects of policy choices. From a systems perspective, a multitude of such feedback loops act concurrently to shape a region’s development (Collste, Pedercini and Cornell, 2017).

The aim of the paper is to design a system dynamics model for each CLD developed together with stakeholders and experts from the Danube’s Mouths-Black Sea area. Further, the goal of the model is to explore alternative scenarios to improve the quality of life and sustainability within Danube Delta Biosphere reserve and its marine waters (Black Sea) as one of the most impacted area along the Romanian littoral.

EXPERIMENTAL

Local actors and experts from the Danube Delta and Black Sea rural and coastal zone participated in six collaborative workshops to analyse problems, the underlying causes, propose and discuss solutions, and validate and interpret the impacts of simulated business and policy decisions. Discussions and qualitative techniques were combined in this co-creation process supported by graphical tools to gain in-depth understanding of the systemic transitions underlying the land-sea interactions in each specific domain. During the workshops, stakeholders were actively involved in identifying the main connections between the drivers, specifically tailored for the activity sectors.

All identified interactions between drivers were further introduced into the Vensim software, to graphically represent the cause-effects relationships. These systemic transitions will further be synthesized and analysed with system dynamic models to produce multiple transition scenarios for key business and policy indicators, in a process of fostering co-creation as a must have approach of current environmental and societal issues.

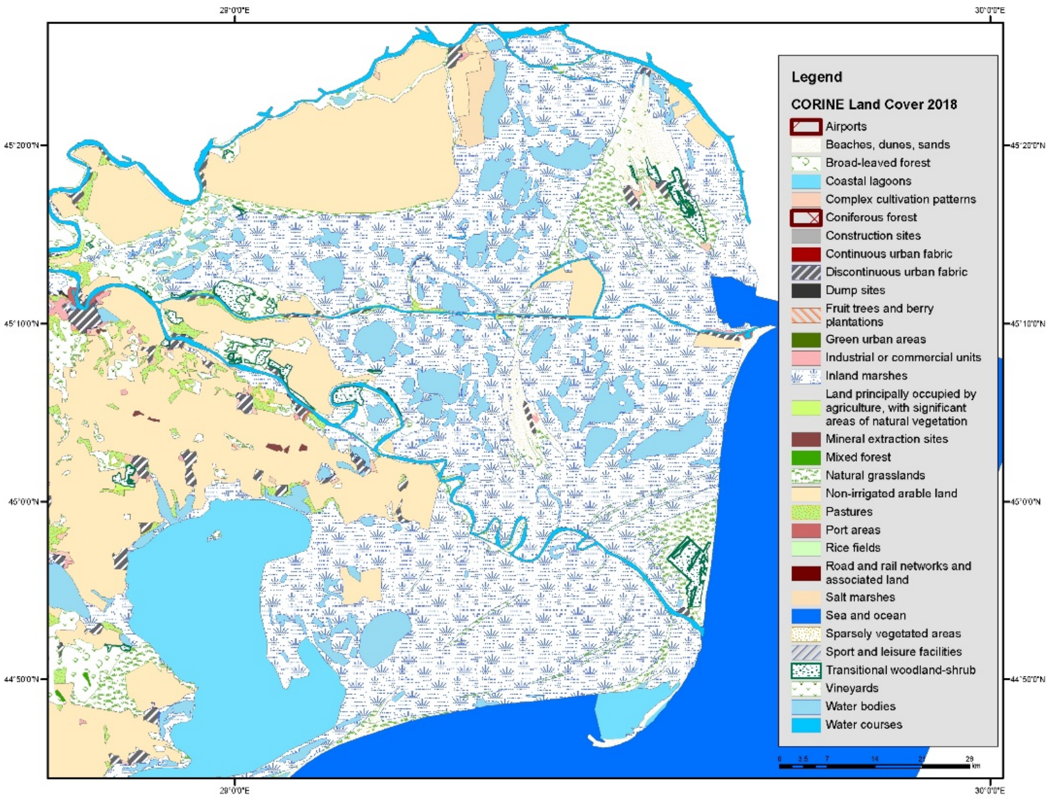

Fig.1. Map of the studied area – Danube's Mouths-Black Sea

The CLDs and model structure were developed with Vensim software, an industrial-strength simulation software for improving the performance of real systems which set emphasizes model quality, connections to data, flexible distribution, and advanced algorithms. Vensim is used for developing, analysing, and packaging dynamic feedback models [1].

RESULTS AND DISCUSSION

The meetings' conclusions were in line with the 2030 vision for Danube Delta "An attractive area – with precious biodiversity and vibrant, small/medium scale (artisanal and modern) agriculture and business - where people live in harmony with nature; integrating economies of tourism, farming and fishery; and supported by urban service centres". The vision represents a challenge of reconciling economy, society and the environment which becomes prominent in biosphere reserves, and the human settlements situated within Danube Delta must be managed such that they achieve equally social, economic and environmental sustainability and make up a successful case study (MDRAP, 2016).

The general conclusions of the stakeholder's meetings outlined also that governance and excessive bureaucracy are disturbing the economic activity (planning, facilities for investors (lack of), lack of compensatory measures, tourism, infrastructure) and social field (health, incomes, protection, jobs), avoid real problems like the conflict between Marine Protected Areas restrictive measures and the exploitation of resources or the Danube Delta's clogged canals and invasive species. Agriculture has clear impacts on both inland and coastal water quality and the locals are not aware of causes, effects and impacts of the pollution on the Black Sea and even on the surrounding neighbourhood. The agriculture is for subsistence and the area is very poor developed. On the contrary, due to the Danube Delta protected area there is a pressure downward the coastal zone for the seasonal tourism. Thus, there is an artificial population "growth" which is not sustained by the "real" economic development. Considering all the collected information, land-sea interactions considered in the model were reformulated and defined by the ecosystem-based management approach:

• Improve Sustainability of the area. Setting up coherent regulatory framework on development strategies for land (agriculture, rural development, freshwater fisheries, tourism) and marine (fishery and aquaculture) activities will lead to proper implementation of ecosystem-based management principles.

• Adaptation and Mitigation to Climate change. As the Danube's discharge receiver, the Black Sea is impacted by increased/decreased discharge of freshwater and pollutants (from agriculture and inadequate infrastructure of rural development) and seawater temperature increase (marine fishery).

• Use of Knowledge to improve sustainability and climate change impacts in the area- Education, training and research at different levels – workforce, economic activities development, environmental monitoring, scientific research.

Therefore, based on the sectoral CLDs it was designed sub models for: Agriculture, Fishery (freshwater and marine), Tourism, Rural development, and Ecosystem management. The transition of CLDs to SD is not straightforward. The information for the SDs is hidden in the CLDs, collapsed into links and factors. Extracting stocks, flows and auxiliaries from the CLDs requires further investigation of the links and what they represent. This process may change the number of factors in the system (Binder *et al.*, 2004). Thus, between workshops, the CLDs were cleaned up and set up experts consultations (mainly scientists) agreed by all participants. Consequently, the changes to the CLDs, did not go beyond what was agreed during the stakeholders' meetings.

Quantification of land-sea interactions

1. Agriculture

The initial CLD from the Agriculture stakeholders meeting has 19 variables of which three exogenous (*Climate change*, *Training* and *Demographics*) (Fig.2).

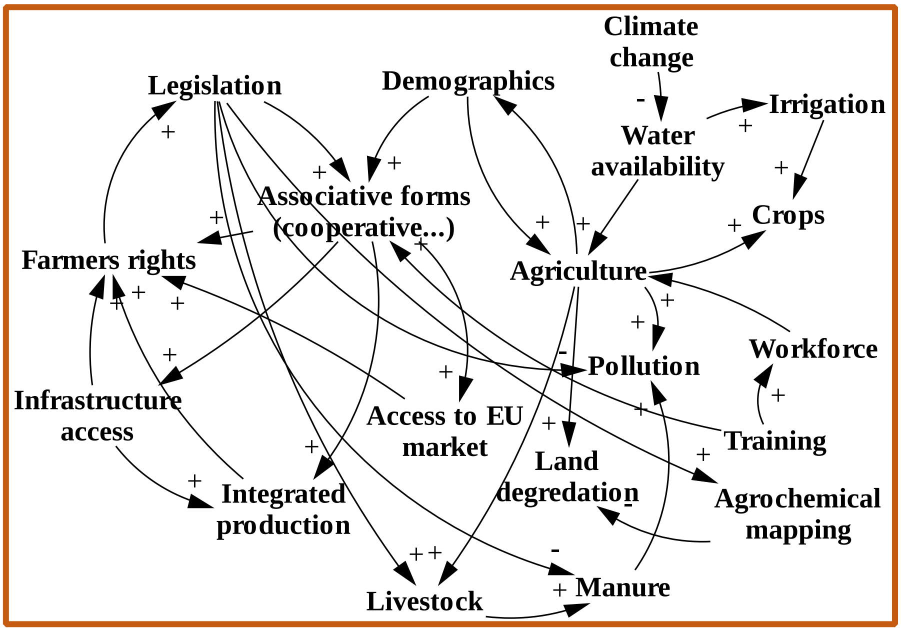

Fig.2. Initial CLD - *Agriculture* stakeholders meeting

In the process of translation CLD to SD we identified as stocks *Agriculture*, *Farmer rights, Water availability* and *Pollution.* However, because the meaning of these variables was not consistent with what was intended during the discussions in Romanian, we renamed or redefined some of them. *Agriculture* was reconsidered as *Agriculture productivity* (based on crop production), Farmer rights was changed to *Farmers welfare* and Pollution was further specified to be *Pollution from Agriculture* as pollution also is considered in other sub-models. Other variable name adjustments were: *Associative forms (cooperative…)* to *Farmers cooperation*, *Access to EU market* to *Access to a wider market*, *Land degradation* to *Soil quality*.

Demographics was changed to *Population* and an extra link was added to workforce as population is the main input for *workforce*. According to the model structure (Fig.11) the farmers welfare is increased by their cooperation particularly through sharing their assets and integrated production that ensures sustainable agriculture by adjusting agricultural practices and the use of alternatives over time, considering new knowledge and new methods.

The pollution from agriculture is decreased by the implementation of bio-economy which is meant to reduce the dependence on natural resources, to transform manufacturing, to promote sustainable production of renewable resources from land, fisheries and aquaculture and their conversion into food, feed, fibre, bio-based products and bio-energy, while growing new jobs and industries [2]. But agriculture productivity gains can mean little without improving the access to markets. Market structures are very weak, so the allocative efficiencies that markets achieve in fast-growing sectors of their economies do not materialize. Instead, undeveloped market demand for outputs discourages producers from raising production, while the consequent failures of incomes to rise in rural areas deters private traders and rural enterprises from entering and doing business.

In the absence of functioning markets, rural areas remain trapped in a subsistence economy in which neither the narrow agricultural production sector nor the wider rural economy (both of which generate off-farm employment opportunities) can grow (OECD, 2007). Although not specifically mentioned by the stakeholders, the variables *Expenditure* and *Forest belts* were added to the model. The farmers welfare is decreased by the cost of production including raw materials, fertilizers, costs with workforce and investments all considered as expenditure. The forest belts will improve water availability and that this will increase the agricultural productivity. It is to be highlighted that establishment of protective forest belts and increasing the forested area is part of several policy papers in the development of the Danube Mouths region such as Danube Delta strategy, National Regional Development Program etc. The forest belts offer multiple beneficial effects including biodiversity increase, reducing soil erosion, mitigating of flood risks, trapping snow, and increasing crop yields. The sub model drivers/boundaries are given by *Legislation, Bioeconomy, Climate change, Forests belts, Access to a wider market, Population, Livestock, farmers expenditures, and Training*.

2. Fishery

The fishery stakeholders' meeting gathered both freshwater (Danube Delta) and marine (Black Sea) fishermen. Even though several issues were common (e.g. legislation, fish market, fishermen welfare, etc.) we chose to separate the model into two types of fish stocks mainly due to the aquaculture topic. Currently aquaculture is relatively developed in the rural area (freshwater) and deficient in the Black Sea, due to the lack of a legislative framework to allow the concession of the coastal waters. Aquaculture is considered one of the future businesses in the Romanian Black Sea. To allow calculating marine aquaculture in future scenarios we therefore also need to add it to the marine fishery model. Initially, the CLD for the fishery had 18 variables of which 6 were exogenous – climate change; education, training and research, invasive species; legislation; pollution and recreational fishing (Fig.3). By deleting freshwater fish stock, freshwater fisheries, recreational fishing, and tourism (as not being relevant for marine fishery) and due to spatially different areas we achieved the Marine Fishery initial CLD (Fig.4).

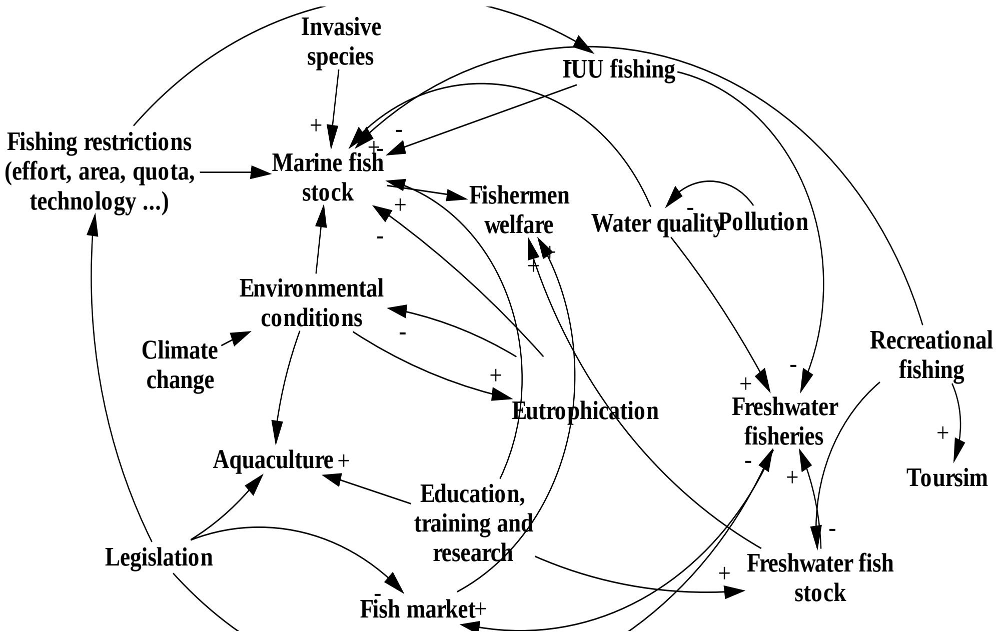

Fig.3. Initial CLD - Fishery stakeholders meeting

In the new CLD (Fig.4) we found four variables linked to the environmental aspects – *environmental conditions*, *water quality, eutrophication,* and *pollution*. As water quality and eutrophication, are included in the sub-models for environment, we remove these from the current sub-model. As the general term environmental conditions also appears in other sub-models, we rename this variable here to mean the natural characteristics suitable for marine fish and aquaculture (variable marine *environmental conditions*). At this stage, the model structure has two stocks – *Marine fish stock (MFS)* and *Aquaculture* which increase with in- and outflows (increase/decrease marine Fish Stock, increase/decrease aquaculture). A third stock, *marine fishermen welfare,* is added to quantify the net income. *Awareness and marketing* were added as one of the important drivers for an increase of the consumption of aquaculture products.

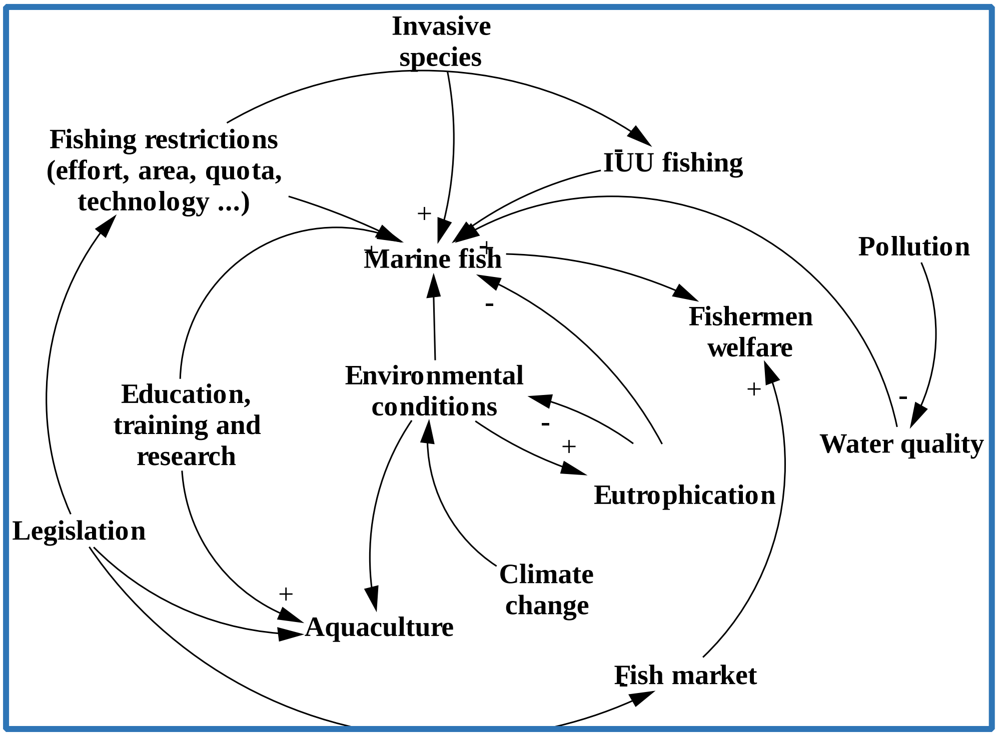

Fig.4. *Marine Fishery* CLD (from initial)

Thus, in described model (Fig.11) the marine fish stock's dynamics is dependent on the *Education, training and research* as scientific support for policies and decision makers (*Legislation*) regarding the fishing restrictions. Another important aspect is represented by the illegal fishing (*IUU*) and *Pollution* which are reinforcing the marine fish stock fall. The *marine aquaculture* production and the *marine fish stock* is increased by the

Education, training and research and the *fish market* as one of the main components of the growing fishermen's welfare. The sub model drivers are *Climate change, IUU (illegal) fishing, Fishing, Pollution, Awareness and marketing, Legislation* and *Education, training and research*. It was obtained the Freshwater fishery's CLD by deleting from the initial one, the *marine fish stock* (Fig.5).

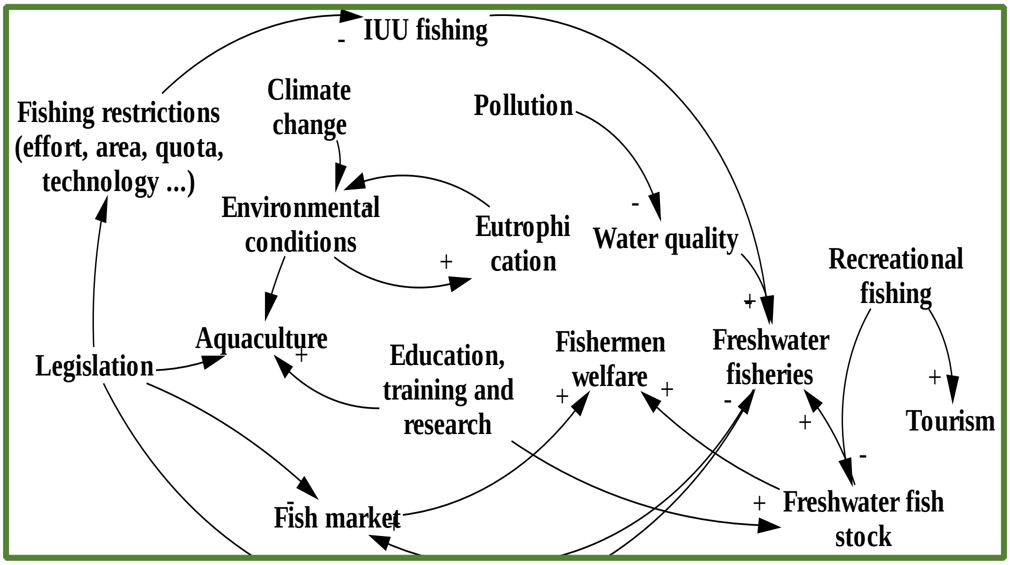

Fig.5. Freshwater Fishery CLD (from initial)

Like in the marine fishery model, the Danube Delta water quality and eutrophication were included in Pollution and as was the case for the marine environment the environmental conditions are in the context of this sub-model restricted to the 'freshwater environmental condition' of the Danube Delta natural characteristics (including the background from the upstream). In this regard, our research (MDRAP, 2016) shows that the water quality, mainly due to the hydrological changes into the Danube Delta was one of the reasons that the low economic value fish species (e.g. Gibel carp) have proliferated to the detriment of valuable species.

This aspect was often discussed by stakeholders referring to *clogged channels*. During the meetings it was considered that clogged channels are only causing water level concerns linked to transportation and tourism. The model structure (Fig.11) has three stocks – *Freshwater fishermen welfare, Freshwater fish,* and *Freshwater aquaculture*. The sub model drivers are *Climate change, Danube Delta Biosphere Reserve Administration (DDBRA),* *Legislation, Education, training and research, Hydrological restoration, Recreational fishing.*

3. Tourism

Two stakeholders' meetings were dedicated to tourism – one for rural (Danube Delta neighbourhood) (Fig.6) and the other for coastal (core Danube Delta and Black Sea coastal operators) (Fig.7). The meetings' outputs were similar for the rural and coastal tourism outlining that tourism has significant potential as a driver for growth for the local economy. However, the protected areas restrictions are limiting its growth which is usually accompanied by significant changes. Thus, the need for ecotourism was emphasized, as well as its diversification (*touristic activities*) leading to slow tourism in the benefit of the protected area (*biodiversity*) and local people (*workforce*).

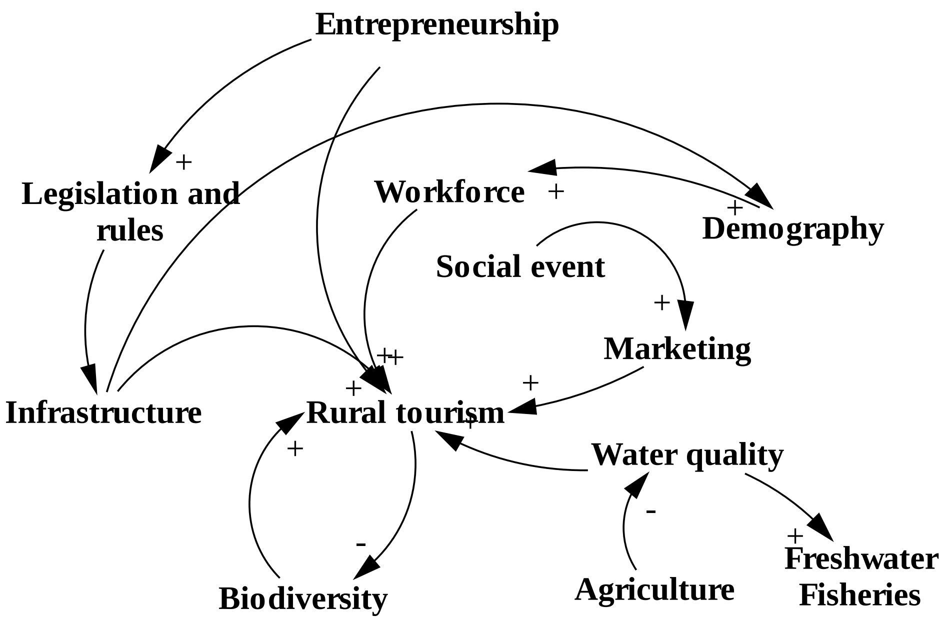

Fig.6. Initial CLD – *Rural tourism* stakeholders meeting

Destination planning and development strategies (*marketing, social events*) are important steps towards the greening of tourism. The important role of the governance (*legislation and rules, administration of the Danube Delta, bureaucracy*) and investments (infrastructure) was mentioned in terms of hydrological restoration (*clogged canals*), environmental protection and sanitation (*waste and discharge management*).

Although the initial CLDs (Fig.6 and Fig.7) have only one common variable, *infrastructure*, as the main interaction between areas, we merge it into the Tourism CLD (Fig.8) which could be applied for coastal Black Sea and core Danube Delta and its neighbouring areas (rural). The merged tourism sub model has the following drivers (yellow boxes) – *Climate change, Education, Administration of Danube Delta, Social events,* and *Entrepreneurship* (Fig.11). Agriculture and freshwater fisheries were deleted as being developed in previous sub models.

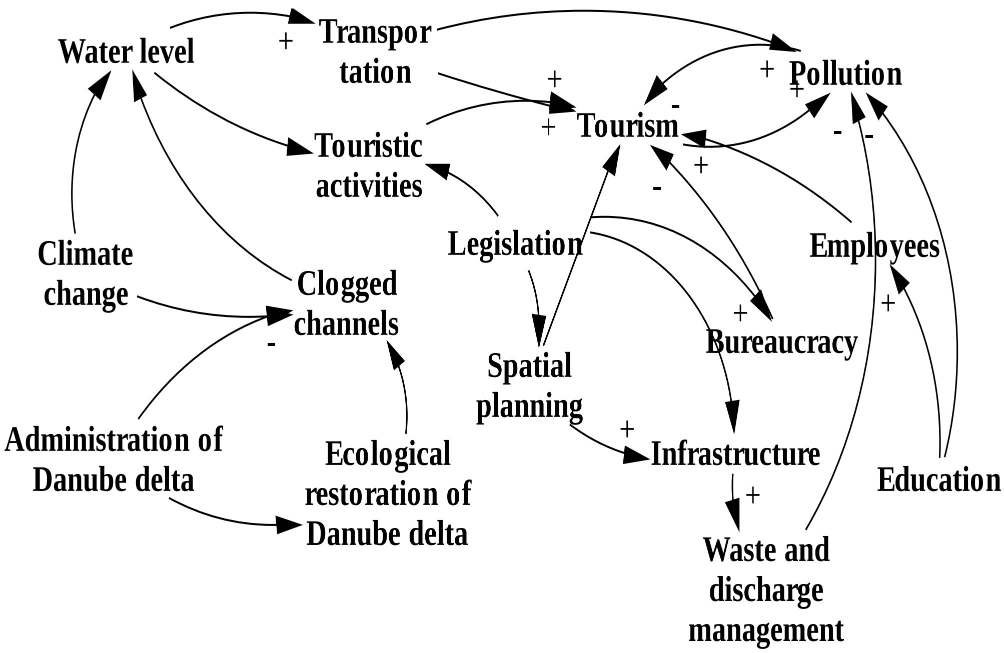

Fig.7. Initial CLD – *Coastal tourism* stakeholders meeting

The sub model structure (Fig.11) has as main balancing loop *Tourism – Pollution – Biodiversity - Tourism*. Thus, the sub model considers that the increase of tourism has as main consequence the increasing pollution which led to biodiversity decreasing. Once the biodiversity has decreased the area is no more a touristic attraction. *Pollution from Tourism*, *Tourism business development*, *Biodiversity* and *Clogged channels* stocks in the sub model structure. The sub model drivers are *Climate change*, *Legislation*, *Administration of the Danube Delta Biosphere Reserve*, *Education, Spatial planning*, *Marketing*.

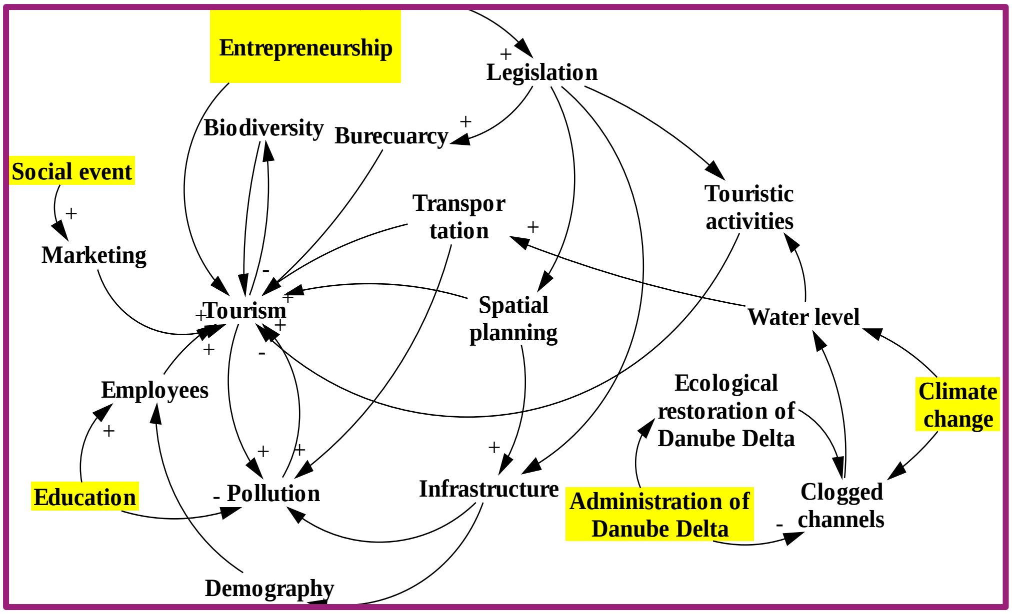

Fig.8. Tourism merged CLDs

4.Rural development

From its initial 21 variables, the *Rural development* CLD (Fig.9) was firstly simplified by excluding the variables which were already included in other sub-models (Agriculture, Fishery, and Tourism) (Fig.10).

To derive the SD from the rural development CLD, furthermore cleaning of the variables and their relations was performed. The variable *New green industry* was renamed to *rural innovative business* mainly because the stakeholders are not used to using the word "green" in this context. The rationale behind the choice of new name can be explained by going back to the original CLD from the stakeholders meeting, where this variable was originally named "*industrial development*" and it included the non-agricultural business in the rural economy, excluding tourism, such as: circular economy business models, manufacture etc. The variable *lifestyle* will be used to describe how attractive living in the rural coastal area is. This is like measuring the quality of life. Quality of life is identified in terms of service provision, and it affects the demographics (population): if lifestyle is decreasing, people will want to leave the area and the population will decrease. This stock is quantified as the availability of healthcare, education, economic opportunities, environmental conditions, human pressure, and the overall accessibility of the areas. *Pollution from basic services* will be assessed in term of environmental quality of the area.

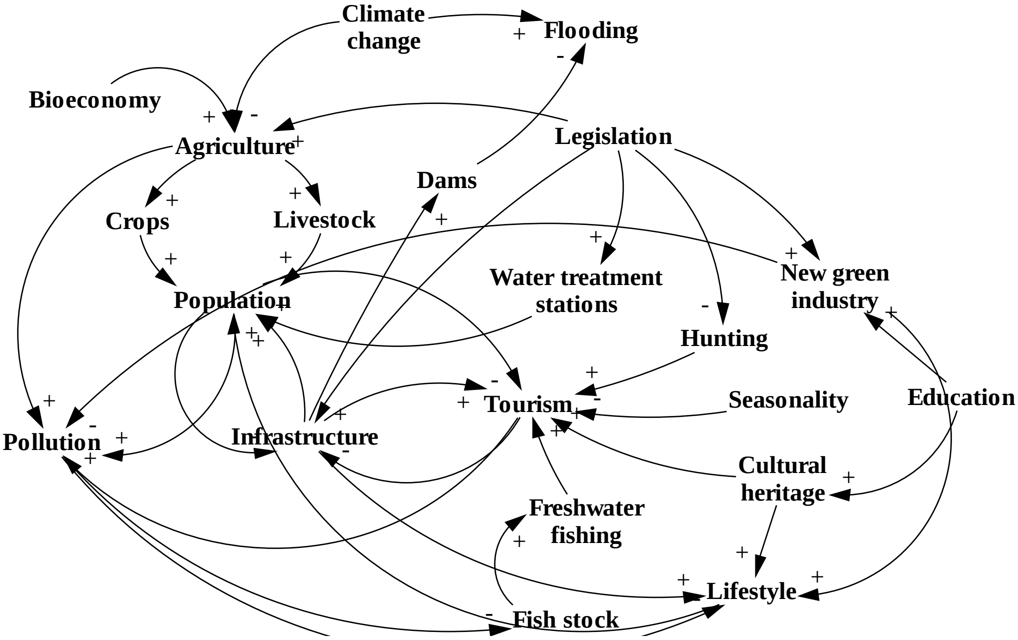

Fig.9. Initial CLD – *Rural development* stakeholders meeting

The flow that increases this stock will originate from *infrastructure* (domestic input - wastewater sewage systems, solid waste, water supply). The pollution will decrease by legislation (i.e., recycling, recovery, etc.) and local development strategies and infrastructure's component (water treatment stations). *Infrastructure* and basic services in rural communities of Danube's mouths region are considered inadequate both in terms of quality but especially their functionality.

Infrastructure development is an engine in the prosperous economic growth of the rural area being composed of the following components: water treatment stations, healthcare services, connectivity (transportation, ICT), schools (Fig.11). The sub model drivers are *Climate change, Education, Legislation, Funding, Population,* Basic services (*healthcare services, connectivity, schools, water treatment stations*), *Unemployment.*

5. Ecosystem management

During the stakeholder meetings the ecosystem management and the environmental protection were very rarely specified. Variables as pollution, water quality, biodiversity are part of more than one sub model. Additionally, one of the strategic objectives of the Danube Delta Strategy is to keep the unique natural values through an environmental management guided by science and by strengthening local communities in the role their proactive protectors of this unique world heritage (MDRAP, 2016). Consequently, it was decided to develop a new sub model in the future *Ecosystem management*. This requires the maintenance of natural capital (water quality, biodiversity) as a provider of both economic inputs and outputs.

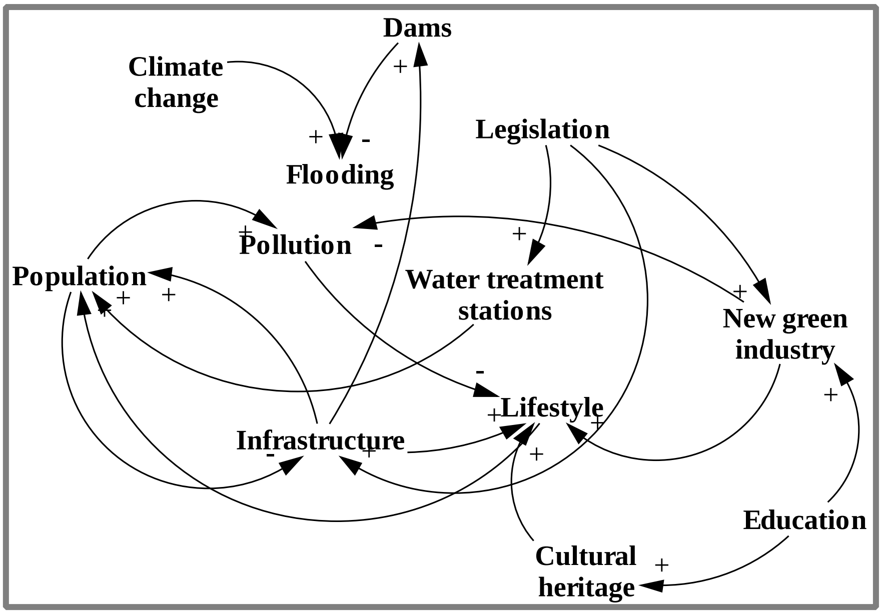

Fig.10. Rural development CLD after removing discussed variables/sub-models

The protection of natural systems represents not an overarching panacea for achieving economic vitality and social justice, but a necessary component of an entire system for achieving economic, social, and environmental ‘sustainability’, in which economic reforms and social reforms are as important (Basiago, 1999). During the process of model structure development several variables linked to the environmental quality or ecosystem management has been found. Consequently, an ecosystem management sub model was developed as a connection with different sub-models from the previous paragraphs.

This sub-model structure contains all relevant stocks, flows and auxiliary variables related to the environment. These are further supplemented with some new ones like *Freshwater Quality* and *Black Sea water Quality*, *Low economic fish species*, *Birds*. The *Biodiversity* stock was moved from the Tourism sub model as the most important ecosystem service of the Danube Delta Biosphere. In this phase links between sub models were created as shadow variables which refer to variables defined in other sub-models: *Pollution from agriculture*, *Pollution from basic services* and *Pollution from tourism* are inputs for the rate of *decreasing freshwater quality*. It was replaced the *pollution* from Freshwater Fishery with *Freshwater quality* (shadow variable defined in the freshwater fishery sub-module) and from Marine Fishery with *Black Sea water quality* (shadow variable defined in the marine fishery sub-module) (Fig.11).

All changes resulted in the Vensim sub-model. Accordingly, the *freshwater quality* in the Danube Delta is calculated as function of the *upstream water quality* and *climate change variable related to the river flow*. The freshwater quality it is also improved through *ecological restoration* and management measures taken based on *research* and *monitoring* activities. The water quality in the Danube Delta is deteriorated by pollution from different sectors – agriculture, tourism, and basic services. The water quality is an important input to the increase in biodiversity which is the main ecosystem service of the biosphere reserve. The water quality it is an important input to the increase in biodiversity conservation which is the main ecosystem service of the biosphere reserve. Another important link is with the Black Sea water quality which is significantly influenced by the river's outflow not only due to freshwater but also pollutants (Fig.11).

A dual challenge for the sustainable development of the Danube Delta Biosphere Reserve is the conservation of its ecological assets and the improvement of the quality of life for its residents and to strike a balance between protecting the unique natural and cultural assets of the DDBR, and meeting the aspirations of the region's inhabitants to improve their living conditions and seek better economic opportunities (World Bank, 2014). The management of the area should take into consideration several needs for the short and medium terms. For example, in the short term, the implementation of a wetland restoration program to increase the natural flooded area in abandoned polders for agriculture and fish farming should be continued. In addition, measures are needed to reduce the impacts of the more ecologically damaging economic activities (including navigation and related hydrotechnical works, over-exploitation of natural resources (especially fish)) and other land uses according to the carrying capacity of the ecosystems and pollution control. The living standards of local communities should be improved through the extension of drinking water supply, wastewater treatment networks, waste management, green energy use, and the involvement of the local communities in the direct management of the wetlands and their resources is another urgent need (Baboianu, 2016). On the other hand, the conflict between conservation (biodiversity) and economic development becomes precarious in developing countries. Many authors consider that environmental issues associated with the lack of environmental awareness are a consequence of poverty or at least connected to it, particularly in developing countries, or when natural resources are not seen as solutions for reducing poverty through their sustainable use (Petrisor et al., 2016).

Among the causes of conflicts, economic activities are the dominant ones; in particular, agriculture seems to be a source of conflicts. Generally, conflicts appear due to restricting access to resources, reducing the rights derived from ownership, ignoring the particularities of local cultures.

Moreover, low accessibility, lack of funding, lack of planning and design and the pressure of tourism are possible sources of conflict. Tourism generates conflicts due to the behaviour of tourists, particularly through cultural differences and their lack of interaction with the locals, which ultimately determine an erosion of the local traditions, but also due to an uneven return of benefits. Tourism attracts jobseekers and even immigration to protected areas. The number of tourists visiting protected areas is conditioned by infrastructure. While the remoteness of these places usually prevents massive tourism, the development of infrastructure resulting from the protection status can generate potential threats. In the Danube Delta, due to its high biodiversity and uniqueness of landscapes, the delta attracts about 150000 tourists every year, which is ten times the number of inhabitants [3]. In accordance with its Biosphere Reserve stature, the Danube Delta is expected to be governed by policies converging towards an integrated economic, societal, cultural, and environmental sustainability (Petrişor et al., 2016).

The conservation management policies for the unique pattern of closely tied habitats and ecosystems in the Danube Delta have often led to tensions among the management authorities and the local populations. Disagreement persists in matters such as the regulation of fishing, hunting and other economic activities, taxation and transport policies or the establishment of restricted areas within the Delta (Bell et al., 2009). While previous anthropogenic activities in the Danube Delta have led to significant impacts on the natural environment, there are also economic activities that can be optimized to become long-term sustainable, such as ecotourism, reed harvesting and processing, small-scale business based on traditional activities (Sbarcea et al., 2019).

CONCLUSIONS

For this study, the first three steps necessary for the full implementation of the SD model in the Danube Delta Biosphere Reserve and its marine area were considered: identify the main stock variables and their flows for each CLD sector, identify or add causal interactions between stock variables, design and combine causal loop diagrams for sectors, supported with dynamic hypotheses.

To have a functional model, the work continues with data collection, models equations and non-linear table functions, to quantify CLD, design, implementation and testing of generic model archetypes and inspirational tutorial examples, implementation of stock-flow models, calibration, testing, and validation, policy development (identification of policy levers) and policy analysis.

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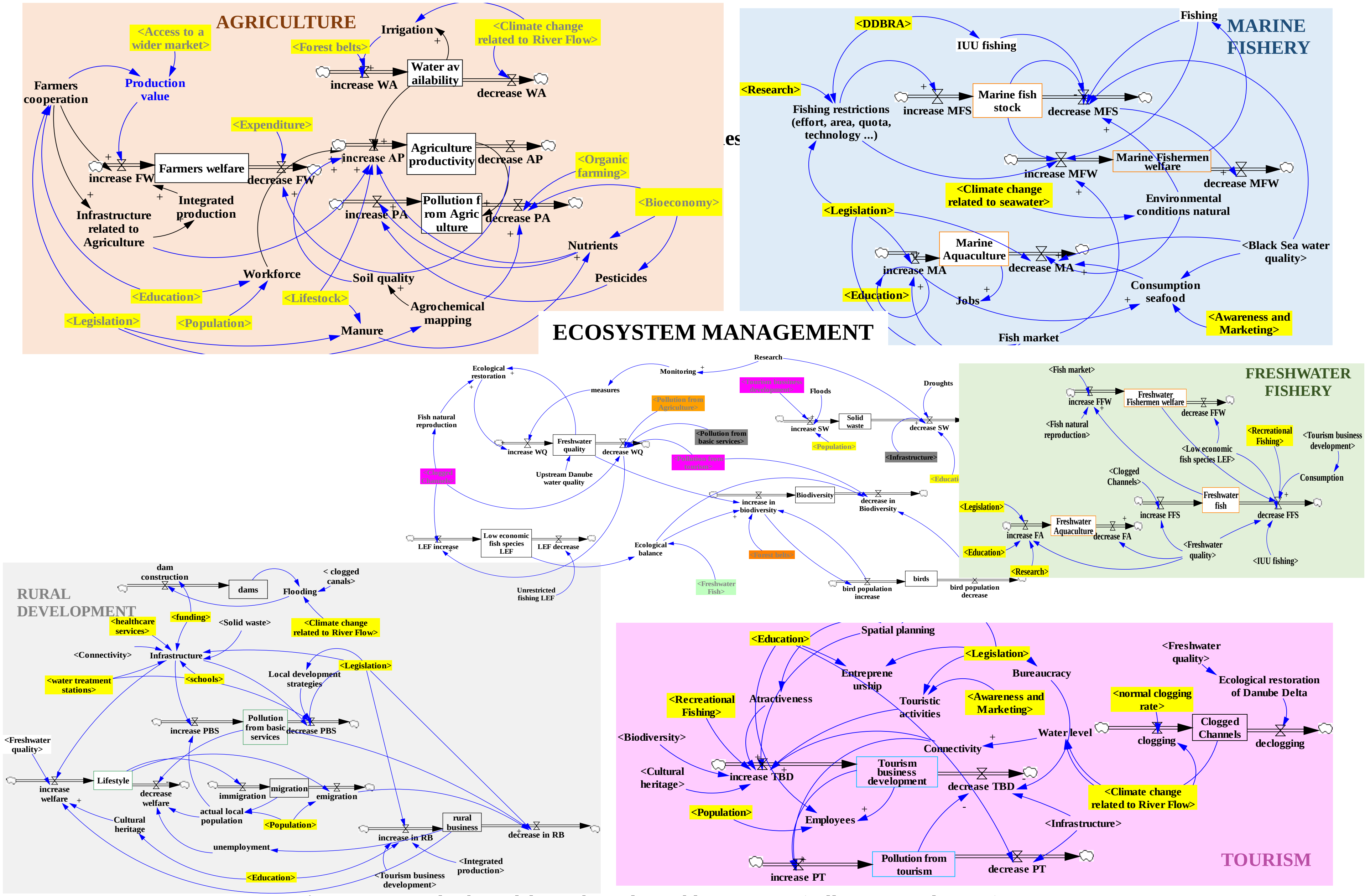

Fig.11. Integrated sub models stocks and variables, MAL05 (yellow-external inputs)

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