Effects of intensive biomass harvesting on forest soils in the Nordic countries and the UK: A meta-analysis

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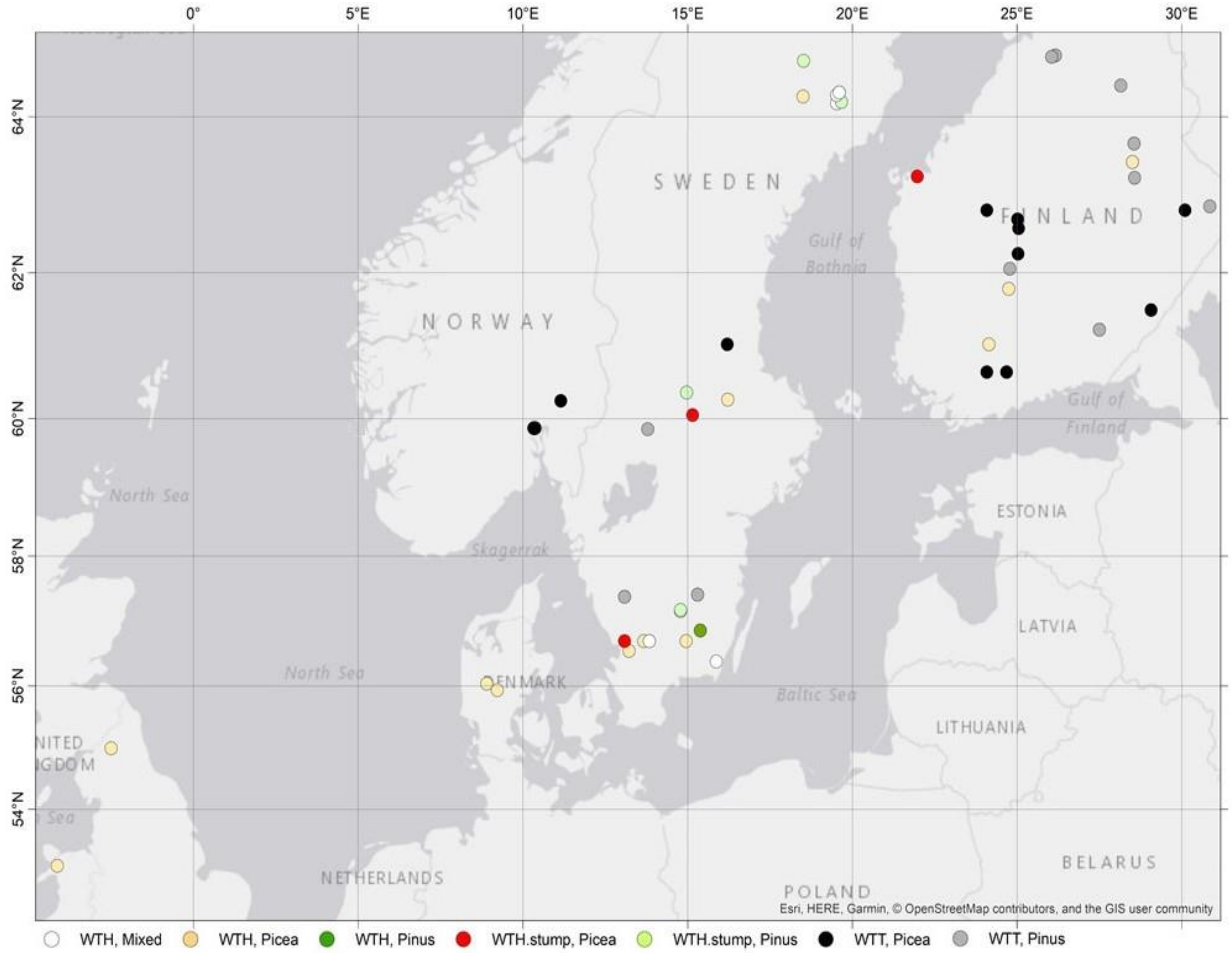
There have been several meta-analyses published on the effects of intensified biomass harvesting in which the scale is worldwide (e.g. Achat et al., 2015a, b; James and Harrison, 2016; Hume et al., 2018; Wan et al. 2018).

However, results obtained on a worldwide scale may not apply to all regions, as there are clear regional differences in factors such as climate and soil types.

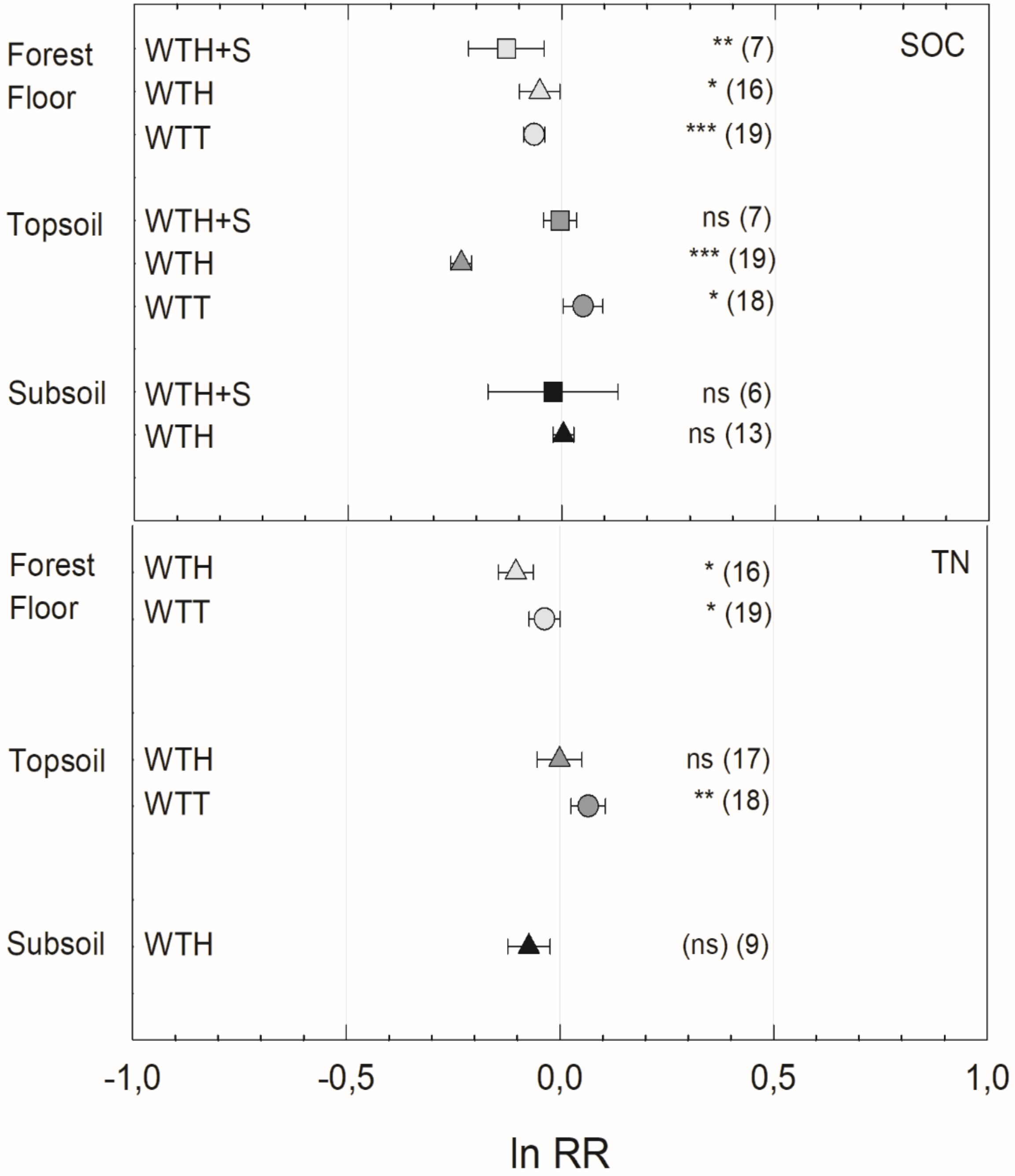
We compiled available data from northern European field experiments on the effects of whole-tree harvesting (WTH) and WTH + stump removal (WTH+S) compared to stem-only harvesting (SOH) on soil organic carbon (SOC), nutrients and further soil chemical properties, and carried out a meta-analysis.



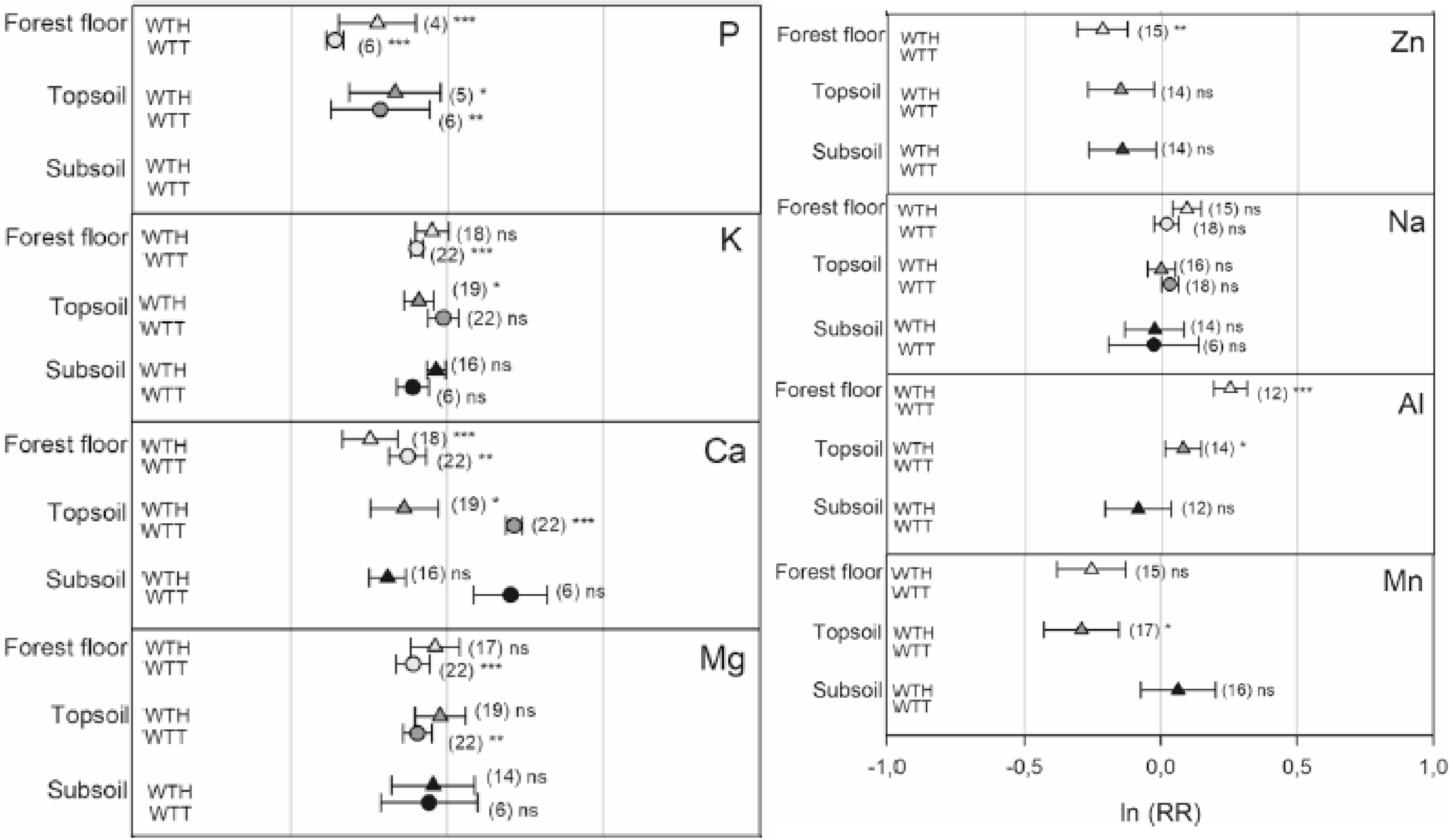
Locations of study sites. Different colours indicate different tree compositions of forest stands and intensive harvest treatments.

Hypotheses:

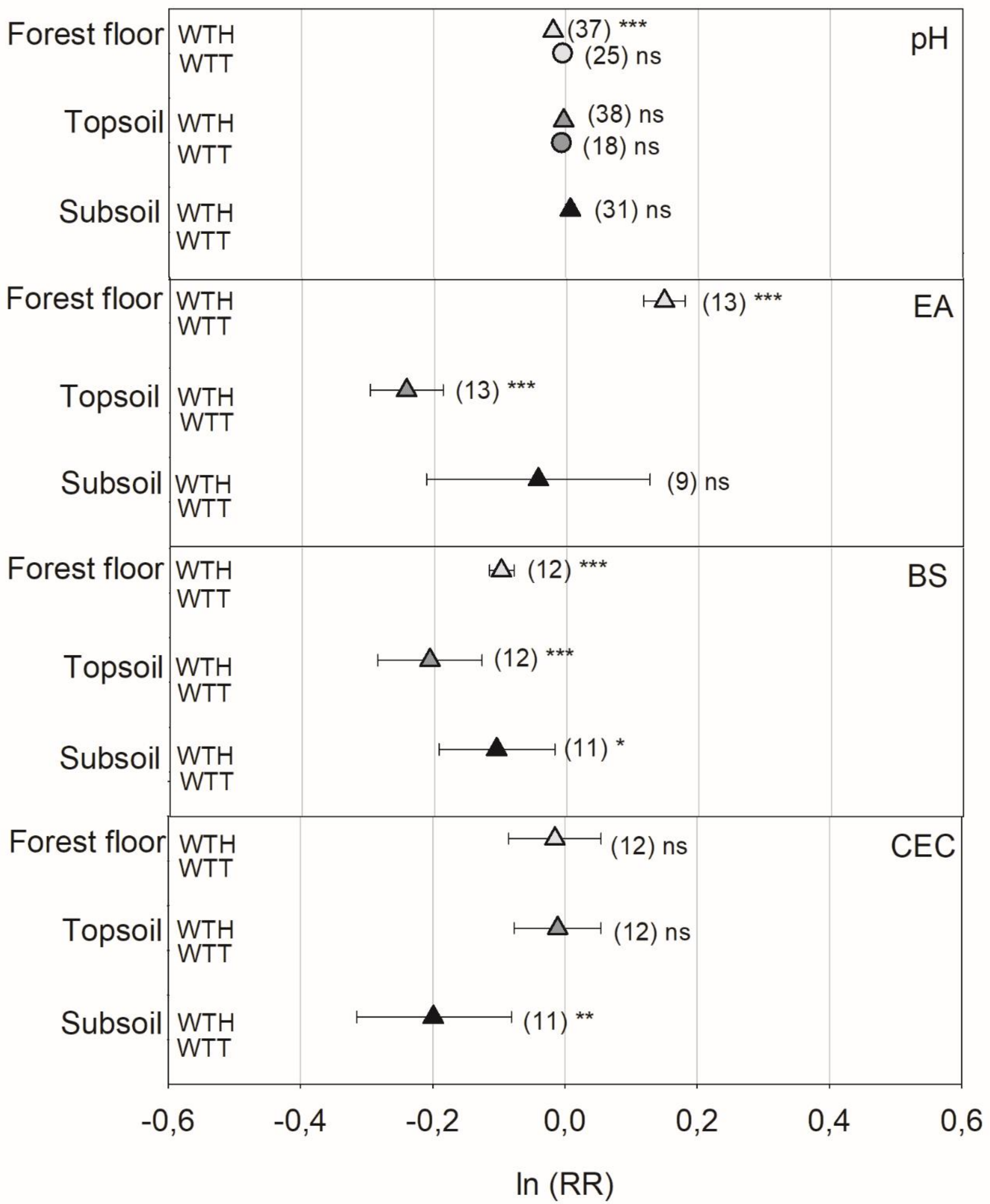
1. Intensive biomass harvesting methods used in northern European forests reduce soil nutrient contents;
2. Intensive biomass harvesting decreases forest SOC stocks which reduces the climate mitigation potential of production forests;
3. The most intensive harvesting methods in terms of the amounts of removed nutrients and C (clear-cut WTH and WTH+S compared to SOH) lead to greater reductions in soil nutrient and SOC stocks than whole-tree thinning (WTT) that is performed as part of forest management during stand development and where only part (<40%) of standing trees is typically removed;
4. Soils under Norway spruce and Scots pine have different sensitivity to the intensity of biomass harvesting;
5. Reductions in soil nutrients and SOC contents after intensive biomass harvesting diminish with time elapsed since harvest.



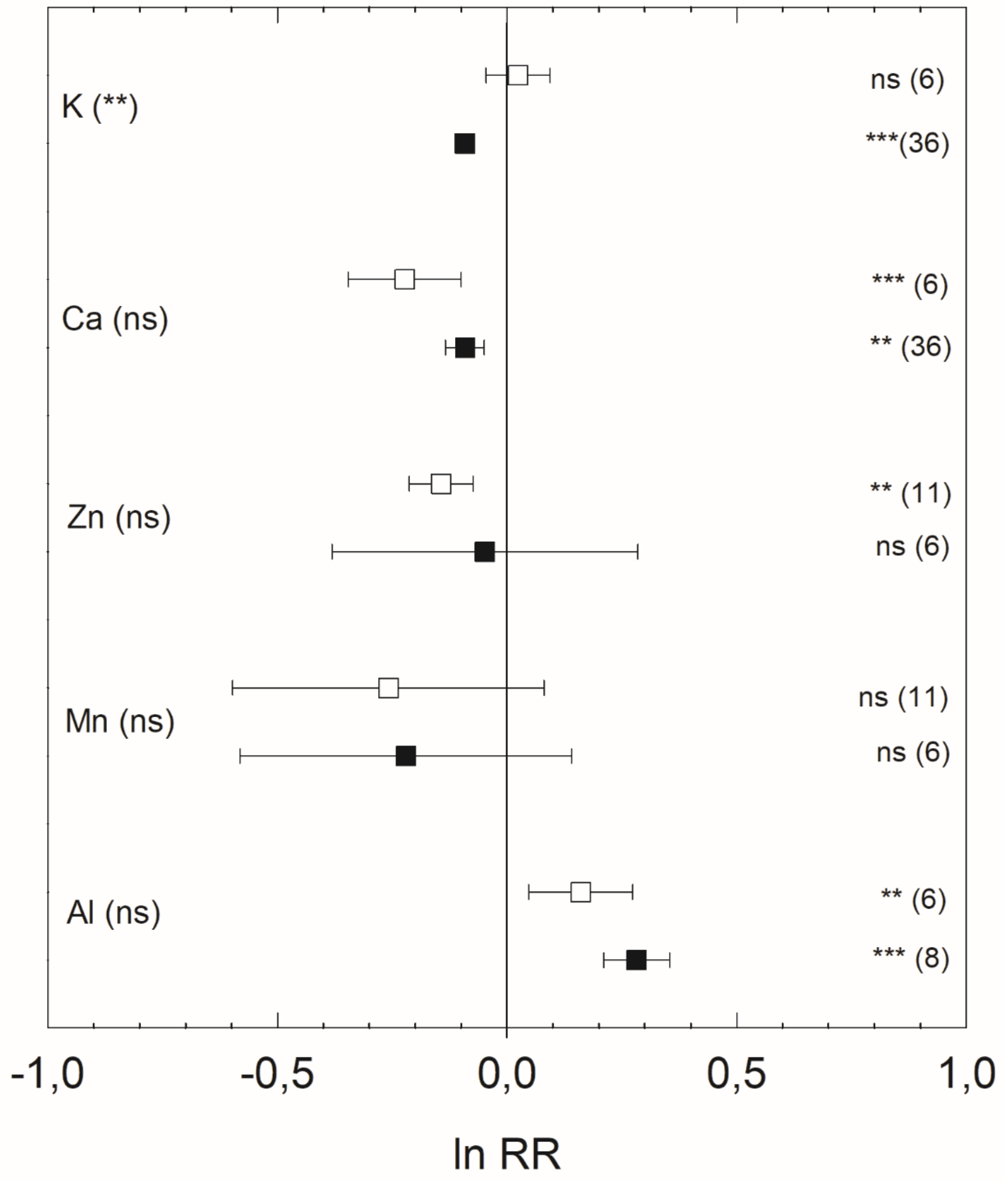
Log-transformed response ratios, ln(RR), of SOC and soil total nitrogen (TN) in the forest floor, topsoil, and subsoil layers following WTT, WTH and WTH+S as compared to conventional stem-only thinning or harvesting (SOH). Enough observations for the WTH+S treatment were only available for SOC. Significance levels are indicated as ns ($P \geq 0.10$), (ns) ($P=0.05-0.10$), * ($P<0.05$), ** ($P<0.01$), *** ($P<0.001$) and number of observations included is shown in parentheses.



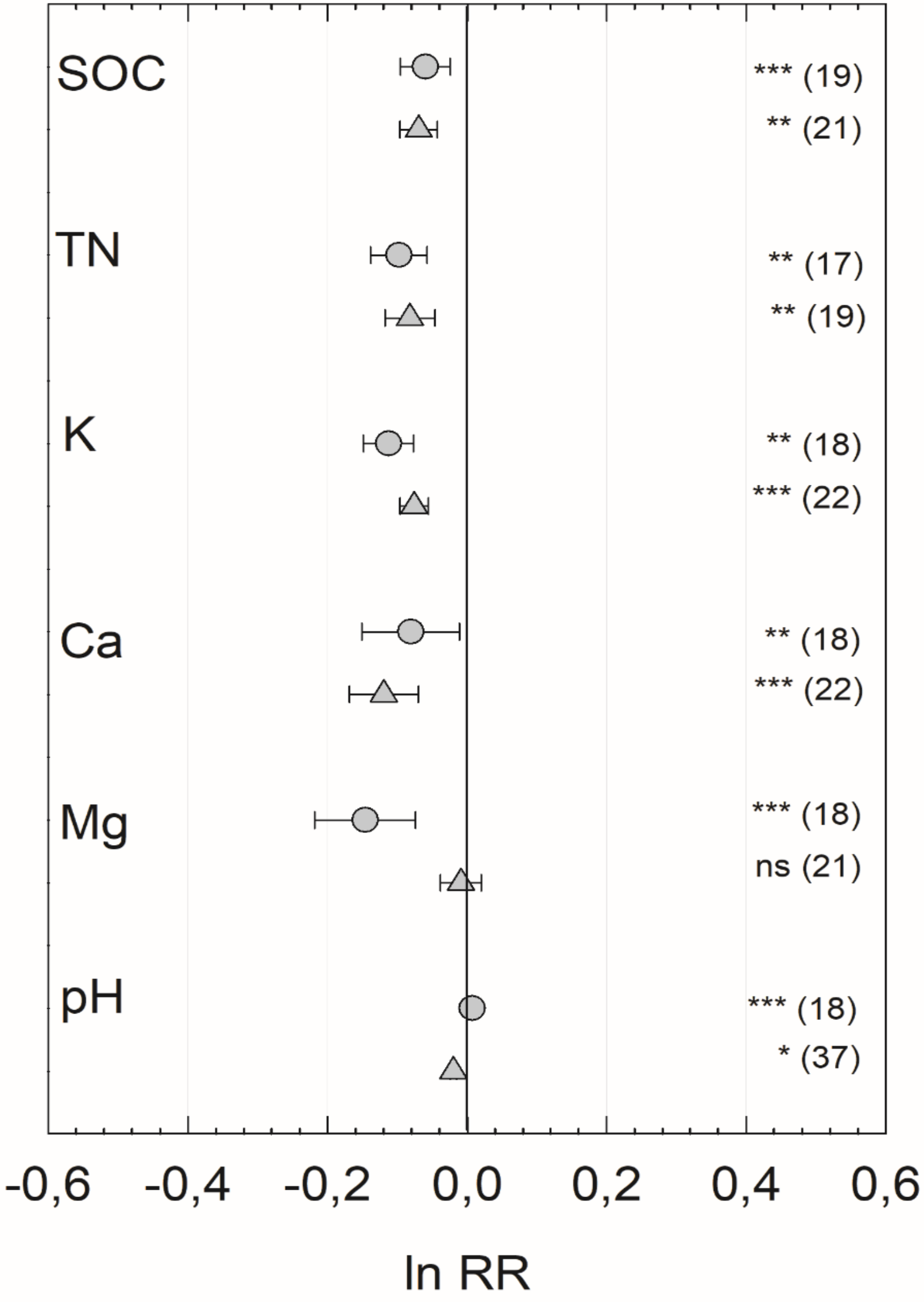
Log-transformed response ratios, ln(RR), of exchangeable nutrients and Al in forest floor, topsoil and subsoil layers following WTT and WTH as compared to SOH. Significance levels are indicated as ns (P≥0.05), * (P<0.05), ** (P<0.01), *** (P<0.001) and number of observations included is shown in parentheses. For P, too few observations were available for analysing in the subsoil. For Zn, Al and Mn, response ratios were only calculated for WTH, as there were too few observations to calculate the effect of the WTT treatment.



Log-transformed response ratios ln(RR) of pH, exchangeable acidity (EA), cation exchange capacity (CEC) and base saturation (BS) in forest floor, topsoil and subsoil layers following WTT and WTH as compared to conventional stem-only thinning or harvesting (SOH). Significance levels are indicated as ns (P≥0.05), * (P<0.05), ** (P<0.01), *** (P<0.001). For EA, BS and CEC there were only enough observations available for testing for the WTH treatment. For pH, enough observations for testing for the subsoil were only available for the WTH treatment.



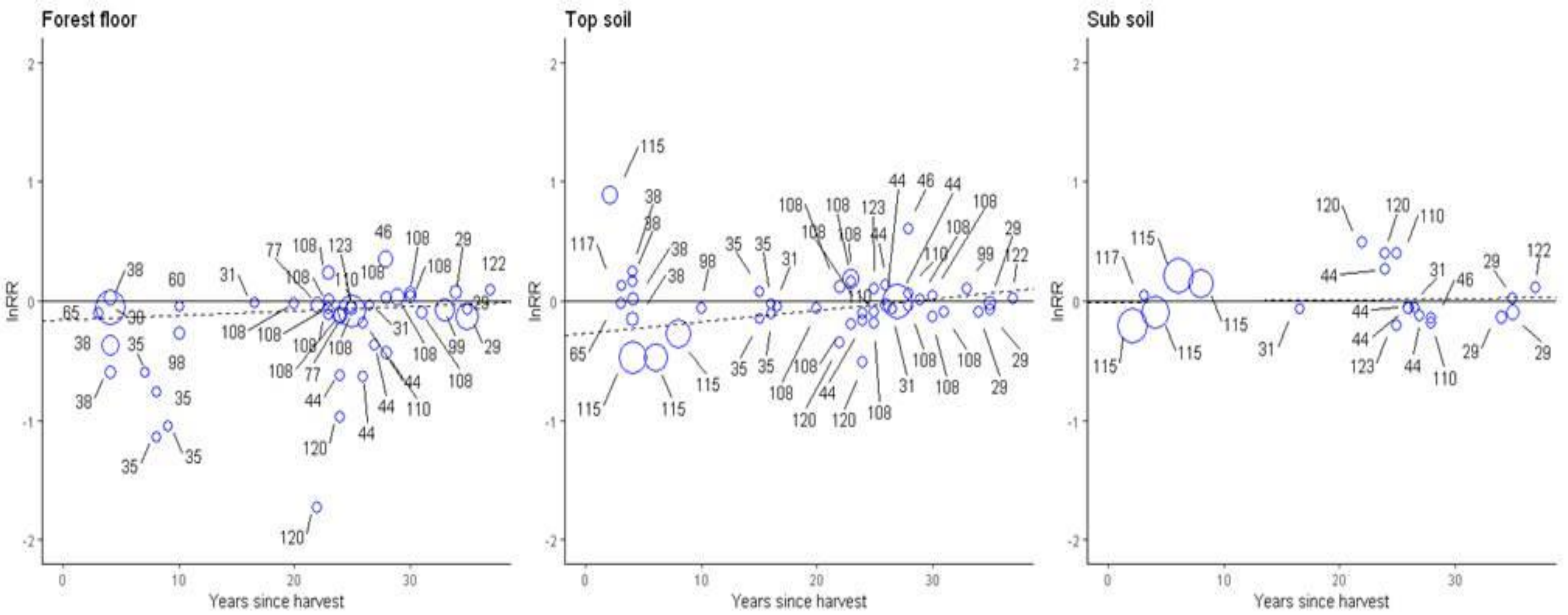
Log-transformed response ratios, ln(RR), of exchangeable nutrients and aluminium in forest floors when expressed in stock units (filled squares) or concentration units (open squares) following WTT, WTH, or WTH+S compared to conventional stem-only thinning or harvesting (SOH). Significance levels for the differences between ln(RR) for the two unit groups are indicated as ns ($P \geq 0.05$), * ($P<0.05$), ** ($P<0.01$), *** ($P<0.001$) to the right of the observation number in parentheses, while significance levels to the left of the observation number shows if the individual ln(RR)s are significantly different from zero.



Log-transformed response ratios, ln(RR), for SOC, TN, exchangeable base cations and pH (k≥4) in forest floors of pure Scots pine (circles) and Norway spruce (triangles) stands following WTT, WTH or WTH+S compared to conventional stem-only thinning or harvesting (SOH). Mixed coniferous forests were excluded from this analysis due to few replicates. Significance levels indicate ns (P≥0.05), * (P<0.05), ** (P<0.01), *** (P<0.001).

	$T_{May\text{-}Aug}$		$P_{May\text{-}Aug}$	
	Slope	N	Slope	N
SOC	−0.042**	42	−0.001*	42
TN	−0.056*	38	NS	38
P	+0.222***	11	−0.003***	11
K	NS	42	−0.001*	42
Ca	−0.089**	42	−0.002**	42
Mg	NS	41	−0.001**	41
Zn	NS	17	+0.003*	17
Mn	NS	17	NS	17
Na	NS	33	NS	33
Al	+0.169*	14	NS	14
EA	NS	14	−0.002*	14
CEC	NS	14	NS	14
BS	−0.029**	15	−0.003***	15
pH	−0.013***	63	+0.0004*	63

Regression slope parameters of meta-regressions of the log-transformed response ratios for SOC and TN stocks, exchangeable element concentrations, exchangeable acidity (EA), cation exchange capacity (CEC), base saturation (BS) and pH in the forest floor against **mean growing season temperature** or **mean growing season precipitation** for the period May to August ($T_{May\text{-}Aug}$, °C, and $P_{May\text{-}Aug}$, mm, respectively), comparing intensive harvesting (WTT, WTH, and WTH+S) with stem-only thinning or harvesting (SOH). Significance levels: * (P<0.05), ** (P<0.01), *** (P<0.001), NS = not significant.



Meta-regressions of ln(RR) with time since harvest for SOC in forest floor, topsoil and subsoil. Numbers refer to different studies and circle diameters reflect the weight of the estimate in the meta-analysis.

	Forest floor				Topsoil			
	Slope ln(RR) ($year^{-1}$)	Intercept ln(RR)	Age (years)	N	Slope ln(RR) ($year^{-1}$)	Intercept ln(RR)	Age (years)	N
SOC	+0.002*	−0.107***	3–37	42	+0.010***	−0.268***	2–37	44
TN	NS	−0.166**	3–37	38	NS	NS	3–37	38
P	+0.010***	−0.409***	3–37	11	NS	NS	3–37	11
K	+0.004**	−0.159***	3–37	42	NS	−0.113*	3–37	41
Ca	+0.011**	−0.39**	3–37	42	−0.012*	+0.445**	3–37	42
Mg	+0.008**	−0.284**	3–37	41	NS	NS	3–37	42
Zn	+0.006*	−0.261**	2–37	17	NS	NS	2–37	16
Mn	NS	NS	2–37	17	NS	NS	2–37	19
Na	NS	NS	3–37	33	NS	NS	3–37	34
Al	NS	+0.627*	3–37	14	NS	NS	3–37	16
EA	−0.006***	+0.226***	8–35	14	+0.017***	−0.596***	8–35	14
CEC	NS	NS	3–37	14	NS	NS	3–37	14
BS	+0.005***	−0.151***	3–37	15	+0.008*	−0.348***	3–37	15
pH	NS	−0.011**	1–37	63	+0.001**	−0.015**	1–37	56

Regression parameters of a regression of the log-transformed response ratios, ln(RR), and time since harvesting for SOC, soil exchangeable elements, exchangeable acidity (EA), cation exchange capacity (CEC), base saturation (BS) and pH for intensive harvesting (WTT, WTH and WTH+S) in forest floor and topsoil. Significance levels are indicated as * ($P<0.05$), ** ($P<0.01$), *** ($P<0.001$). NS = not significant. N = total number of paired plots (*k)* used for the analysis.

- Our results generally support greater reductions in nutrient concentrations, SOC and TN after WTH compared with SOH in northern European temperate and boreal forest soils, consistent with the results obtained on a worldwide scale;
- Effects were greater in the forest floor than in the mineral soil, and greater in the topsoil than the subsoil;
- Spruce- and pine-dominated stands had for most elements comparable negative relative responses in the forest floor;
- There appeared to be greater effects of WTH relative to SOH in a warmer climate;
- The differences between effects of different harvest types in the forest floor and topsoil were generally reduced with time but were likely to last for several decades;
- Increased loss of nutrients and SOC after intensified harvesting might lead to reduced productivity in the next forest rotation as well as lower carbon sequestration in the forest soil, but loss of nutrients could be counteracted using fertilization.

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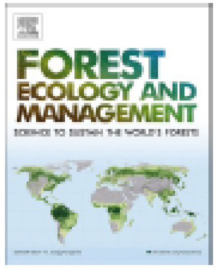

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