Biodiversity modelling and optimization in pond networks

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1 Ecological background

Shallow lakes and ponds represent a high proportion of aquatic ecosystems and, despite being highly managed, have been demonstrated to be hot spots of biodiversity ([2]). Aquatic plants are good indicators of their ecological status. Indeed, besides their direct contribution to biodiversity, they provide shelters, support, and food for many organisms, and therefore contribute significantly to increase the complexity of trophic chains and thus to increase biodiversity. However, aquatic plants are potentially vulnerable to human activities and global change through several factors:

1. eutrophication, which lead to an increase of competition pressure by phytoplankton and ultimately to the disappearance of vegetation,
2. landscape fragmentation and decrease of connectivity between communities, which lead to erosion of biodiversity due to dispersal limitation,
3. global change, that leads to water deficiency, increasing dewatering frequency and duration ,
4. fish farming, that leads ultimately to plant disappearance, because fishes uproot and graze plants.

The fish-ponds of Dombes region (France) appear as a perfect ecosystem network to study how these different constraints may rule plant biodiversity. In this paper, we present a starting project, newly linking an ecology laboratory and a computer sciences laboratory, and aiming at the conservation of biodiversity in the context of ponds.

2 Computer modelling

The inherent systemic complexity of ecosystems give birth to a wide range of structural and dynamic phenomena like self-organisation, emergence of global spatiotemporal patterns based on local interaction, non predictability at long term, etc ([1]). Description, computer modelling and simulation of such systems thus raise several issues, because the mechanisms at the origin of these phenomena are deployed and interconnected across several interwoven organisational levels. In order to tackle these constraints, the modelling of the biodiversity of the ponds of Dombes is made with an approach linking both ends of the spectrum of modelling tools. On one hand, we use high level formalization, mainly based on partial differential equations, as a means of structuring data collected on the field and describing phenomena at a global scale. On the other hand, we use a low level individual-based model to describe the interindividual interactions at low scale, as well as the spatial organisation specific to the Dombes ponds. Finally, the link between these two models is made with dynamic graphs. Several data mining techniques like supervised learning and pattern extraction methods are also used at different stages of the modelling.

We are currently focusing on the modelling of the parameters describing the main threatening factors depicted in Section 1:

1. eutrophication level with nutrient concentrations in ponds and phytoplankton biomass,
2. spatial relationship between ponds in the pond networks and in the landscape,
3. periodicity of pond dewatering,
4. fish density that may inform about potential disturbances by fishes.

3 Optimization of biodiversity conservation and promotion of optimized practices

Two main problems of biodiversity conservation are that the dedicated resources[1] are limited, and that one has to take into account the economical functions of ecosystems. The objective of species safeguarding must then be achieved by considering the efficiency of the conservation actions peculiar to the concerned species, but also by taking into account these constraints.

We propose to address this key issue by applying computer optimization techniques to solve the constraints discovered and extracted from a low-level model. We plan to implement a medium-scale data extraction tool that will identify the spatiotemporal structures in the dynamic interaction graphs of the individual-based model, and translate them into a higher level representation. This representation will thus make a link between the "ecosystem-based" constraints at the bottom (the minimization of phytoplankton, for example), and the "human-based" constraints at the top (like the optimization financial resources). These unified constraints, linking parameters, variables and functions to be optimized, will then be solved by a dedicated engine using existing constraint programming languages. This method can also act as a validating framework for reinforcement learning methods seeking to converge on the most rewarding conservation plan. In every instance, the pertinence of the solution will be checked with the global communities model.

With this framework, we can envision to optimize several actions –like sampling strategies, conservation plans, allocation of money resources–, as well as explore more global questions like the pertinence of agricultural practices in relation to biodiversity. In order to spread the learnt practices, these recommendations could be applied to other fish-ponds regions of France, Eastern Europe, or Asia. They could also be adapted in other managed wetlands like irrigation ponds and paddy fields, or in restoration of natural wetlands.

4 Computer science at the service of ecology

The evaluation of ecosystems for the millennium performed in 2005 ([3]) showed that 10% to 30% of avian, mammal and amphibian species were threatened of extinction. Plant species are also following this trend. More than a simple moral or ethical act, trying to protect the remaining species is a major and urgent stake for the sustainability of our societies. Furthermore, the Water Framework Directive ([4]) commits European Union member states to achieve good ecological status of all water bodies by 2015. Accordingly, it is now time for computer science to provide workforce and solutions for such pressing environmental problems. It can be done in many forms. Indeed, computer science can provide tools to understand complex ecosystems, simulate and predict their evolution, and help to plan optimal actions to maximize their protection. It is also time to bring together computer science and ecology, heading for the sake of fertile interactions.

References

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[1] Financial resources, among others.