The Importance of Riparian Forest Cover to the Ecological Status of Agricultural Streams in a Nationwide Assessment

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Abstract

Forested riparian corridors are a key management solution for halting the global trend of declining ecological status of freshwater ecosystems. There is an increasing body of evidence related to the efficacy of these corridors at the local scale, but knowledge is inadequate concerning the effectiveness of riparian forests in terms of protecting streams from harmful impacts across larger scales. In this study, nationwide assessment results comprising more than 900 river water bodies in Finland were used to examine the importance of adjacent land use to river ecological status estimates. Random forest models and partial dependence functions were used to quantify the independent effect of adjacent land use on river ecological status after accounting for the effects of other factors. The proportion of adjacent forested land along a river had the strongest independent positive effect on ecological status for small to medium size rivers that were in agricultural landscapes. Ecological quality increased by almost one status class when the adjacent forest cover increased from 10 to 60%. In contrast, for large rivers, adjacent forested land did not show an independent positive effect on ecological status. This study has major implications for managing river basins to achieve the EU Water Framework Directive (WFD) goal of obtaining good ecological status of rivers. The results from the nationwide assessment demonstrate that forested riparian zones can have an independent positive effect on the ecological status of rivers, indicating the importance of riparian forests in mitigating the impacts of catchment-level stressors. Therefore, forested buffer zones should be more strongly considered as part of river basin management.

Keywords Environmental assessment · Riparian forests · Buffer zone · Streams · Water framework directive · Water bodies

1 Introduction

The ecological status of freshwater ecosystems has degraded worldwide, requiring urgent management efforts and policy actions to counter the prevailing trend (Grizzetti et al. 2017; Reid et al. 2019). Agriculture is among the most influential and widespread

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human-induced land uses affecting freshwater ecosystems (Davies et al. 2009; Flavio et al. 2017). An important mitigation action to counter the negative effects of agricultural land use on the ecological status of freshwater is to maintain or restore forested buffer zones along water courses (e.g., Singh et al. 2021; Cole et al. 2020; Pavlidis and Tsihrintzis 2018; Stutter et al. 2012). Forested riparian zones form a natural buffer adjacent to streams, and they are important for achieving good water quality and maintaining high biodiversity levels (e.g., Naiman et al. 2010). However, evaluations of the importance of forested buffers on ecological status in large river assessments are lacking, which is a significant knowledge gap regarding the efficient implementation of environmental policies such as the European Union Water Framework Directive (WFD, European Commission 2000).

Most freshwater ecosystems are intimately coupled with adjacent riparian areas through lateral and longitudinal fluxes of organisms, matter and energy (Nakano and Murakami 2001; Soininen et al. 2015). Riparian forests play an important role in river ecosystems, for example, by supplying coarse organic material to stream food webs, as well as by regulating stream metabolism and nutrient cycling associated with shading (Perkins et al. 2010; Johnson and Almlöf 2016; Warren et al. 2016). Forested riparian zones could also help mitigate climate warming effects on freshwater biotas (Sponseller et al. 2001; Thomas et al. 2016; Turunen et al. 2021) and contribute to the retention of excess nutrients, contaminants and organic material originating from human land use in a catchment (e.g., Kiffney et al. 2003).

The influence of forested buffer zones on rivers in human-influenced catchments has been studied previously. However, our understanding of whether management actions should aim at local reach or catchment scales is inadequate at present. Some studies emphasize the importance of catchment land use, while others suggest that land use adjacent to a river is more important to the structure and function of stream ecosystems (Jones et al. 1999; Lammert and Allan 1999; Death and Collier 2010; Wahl et al. 2013). Forested buffer zones may be most suitable in stream systems that are under moderate agricultural land use (Turunen et al. 2019). In such streams, forested zones may contribute to the retention of excess nutrients, contaminants and organic materials, whereas in streams draining catchments with intense agricultural actions, the potential positive effect of forested zones is not adequate to mitigate ecological degradation (Wahl et al. 2013; Feld et al. 2018).

The importance of land use adjacent to streams may be further associated with stream size. It can be assumed that the positive effects of riparian forests on ecological status should be more pronounced in low-order streams than in larger rivers. This is because of differences in allochthonous and autochthonous primary energy sources between small streams and larger rivers, which is the basic tenet of the river continuum concept (Vannote et al. 1980). Some previous studies have addressed the importance of forested buffers to small streams owing to shading effects (Greenwood et al. 2012; Burdon et al. 2020), thereby supporting the idea that land uses adjacent to a stream are more significant in smaller streams than in larger rivers. Furthermore, for rivers that have large catchment areas, forested zones may not be able to mitigate the effect of agricultural land use on ecological quality. In large rivers, catchment-scale anthropogenic pressures may diminish the positive effects of forested zones on ecosystem structure and function. Hence, it is important to understand how stream size and agricultural land use gradients interact to determine the effect of forested buffer zones on ecological quality.

1.1 Hypothesis

In this study, we examined the importance of the proportion of forested, non-agricultural land (forested buffer zones) on the ecological status estimates of river water bodies in Finland. The study tested whether forest cover adjacent to a stream or catchment-scale forest cover would be more strongly associated with the ecological status of rivers. We assumed that at a given level of agricultural pressure, increasing the percentage of forested land adjacent to rivers would have a positive effect on their ecological status. In this study, we further assumed that in comparison to the proportion of forest in the entire catchment area, forested buffer zones would be more important to ecological status. The expectation was that the effect of forested buffer zones on ecological status would be more comprehensive in rivers suffering from moderate to high agricultural pressures. We also expected that forested zones would be more important in small and medium streams than in large rivers.

2 Materials and Methods

2.1 Study Dataset

The study area encompasses most of the Finland mainland (60° to 65°N, 20° to 32°E) but excludes northern Finland. In general, the main anthropogenic land use in southern and western Finland is associated with agriculture, whereas forestry is a more important land use type than agriculture in central and eastern Finland (Fig. 1). Northern Finland was excluded from this study because agricultural pressure is generally low in the area.

The study used data from the Finnish National Freshwater Assessment from the third cycle of WFD river basin management planning. These data are available in a public database maintained by the Finnish Environment Institute (SYKE, https://www.syke.fi/en-US/Open_information). The assessment includes all major river water bodies and a portion of small rivers across the country ($N=1911$). The river water bodies are delineated as channel stretches, which are the spatial units used in planning WFD river basin management. Excluding northern Finland, the study included 924 river water bodies that were consistently classified based on ecological, physicochemical and hydromorphological status (see below how ecological status is classified in the WFD). The data represent a large gradient in river size, with catchment areas varying from 0.7 to 40,756 km² (median 133 km²). The river stretch length ranged from 0.14 to 187.7 km (median: 12.5 km).

The ecological status classifications in the context of the WFD are official estimates of the ecological quality of water bodies that are widely used in river basin management and are legally binding environmental objectives of good status for all freshwater bodies. Ecological status incorporates estimates of anthropogenic biological quality impairment (i.e., based on macrophytes, phytobenthos, invertebrates and fish), as well as assessments of alterations in physico-chemical, hydrological and morphological conditions, which are compared to their least-disturbed reference conditions (e.g., Birk et al. 2012; Poikane et al. 2015). Ecological status is classified into five classes, i.e., high, good, moderate, poor and bad, which describe the extent of deviation of biological quality elements from their least-disturbed river-type specific reference conditions. The best status (high) corresponds to reference conditions, whereas in the good status class, slight deviations from reference conditions are allowed. In the moderate status class, deviations have to be moderate, and in

Fig. 1 Map of the study area, showing the river water bodies and the ecological status (left picture) (bad=red, poor=orange, moderate=yellow, good=green, and high=blue), and agricultural land use (black) in Finland (right picture) (Ecological Status and Corine Land Cover: Finnish Environment Institute 2021)

the poor status class, deviations are substantial. In bad status class, deviations are severe. In this study, ecological status estimates were performed by regional water authorities to spatially represent a whole water body (i.e., river stretch) between 2012 and 2017 using all available monitoring data and expert knowledge about the status following national guidance (Aroviita et al. 2019).

This study used land cover data for adjacent stream zones and entire catchments for all water bodies using ArcGIS. The adjacent stream zone polygons were delineated as 50-m buffers around the channel line, or in the case of larger rivers, they were delineated with digitalized water areas. The catchment polygons were based on national third division level catchments. We then calculated the relative coverage (%) of land cover types (CORINE 2012 20*20 m national raster data level 4; (http://geoportal.ymparisto.fi/meta/julkinen/dokumentit/CorineLandCover2012_en.pdf) for all adjacent stream zones in each catchment. All land cover types, including forested land (CORINE classes 2441–3133), were merged to form the ‘forest type’, whereas ‘agricultural fields’ comprised cultivated areas and pastures (CORINE classes 2111–2312).

2.2 Statistical Methods

In this study, we used Random Forest (RF) (Breiman 2001) to model the individual effects of riparian land use and catchment-level land use on river ecological status. Random Forests is known to be able to handle complex relationships between response and predictor

variables. Random Forests is a combination of tree predictors such that each tree depends on the values of a random vector sampled independently, with the same distribution for all trees in the forest (Breiman 2001). Two outputs of the method were used: (1) the relative importance of the predictor variables, which shows the variables included in the model in the order of relative importance in explaining variation in the response variable, and (2) partial dependency plots, which show the directions and forms of the relationships between the response and predictor variables (Zhao and Hastie 2021). The partial dependency plots show the individual effect of each of the predictor variables on the response variable after accounting for the effect of the other predictor variables on the response variable.

In this study, separate RF regression models were built for three different catchment sizes ($< 100 \text{ km}^2$, $100\text{--}1000 \text{ km}^2$, and $> 1000 \text{ km}^2$) and for three agricultural land use classes ($< 10\%$ agricultural land use, $10\text{--}20\%$ agricultural land use, and $> 20\%$ agricultural land use) to a priori control for and compare the relationships among varying river sizes and levels of agricultural pressure. Although the study controlled for the effect of agricultural land use using three different agricultural land use classes, agricultural land use percentage was also included as a predictor variable to explore how the agricultural land use gradient was related to ecological status within each of these classes. Because of the complexity of the response-predictor variable relationships in nature, hydromorphological degradation was also used in the analysis and considered a nonlinear relationship between water body ecological status and the predictor variables.

Regression mode of Random Forest was used to explore the variation in ecological status using agricultural field percentage in the catchment, forest percentage in the 50-m buffers, forest percentage in the catchment, and scores of hydromorphological alteration in the river channel as predictor variables. As no predictors explained the variation in ecological status within the large size river class ($> 1000 \text{ km}^2$), probably due to the low number of sites, we further combined all agricultural land use classes for large rivers ($> 1000 \text{ km}^2$) to examine the effect of forested buffer zones on large rivers. As we wanted to study how a priori selected predictors explain variation in ecological status, we included all selected predictors in the RF analysis and did not fit the models. RF models performance were evaluated based on the Out-Of-Bag (OOB) percent variance explained.

The R package ‘randomForest’ (Liaw and Wiener 2002) and the functions *randomForest*, *varImpPlot*, and *partialPlot* were used to conduct the actual modelling and draw the variable importance plots and partial dependency plots, respectively.

3 Results

Most of the river water bodies examined were classified in good ecological status (47%), followed by moderate (36%), poor (10%), high (4%), and bad status classes (3%) (Fig. S1). The mean forest cover in the 50-m adjacent riparian zone varied from 30 to 66% in the different classes. Forest percentage was highest for small streams with low amounts of agricultural land use in the catchment, and forest percentage was lowest in medium size streams with high amounts of agricultural land use in the catchment. As expected, ecological status was highest in the low agricultural impact stream classes and lowest in the classes with more than 20% agriculture in the catchment area.

The random forest model, with agricultural field cover, forest cover of entire catchments, the 50-m forest buffer zone and hydromorphological alteration as predictors, explained more variation (15.6 to 27.2%) in ecological status in small rivers ($< 100 \text{ km}^2$)

than in medium rivers (100–1000 km²) (5.5–8.7%) (Table 1) (Fig. 2). The area of the forested buffer zone was the most influential factor for ecological status in small rivers with intermediate agricultural land use pressure (10–20%) and in medium rivers with intermediate and high (10–20% and > 20%) agricultural land use pressure (Fig. 2). Forested buffer zone was the second-most influential variable in small rivers that had high (> 20%) and low (< 10%) agricultural land use pressures (Table 1) (Fig. 3). Forested buffer zones did not account for the variation in ecological status of large rivers (> 1000 km²) (Table 1). In large rivers, the percentage of agricultural fields and hydromorphological alteration explained most of the variation in ecological status. In small to medium rivers with > 10% agricultural land use, ecological status increased with an increasing proportion of forest buffer zones, indicating that increasing forest cover in buffer zones increased the ecological status of the river. The independent effect of forest buffer zones seemed to be strongest for intermediate agricultural land use classes (Fig. 2). Overall, the ecological status increased by almost one class when the forest cover in the buffer areas increased from 10 to 60%.

Although we controlled for the agricultural pressure levels by the *a priori* classification, field percentage was still influential in small and medium rivers (Table 1) (Fig. S1). Ecological status decreased with an increasing percentage of agricultural fields in the catchment and with increasing levels of hydromorphological alterations. The individual influence of the hydromorphological alteration was minor for all river classes (Fig. S2). Also the individual influence of forest coverage of entire catchment was moderate (Fig. S3).

4 Discussion

Despite increasing concern about the impairment of freshwater ecosystems and the urgently required mitigation efforts (Wohl and AG 2018; Cantonati et al. 2020), empirical evidence on the effectiveness of current adjacent forested areas in reducing adverse effects on river ecosystems is still scarce. This study explored national WFD assessment data and showed that adjacent forested land indeed had a positive independent effect on the ecological status of agricultural streams. The effects were most pronounced in the groups of small and medium sized rivers, where adjacent forest cover increases from approximately 10 to 60% resulted in an improvement in ecological status by almost one status class.

Table 1 Summary of Random Forest (RF) models describing relationships between ecological status and stressors within each of the three river size classes (< 100 km², 100–1000 km², and > 1000 km²) and within each of the three agricultural pressure classes (< 10%, 10–20%, and > 20% agriculture in catchment area). % var = % variation accounted for by the model in each land use class. Predictor variables are listed from left to right in order of importance in the model. *n* = number of classified rivers. Due to the low number of sites, all agricultural pressure classes are combined in the > 1000 km² river size classes

Catchment size and agricultural cover	% var	<i>n</i>	Predictors
Catchment < 100 km ² , < 10% Field	15.6	211	FIELDSc, FOREST50, FORESTca, HyMo
Catchment < 100 km ² , 10–20% Field	22.4	82	FOREST50, FIELDSc, FORESTca, HyMo
Catchment < 100 km ² , > 20% Field	27.2	44	FIELDSc, FOREST50, FORESTca, HyMo
Catchment 100–1000 km ² , < 10% Field	8.7	306	FIELDSc, FORESTca, FOREST50, HyMo,
Catchment 100–1000 km ² , 10–20% Field	5.5	99	FOREST50, FIELDSc, FORESTca, HyMo
Catchment 100–1000 km ² , > 20% Field	7.8	107	FOREST50, FIELDSc, FORESTca, HyMo
Catchment > 1000 km ²	32.7	75	FIELDSc, HyMo, FOREST50, FORESTca

Fig. 2 Partial dependency plots from the Random Forest analysis showing the relationships between ecological quality status (EQ) and forested land adjacent to a river stretch (forest buffer %) for the three river size classes (<100 km², 100–1000 km², and >1000 km²) and the three agricultural pressure classes (<10%, 10–20%, and >20% agriculture in catchment area). The plots characterize the average individual effects of forested buffer on the EQ after the effects of other predictor variables (Fig. 3) were accounted for. The y-axis values thus do not represent the raw data. Ecological status (bad=0.1, poor=0.3, moderate=0.5, good=0.7, and high=0.9)

The positive effect of riparian buffer zones has already been supported by evidence from smaller-scale studies. Studies addressing riparian zones have typically reported a positive relationship between biodiversity and forest cover percentage adjacent to a stream (e.g., Grizzetti et al. 2017; Turunen et al. 2019; Forio et al. 2020). These previous results are parallel to our novel findings from the large nationwide assessment dataset. One explanation for why the importance of adjacent forests depends on river size is that small streams are more strongly associated with the riparian zone than large rivers (Allan and Castillo 2007); therefore, small streams are more likely to suffer from anthropogenic changes in the riparian zone (Tolkkinen et al. 2020). Catchment-scale pressures in larger

Fig. 3 Variable importance plots based on node purity for ecological status for the three river size classes (<100 km², 100–1000 km², and >1000 km²) and three agricultural pressure classes (<10%, 10–20%, and >20% agriculture in catchment area)

ivers may overwhelm any positive effects of local riparian management, including the potential of forested zones for river management efforts (Burdon et al. 2020). Therefore, local management actions are often seen as most effective in small streams (Craig et al. 2008; Greenwood et al. 2012). Moreover, restoring and protecting headwater streams not only have positive local effects but also may enhance the ecological status of downstream reaches in larger rivers (Greenwood et al. 2012). The effect of forested zones on ecological status in this study could have been even stronger if forested buffer zones were actively used in the management of agricultural watersheds. Therefore, enhancing forested buffers as an effective management tool would require the implementation of more extensive and continuous buffer zones in agricultural watersheds.

Negative effects of agriculture on stream ecosystems through increased inputs of nutrients and contaminants have been detected both in broad-scale assessments and small-scale surveys (e.g., Moss 2008; Tolkkinen et al. 2013; Reid et al. 2019). This common finding is in line with what was detected in this study; i.e., agricultural land use was negatively associated with ecological status in a river assessment. In addition to agriculture, river

hydromorphological alterations also had negative effects on ecological status in this study, supporting previous findings that hydromorphological alteration has negative impacts on river ecological quality (e.g., Negishi et al. 2002; Wyzga et al. 2012; Grizzetti et al. 2017). However, the independent effect of hydromorphological alteration was generally low in this study, and other variables surpassed its importance to ecological status. Hydromorphological alteration accounted for some of the variation in the ecological status of large rivers, especially those that are more heavily modified and under ongoing water management actions. One explanation for why we saw only low hydromorphological effects is that hydromorphological degradation in small and medium size rivers may not be that detrimental to near-bed characteristics; thus, suitable habitats remain for most organisms (Muotka and Syrjänen 2007). Nevertheless, disentangling the effects of hydromorphological alteration and catchment land use is challenging in the context of agricultural streams that are often also hydromorphologically strongly modified.

5 Conclusions

This study has major implications for achieving the WFD goal of rivers with good ecological status levels. The expected positive effect of riparian forests on ecological status in this study provides an important guideline for authorities responsible for river basin management. Considering the efficacy of riparian forested buffers to ecological status at large spatial scales, it is highly likely that forested buffers are highly relevant to the management of agricultural river catchments across entire nations. The results emphasize the importance of adequate management actions in both the entire catchment and riparian areas. In this context, this paper highlights that small streams will specifically benefit from the protection and restoration of their forested buffer zones, whereas overall catchment land use may override the role of forested zones in large rivers. Thus, protecting and restoring headwater riparian zones are likely to have advantages for ecological quality further downstream as well. Because land-use intensification is an ongoing trend, there is a strong need to restore and protect freshwater ecosystems and organisms in agricultural landscapes (e.g., Stoate et al. 2009; Hill et al. 2019). Therefore, the positive independent effect that forested buffer zones can have on river ecological status is an important message to environmental managers and policy makers.

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Author Contribution All authors contributed to the study conception and design. Material preparation and data collection were performed by Mikko Tolkkinen, Saku Vaarala and Jukka Aroviita. Analysis were performed by Mikko Tolkkinen, and Jukka Aroviita. The first draft of the manuscript was written by Mikko Tolkkinen. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability Data are available at the public database (https://www.syke.fi/en-US/Open_information).

Code Availability All analyses were made by open software R.

Declarations

Ethics Approval Not applicable.

Consent to Participate Authors give their permission.

Consent to Publish Authors give their permission.

Competing Interests The authors declare no conflicts of interest.

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