water

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*Article*

# Climate Change and Water Exploitation as Co-Impact Sources on River Benthic Macroinvertebrates

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## Supplementary Materials

**Table S1.** Sampling dates (day/month/year) of benthic macroinvertebrates at the three study sites (IF1, MF1, MF2) and in the two considered periods (I-warm = Irrigation warm period, NI-cold= Non-Irrigation cold period).

| Period | IF1 | MF1 | MF2 |
|---|---|---|---|
| I-warm | 25 August 2010 | 26 August 2010 | 26 August 2010 |
| NI-cold | 10 February 2011 | 10 February 2011 | 10 February 2011 |
| NI-cold | 07 April 2011 | 07 April 2011 | 07 April 2011 |
| I-warm | 15 June 2011 | 15 June 2011 | 15 June 2011 |
| I-warm | 16 September 2011 | 09 September 2011 | 09 October 2011 |
| NI-cold | 07 December 2011 | 07 December 2011 | 07 December 2011 |
| NI-cold | 20 March 2012 | 13 March2012 | 13 March 2012 |
| I-warm | 10 September 2012 | 03 September 2012 | 10 September 2012 |
| NI-cold | 13 December 2012 | 13 December 2012 | 13 December 2012 |
| NI-cold | 01 March 2013 | 28 February 2013 | 01 March 2013 |
| NI-cold | 18 April 2013 | 19 April 2013 | 18 April 2013 |
| I-warm | 29 August 2013 | 29 August 2013 | 28 August 2013 |
| I-warm | 03 October 2013 | 03 October 2013 | 04 October 2013 |
| NI-cold | 05 December 2013 | 05 December 2013 | 06 December 2013 |
| I-warm | 05 September 2014 | 05 September 2014 | 04 September 2014 |
| NI-cold | 03 November 2014 | 03 November 2014 | 03 November2014 |
| NI-cold | 12 February 2015 | 11 February 2015 | 12 February 2015 |
| I-warm | 13 July 2015 | 13 July 2015 | 15 July 2015 |
| I-warm | 03 August 2015 | 03 August 2015 | 04 August 2015 |
| I-warm | 24 August 2015 | 24 August 2015 | 24 August 2015 |

**Table S2.** Values (average ± standard deviation) of the 33 Indicators of Hydrological Alteration (IHA, Richter et al., 1996) calculated on the Ticino River flows for the three sampling sites (IF1, MF1, MF2) for the period 2010–2015.

| IHA | IF1 | MF1 | MF2 |
|---|---|---|---|
| January | 57 ± 53 | 50 ± 48 | 35 ± 48 |
| February | 62 ± 89 | 56 ± 88 | 43 ± 82 |
| March | 89 ± 120 | 86 ± 125 | 67 ± 102 |
| April | 78 ± 70 | 72 ± 69 | 56 ± 63 |
| May | 313 ± 235 | 306 ± 235 | 272 ± 194 |
| June | 158 ± 109 | 147 ± 109 | 135 ± 109 |
| July | 75 ± 65 | 65 ± 63 | 55 ± 59 |
| August | 67 ± 111 | 61 ± 110 | 40 ± 73 |
| September | 29 ± 6 | 25 ± 5 | 10 ± 3 |
| October | 54 ± 50 | 49 ± 49 | 38 ± 54 |
| November | 255 ± 389 | 249 ± 389 | 197 ± 318 |
| December | 69 ± 55 | 62 ± 52 | 48 ± 68 |
| 1-day min | 17 ± 2 | 13 ± 2 | 5 ± 1 |
| 3-day min | 18 ± 3 | 13 ± 2 | 6 ± 1 |
| 7-day min | 20 ± 7 | 16 ± 7 | 6 ± 1 |
| 30-day min | 22 ± 7 | 17 ± 7 | 8 ± 1 |
| 90-day min | 45 ± 41 | 39 ± 41 | 24 ± 25 |
| 1-day max | 907 ± 466 | 896 ± 469 | 735 ± 314 |
| 3-day max | 880 ± 455 | 871 ± 457 | 714 ± 320 |
| 7-day max | 830 ± 451 | 819 ± 454 | 672 ± 317 |
| 30-day max | 546 ± 297 | 537 ± 298 | 458 ± 235 |
| 90-day max | 280 ± 140 | 272 ± 139 | 235 ± 120 |
| Zero days | - | - | - |
| Base flow | 0.16 ± 0.05 | 0.13 ± 0.04 | 0.07 ± 0.04 |
| Date min | 210 ± 28 | 159 ± 27 | 172 ± 72 |
| Date max | 194 ± 82 | 229 ± 90 | 195 ± 84 |
| Lo pulse # | 6 ± 3 | 4 ± 1 | 14 ± 3 |
| Lo pulse L | 10 ± 7 | 8 ± 6 | 3 ± 1 |
| Hi pulse # | 9 ± 4 | 9 ± 4 | 8 ± 4 |
| Hi pulse L | 7 ± 2 | 7 ± 3 | 8 ± 2 |
| Rise rate | 8 ± 8 | 25 ± 7 | 7 ± 5 |
| Fall rate | −16 ± 7 | −28 ± 6 | −12 ± 8 |
| Reversals | 91 ± 38 | 63 ± 21 | 118 ± 30 |

**Table S3.** Values (average ± standard deviation) of the water physico-chemical parameters measured at the three study sites (IF1, MF1, MF2) on each benthos sampling date (see Table S1). T = temperature, DO = dissolved oxygen concentration (mg $L^{-1}$) and saturation (%), EC = electrical conductivity, $NH_4^+$–N = concentration of ammonia nitrogen, $NO_3^-$–N = concentration of nitrate nitrogen, TN = concentration of total nitrogen, TP = concentration of total phosphorus, COD = chemical oxygen demand, $BOD_5$ = biochemical oxygen demand in five days.

| Parameter | IF1 | MF1 | MF2 |
|---|---|---|---|
| T (°C) | 15.3 ± 6.4 | 15.9 ± 6.6 | 15.9 ± 7.3 |
| DO (mg $L^{-1}$) | 10.3 ± 1.8 | 10.3 ± 2.2 | 11.7 ± 2.2 |
| DO (%) | 102 ± 10 | 103 ± 13 | 118 ± 22 |
| EC (µS $cm^{-1}$) | 172 ± 29 | 162 ± 24 | 179 ± 27 |
| pH | 7.8 ± 0.6 | 8.1 ± 0.6 | 8.4 ± 0.7 |
| $NH_4^+$–N (mg $L^{-1}$) | 0.024 ± 0.014 | 0.026 ± 0.013 | 0.033 ± 0.022 |
| $NO_3^-$–N (mg $L^{-1}$) | 0.87 ± 0.23 | 0.65 ± 0.16 | 0.85 ± 0.18 |
| TN (mg $L^{-1}$)* | 1.37 ± 0.44 | 1.19 ± 0.33 | 1.32 ± 0.36 |
| TP (mg $L^{-1}$) | 0.022 ± 0.022 | 0.024 ± 0.017 | 0.030 ± 0.016 |
| COD (mg $L^{-1}$)* | 5.92 ± 1.84 | 6.51 ± 4.92 | 6.34 ± 2.30 |
| $BOD_5$ (mg $L^{-1}$) | 0.99 ± 0.46 | 1.32 ± 1.89 | 1.04 ± 0.52 |

*TN and COD were mostly below the detection limit (0.9 mg $L^{-1}$ for TN and 4.9 mg $L^{-1}$ for COD).

**Table S4.** Average values of the hydrological variables calculated for the pre-sampling periods at the three sampling sites (IF1, MF1, MF2) during I-warm (irrigation and warm) and NI-cold (non-irrigation and cold) periods. $Q_M$: mean flow, $Q_{CV}$: coefficient of variation, $Q_{min}$: minimum flow, $Q_{max}$: maximum flow, $Q_{P25}$, $Q_{P50}$, and $Q_{P75}$: 25th, 50th and 75th flow percentiles, $\Delta Q$: $Q_{max}$-$Q_{min}$, $Q_S$: mean flow of the sampling date; $INC_M$ and $INC_{Max}$: mean and maximum increase of flows between two consecutive days; $DEC_M$ and $DEC_{Max}$: mean and maximum decrease, $INC_L$ and $DEC_L$: last increase and decrease; $FRE_{LF}$: n. of low-flow days; $FRE_{HF}$: n. of high flow days; $DUR_{LF\text{-}max}$: maximum duration of low-flows; $DUR_{LF\text{-}last}$ : duration of the low flow period immediately before the sampling; $TIM_{HF}$: n. of days from the last high-pulse day.

| | | I-warm | | | NI-cold | | |
|---|---|---|---|---|---|---|---|
| **Group** | **Variable** | **IF1** | **MF1** | **MF2** | **IF1** | **MF1** | **MF2** |
| Magnitude | $Q_M$ | 110 | 103 | 81 | 99 | 92 | 67 |
| | $Q_{CV}$ | 1.09 | 1.19 | 1.25 | 1.10 | 1.16 | 1.33 |
| | $Q_{min}$ | 18 | 13 | 6 | 24 | 20 | 7 |
| | $Q_{max}$ | 447 | 448 | 345 | 552 | 529 | 399 |
| | $Q_{P25}$ | 24 | 17 | 11 | 27 | 22 | 9 |
| | $Q_{P50}$ | 63 | 54 | 40 | 35 | 32 | 20 |
| | $Q_{P75}$ | 161 | 153 | 126 | 108 | 99 | 81 |
| | $\Delta Q$ | 429 | 435 | 339 | 528 | 509 | 392 |
| | $Q_S$ | 25 | 20 | 10 | 27 | 21 | 9 |
| Rate of change | $INC_M$ | 58 | 67 | 40 | 54 | 65 | 42 |
| | $INC_{Max}$ | 262 | 271 | 201 | 240 | 232 | 185 |
| | $DEC_M$ | 41 | 41 | 30 | 39 | 40 | 31 |
| | $DEC_{Max}$ | 137 | 140 | 113 | 105 | 106 | 91 |
| | $INC_L$ | 48 | 48 | 32 | 5 | 33 | 9 |
| | $DEC_L$ | 26 | 23 | 25 | 36 | 38 | 28 |
| Frequency | $FRE_{LF}$ | 41 | 45 | 51 | 50 | 52 | 59 |
| | $FRE_{HF}$ | 27 | 28 | 37 | 18 | 17 | 22 |
| Duration | $DUR_{LF\text{-}max}$ | 28 | 39 | 42 | 52 | 56 | 62 |
| | $DUR_{LF\text{-}last}$ | 17 | 32 | 35 | 35 | 36 | 37 |
| Timing | $TIM_{HF}$ | 37 | 36 | 36 | 44 | 45 | 41 |

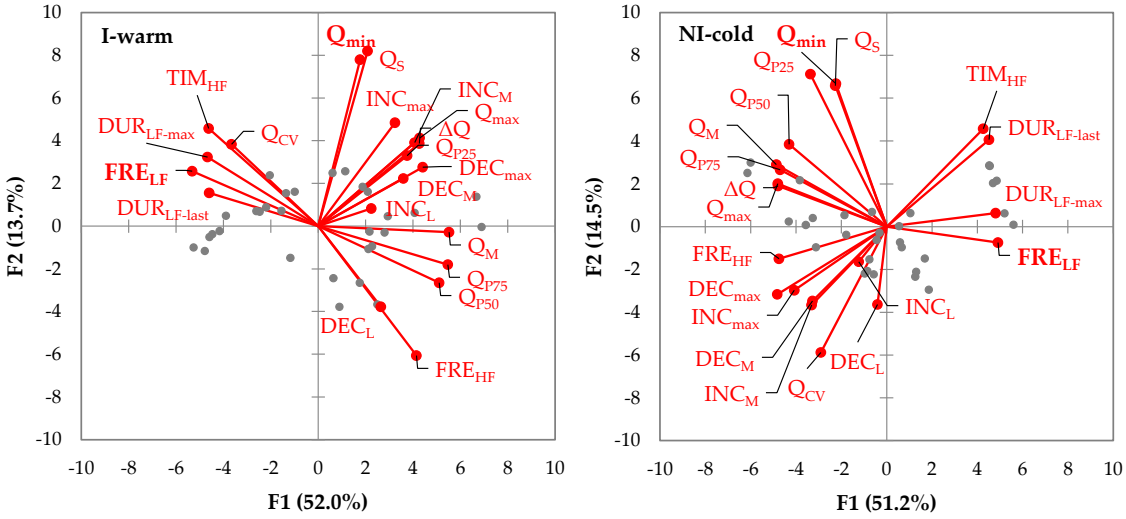


**Figure S1.** Principal component analysis (PCA) of the hydrological variables calculated for the pre-sampling periods at the three sampling sites (IF1, MF1, MF2) during I-warm (irrigation and warm) and NI-cold (non-irrigation and cold) periods. $Q_M$: mean flow, $Q_{CV}$: coefficient of variation, $Q_{min}$: minimum flow, $Q_{max}$: maximum flow, $Q_{P25}$, $Q_{P50}$, and $Q_{P75}$: 25th, 50th and 75th flow percentiles, $\Delta Q$: $Q_{max}$-$Q_{min}$, $Q_S$: mean flow of the sampling date; $INC_M$ and $INC_{Max}$: mean and maximum increase of flows between two consecutive days; $DEC_M$ and $DEC_{Max}$: mean and maximum decrease, $INC_L$ and $DEC_L$: last increase and decrease; $FRE_{LF}$: n. of low-flow days; $FRE_{HF}$: n. of high flow days; $DUR_{LF\text{-}max}$: maximum duration of low-flows; $DUR_{LF\text{-}last}$ : duration of the low flow period immediately before the sampling; $TIM_{HP}$: n. of days from the last high-pulse day.