Trajectories of nitrate input and output in three nested catchments along a land use gradient

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1 Background

- Excessive agricultural nitrogen (N)-input causes exceeding drinking water limits in groundwater and eutrophication in surface waters
- Nitrate- and Water Framework Directive partly miss their targets
- Reduced N-inputs do not result in a immediate decrease of riverine concentrations
- **Legacy problem**: Time lags in soil- and groundwater and accumulation of N in soils can mask measures
- Need to improve river management and assessment of measures by quantifying and understanding legacy effects

2 Approach, data and methods

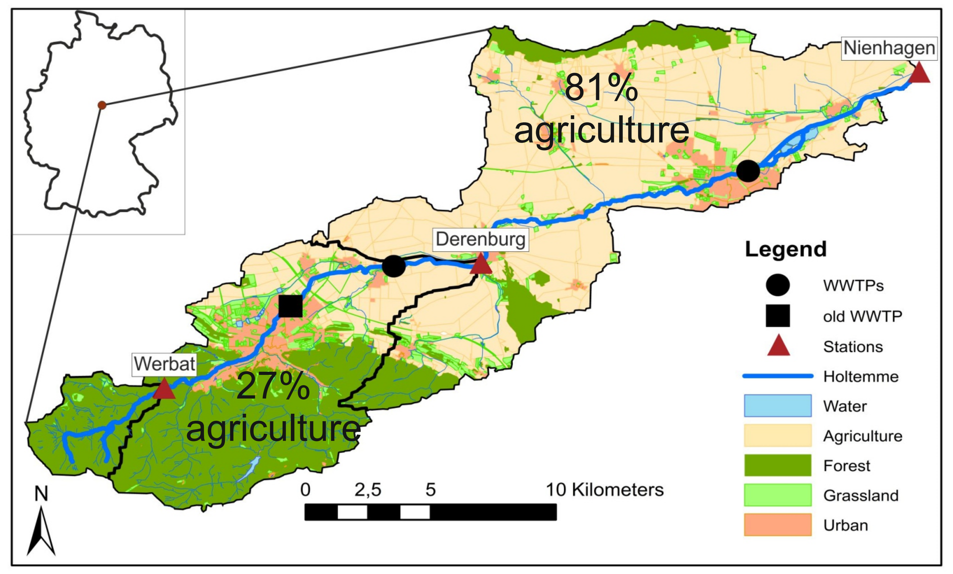
Objectives

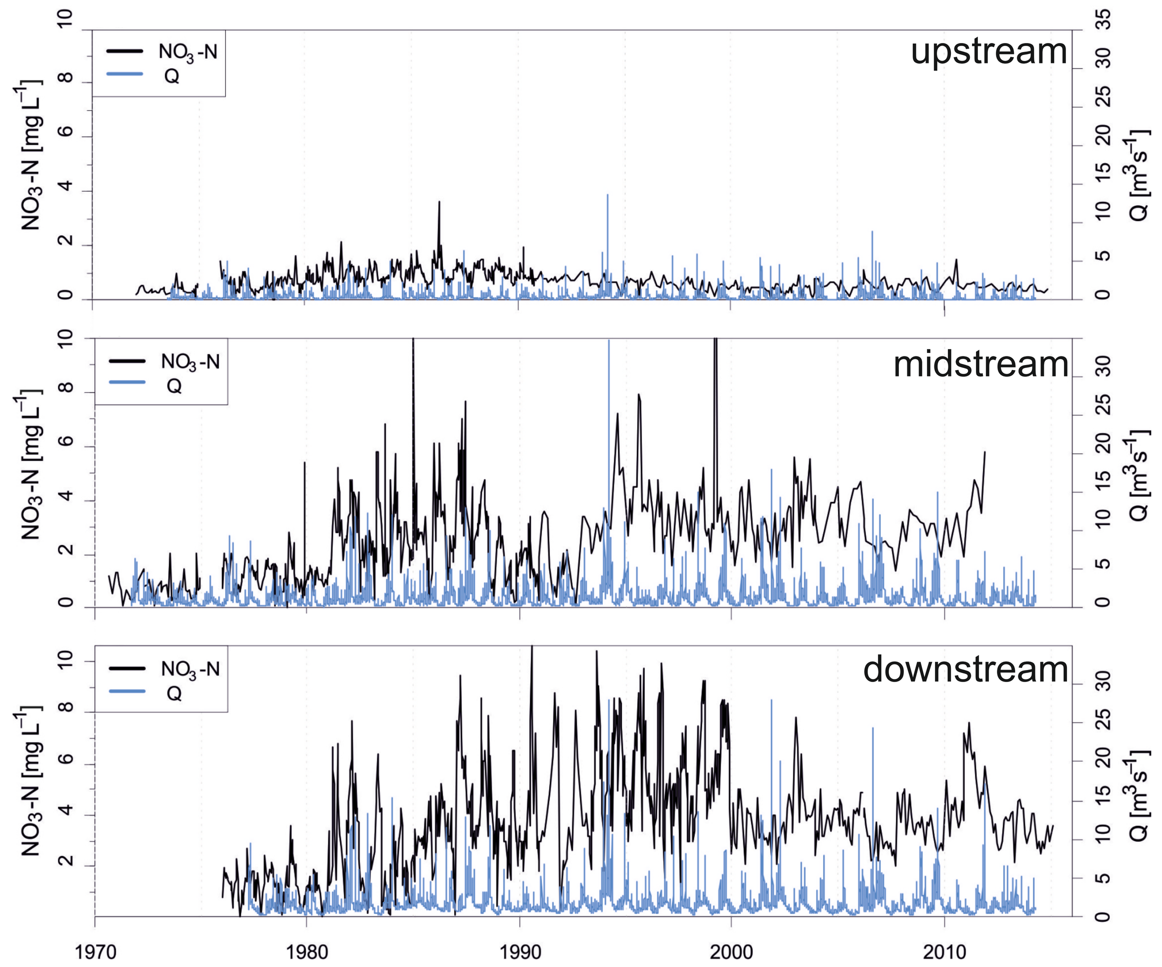
- Quantify the retention of N and discuss removal vs. legacy effects
- Characterize the travel time of N between fertilizer application and riverine exports
- Characterize the tracjectories of concentration-discharge relationships and discuss linkages to the N-legacy

- Utilize a long-term observational dataset of N-input and -exports in a well studied mesoscale catchment

Data basis and methods

- Holtemme catchment (270 km²) in Central Germany
- Three nested stations from pristine mountainious headwaters to lowland intensive agriculture
- Water quantity and quality observations from 1970-2016

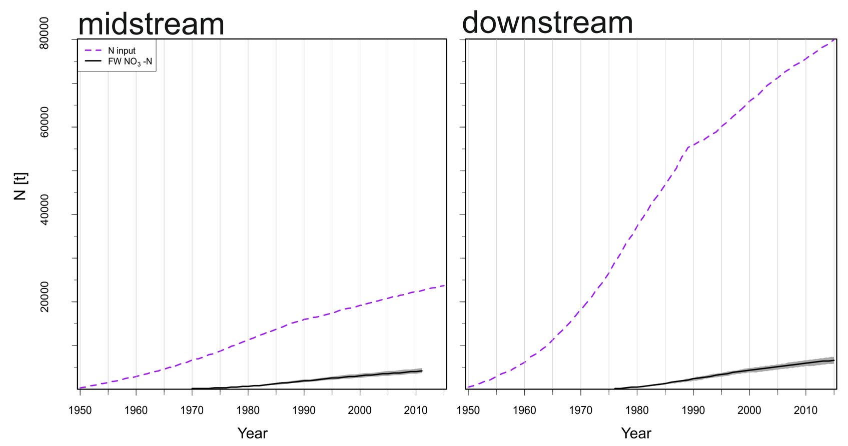




- Input: Annual agricultural N-surplus and atmospheric depositions, biological fixation,wastewater contributions
- Output: Seasonal to annual nitrate concentrations using WRTDS, Hirsch et al. (2010)
- Lognormal effective travel time distributions as transfer functions between annual diffuse N-inputs and seasonal/ annual riverine nitrate exports
- Annual C-Q relationships based on the daily WRTDS

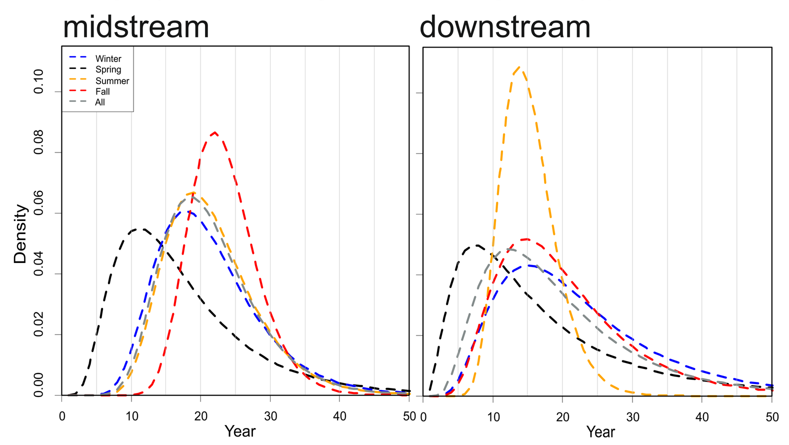
3 Results

Nitrogen budget and effective travel times



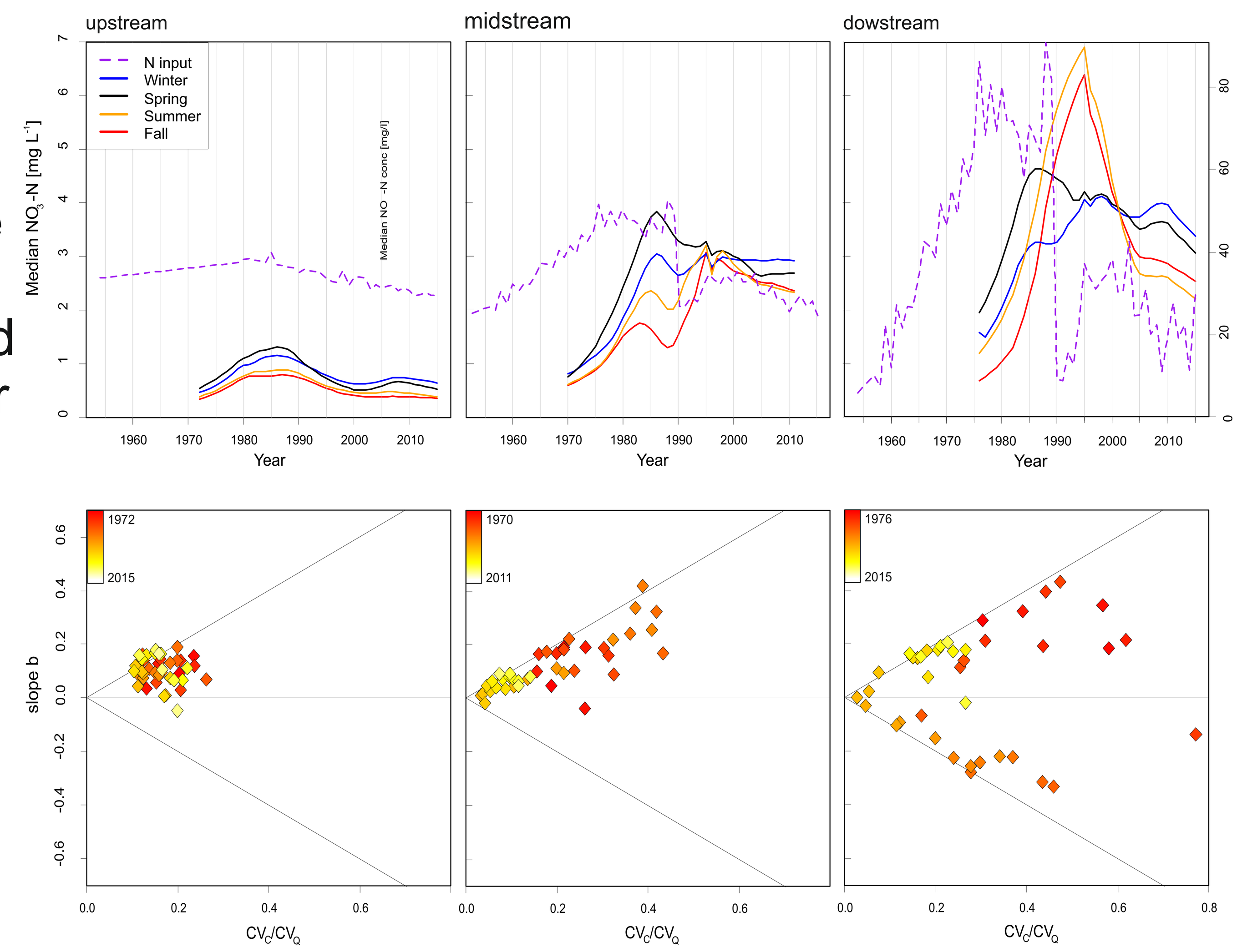
- Midstream station: 75% (28.42 kg N/(ha a)) of diffuse N inputs are retained in the catchment
- Downstream station: 88% (58.82 kg N/(ha a)) of N retained
- Significant removal by denitrification is not likely (oxic aquifers) → N still in the catchment storage (legacy)

- Lognormal travel time distributions of N with modes from 7 to 22 years
- Systematically younger nitrogen is exported in the high flow seasons winter and spring while summer and autumn travel times are older
- Convolution of N-input with travel times explains 29-40 % of missing N (hydrological legacy)



Nitrate export regimes

- All sub-catchments evolve to a chemostatic export regime
- Under conditions of changing input, the export regime is more chemodynamic
- Phases of increasing inputs lead to enrichment patterns (younger water ages with higher C)
- Phases with decreasing inputs can lead to dilution pattern (older water ages still high in C)
- Nitrate chemostasis only under stable N-inputs
- N accumulation in soil would dampen C-Q changes



4 Conclusions

- Catchments may store but not remove a large legacy of N
- Travel times of N through the catchment can be long - changing agricultural inputs will need time to change low flow and high flow concentrations
- Chemostasis of nitrate exports may be not an endpoint of intensive agriculture but rather a reflection of a constant N-input
- Water quality management should address both, longer-term reduction of N-inputs and shorter term enhancement of removal

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Hirsch, R. M., Moyer, D. L., and Archfield, S. A.: Weighted Regressions on Time, Discharge, and Season (WRTDS), with an Application to Chesapeake Bay River Inputs, Journal of the American Water Resources Association, 46, 857–880, 2010.

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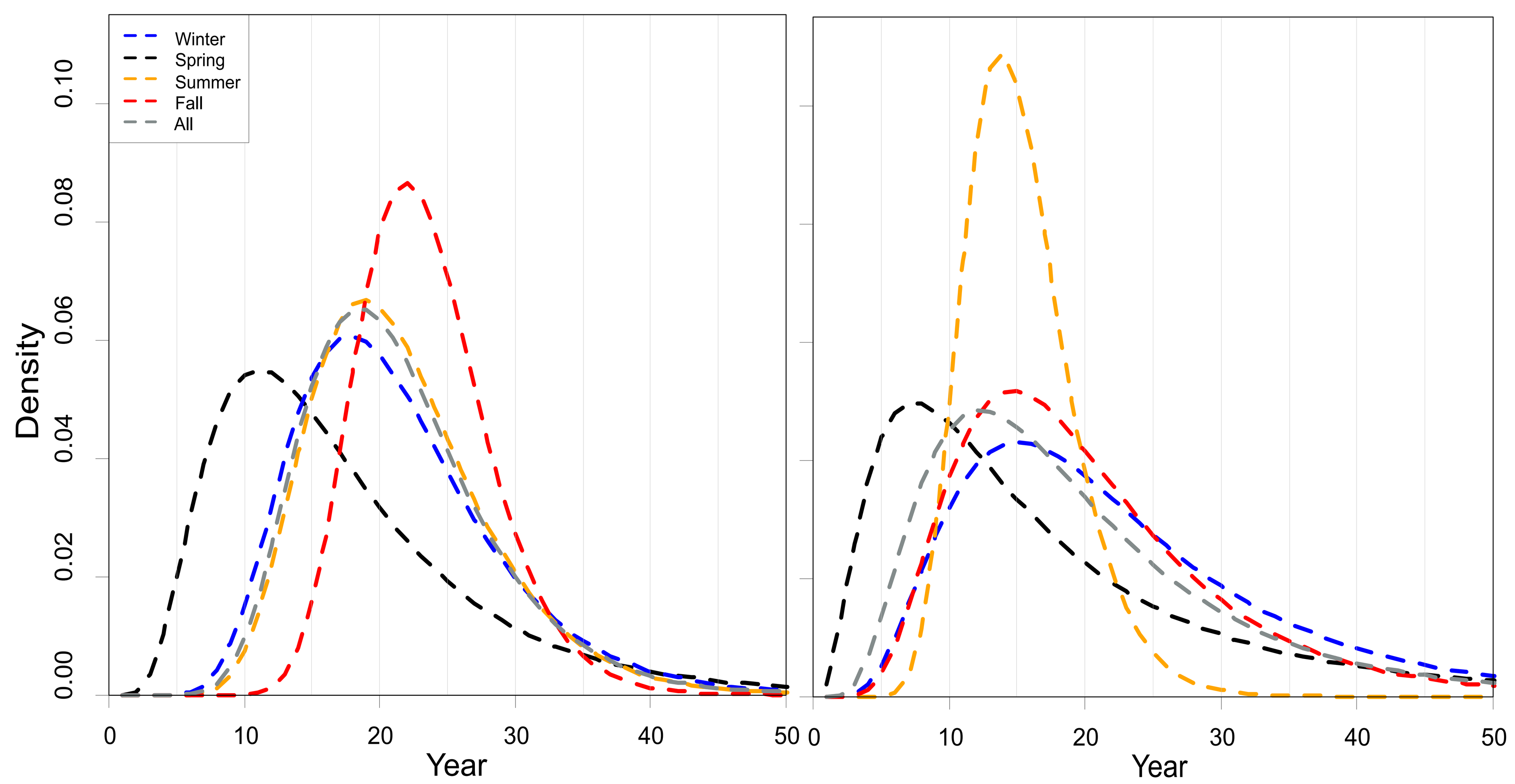
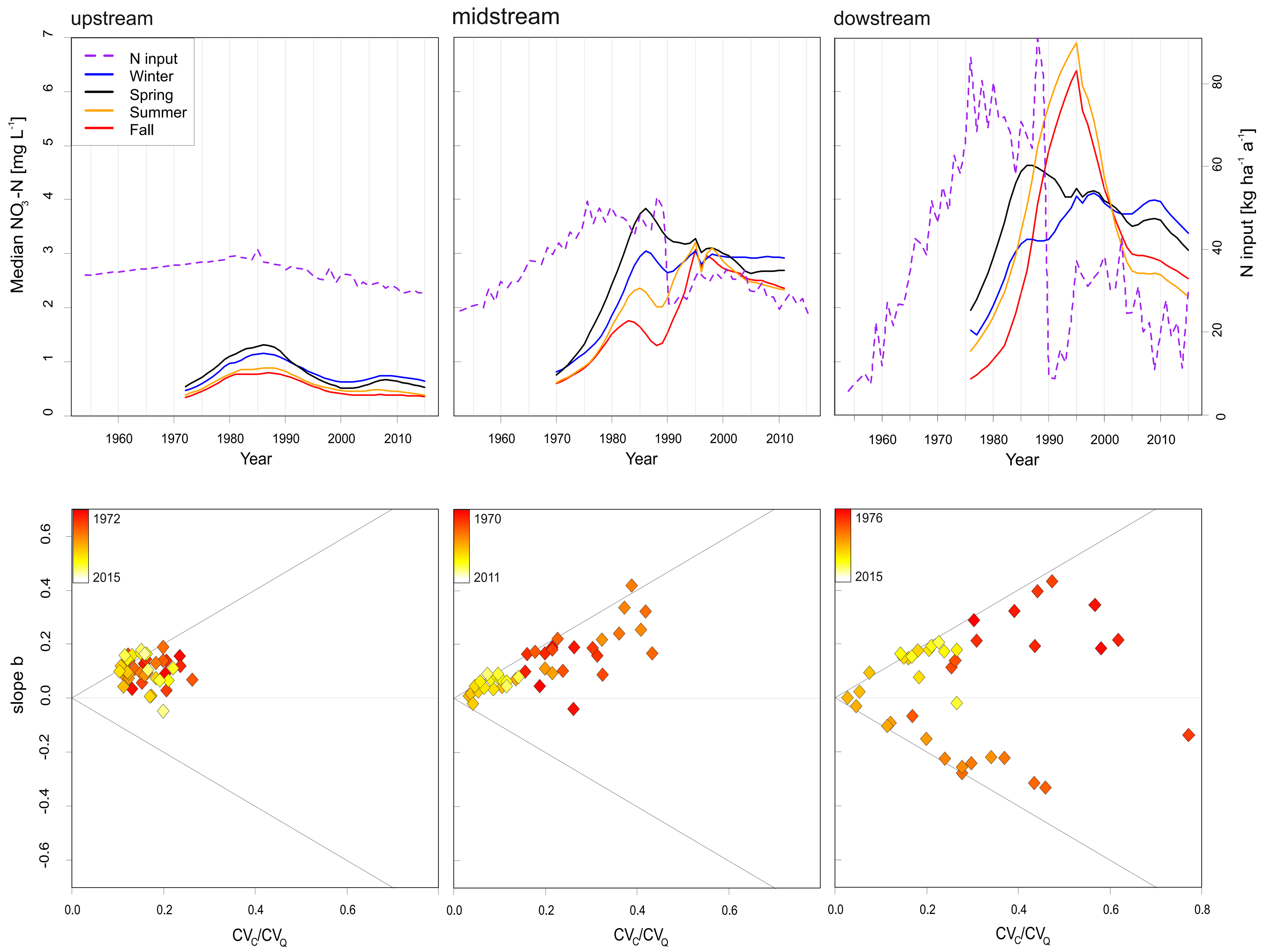


Winter
Spring
Summer
Fall
All
Density
0.00
0.02
0.04
0.06
0.08
0.10
0
10
20
30
40
50
Year
0
10
20
30
40
50
Year



upstream
midstream
dowstream
N input
Winter
Spring
Summer
Fall
Median NO_3-N [mg L^{-1}]
N input [kg ha^{-1} a^{-1}]
Year
slope b
CV_C/CV_Q
1972
2015
1970
2011
1976
2015