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False positive and false negative errors in the design and implementation of agri-environmental policies: A case study on water quality and agricultural nutrients

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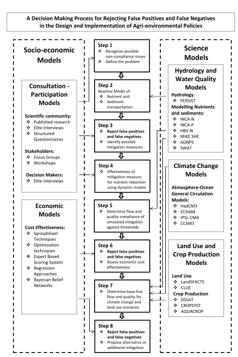
HIGHLIGHTS

- Significant amount of public funds are devoted to EU's agri-environment policy and commitments undertaken by farmers are long term.
- It is important to assure policy decision makers that such funds are directed to the areas in need and in a cost effective way
- We advocate a decision making process integrating science and social science models to protect policy design from committing false positives or false negatives
- The Louros watershed in Greece is used as a case-study for examining the economic loss under a false positive decision
- Climate and land use change can alter the effects of agriculture on water bodies in the future and policy should be prepared to confront this evolution

GRAPHICAL ABSTRACT



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ABSTRACT

When designing and implementing agri-environmental policies to reduce nutrient loss, action programmes may falsely address areas where the nutrient issue from agricultural activity is not currently important and is not likely to become so in the future (a false positive), or may fail to address areas where the agricultural nutrient issue is currently important or may likely become so in the future (a false negative). Based on a case study of the Louros watershed in Greece, this work identifies database and modelling sources of false positives and negatives and proposes a decision making process aimed at minimizing the possibility of committing such errors. The baseline is well simulated and shows that the Louro's watershed falls behind a Good Environmental Status, at least marginally. Simulated mitigation measures show that the river's status can be upgraded to "Good", at least as

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concerns nitrates and ammonium. Simulated climate change does not seem to exert an important positive or negative effect. Land use changes forecasting considerably less cultivated area have a significant effect on Total Phosphorous but not on nitrates or ammonium concentrations. The non-linearity between nutrient disposition (inputs) and nutrient concentration in downstream water bodies (output) and the many factors that affect the nutrient disposition-transportation-concentration chain, highlights the importance of simulating the effects of mitigation actions and of future climate and land use changes before adopting and establishing agri-environmental measures.

1. Introduction

Mineral fertilizers and livestock manures are the main sources of nutrients which, very often, are out of balance with land availability and in excess of crop needs. This imbalance creates a surplus of nutrients, some of which is lost to water, mainly as nitrates and phosphates, and air mainly as ammonia and nitrogen oxides (MacDonald et al., 2011; Fowler et al., 2015). As a result, eutrophication due to nutrient emission from agriculture and urban and industrial runoff is a major threat to wetland ecosystem health (Verhoeven et al., 2006). In the European Union (EU), agri-environment measures (AEM) constitute one of the main types of policy response for meeting society's demand for environmental outcomes provided by agriculture.

The application of AEM is compulsory at the Member State level, but optional at the farmer level. Consequently, the design of AEM is foreseen to meet public demand for environmental goods under the budgetary constraint of payments to farmers that aim to cover the costs incurred and income forgone as resulting from voluntary environmental commitments. The involvement of farmers is usually medium to long-term with a minimum participation of five years. The agri-environment policy has an embedded “Nitrates” component in its mandatory part, i.e. the Nitrates Directive (EEC, 1991), and implements action programmes for controlling nutrients balance that are voluntary for farmers within the so called Nitrates Vulnerable Zones (NVZs) and through the national and regional Rural Development Programmes (RDPs). The Nitrates Directive is an important building block of the wider European environmental and nature conservation policy as it is directly connected to the Water Framework (WFD) and the Habitats and Birds Directives. Over the years, agri-environment policy has emerged as one of the most important elements of the Common Agricultural Policy (CAP) in terms of its budgetary size and the proportion of participating farmers and farmland.

The effectiveness of AEMs to enhance biodiversity (Batáry et al., 2015; Kleijn and Sutherland, 2003) and protect aquatic environments from agricultural pollution has been reviewed very extensively, has been questioned and criticized (Grinsven van et al., 2016; Buckley et al., 2016; Matzdorf and Lorenz, 2010; Randall et al., 2015). The results are disparate mainly due to the plethora of applied measures, the heterogeneity in the application agroecosystems and their baseline status, the variability in set targets and the way these targets are monitored. Decision making for the adoption and establishment of AEMs targeting the reduction of nutrient concentration in water is implemented, very frequently, without a comprehensive and integrated plan. For example, AEM decision makers may be unable to control for non-agricultural nutrient contributing activities, industrial or municipal, which are beyond their institutional jurisdiction. As a result, AEM decision makers tend to set program targets on inputs (quantities of mineral fertilizers, manure or irrigation water) rather than on downstream chemical water quality or environmental status. Consequently, an AEM can be considered to be very effective because it managed to reduced inputs to the targeted level when, in reality, the AEM had marginal or no effect in reducing nutrient loads downstream.

In decision-making, a false positive, known in statistics as Type I error, refers to the situation where the presence of a condition is assumed when in reality there is not such a situation. A false negative, known in statistics as Type II error, refers to the situation where no presence of a condition is assumed when in reality there is one. As such, the words “positive” and “negative” correspond to the answers “yes” or “no” to the question “is upstream agricultural activity responsible for downstream pollution?”. In this sense, a false positive coincides with “yes (positive) agriculture is responsible for downstream pollution” when in reality this is not true (false). Correspondingly, a false negative decision is committed when answering “no (negative) agriculture is not responsible for downstream pollution” when in reality it is responsible (false). In addition to the current situation, action programmes should consider whether the nutrients issue is likely to increase or decrease in the future. In this case the decision question “is upstream agricultural activity likely to become responsible for downstream pollution in the next 7–10 years?” can lead to false positives if action programmes address areas where the nutrients issue is neither currently nor in the future likely to become important. In this context, false negatives emerge when action programmes address areas where the nutrients issue is currently very important and may likely remain so in the future (false negative). In any case, an informative forecast of the future effects of agriculture on the environment can alert policy to be ready to establish programmes or to respond by modifying the incentives provided in existing programmes.

The aim of this paper is to propose an integrated decision making framework for designing and establishing AEMs targeting nutrient reduction. This decision making framework reduces the risk of committing false positives and wasting financial resources or the risk of committing false negatives and not protecting the environment. Section 2 of this work, briefly reviews the sources contributing to the risk of committing either false positives or false negatives and sketches the proposed decision making processes. Section 3 presents the Greek case study of the Louros watershed and describes the methods, information sources and underlying assumptions in the derivation of the various alternative scenarios associated with the adoption of agri-environment programmes, CAP reform and climate changes affecting both the hydrology of the catchment and the nutrient uptake rate of plants. Section 4 presents the results of the analysis, while Section 5 concludes and draws policy recommendations for a safer decision making process during the design and implementation phases of AEMs.

2. Sources of false positives and negatives in the design of agri-environmental policy

Mandatory and voluntary AEM aim, among others, to reduce nutrient concentrations in downstream rivers, lakes and wetlands. Most frequently, such measures directly target nutrient deposition (inputs) to land by setting maximum application rates. For example, the Nitrates Directive states that the amount of livestock manure applied on agricultural land each year, including that applied by animals themselves, should not exceed a maximum of 170 kg of nitrogen per hectare. Other measures attempt to manage nutrients on the field, by promoting favourable farm practices such as crop rotation systems, while others aim at restricting leaching of nutrients from the field, through (e.g.) the maintenance of buffer strips. The design and implementation of agri-environment action programmes for nutrient control is based on information about nutrient deposition from agricultural and livestock