Sensitivity of headwater stream temperature to riparian land management

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Structure

- Context and research gaps → aims
- Field area and sites: Girnock burn (forest vs. moorland)
- Data and methods
- Results:
  - stream temperature → variation
  - microclimate → boundary conditions
  - energy balance (heat budget) → processes
- Conclusions for Girnock burn
- Extension of research to Loch Ard
- Future research

Context and research gaps

- Water temperature is an important and highly sensitive variable → physical, chemical and biological processes
- Poikilotherms: aquatic organisms that cannot regulate body temperature (including invertebrates and fish)
- Stream temperature anticipated to increase with climate warming
- Stream temperature controlled by transfers of heat and water to/ from the river system
- Very few stream energy balance studies of fundamental processes

Gains (Sources):

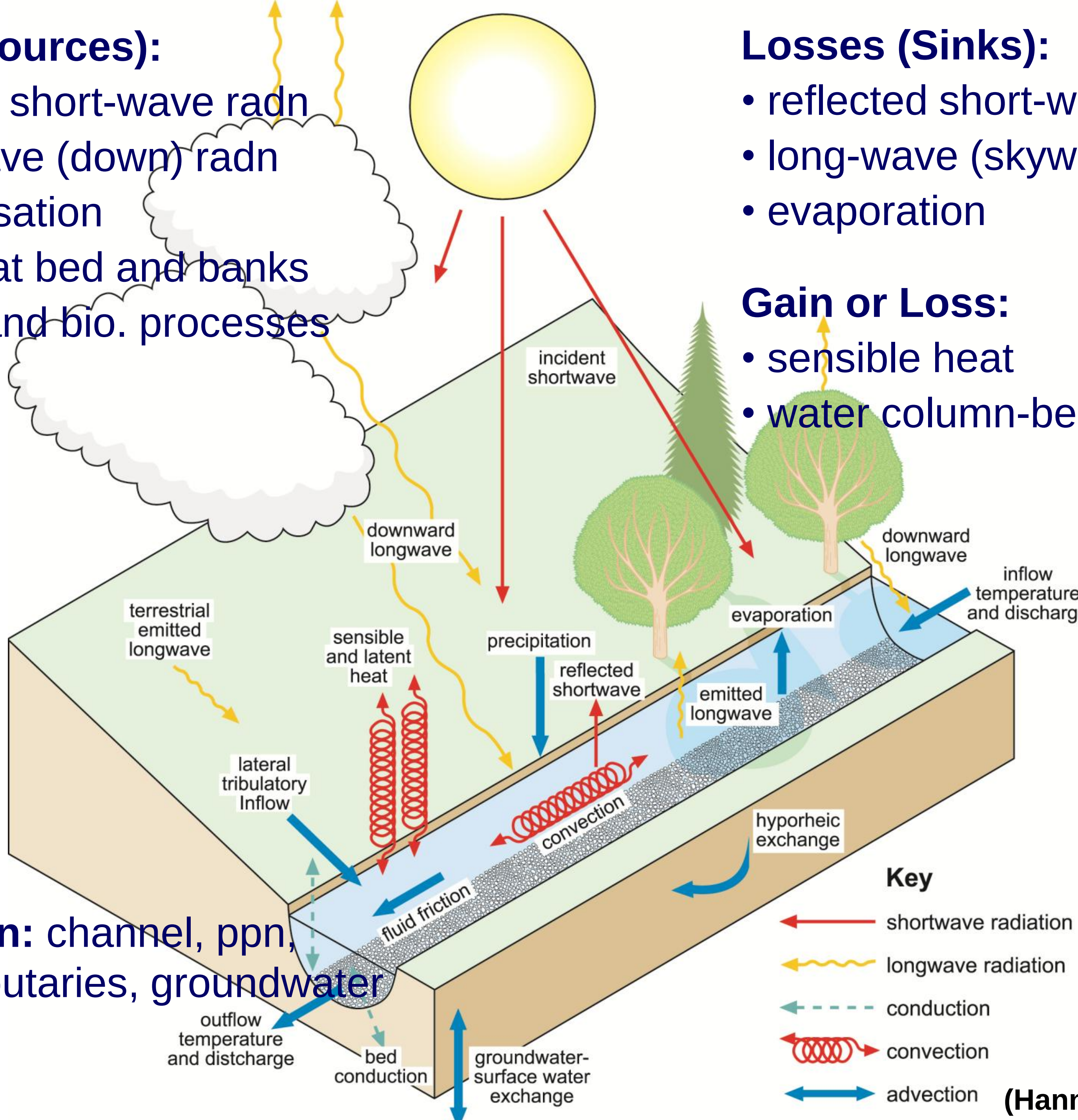
- incident short-wave radn
- long-wave (down) radn
- condensation
- friction at bed and banks
- chem. and bio. processes

Losses (Sinks):

- reflected short-wave radn
- long-wave (skyward) radn
- evaporation

Gain or Loss:

- sensible heat
- water column-bed transfers



Advection: channel, ppn, evap., tributaries, groundwater

(Hannah *et al.*, 2008)

Context and research gaps

- Land and water management impact on heat exchanges → modify river thermal characteristics
- Several organisations promoting riparian forest planting as climate change adaption measure → reduce water temperature extremes → improve river thermal habitat
- However, scientific evidence is limited for management decisions due to lack of:
  - high quality, medium- to long-term data
  - information on semi-natural and native forest
  - understanding of physical process (energy exchange)
- Address research gaps → assess headwater stream temperature sensitivity under different land management (forest) treatments

Aims

1. To characterise spatial and temporal variability in riparian microclimate and stream water temperature regime across different land management (forest) treatments

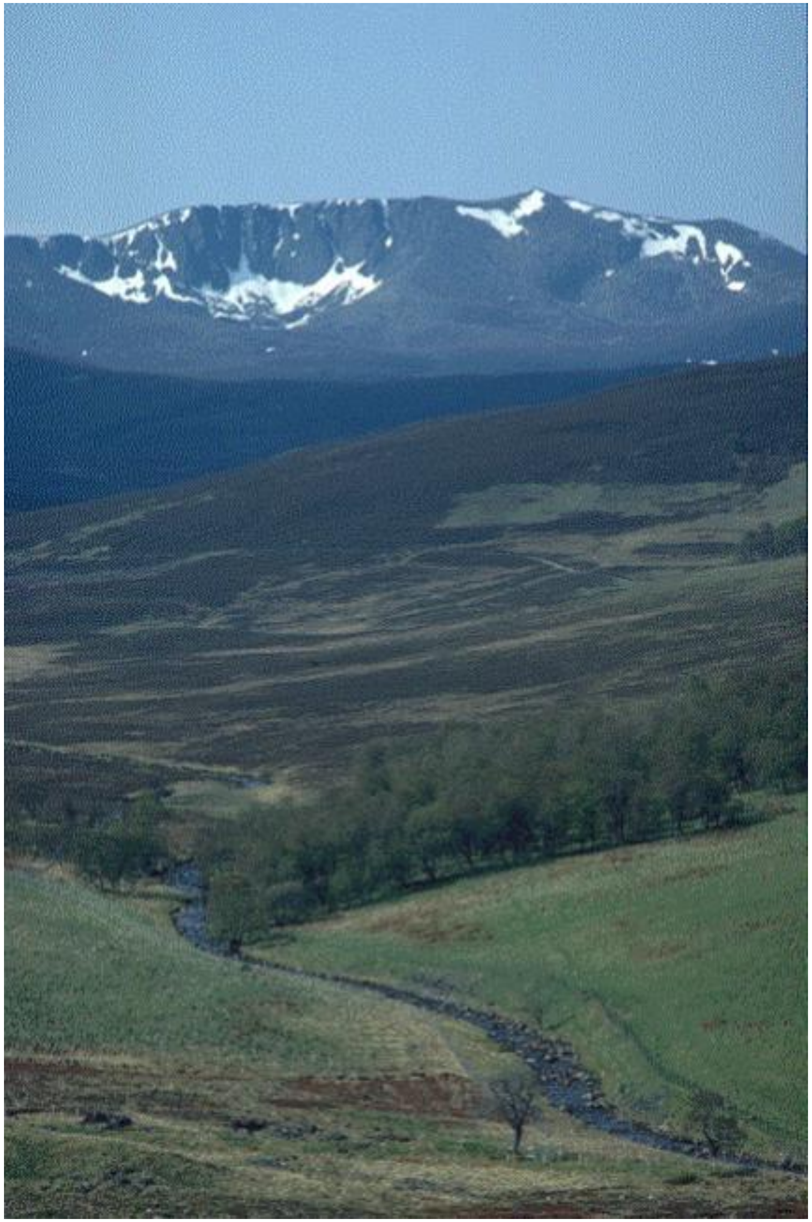
2. To identify the hydrological, climatological and site-specific factors affecting stream temperature

3. To estimate the energy balance at sites representative of each treatment → physical process understanding about dominant heat exchanges driving thermal variability

4. To use 1-3 to assess stream temperature sensitivity under different land management treatments and hydroclimatological scenarios

Glen Girnock, Cairngorms

- Semi-natural, upland
- Lochnagar massif → drains to River Dee
- 230-862 masl; 30.3 km^2
- Heather moorland with semi-natural forest
- Sub-Arctic climate
- 1100 mm precipitation (25% snowfall)
- Air temperature range: -27°C to 25°C



Girnock burn study reaches

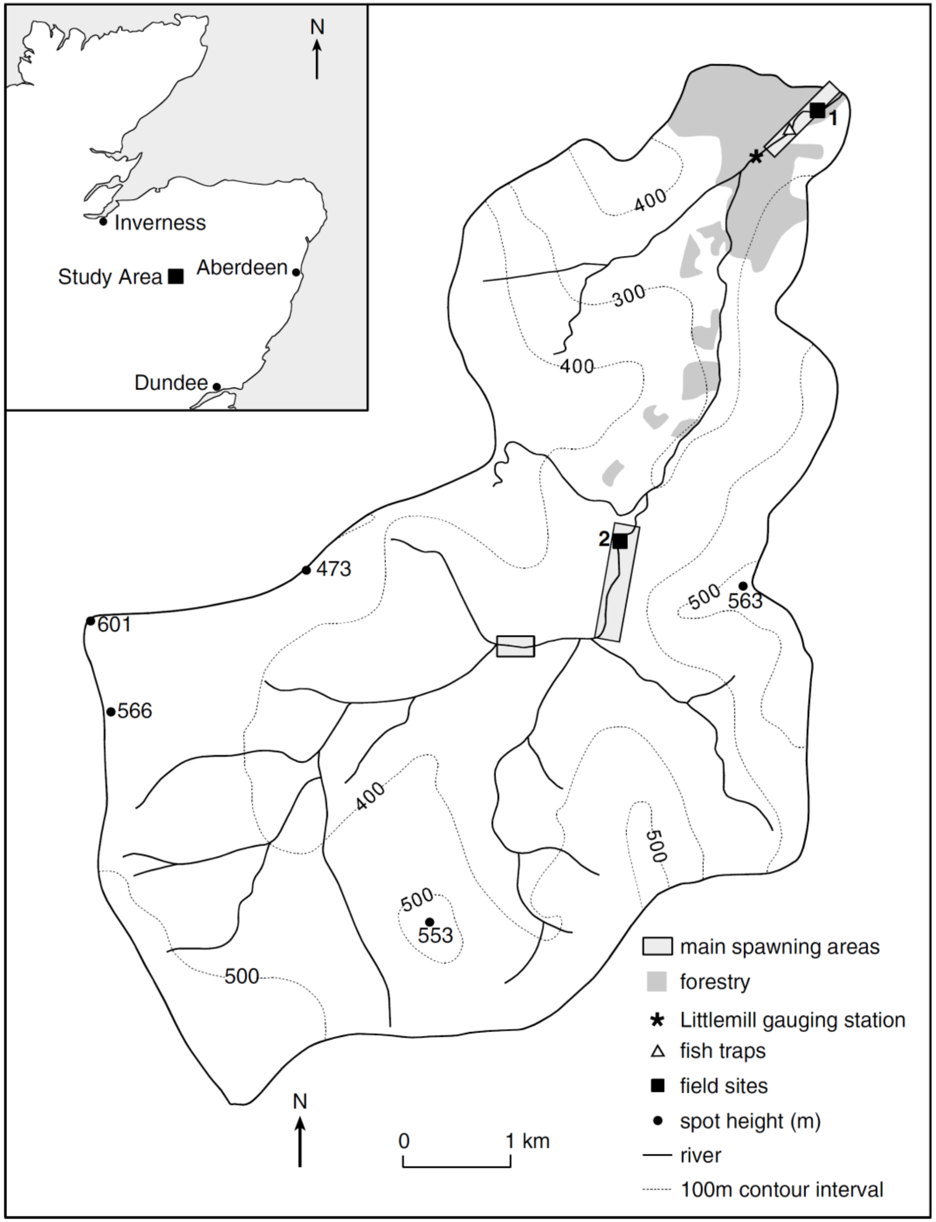
Heather moorland (no trees)

- 310 masl; 20.7 km^2
- 9.5 m wide; 0.01 m m^{-1}

Semi-natural forest

- Birch, Scots pine, alder, willow → mixed
- 230 masl; 31.0 km^2
- 7.6 m wide; 0.02 m m^{-1}

- No tributary inflows
- Very similar geomorphology
- Detailed previous research



Data and methods

- 15 min data collected over 2003-2004 calendar years
- Moorland site dewatered in summer 2003
- Measured microclimate (including K and Q^*), water column and streambed temperature, bed heat flux, and water level

Girnock burn open moorland

Girnock burn semi-natural forest

Data and methods

- Estimated energy balance components:

$$Q_n = Q* + Q_h + Q_e + Q_{bhf} + Q_f$$

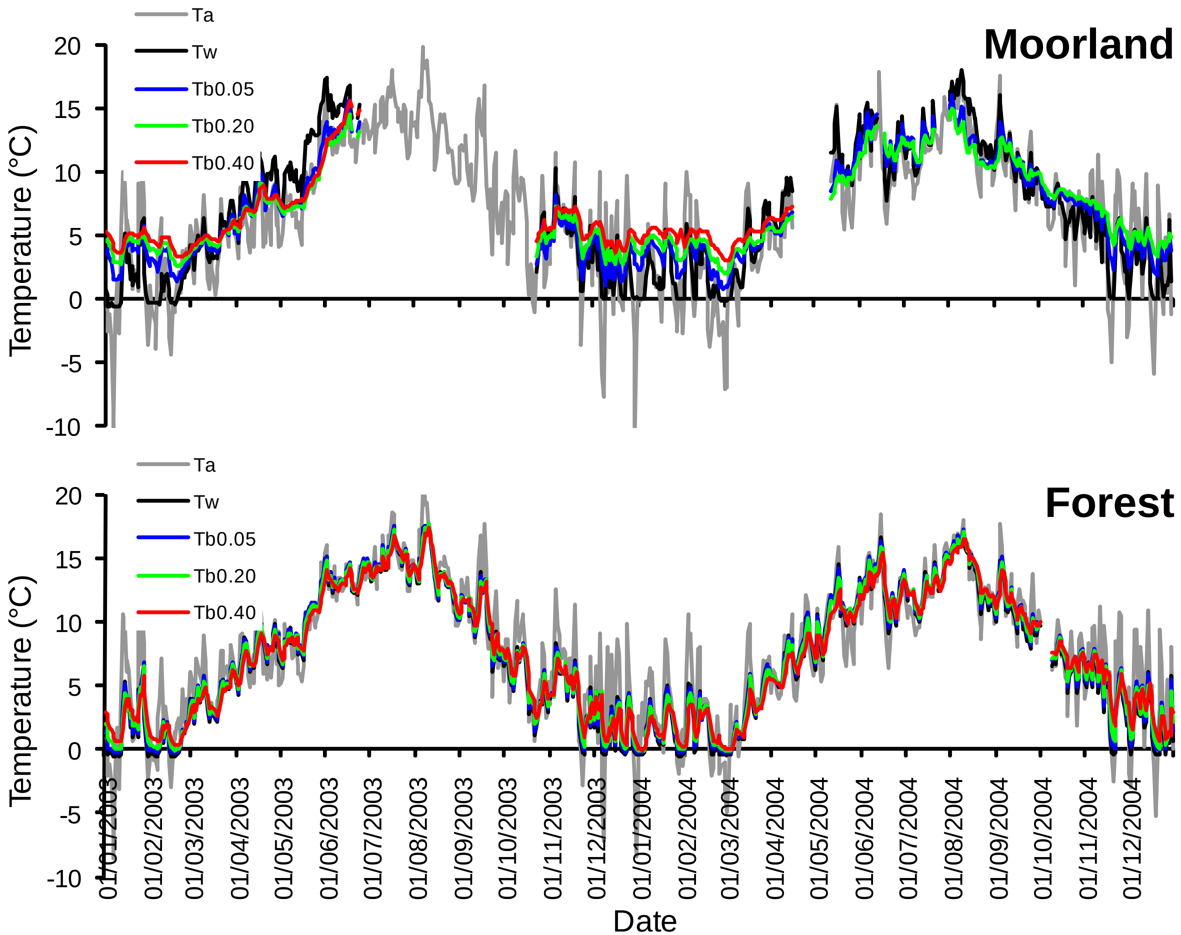
- Latent heat (Q_e) by Penman-style equation for evaporation

- Sensible heat as product of Q_e and Bowen ratio

- Fluxes positive (negative) towards (away) surface → add (remove) heat to (from) water column

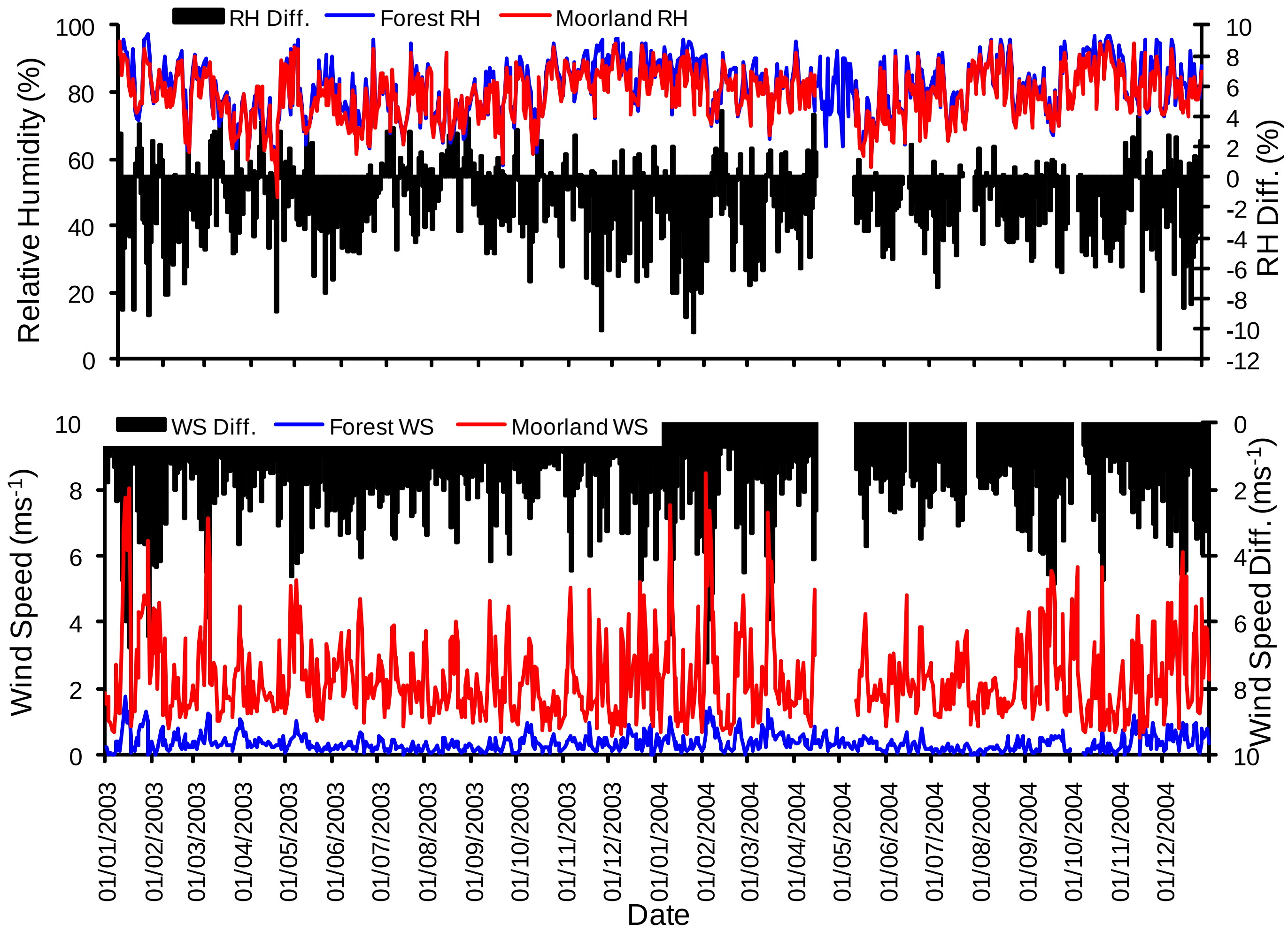
- 15 min fluxes (Wm^{-2}) → daily totals ($MJm^{-2}d^{-1}$)

Temperature



- **Water column (moorland cf. forest):** mean warmer in winter-spring but slightly cooler in summer; minimum warmer in spring and autumn-winter; maximum warmer with greater differences in summer; range greater
- **Streambed:** forest tracks water column; moorland vertical diff. and lags → streambed warmer in winter and cooler in summer = GW-SW interactions
- **Air (moorland cf. forest):** mean very slightly cooler but minimum cooler, maximum warmer and range greater (80 m altitude diff. ≈ 0.5°C diff.)

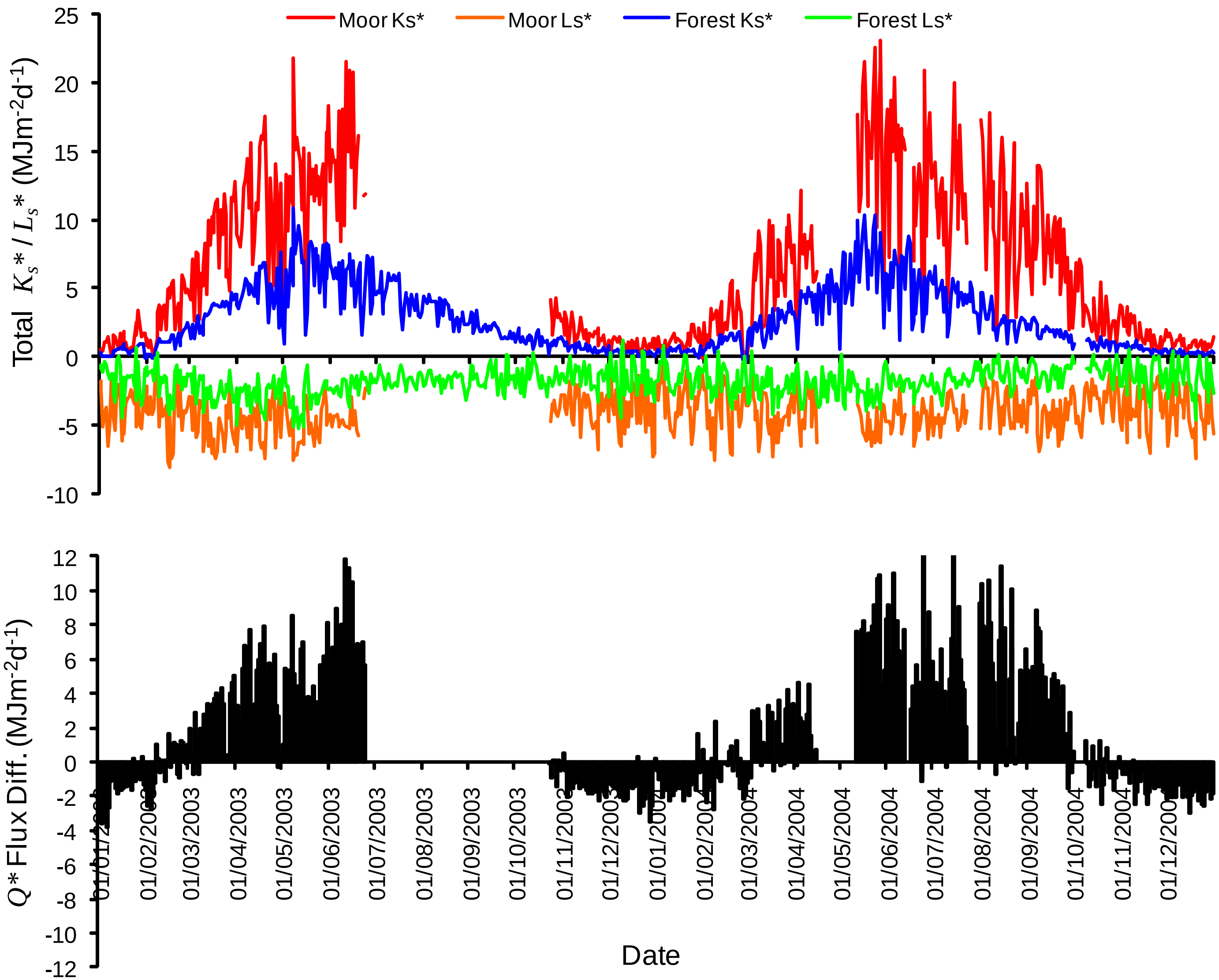
Riparian microclimate



Diff. = moor - forest: + higher; - lower

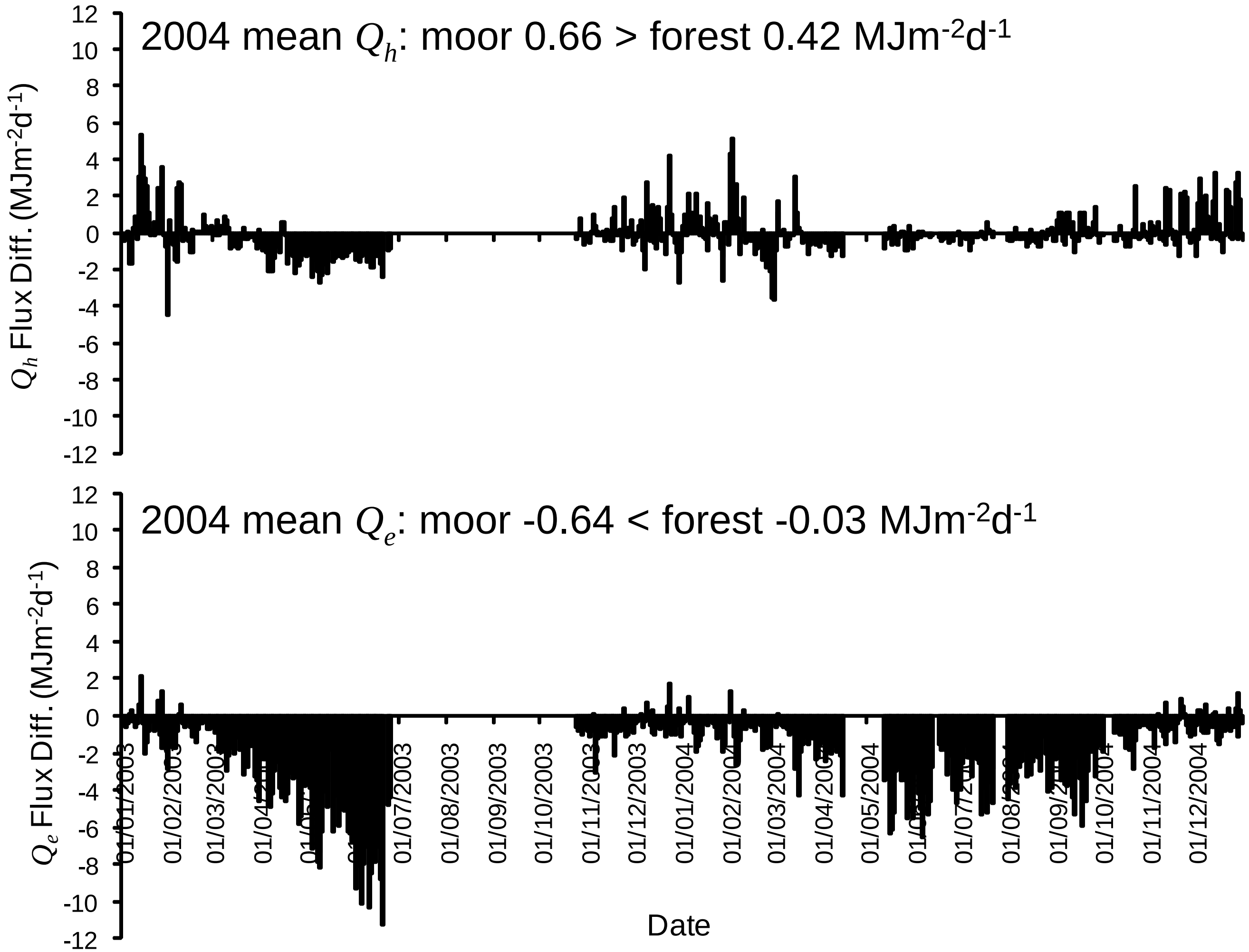
- **Relative humidity:** lower for moorland probably due to greater wind venting of moist air
- **Wind speed:** much higher (>6 times) and much more variable for moorland owing to greater exposure

Energy balance: radiation



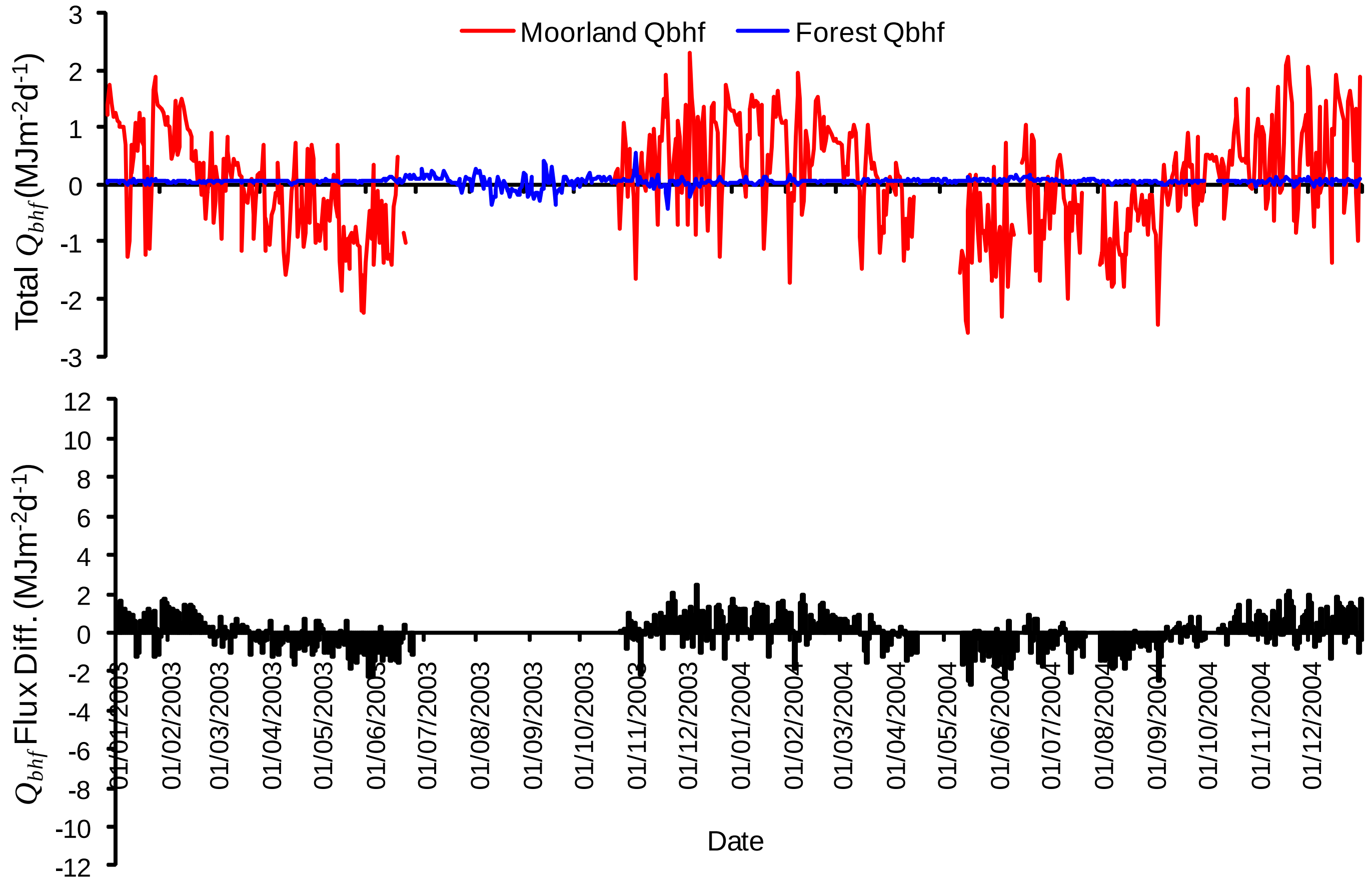
- **Net shortwave radiation (K_s^*):** greater for moorland; max. diff. summer
- **Net longwave radiation (L_s^*):** greater for forest due to canopy effects
- **Net radiation (Q^*):** greater for moorland, except in winter. For forest, winter L_s^* offsets K_s^*; but, in other seasons, forest shading → lower Q^*

Energy balance: sensible and latent heat



- **Sensible heat (Q_h):** heat source in autumn-winter and sink in spring-summer due to changing air-water column temperature gradients, with gain (loss) greater in winter (summer) for moorland
- **Latent heat (Q_e):** predominantly heat sink (i.e. evaporation) but magnitude and variability higher for moorland due to higher wind speed and lower RH; Q_e is energy source (i.e. condensation) during river icing

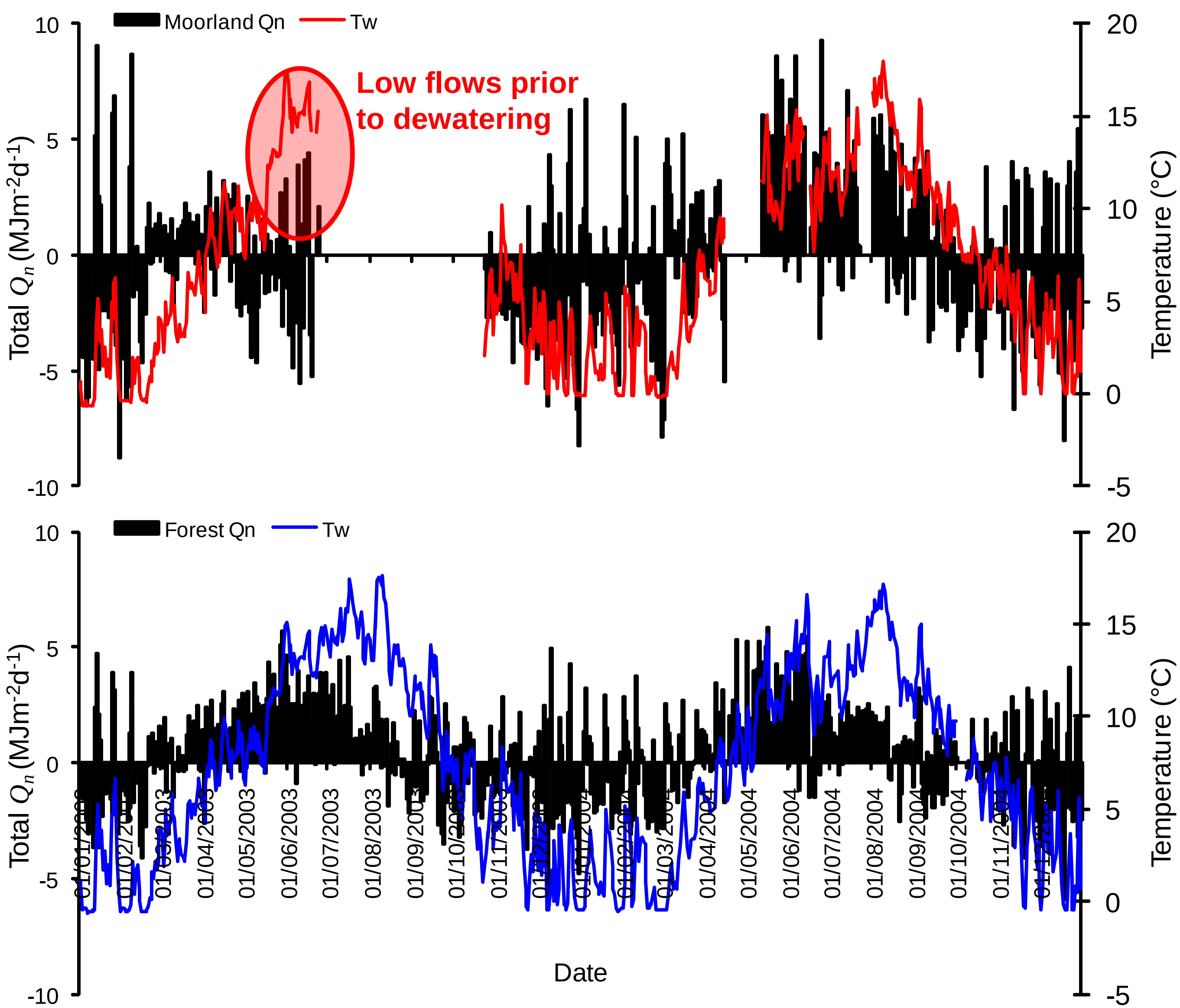
Energy balance: bed heat flux



Diff. = moor - forest: + warmer; - colder

- Q_{bhf} much smaller than fluxes at air-water interface, esp. for forest
- Greater (less) in winter (summer) for moorland, with spring and autumn transition because: (1) small, consistently positive Q_{bhf} for forest (i.e. warmer sediments at depth); but (2) clear Q_{bhf} annual cycle for moorland (i.e. summer sink: winter source) due to reversal of bed thermal gradients
- Contrasts between reaches probably due to GW-SW interactions (e.g. Malcolm *et al.*, 2005).

Energy balance: total energy



- Q_n heat source in summer and sink in winter with autumn/ spring transitions
- **Forest:** Q_n dominated by energy receipt at air-water interface (Q_{sn})
- **Moorland:** Q_n tracks Q_{sn} but offset by Q_{bhf} cycle → reduce inter-site diff.

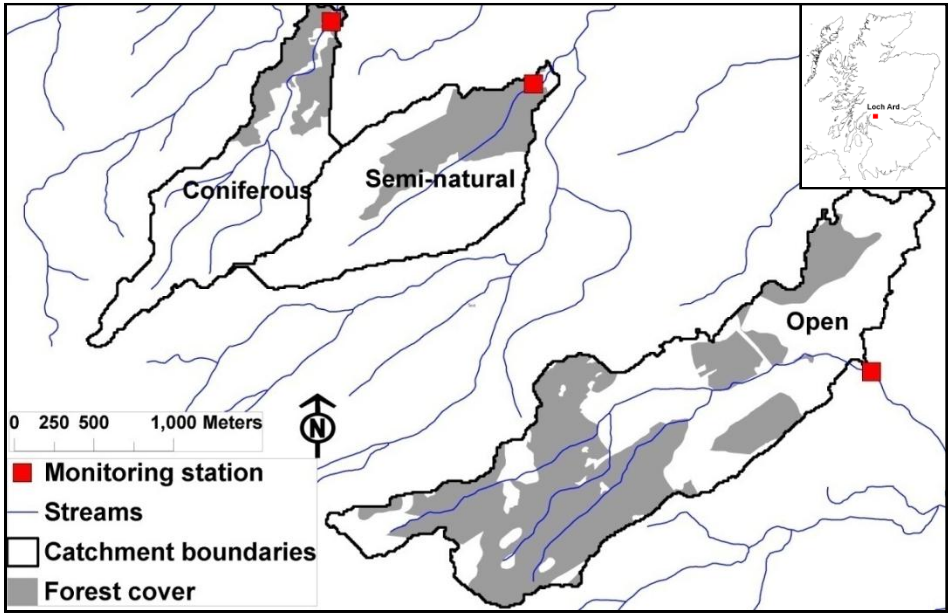
Conclusion for Girnock burn

- Unparallel longer-term view on stream thermal dynamics under different land management (forest) treatments
- Riparian forest moderates: microclimate → heat budget → stream thermal variation
- Forest (cf. moor) stream temp cooler; but need to consider range of stream temperature descriptors and seasonality
- Riparian microclimate altered by forest (cf. moorland):
  - reduced solar radiation, longwave loss and wind speed
  - increased humidity
  - limited mean air temperature difference but lower range
- Highlights importance of energy transfer processes and hydrological fluxes (i.e. GW-SW interactions) in controlling stream temperature

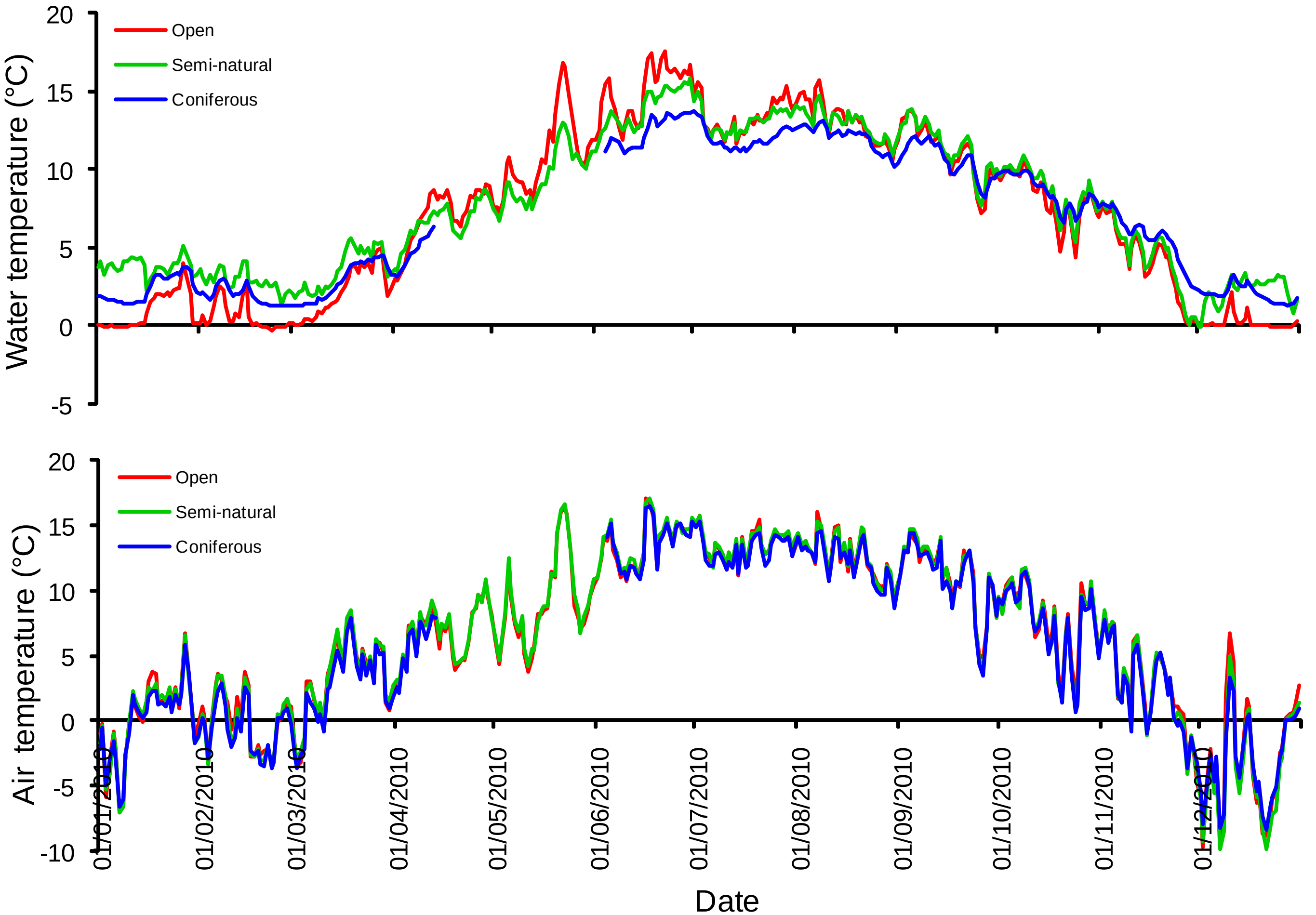
Conclusion for Girnock burn

- Net radiation dominant heat source (sink) in summer (winter); sensible heat is sink (source) in summer (winter); latent heat predominantly sink
- Stream energy balance modified by forest (cf. moorland):
  - net radiation lower in summer and higher in winter
  - sensible heat and latent heat fluxes less variable
- First study of mixed, semi-natural woodland → notably different results to work on coniferous forest → debate remains about impact of riparian land management
- Lesser difference for mixed woodland may be due to forest architecture and tree planting practice, but confounding factors other than forest (hydrology, latitude etc.) → assess transferability of findings → Loch Ard

Loch Ard, western Scottish Highlands

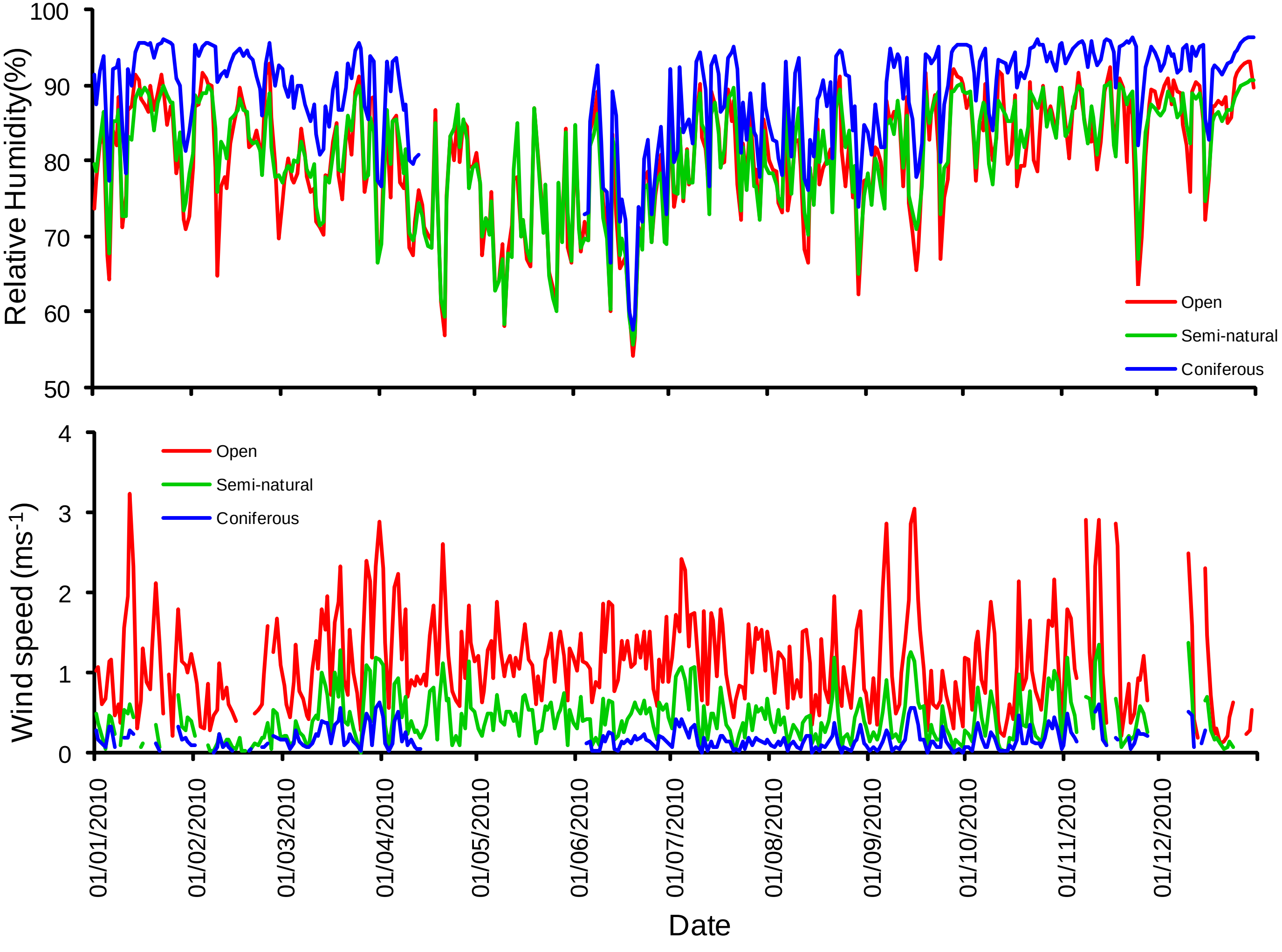


Loch Ard: temperature



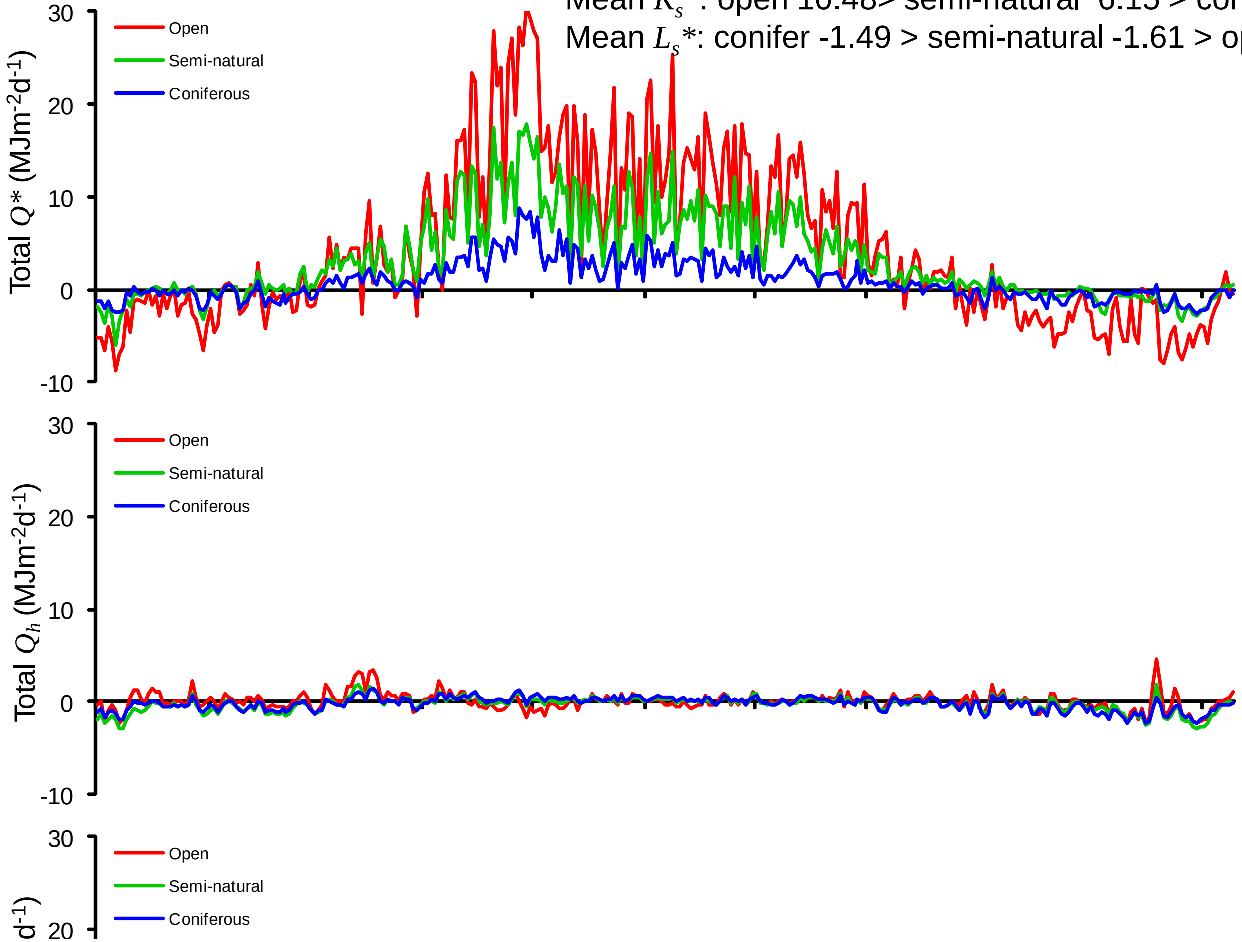
- **Water column:** <u>mean</u> and <u>maximum</u> open > semi-natural > conifer. in summer, but semi-natural > conifer. > open in winter; <u>minimum</u> conifer. > semi-natural > open; <u>range</u> very subdued for conifer.
- **Air:** <u>mean</u> open > semi-natural > conifer but seasonality less marked than for water column; <u>range</u> much larger for open ≈ semi-natural cf. conifer.

Loch Ard: riparian microclimate

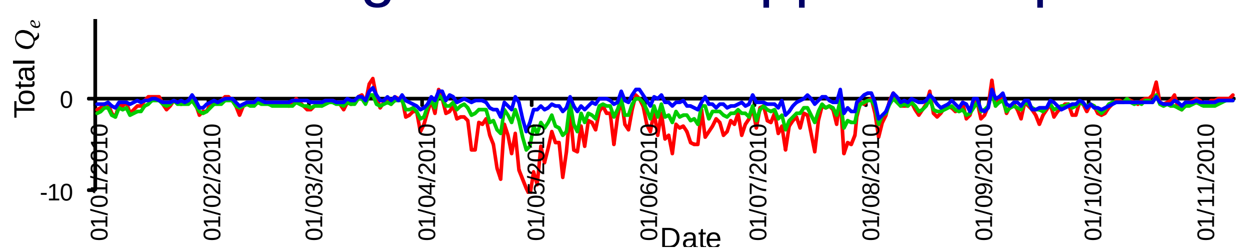


Loch Ard: energy balance

Mean K_s*: open 10.48> semi-natural 6.15 > conifer. 3.06 $MJm^{-2}d^{-1}$
Mean L_s*: conifer -1.49 > semi-natural -1.61 > open -1.96 $MJm^{-2}d^{-1}$



- Thus, Loch Ard findings seem to support our previous research



Mean Q_{bhf}: semi-natural 0.42 > open 0.01 > conifer. -0.11 $MJm^{-2}d^{-1}$
Mean Q_n: open 4.58 > semi-natural 4.48 > conifer. 0.77 $MJm^{-2}d^{-1}$

Future research

- Process basis to understand and model stream thermal impact of riparian forest practice → inform decisions by land and water resource managers → fisheries managers
- Finer scale processes vs. upstream landscape controls:
  - role of hydrology (water sources and flowpaths)
  - landscape configuration
  - hydraulic retention time for reach scale equilibration
  - sub-reach heterogeneity
  - energy flux estimation methods
- Better understand scales of influence of riparian land cover on headwater stream temperature response

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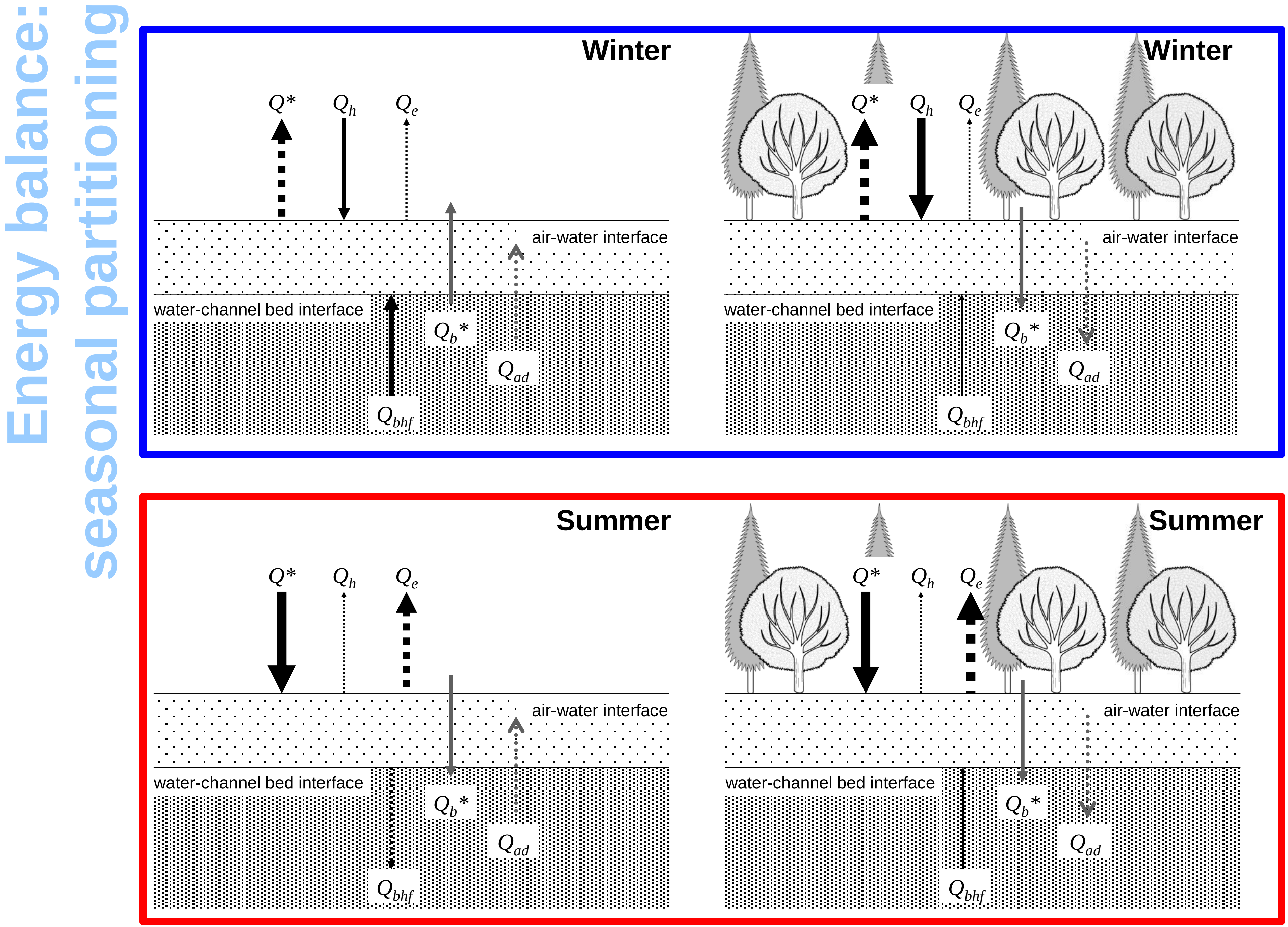

Energy balance:
seasonal partitioning
Winter
Q*
Q_h
Q_e
air-water interface
water-channel bed interface
Q_b*
Q_{ad}
Q_{bhf}
Winter
Q*
Q_h
Q_e
air-water interface
water-channel bed interface
Q_b*
Q_{ad}
Q_{bhf}
Summer
Q*
Q_h
Q_e
air-water interface
water-channel bed interface
Q_b*
Q_{ad}
Q_{bhf}
Summer
Q*
Q_h
Q_e
air-water interface
water-channel bed interface
Q_b*
Q_{ad}
Q_{bhf}