

Article

Forested Riparian Zones Provide Important Habitat for Fish in Urban Streams

Benjamin Kupilas^{1,2*}, Francis J. Burdon³, Jens Thaulow¹, Johnny Häll¹, Petra Thea Mutinova¹, Marie Anne Eurie Forio⁴, Felix Witing⁵, Geta Rîșnoveanu^{6,7}, Peter Goethals⁴, Brendan G. McKie³ and Nikolai Friberg^{1,8,9}

Supplementary Materials

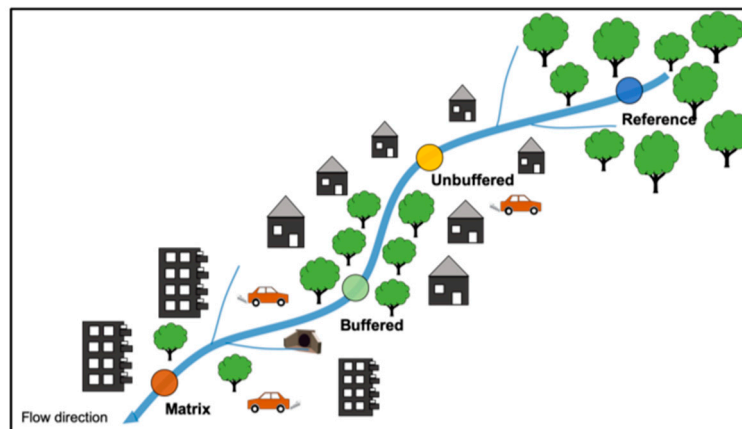


Figure S1. Experimental design in the Oslo Fjord Basin with pristine or least-impacted 'Reference' sites (blue), site pairs with an 'Unbuffered' upstream site (orange) and a downstream 'Buffered' site (green) with a woody riparian buffer on both banks, and 'Longitudinal' sites (red) that were typically located further downstream from the other site types to capture cumulative land use impacts with different configurations of the riparian zones.

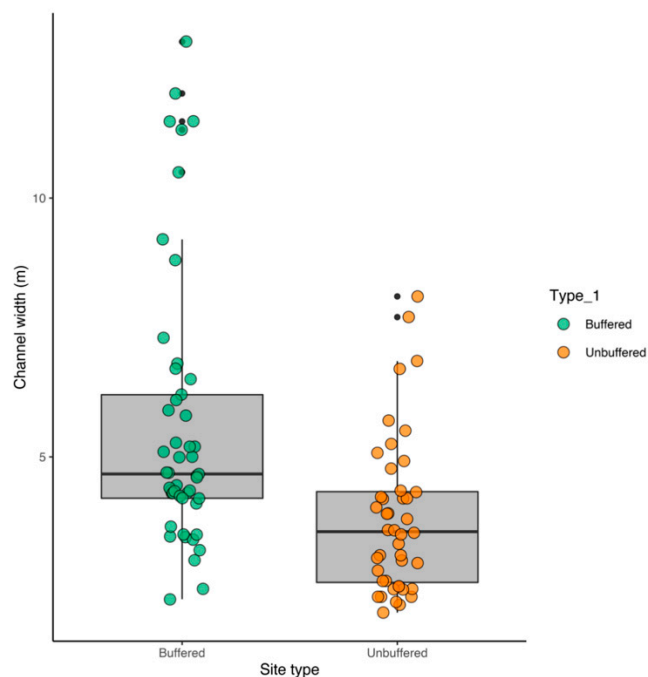


Figure S2. Wetted channel widths from transect measurements at buffered and unbuffered sites in the Oslo Fjord Basin.

Table S1. Description of scores for riparian attributes used to calculate the Riparian Condition Index (after Burdon et al. [1]).

Attributes		Scores 1	Scores 2	Scores 3	Scores 4	Scores 5
Shading of water		Little or no shading	10–25% shading	25–50%	50–80%	>80%
Buffer width		<1 m	1–5 m	5–15 m	15–30 m	>30 m
Buffer intactness		Buffer absent	50–99% gaps	20–50% gaps	1–20% gaps	Completely intact
Vegetation comp. of buffer and/or adjacent land to 30 m from stream-bank	Buffer					
	Adjacent land	Short, grazed pasture grasses to stream edge, or impervious surfaces	Invasive weedy shrubs gorse, blackberry, broom, or mainly high grasses or low shrubs 0.3–2 m	Deciduous tree dominated; small tree dom. (2–5 m); or forest plantation with <25% cover of >5 m trees; or natural grassy veg.	Regenerating forest or woodlot evergreens with >25% cover sub-canopy (>5 m) trees but <10% canopy trees (>12 m); or natural grassy veg.	Maturing forest including >10% cover canopy trees (>12 m); or natural wetland or natural grassy vegetation
Bank stability		Very low: uncohesive sediments & few roots & >40% recently eroded	Low: uncohesive sediments & few roots/low veg. cover & >15–40% recently eroded	Moderate: stabilized by geology (e.g. cobbles), veg cover &/or roots & >5–15% recently eroded	High: stabilized by geology (e.g. bedrock), veg. cover &/or roots; & 1–5% recently eroded	Very high: stabilized by geology (e.g. bedrock), veg. cover &/or roots; <1% recently eroded
Livestock access		High: unfenced and unmanaged with active livestock use	Moderate: some livestock access	Limited: unfenced but low stocking, bridges, troughs, natural deterrents	Very limited: temporary fencing of all livestock or naturally very limited access	None: permanent fencing or no livestock
Riparian soil denitrification potential		Soils dry/firm underfoot or moist-wet but frequent tile drains bypass riparian soils (≥3 per 100 m)	1–30% streambank soils moist but firm or moist-wet with infrequent bypass drains (1–2 per 100 m)	≥30% streambank soils moist but firm underfoot. No drains.	1–30% streambank soils water-logged, soft underfoot with black soil. No drains.	≥30% of streambanks water-logged, surface moist/fluid underfoot. No drains.
Land slope 0–30 m from stream bank		>35°	>20–35°	>10–20°	>5–10°	0–5°
Groundcover of buffer and/or adjacent land to 30 m from stream-bank	Buffer					
	Adjacent land	Bare	Short/regularly grazed pasture (<3 cm)	Pasture grass/tussock with bare flow paths or 2–3 cm tree litter layer	Moderate density grass or dense (>3 cm) tree litter layer	High density long grass
Soil drainage		Impervious (e.g. sealed) or extensively pugged and/or compacted soil	Low permeability (e.g. high clay content) or moderately pugged/compacted soil	Low-moderate permeability (e.g. silt/loam) and not pugged/compacted	Mod-high permeability (e.g. sandy loam) & not pugged/compacted	Very high permeability (e.g. pumice/sand) & not pugged/compacted
Rills/channels		Frequent rills (> 9 per 100 m) or larger channels carry most runoff	Common rills (4–9 per 100 m) or 1–2 larger channels carry some runoff	Infrequent rills (2–3 per 100 m) and no larger channels	Rare rills (1 per 100 m) and no larger channels	None

Table S2. Information about buffered/unbuffered sites including RCI, total number of fish per site, and density calculated per m reach and per m². UBF = unbuffered site, FBF = buffered site, RCI = Riparian Condition Index.

Site Number	Site Type	Stream	RCI	Total Number Fish	Density (m Reach)	Density (m2)
6	UBF	Alna	31	0	NA	NA
7	FBF	Alna	51	0	NA	NA
8	UBF	Hovinbekken	51	4	0.13	0.05
9	FBF	Hovinbekken	52	42	1.4	0.64
14	UBF	Frognerelva	39	59	1.97	0.74
15	FBF	Frognerelva	51	107	3.57	1.24
18	UBF	Gaustadbekken	32	0	NA	NA
19	FBF	Gaustadbekken	36	0	NA	NA
21	UBF	Skådalsbekken	39	26	0.87	0.37
22	FBF	Skådalsbekken	39.5	30	1	0.69
25	UBF	Midtstubekken	40.5	21	0.70	0.37
26	FBF	Midtstubekken	51	13	0.43	0.14
28	UBF	Makrelbekken	35	0	NA	NA
29	FBF	Makrelbekken	48.5	0	NA	NA
32	UBF	Mærradalsbekken	46.5	104	3.47	3.05
33	FBF	Mærradalsbekken	53.5	157	5.23	2.28
35	UBF	Sandvikselva	33.25	25	0.83	0.18
36	FBF	Sandvikselva	42.5	39	1.30	0.34

Table S3. Variables and loadings for Principal Components Analysis (PCA) decomposing catchment land use and water quality variables into a single index of urbanization for all 30 sites in the Oslo basin. PC1 explained 56.3% of the variation among sites, whereas PC2 explained 16.5%. TIN = Total Inorganic Nitrogen (NH₄ N + Nitrate), NH₄ = Ammonium (NH₄ N), Nitrate = NO₂+NO₃ N, SRP = Soluble reactive phosphate (PO₄ P), TP = Total phosphorous.

Group	Parameter	PC1	PC2
Water quality	pH	0.9	-0.06
	Cond.	1.03	0.25
	TIN	1.1	0.27
	NH ₄	0.84	-0.51
	Nitrate	1.04	0.36
	SRP	1.01	-0.52
	TP	1.04	-0.48
Land use	%Arable	-0.11	-0.89
	%Forest	-1.16	-0.13
	%Natural	-0.43	0.25
	%Other	1.03	-0.05
	%Urban	1.13	0.19
	%Water	-0.26	-1.13

Table S4. Fish species and their abundances from study sites across the Oslo Fjord basin.

Fish species	Abundance
<i>Salmo trutta</i>	1026
<i>Salvelinus fontinalis</i>	56
<i>Phoxinus phoxinus</i>	1
<i>Pleuronectidae</i>	2

Table S5. Results from the Generalised Linear Mixed model testing the relationship between the Riparian Condition Index (RCI) and fish abundances.

Predictors	Fish numbers		
	Incidence Rate Ratios	CI	p
(Intercept)	0.67	0.07–6.75	0.735
RCI	1.05	1.03–1.07	<0.001
Random Effects			
σ^2	0.19		
τ_{00} Site_block	8.58		
ICC	0.98		
N Site_block	9		
Observations	18		
Marginal R ² / Conditional R ²	0.014 / 0.979		

References

1. Burdon, J.F.; Ramberg, E.; Sargac, J.; Forio, A.M.; de Saeyer, N.; Mutinova, T.P.; Moe, F.T.; Pavelescu, O.M.; Dinu, V.; Cazacu, C., et al. Assessing the benefits of forested riparian zones: A qualitative index of riparian integrity is positively associated with ecological status in european streams. *Water* 2020, 12. <https://doi.org/10.3390/w12041178>