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PERSPECTIVE

Protecting our streams by defining measurable targets for riparian management in a forestry context

Lenka Kuglerová[1] | Timo Muotka[2] | Darshanaa Chellaiah[1,3] | Jussi Jyväsjärvi[2] | John S. Richardson[4]

[1]Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, Umeå, Sweden

[2]Ecology and Genetics Research Unit, University of Oulu, Oulu, Finland

[3]School of Science, Technology and Engineering and Centre for Bioinnovation, University of the Sunshine Coast, Maroochydore, Queensland, Australia

[4]Department of Forest and Conservation Sciences, University of British Columbia, Vancouver, British Columbia, Canada

Correspondence
Lenka Kuglerová
Email: lenka.kuglerova@slu.se

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Abstract

1. Generally, governments and industry have implemented some degree of protection to reduce the impacts of forestry on aquatic ecosystems. Here, we consider the widespread application of streamside management in terms of riparian buffer retention to protect freshwaters from forestry practices across three jurisdictions with large and intensive forestry sectors (British Columbia, Finland and Sweden).
2. This perspective was developed by working with researchers, practitioners and policymakers on mitigation measures to decrease the impacts of forestry on streams. We demonstrate that it is exceedingly rare for policies and guidelines to specify concrete objectives and measurable targets that can be assessed against riparian buffer management outcomes. Most often, policy objectives for riparian management prescribe 'to prevent or mitigate impacts', and this vagueness is insufficient to protect our waters. We argue that we should be clearer about the targets (outcomes) for riparian management and go beyond the simple idea that buffer presence, without further specification of its conditions, is always a successful protection strategy. One cannot measure the effectiveness of rules and guidelines without quantitative targets.
3. *Policy implications*: In this paper, we suggest that locally developed and adjusted targets for riparian buffers must include quantifiable, measurable goals that specify what is supposed to be achieved and protected with respect to ecological functions, biological communities or other values. It should be relatively simple to move from current vague objectives such as 'protect and prevent' to a defined range of values for ecological parameters that buffers are supposed to provide. For example, these can include region-specific shading levels and microclimate targets, large wood volumes, or riparian forest species composition. We stress that these targets must be developed through an open dialogue between agencies, practitioners, land owners and scientists. We acknowledge that there are trade-offs between being too prescriptive and too vague. However, when excessively broad goals are the norm, we lose the capacity to effectively implement, monitor or evaluate the outcomes of protection measures.

KEYWORDS
conservation, forestry, freshwater, resource management, riparian buffer, targets

1 | INTRODUCTION

Forest harvest around streams can negatively affect aquatic and riparian ecosystems. It increases light reaching water surfaces, thereby raising summer temperatures and intensifying temperature fluctuation (Oldén, Peura, et al., 2019; Warren et al., 2016). Streamside harvest also changes rates of terrestrial inputs (Kiffney & Richardson, 2010), increases sediment transport (Kreutzweiser et al., 2009), causes short-term increases in stream flow (Moore & Wondzell, 2005) and alters solute concentrations (Kreutzweiser et al., 2008). These physicochemical changes usually manifest through the entire food web with negative effects on local biota, including decreases in diversity and abundance of sensitive organisms and/or increases in dominance of few tolerant species, and decreased rates of processing of organic matter (Erdozain et al., 2022; Johnson & Almlöf, 2016; Kiffney et al., 2003).

The application of riparian buffers, that is, strips of retained forest along streams, where operations are limited, is by far the most common practice to mitigate forestry effects on streams (Richardson et al., 2012). It is assumed that retaining riparian buffers will protect aquatic conditions by regulating energy exchanges between terrestrial and aquatic systems (Kiffney & Richardson, 2010; Tolkkinen et al., 2020) through several biological, physical and chemical processes (Figure 1). Yet, how effectively buffers protect aquatic conditions is variable, based on the climate, geology, riparian forest composition, local environmental conditions and harvesting practices (Richardson & Béraud, 2014). However, those conditions are rarely considered when buffers are being implemented and a general rule to 'leave a buffer' without further specification has become a common practice (Richardson et al., 2012).

In this paper, we demonstrate a frequent lack of clear objectives and measurable targets for riparian buffers and argue that this causes insufficient protection of streams. We suggest that ecosystem functions must be directly tied to riparian management objectives to ensure adequate protection. We draw on our experience working on riparian buffers with other researchers, managers, practitioners and policymakers in Canada (the province of British Columbia—BC), Finland and Sweden (e.g. Hasselquist et al., 2021; Jyväsjärvi et al., 2020; Kuglerová et al., 2020; Rajakallio et al., 2021; Richardson et al., 2012; Richardson & Béraud, 2014), but our conclusions are likely applicable to other forestry jurisdictions. We write this perspective to highlight that a dialogue among policymakers, managers and scientists is urgent to identify key priorities and actions aimed at improving local best-management-practices for freshwater and riparian protection.

2 | OBJECTIVES OF RIPARIAN MANAGEMENT

Ecosystem functions provided by streams, including water flow regulation and filtration, nutrient cycling, habitat provision, biodiversity and carbon storage and cycling, directly result in important ecosystem services (Hanna et al., 2018). It is well-recognized that stream ecosystem functions are dependent on their riparian areas (Tolkkinen et al., 2020; Figure 1). This is why governments, forestry industry and certifying bodies generally implement some degree of riparian protection (see Table S1 in Supporting Information), and their policies are a function of tradeoffs between timber value (or fibre demand) versus protection of freshwater ecosystems and water security (Richardson et al., 2012). This is because streams and rivers are recognized in national and international legislations as assets that need to be protected (e.g. EU Water Framework Directive, US Clean Water Act). However, riparian areas do not obtain the same level of recognition (Urbanič et al., 2022) and are typically used only as one of the tools to achieve goals for waters. Consequently, objectives in policy documents for riparian buffer application in forestry are regularly stated as leaving a riparian buffer to 'protect', 'mitigate change' or 'minimize impact' on streams (Table S1). It is unclear how to meet those goals without clearly specified actions that can be implement within the riparian zone itself. One cannot measure the effectiveness or efficiency of rules and guidelines without specific measurable (quantitative) environmental targets (Biddle & Koontz, 2014; Hughes et al., 2023).

3 | CURRENT TARGETS

A scan of governmental documents that outline guidelines for riparian buffers across the three jurisdictions shows the shortcomings of their objectives (Table S1). British Columbia, Canada, applies a 'results-based regime', stating that no practice should be carried out that 'results in damage to the environment' (unless authorized, British Columbia Ministry of Forests, 2022). The words 'no damage' would seem to mean minimal change, but in practice industry is not held to such standards because no thresholds for 'damage to the environment' are quantified. For instance, Kuglerová et al. (2020) showed that 45% of streams had no riparian trees retained in a survey of 80 headwaters across BC (Figure 2). While harvesting all trees along the smallest streams is technically allowed in BC (Table S1), the absence of riparian buffers has been directly linked to dramatic changes in, for example, light and temperature leading to large shifts in the aquatic community (Kiffney et al., 2003). In Finland, the current Forest Act (Ministry of Agriculutre and Forestry, Finland, 1993) forbids all practices that change the key features, defined as 'growing conditions' or 'microclimate', of natural or

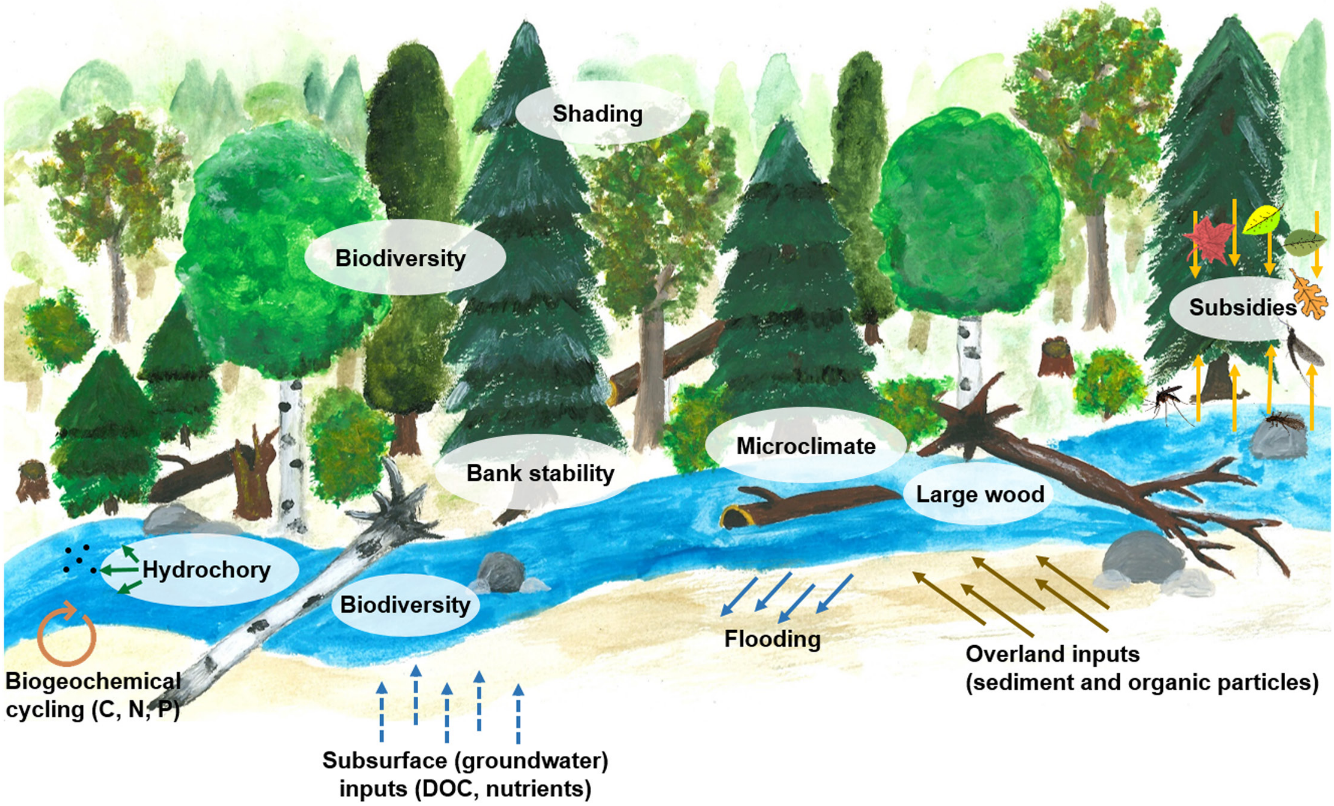

FIGURE 1 Main functions and processes maintained by properly functioning riparian forests and streams. Riparian forests and headwater streams contribute to local and regional *biodiversity*. Riparian forests provide *organic matter inputs* (*subsidies*) to streams in the form of leaf litter and falling insects, and streams provide subsidies to riparian zone in the form of emerging aquatic insects. Trees provide *shade*, *stabilize* stream banks and contribute *large wood*. Riparian vegetation also *filters* material (sediment, nutrients and carbon) delivered by *subsurface flow* (groundwater) and *overland flow*. Streams provide physical disturbance to riparian zones during *floods*, redistribute nutrients and sediments, and assist dispersal (*hydrochory*). Illustration by L. Kuglerová.

nearly natural riparian forests (Table S1). Yet, no further specifications for how to ensure that microclimate or growing conditions are optimally protected are suggested, let alone measured. In Sweden, targets are suggested by the Swedish Forest Agency as six ecological functions that are important to maintain by well-functioning buffers (Table S1): (1) preserve soil biogeochemical processes, (2) provide large wood, (3) maintain biodiversity, (4) provide subsidies to aquatic organisms, (5) maintain shading and (6) prevent sediment transport (Chellaiah & Kuglerová, 2021). At first sight, these go beyond non-specific criteria as they clearly centre on ecological functions of the riparian vegetation. However, if these ecological functions should really result in no harm to waters, one also needs to articulate concrete thresholds or ranges of values for 'preserve' or 'provide' (Figure 2). A survey of 111 small streams in Sweden showed that riparian buffers were on average <5 m wide (Kuglerová et al., 2020), and such buffers, while not against the rules, 'preserve' or 'provide' very little (Chellaiah & Kuglerová, 2021), ratifying that in the absence of targets that can be measured, the evaluation for efficacy of riparian protection remains ambiguous.

All the three countries have further guidelines for riparian management specified in certification programs, as well as in organization-specific documents (Table S1). Those programmes, while based on voluntary participation, have to comply with governmental standards, but some offer further specificity. For example, the Finnish FSC (Forest Stewardship Council, 2010) certification requires retention of at least 15-m wide, intact buffers on FSC-certified forests while no width is specified in the Forestry Act. However, since the objective is to leave a 15 m buffer, protection can be deemed successful each time 15 m of forest around a stream is retained. The obvious shortcoming here is that riparian buffer width represents only a proxy for functionality. Recent work has shown that the relationship between buffer width and biodiversity, sediment transport, temperature, primary production and/or large wood is not linear and sometimes does not exist at all (Chellaiah & Kuglerová, 2021; Jyväsjärvi et al., 2020; Marker et al., 2022) because habitat quality often matters more than habitat quantity. It seems that the research community has not successfully articulated those scientific advances to stakeholders (Rodríguez-González et al., 2022).

4 | WAYS FORWARD

Others have suggested that riparian forests with their unique vegetation must be awarded a separate status at all levels of decision-making in water resource management (Rodríguez-González

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FIGURE 2 Objectives for stream and riparian protection. On the left in green arrows are examples of quantitative targets that can be assessed leading to functional buffers that protect microclimate, provide diverse shading, have diverse species composition, and large wood (indicated by the photographs to the left). Note these are examples only and not official targets in any forest management scheme. On the right, in red are some examples of outcomes that are not measureable or enforceable, but that are typical for contemporary management. These practices can be deemed successful if evaluated against current buffer management objectives, but that are likely failing to adequately protect streams and riparian habitats. Typical example from Sweden (upper right photograph) shows very narrow buffer (<5 m wide) that is likely providing all listed ecological functions because their thresholds are not specified. Yet, from an ecological perspective, this buffer is not fully functional as it has been shown that such narrow buffers do not protect streams. In BC (lower right photograph), small streams that are not fish bearing do not require a treed riparian buffer. As such, the conditions in the photograph are not against the rules, yet absence of a treed buffer provides very little ecological functions.

et al., 2022; Urbanič et al., 2022). Our suggestions for ways forward lean heavily on this idea, but we further advocate for the development of specific and measurable targets for riparian forests. Below, we introduce four examples of how targets can be set so that they directly relate to riparian buffer objectives that aim to protect waters (Figure 2). We have chosen targets that are possible to implement within the riparian area and importantly are relatively easy to manipulate during operations. We further present some criteria on how these targets can be adapted based on local conditions (Table 1). We fully appreciate that the specific targets must be considered at different spatial and temporal scales and that averages can be met across larger scales, for example, within catchments.

4.1 | Microclimate target

While it might not be possible to monitor all local biological communities to 'protect' biodiversity, it should be fairly straightforward to monitor the environment that the organisms require. For example, Oldén, Selonen, et al. (2019) documented the importance of sustaining specific riparian microclimate (temperature and humidity) for bryophyte diversity during and after forest harvest. In an effort to contribute to evidence-based management, they also investigated how microclimate changes with different buffer configurations (Oldén, Peura, et al., 2019). This existing scientific evidence can be directly implemented in management. That is, if the aim for riparian buffer is to 'preserve' biodiversity at a particular location (e.g. where bryophyte diversity is known to be high), then specific targets for humidity and temperature can be set (and monitored). While one can argue that microclimatic variables are inherently dynamic in time and hard to use as baselines, temperature targets are implemented in some jurisdictions in forestry (e.g., maximum of 0.3°C increase in water temperature above pre-impact levels in Washington State, USA, Washington Department of Ecology, 2003). As long as they are measured over time according to standardized methods, microclimate variables can be used to support environmental policymaking (Hylander et al., 2022). Such a strategy would allow us to implement adaptive, site-specific management and take further actions if the physicochemical templates are not met.

TABLE 1 Examples of how targets can be locally adjusted based on site-specific conditions.

Site-specific parameters	Objective	Specific refinement of targets
Stream size (order/width)	Shading, microclimate	Larger streams have more open canopies compared with small headwaters. Shading targets should be refined by stream size to consider existing light levels and microclimate that organisms are exposed to
	Biodiversity (riparian forest)	Larger streams are associated with higher vegetation (tree) diversity in the riparian zone. Targets for riparian tree species composition should be directed at smaller streams with single-species riparian forests
	Large wood	LW function in streams is determined by stream size (magnitude of flow). Larger streams have a capacity to move LW objects, while LW in small headwaters is more stable. LW targets should be evaluated against flow metrics
Stream geomorphology	Shading	Incised channels are naturally shaded. Shading targets should be more directed to streams with shallow/braided channels
	Large wood	Higher LW target for streams lacking LW
Riparian slope/aspect	LW	Steep slopes are less stable and might provide LW naturally. Target for LW should aim to sites with flat topography (and low volumes of LW)
	Shading, microclimate	The orientation of the banks determines sun exposure. Southern sloping banks are more susceptible to changes in microclimate due to higher light exposure and should consider higher shading targets
Riparian forest composition	Biodiversity	Mixed forests are preferred in riparian zones to increase heterogeneity and enhance ecosystem functions. Targets for long-term recruitment of deciduous trees into the riparian forests should be outlined for single-species (coniferous) sites
Upstream conditions	Microclimate	Catchments with high proportion of clearcuts exhibit larger changes in water temperature. Higher shading and more stringent microclimate targets to prevent cumulative effects should be directed at sites situated in heavily managed catchments

4.2 | Large wood (LW) target

Large wood serves multiple functions in riparian-stream ecosystems: wood (i) reduces water flow and diverts part of it into the riparian forest, (ii) retains sediments, nutrients and organic matter, (iii) diversifies habitats and (iv) enhances biodiversity on land and water (Martens et al., 2020). In managed forests, most LW enters the streams soon after harvest, with less recruitment during the rest of the rotation (Kuglerová et al., 2023). Thus, LW may limit stream fish biomass and biodiversity in streams, as well as riparian organisms that utilize wood as substrate in second-growth forests, for more than 200 years (Hylander et al., 2005; Johnson & Almlöf, 2016; Martens et al., 2020). The addition of LW may therefore be needed to expedite the recovery of the stream ecosystem from logging and is increasingly used in stream restoration to enhance fish production and/or biodiversity, usually with at least some (and often great) success (e.g. Foote et al., 2020; Turunen et al., 2017). On the terrestrial side, some forest certificates have set clear targets for a minimum number of retained trees to continuously supply LW (10 trees/hectare of clear-cut in FSC Sweden and Finland). Similarly stringent post-harvest targets could be imposed also for stream and riparian ecosystems, aiming at, for example, an average volume or pieces of LW per stream length and/or riparian area (Figure 2). Forest managers then could make a local assessment whether the target is possible to achieve through natural LW recruitment from riparian buffers (Kuglerová et al., 2023, Table 1) or whether harvesting and adding logs is necessary, a practice that is being tested in Washington State (Martens et al., 2021). Such evaluations should also target long-term consequences, that is, how persistent and functional such structures will be decades after the initial placement (Marttila et al., 2016).

4.3 | Forest composition target

Another example of a specific target that can be set by managers and is directly related to ecosystem functions and biodiversity is the tree species composition of the riparian buffer. In many production forestry systems in the northern hemisphere, commercial trees grow all the way to the stream edges, while competing species that are native but not commercially valuable have been suppressed (Hasselquist et al., 2021). The dominance of crop trees in riparian zones largely affects the decomposition of organic matter, detrital-based food webs and nutrient cycling (Gessner et al., 2010; Kiffney & Richardson, 2010). Furthermore, mixed stands have been associated with higher diversity of understory vegetation as well as enhancement of soil carbon storage and biomass production (Gamfeldt et al., 2013), aspects that are expected from riparian zones. Mixed stands are also likely more resilient to climate change (Neuner et al., 2015). In recent years, the need for increasing diversity of riparian trees has been recognized by the scientific community (e.g. Hasselquist et al., 2021) and is even starting to be implemented into some management guidelines (Ring et al., 2017). In Sweden, both

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national policies and industry-specific guidelines recommend a conversion of riparian forests from spruce-dominated to mixed or deciduous-dominated stands (Table S1). A disadvantage of this recommendation is that in reality deciduous dominance is being created by harvesting most or all coniferous trees, leaving only a few sparse deciduous trees as the buffer (Figure 2). Thus, targets that specify tree species composition (e.g. deciduous vs. coniferous), as well as densities and ages, should avoid situations where deciduous dominance leads to essentially no buffer. Furthermore, this should also allow consideration of future conditions for the riparian forest, including climate change, as the forest ages (Pollock et al., 2012).

4.4 | Shading target

A final example where local quantification and specific targets are easily achievable is shading (Figure 2). Retention of riparian vegetation largely aims to sustain sufficient shading to regulate the warming of surface waters by direct radiation (Tolkkinen et al., 2020; Warren et al., 2016). On the contrary, intensive management of forests close to streams has suppressed natural dynamics and has been argued to cause too little light entering the riparian-stream ecosystems (Chellaiah & Kuglerová, 2021; Hasselquist et al., 2021). The establishment of small canopy gaps in conifer-dominated buffers has been suggested to mimic old-growth forest conditions and consequently increase aquatic primary production and regeneration of deciduous trees, and to create more overall heterogeneity along streams and their riparian corridors (Hasselquist et al., 2021; Kreutzweiser et al., 2012; Swartz et al., 2020). Thus, some range of shading allowing for small canopy gaps can be easily implemented as long as raising of water temperature is prevented (Swartz et al., 2020). The Swedish guidelines recommend maintaining shade of 50%–70% over the stream channel after harvest, which seems to be the only example of a specific and science-based target (Table S1).

5 | IMPLEMENTATION

Within jurisdictions, clearer objectives and specific targets must be implemented at governmental and agency levels responsible for safeguarding sustainable management of our natural resources (Figure 3). The three countries discussed here already list several objectives for riparian buffers in their guidelines (Table S1), but they have to be refined to change from 'preserve' or 'prevent' to more quantitative targets that matches desired outcomes (Figure 2). We highlight the need to develop such refinements through an open dialogue among multiple stakeholders, including agencies, forest owners, industry and researchers (Biddle & Koontz, 2014). But of course, having guiding standards in high-level policy instruments (e.g. EU WFD, EU green deal, UN Convention on Biological Diversity) with specific riparian zone-related regulations (e.g. Urbanič et al., 2022) would not be in conflict with our proposition and, in fact, would implement a necessary degree of prescriptiveness. Certification programmes should also implement more specific criteria, although

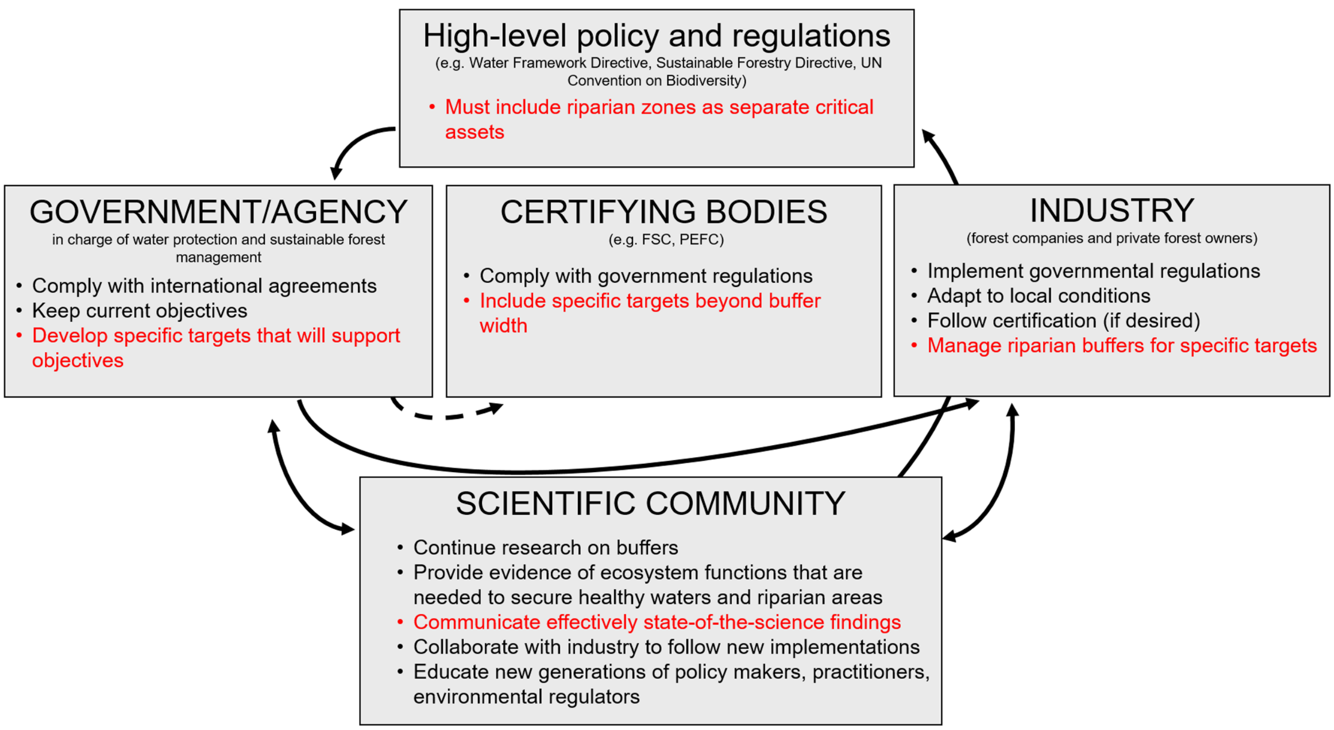

FIGURE 3 Implementation strategy of riparian management solutions proposed in this paper. The black text indicates practices that are already in place, while the red text indicates strategies that have to change or be implemented. Arrows indicate direct (full) and indirect (dashed) dependence of different stakeholders that must be included in co-development of evidence-based riparian buffer management.

their goals and prescriptiveness are not necessarily the same as of agencies (Villalobos et al., 2018). Certification offers an economic incentive that governments have not been able to provide and thus can likely achieve goals more efficiently. Finally, the biggest responsibility will be on the industry to implement actions (Figure 3). So far, retention of riparian buffers has been the primary tool used to meet environmental objectives, and as such industry has generally succeeded in its broad implementation (Kuglerová et al., 2020). Once the presence of a buffer changes to quantifiable targets through governmental regulations, the industry can shift to implement specific actions into forest management plans, as they have done many times before (Hasselquist et al., 2020; Villalobos et al., 2018).

Finally, we need to develop effective monitoring programmes and assign responsible actors that can evaluate the effectiveness of the new strategies. Despite the relatively low cost of monitoring compared with ecosystem services' benefits from environmental protection, monitoring is often neglected as it requires funding and long-term efforts by qualified staff (Lovett et al., 2007). Guideline-compliant (cf. WFD) assessment of the ecological status of forested streams would be needed to improve systematic monitoring and coherent assessment of the impacts of different human interventions. The recent development and availability of low-cost sensors, air-borne applications (e.g. LiDAR) and eDNA methods (e.g. Seymour et al., 2021) will hopefully help to overcome the difficulties with long-term monitoring. Sustainable forestry is a long-term endeavour and many political, societal and climate-related changes happen within one rotation cycle. Establishing long-term monitoring data sets of ecological responses is the only way to aid in the development of management programmes to efficiently guide future management decisions. We are hopeful that synergies between already existing monitoring programs for both water and forests, including forest certification schemes, can be found with the new solutions proposed in our paper.

AUTHOR CONTRIBUTIONS

John S. Richardson, Lenka Kuglerová and Timo Muotka conceived the ideas and the original concepts, with considerable inputs from Jussi Jyväsjärvi and Darshanaa Chellaiah. Lenka Kuglerová led the writing of the manuscript and all co-authors contributed equally to finalizing the ideas, reviewing literature and summarizing local policies and management strategies in their respective countries. All authors gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

This article does not use data.

ORCID

Lenka Kuglerová https://orcid.org/0000-0003-3896-8466
Darshanaa Chellaiah https://orcid.org/0000-0002-5303-4541
Jussi Jyväsjärvi https://orcid.org/0000-0003-3886-7024
John S. Richardson https://orcid.org/0000-0001-8135-7447

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. An overview of different policies and guidelines for riparian buffers in forestry land-use in Canada, Finland and Sweden. In Canada, the province of British Columbia is used in this example because guidelines are set by provinces and territories individually.

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