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Implications for forest management of the EU Water Framework Directive's stream water quality requirements — A modeling approach

Ljusk Ola Eriksson [a,*], Stefan Löfgren [b], Karin Öhman [a]

[a] Swedish University of Agricultural Sciences, Department of Forest Resource Management, S-901 83 Umeå, Sweden
[b] Swedish University of Agricultural Sciences, Department of Aquatic Sciences and Assessment, P.O. Box 7050, S-750 07, Uppsala, Sweden

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ABSTRACT

The EU Water Framework Directive (WFD) stipulates that measures should be taken to ensure that all lakes and streams in the EU have good ecological and chemical status, comparable to that of waters unaffected by human activities. This has profound potential implications for forestry, since operations such as harvesting and fertilization tend to reduce the quality of ground and stream water in affected catchments. The aim of this study is to assess the implications for forestry of limiting the concentrations of chemical substances reaching lakes and streams. A forest planning model with a horizon of 100 years that includes requirements regarding water concentrations of nitrogen (N), phosphorus (P), methyl mercury (MeHg) and dissolved organic carbon (DOC) was applied to three intensively-studied sub-catchments at Balån in the boreal part of northern Sweden. Limiting maximum increases in concentrations of these substances to 10% above reference values resulted in an economic loss of ca. 20% or 35%, depending on whether the limits were applied to the whole area or to each sub-catchment individually. The results were also highly dependent on the assumptions, especially regarding the flux of MeHg. The results should be interpreted with caution as there are still major uncertainties concerning the cause and effect relationships. We also need to consider additional aspects to those addressed here, such as acidification, erosion and the biological effects of the operations.

1. Introduction

The EU Water Framework Directive (WFD, 2000/60/EC) has set an objective to ensure that by 2015 the ecological and chemical status of all lakes and streams in Europe should be ‘good’, defined in terms of comparability to the water quality in pristine areas, unaffected by human activities. This is likely to have consequences for forestry operations at both stand and catchment levels, since hydrological, biological and chemical processes are all influenced by forestry activities (in addition to forest yields). Most importantly, in this context, operations such as forest harvesting and fertilization tend to reduce the water quality of streams and lakes receiving water from the forests, relative to those receiving water from non-managed forests (Piirainen et al., 2007; Kreutzweiser et al., 2008). However, the magnitude of these effects is clearly related to the proportion of the catchment affected by forestry operations and how these operations are performed (Ring et al., 2008).

In Sweden, implementation of the WFD is led by five water authorities, which are authorized to apply management plans to enhance water quality, including plans to address effects of forestry, where necessary to meet WFD requirements. A key task for these authorities is to assess the ecological status of waters. For this purpose, the Swedish Environmental Protection Agency (SEPA) has developed a classification system, which includes biological, chemical and hydro-morphological variables (SEPA, 2007, 2008). Hence, knowledge of the effects of forestry activities on values of these parameters is essential for understanding the adaptations forestry will need to make to meet the stipulations of the WFD as interpreted by the Swedish water authorities. Based on the SEPA system, the water authorities classify the ecological status as less than good in 39% and 44% of Swedish lakes and streams, respectively (Water Authorities, 2010). One reason for this is that the chemical status of the water in many forest streams tends to be close to the border between good and moderate classes (Löfgren et al., 2009a), which is the threshold for remedial actions according to the WFD. In many of these limnic systems, forestry is the major human influence, and a small increase in (for instance) phosphorus concentration caused by forestry might induce a shift from good to moderate class, and thus initiate a requirement for remedial actions. Another contributory factor, in some cases, may be incorrect classification based on the biological indices (Löfgren et al. op. cit., see below).

Guidelines for mitigating the adverse effects of forest operations on water quality have been issued by the Swedish Forest Agency (2000) and the Swedish Forest Stewardship Council (1998). Ways in which forestry could adapt to meet water quality requirements have

* Corresponding author at: Department of forest resource management, SLU, S-901 83 UMEÅ, Sweden. Tel.: +46 706440004; fax: +46 90778116.
E-mail addresses: Ola.Eriksson@slu.se (L.O. Eriksson), Stefan.Lofgren@slu.se (S. Löfgren), Karin.Ohman@slu.se (K. Öhman).

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not been thoroughly investigated either. Some “rules of thumb”, such as not allowing more than 30% of a catchment to be harvested (Ring et al., 2008), have been proposed, but it is not clear if they would be either optimal or sufficient. Further, one of few relevant studies under boreal conditions (Öhman et al., 2009) indicated that ensuring that the concentration of dissolved organic carbon (DOC) in streams and lakes fed by groundwater to <10% above the reference value could incur economic losses (relative to current practices) of 5–30%, depending on the assumed magnitude of forestry effects on water quality variables.

A more comprehensive understanding of the relation between water quality and forestry than Öhman et al. (2009) is attempted here by allowing several modeled water quality variables to be simultaneously affected by forest operations. However, limitations in knowledge of the relationships between forestry activities and water quality parameters preclude analysis of many variables. Biological effects are inherently difficult to assess, not the least because the lack of casual relationship between organism status and water quality. For example, it is not possible to distinguish between natural acidity and acidification caused by human activity from the status of benthic fauna and fish (Löfgren et al., 2009a). Hydro-morphological disturbances in the study area are basically of historical origin and less related to present forestry (Löfgren et al., 2009a, see below). Hence, the water quality variables that will be analyzed in this report are limited to water chemistry. In the study area, it is possible to estimate initial chemical parameters of the streams, and to make reasonable quantified assessments of the responses of these parameters to forest activities. The focus is on forestry as a large scale, long-term activity, i.e. the perspective is strategic. Hence, some effects of forestry activities on water quality, such as machinery crossing streams during harvesting operations, are not included as they are dependent on specific operational plans. These aspects, important as they may be (Nisbet, 2001; Kreutzweiser et al., 2008; Ring et al., 2008), are assumed to be accounted for in consistency with the values assigned by the water quality models used in this study. The strategic perspective also reduces the importance of hydro-morphological parameters as they are related more strongly to measures intended to improve the water quality (restoration of rafting channels for example), than normal forest operations. However it should be noted that there are exceptions, like for instance the abundance of large woody debris in streams caused by normal forest operations.

The aim of this study was to assess, in a strategic setting, the potential implications for forestry of limiting the concentrations of selected chemical substances in surface waters below certain threshold values over time. To do this we used a traditional forest planning model aimed at maximizing the net present value (NPV) from future harvest activities subject to traditional forest constraints and requirements regarding water quality. The water quality variables are concentrations of nitrogen (N), phosphorus (P), methyl mercury (MeHg) and dissolved organic carbon (DOC). Model outputs pertain to financial values, forest management activities and concentrations of the substances mentioned above during the next 100 years. The analysis focuses on three intensively studied sub-catchment areas at Balån in the boreal part of northern Sweden (Löfgren et al., 2009b). Further, since water quality (like most ecological phenomena) is dependent on spatial scale, the relationships between forestry activities and water quality are assessed at two geographical scales: sub-catchment and whole catchment.

2. Materials and methods

2.1. Study area

We set parameter values for our model based on data derived from the Balån study area of north-eastern Sweden (Löfgren et al., 2009a, b), situated ca. 60 km from the coast in the county of Västerbotten (63°49′ N, 20°15′ E, Fig. 1). The area was chosen since it has been surveyed since 2004 and much of the data needed were available from the area (see articles in the special issue on Balån in Ambio Vol. 38, No. 7, Nov. 2009). The area consists of a total of 66 stands distributed on three sub-catchments I, II and III (Fig. 1). Areas I and II contain stands that on average are considerably older than those in area III, whereas the three stands together have a fairly even age distribution. The catchment is dominated by Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) with limited occurrence of other species, mostly birch (*Betula* spp.) (Table 1). The forest data for the area were estimated by the k nearest neighbor method (*k*NN) (Reese et al., 2003), with stands delineated with the algorithm developed by Hagner (1990). Note that the description of the area given by Löfgren et al. (2009b) is based on forest data obtained from the land owner and a stump survey, not completely in agree with the *k*NN data. This is reflected, for instance, in the site index, which is lower on average in the *k*NN data.

2.2. Water quality indicators

Changes in concentrations of relevant substances can be used as indicators of the effects of specific forest operations, and can be calculated by dividing their respective fluxes by the water runoff before and after the operations. For example, if the N flux at base level is $1.5\ \mathrm{kg\ ha^{-1}\ y^{-1}}$ and the annual water runoff is $400\ \mathrm{mm\ y^{-1}}$ (corresponding to an annual runoff volume of $0.4\ \mathrm{m^3}$ water from each square meter of the catchment), the N concentration in the runoff water will be $0.375\ \mathrm{mg\ N\ L^{-1}}$ $[(1.5*10^6\ \mathrm{mg\ N}/10^4\ \mathrm{m^2})/0.4\ \mathrm{m} = 375\ \mathrm{mg\ N\ m^{-3}} = 0.375\ \mathrm{mg\ N\ L^{-1}}]$. Additionally, if 10% of the catchment area is clear-felled, leaching $3.0\ \mathrm{kg\ N\ ha^{-1}\ y^{-1}}$ and runoff 560 mm water $\mathrm{y^{-1}}$, the concentration in water from the clear-felled area will be $(3.0*10^6\ \mathrm{mg\ N}/10^4\ \mathrm{m^2})/0.56\ \mathrm{m} = 0.536\ \mathrm{mg\ N\ L^{-1}}]$ and from the entire catchment $0.391\ \mathrm{mg\ N\ L^{-1}}$ $[= 0.375*0.9 + 0.536*0.1]$. This procedure has been followed here, since in most scientific literature the excess loss of a substance coupled to a certain forest operation is usually expressed as annual flux per hectare. Since the functions for growth and yields used in the study operate with a time step of 5 years, the description of the effects on water quality is also given as averages for 5-year periods. Further, in the study it is assumed that the consequences of a forest activity last for at most two 5-year periods, i.e. 10 years.

2.3. Establishing model parameters

The model parameters used in this study are presented in Table 2, which summarizes the average effect per year of various forest operations on selected substances, as well as the base levels in non-managed forests. The rationale for setting these parameters is given below. The increased flux values for all operations except fertilization are based on the rate of estimated increase after a 1 ha harvest (clear-felling). In the case of fertilization, the effect is from fertilizing 1 ha.

2.3.1. Water runoff (W)

The base level runoff is set to $400\ \mathrm{mm\ y^{-1}}$, following data from Balån presented by Löfgren et al. (2009b; Table 3). The increase from final felling is estimated with the model presented by Öhman et al. (2009; Table 1, Case 1a), resulting in an increase in the first 5-year period of 40% and in the second 5-year period of 25% over the base level. Increased water flow following harvest has been assumed when calculating the post-harvest (1st and 2nd periods) concentrations for all substances.

2.3.2. Nitrogen (N) and clear-felling

The data given by Löfgren and Olsson (1990) and the conclusions in Löfgren (2007) indicate that clear-felling increases N fluxes from about 1.5 to $3.0\ \mathrm{kg\ N\ ha^{-1}\ y^{-1}}$ on average over an entire period of 10 years across the Bothnian Bay region. These values describe the total flux, i.e. they include the increases in both concentrations and