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Avoiding social traps in the ecosystem stewardship: The Italian Fontanile lowland spring

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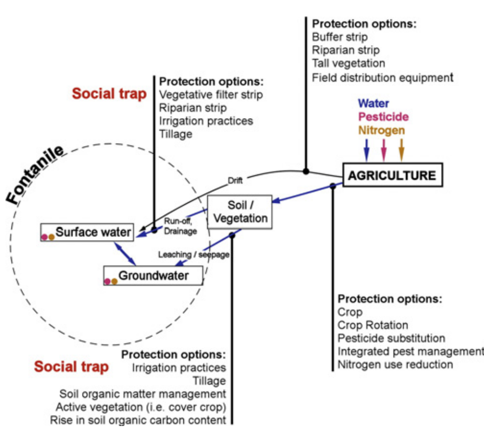
HIGHLIGHTS

- Nitrates concentration water could promote eutrophication, pesticides are below NoEC.
- Climate change scenarios generate uncertainty in the predictions.
- Water saving and conservation technologies are social traps.
- Large buffer strips are social traps because of the Fontanile hydrological settings.

GRAPHICAL ABSTRACT



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ABSTRACT

Fontanile is a Po Valley (Italy) quasi-natural lowland spring built in the middle age. This paper identifies options for the conservation of the Fontanile water dependent ecosystem, using scenarios and simulations, and exploring different policy options. Three modeling analysis have been performed: the first was carried out for estimating groundwater contamination and recharge from above, the second for evaluating the function of vegetative filter strip on the surface water quality and the last one for testing pesticide drift reduction due to the vegetative filter strip. Uncertainty characterization included climate change projections. Despite the nitrate concentration in water could favorite the eutrophication phenomena, this not occurs because of the low phosphate concentration in water and of the presence of arboreal shade. Therefore, the protection strategies must focus on sustaining desirable water quantity conditions. Water saving and conservation technologies that improve the agricultural productivity but reduce the Fontanile water flow and large buffer strips that have a limited efficacy due to the

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Modeling

Fontanile hydrological settings can be judged as ecological traps. Inefficient irrigation systems, good agricultural practices, integrated pest management and arboreal filter strip can preserve the quality of those ecosystems.
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1. Introduction

"The Anthropocene", is defined by (Crutzen, 2002) as the current era, in which ecosystems and life on Earth are subjected to multiple global-change stresses resulting from human activities. These result in habitat loss and degradation, impact water resource demands, create toxic contaminants, introduce invasive species and have impacts on the climate (Grimm et al., 2013). It is well documented that climate change influences the frequency and intensity of extreme events (Grimm et al., 2013), however, quantification of such changes is difficult. This introduces uncertainty to management options and provides an additional pressure for policy makers (Okkonen & Kløve, 2010). A challenge for scientific research is to provide a credible and transparent analysis of this, in order to minimize the potential for manipulation in the face of uncertainty (Polasky et al., 2011).

To effectively respond to the impacts of climate change on biodiversity, natural resource managers and policy makers must embrace approaches that are flexible and can account for multiple uncertainties coming from variability in climate projections, impacts and responses (Staudinger et al., 2013). Additionally they must downscale a global problem to several local actions. Local actions can also limit the risk of environment protection failure, as they require a deep understanding of the linkages between drivers, pressures and impacts, which threaten any local environmental system.

Among the principles developed for protecting ecosystems, ecosystem stewardship is one of the most promising. It is an action-oriented framework intended to foster the social–ecological sustainability of a rapidly changing planet. It integrates three broadly overlapping sustainability approaches: (i) reducing the magnitude of, and exposure and sensitivity to, known stresses, (ii) fostering resilience to sustain desirable conditions in the face of perturbations and uncertainty, and (iii) escaping unsustainable social–ecological traps. (Chapin et al., 2010). Ecological traps are habitats or features of the habitat that mislead an animal's choice, often hampering the completion of its life cycle (Schlaepfer et al., 2002). Social trap is a situation in which a group of people acts to obtain short-term individual gains, which in the long run leads to a loss for the group as a whole (Costanza, 1987, Platt, 1973).

Fontanile (*plural — i*) is a quasi-natural lowland spring built in the middle age in the Po Valley (Italy) by monks starting from Century XI. The ecosystem around the ponds and canals are born from springs. Although the ecosystems have an adaptive capacity and resilience, there is a clear need to identify protection principles and methods to protect the Fontanile ecosystem. Processes such as water flow reduction, changes in the annual flow regime, and pollution can have serious effects on flora and fauna and can damage the ecosystem or wipe out the aquatic ecosystem (Okkonen & Kløve, 2010). Several studies characterized the Fontanile hydrological (De Luca et al., 2009; De Luca et al., 2014; Sacchi et al., 2013; Vassena et al., 2012; Vorlicek et al., 2004) and ecological settings (Abdelahad et al., 2015; Pieri et al., 2007; Ramusino, 1982; Rossetti et al., 2005). At present more than 200 Fontanili have been recorded in the Lombardy region, however historical records show that more than 800 were present in the past (Vassena et al., 2012). Fontanili disappeared because of the need of agricultural land or because of changes in the hydrological regimes. In addition, several cases of water contamination have been reported by agrochemicals, particularly nitrates and herbicides (Bartoli et al., 2012, Laini et al., 2012).

Until now, attempt of integrated management of Fontanile was never done because, policy makers tend to protect each environmental compartment at larger scale, tend to simplify the interaction among the compartments or to act at larger scale (River basin). Several acts protect the surface and the ground water in term of quality (The EU Drinking Water Directive 98/83/EC, the EU Water Framework Directive 2000/60/EC, the Urban Waste Water Treatment Directive 91/271/EEC, the Nitrates Directive 91/676/EEC, the Environmental quality standards applicable to surface water Directive 2008/105/EC, etc.). The water quantity is protected at the river scale (i.e. Environmental flow) or at the field scale (i.e. water use efficiency improvement).

The development of integrated measures to sustain the Fontanili requires the integration of the hydrogeological, biogeochemical, and ecological and conceptual models into an impact-response model (Kløve et al., 2014). Possible mitigation options can be placed within these models and climate change scenarios can better understand the uncertainty and improve the sustainability of the developed measures.

This paper aims to identify options for the *Fontanile* (*plural — i*) conservation. The specific aims are: (i) to identify measures, which will allow the Fontanile to sustain its capacity to provide ecosystem services, using scenarios and simulations, (ii) to explore different policy options in the context of projected changes, (iii) to develop flexible strategies and to minimize the risk of failure.

2. Materials and methods

2.1. Site description

The Po Valley lowland spring belt is located between the Cremona and Bergamo provinces (Fig. 1) and was selected as the location for the modeling exercise. It has an area of 1500 km^2, and its altitude is 90–100 m above the sea level. The mean temperature in winter is 2.5 °C and summer 23 °C, annual precipitation is ≈800 mm with high intensity rainfall peaks in spring and autumn. Soil texture is coarse and skeleton, the soil particles with diameter > 2 mm, is present. Water table begins 2–4 m below the soil surface. Water inputs into the system are precipitation and irrigation (up to 400 mm year^{-1}): water diverted from rivers (from mid-May to August) which is distributed to an extensive secondary canal network. The canals are mostly unlined and irrigation is mainly border with low efficiency; therefore, large volumes of water from plot irrigation and losses from leaky canals infiltrate into the water table and recharge the phreatic aquifer. This induces groundwater flow back to the main rivers which feeds numerous springs and flowing wells (Supplementary info, Table S1, Fig. S1). Groundwater provides the Fontanili ecosystem (Fig. 2) with water and nutrients and helps maintain stable environment conditions (temperature, oxygen, pH and water quality). Two distinctive types of Fontanili characterize the area: the first, with constant flow throughout the year, in the Northern part of the belt, the second with irrigation-fed flow peaks during summer seasons in the Southern part of the belt.

The Fontanile represents a dual water flow system. The upper section drives large fluxes (>15 m^3 s^{-1} in the wells) in the shallow phreatic aquifer (highly permeable sediments), with rainfall and irrigation recharge, interactions with rivers, flowing wells and alluvial terraces, and water abstraction for industrial and agricultural uses. The deeper one takes place in the deep aquifers, where fine-grained less-permeable sediments are more abundant and small fluxes (up to 4 m^3 s^{-1}) are driven mainly by water abstraction from wells for drinkable purposes (Vassena et al., 2012). (Supplementary material, Table S1, Fig. S1).

Traditionally, due to good water availability, irrigation uses border distribution system (Fait et al., 2010, Zucaro, 2011). The local consortium manages the irrigation water and schedules water supply following

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