Sediment management in channel networks: from measurements to best practices

Bozen-Bolzano, November 8-9, 2018

Sediment transport in high-elevation basins and future trends

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Outlook

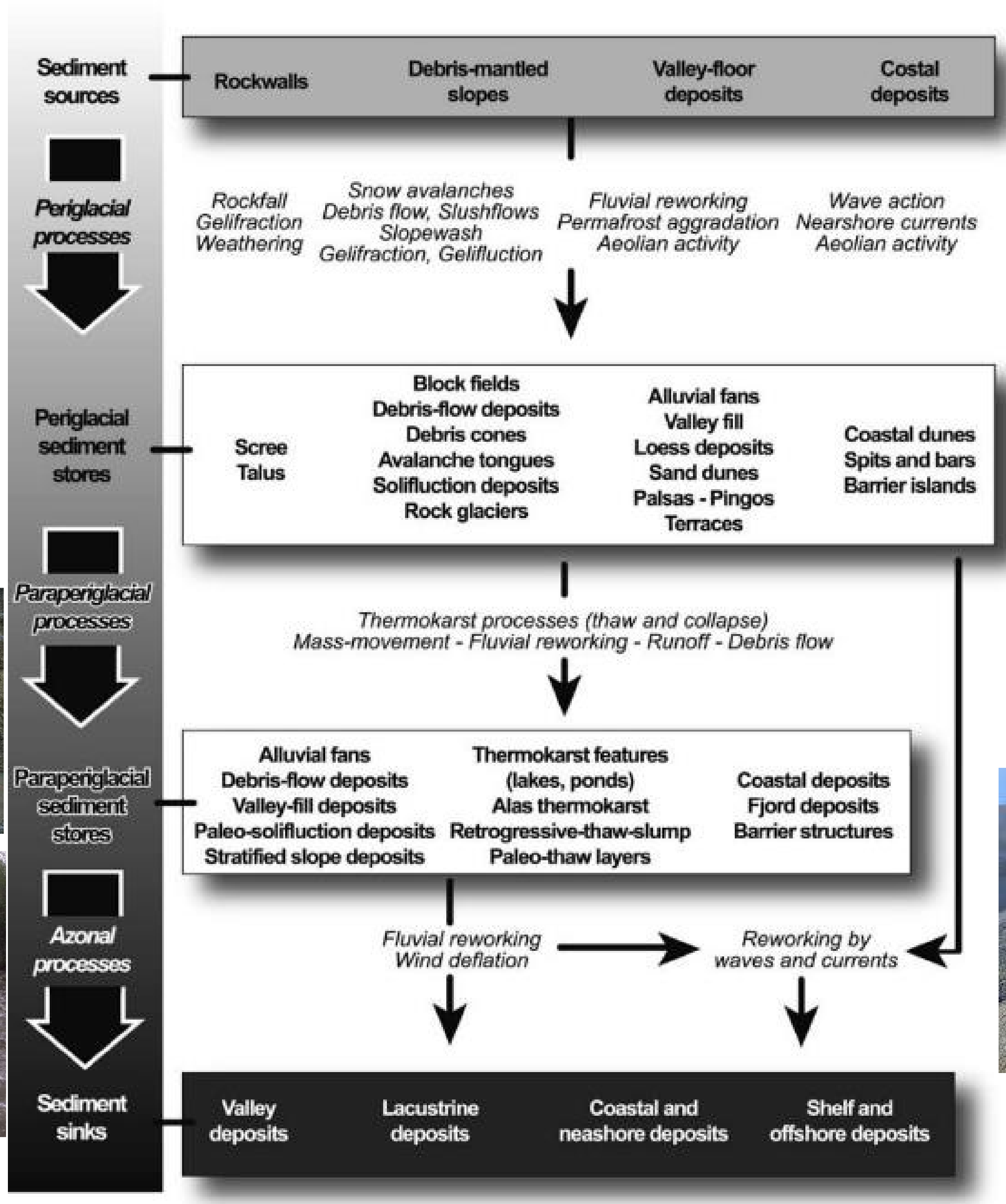
- Overview of recent evidence on temporal dynamics of suspended and bedload transport, with special emphasis on mountain streams
- Complexities and non-linearities in sediment transport
- Long-term dynamics of sediment transport
- Short-term dynamics of sediment transport
- Hysteresis during hydrographs
- Challenges and perspectives

Rivers as “conveyor belts” for sediments

Erosion

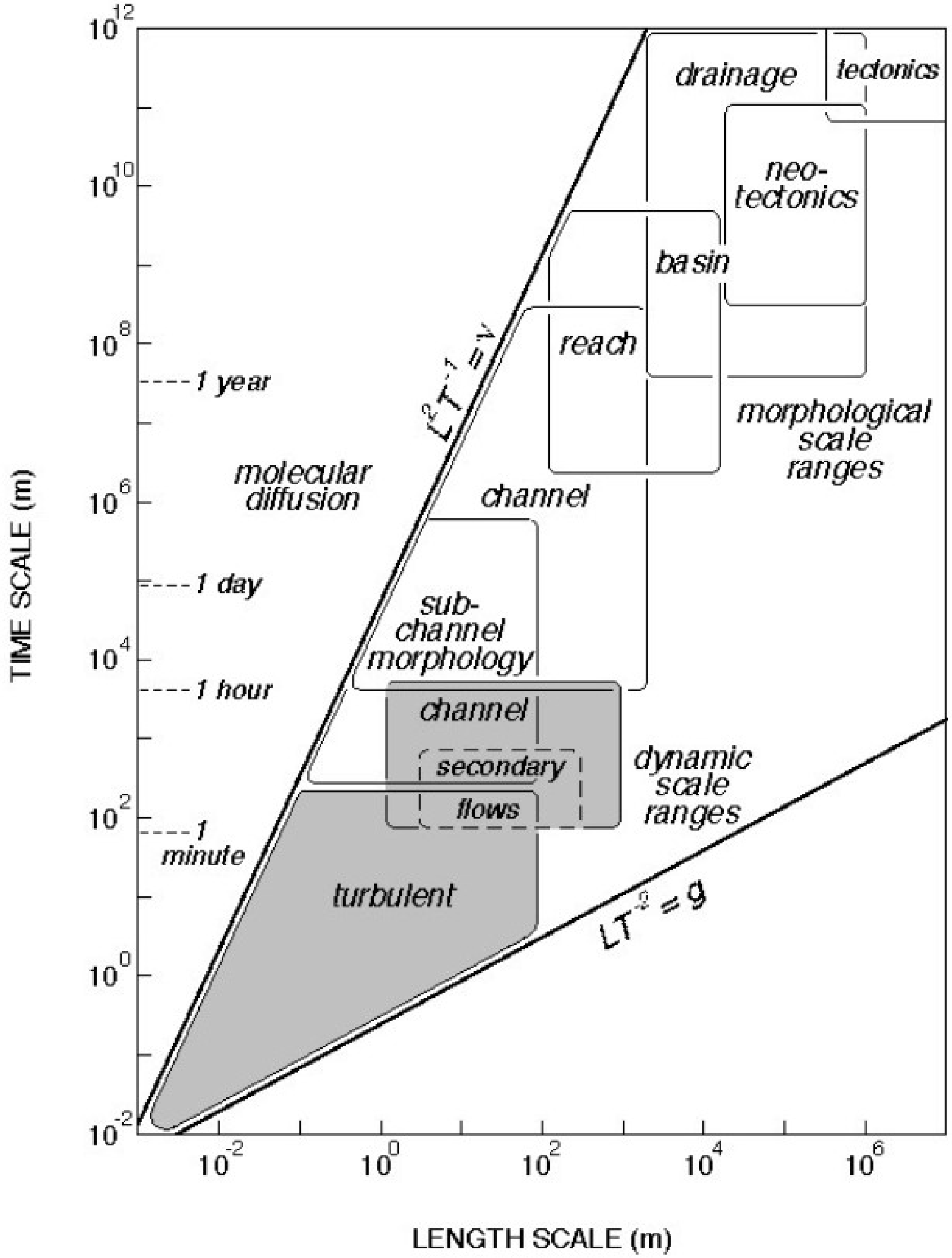
Deposition

Sediment cascade at the basin scale



Mercier (2009)

Sediment cascade at the basin scale



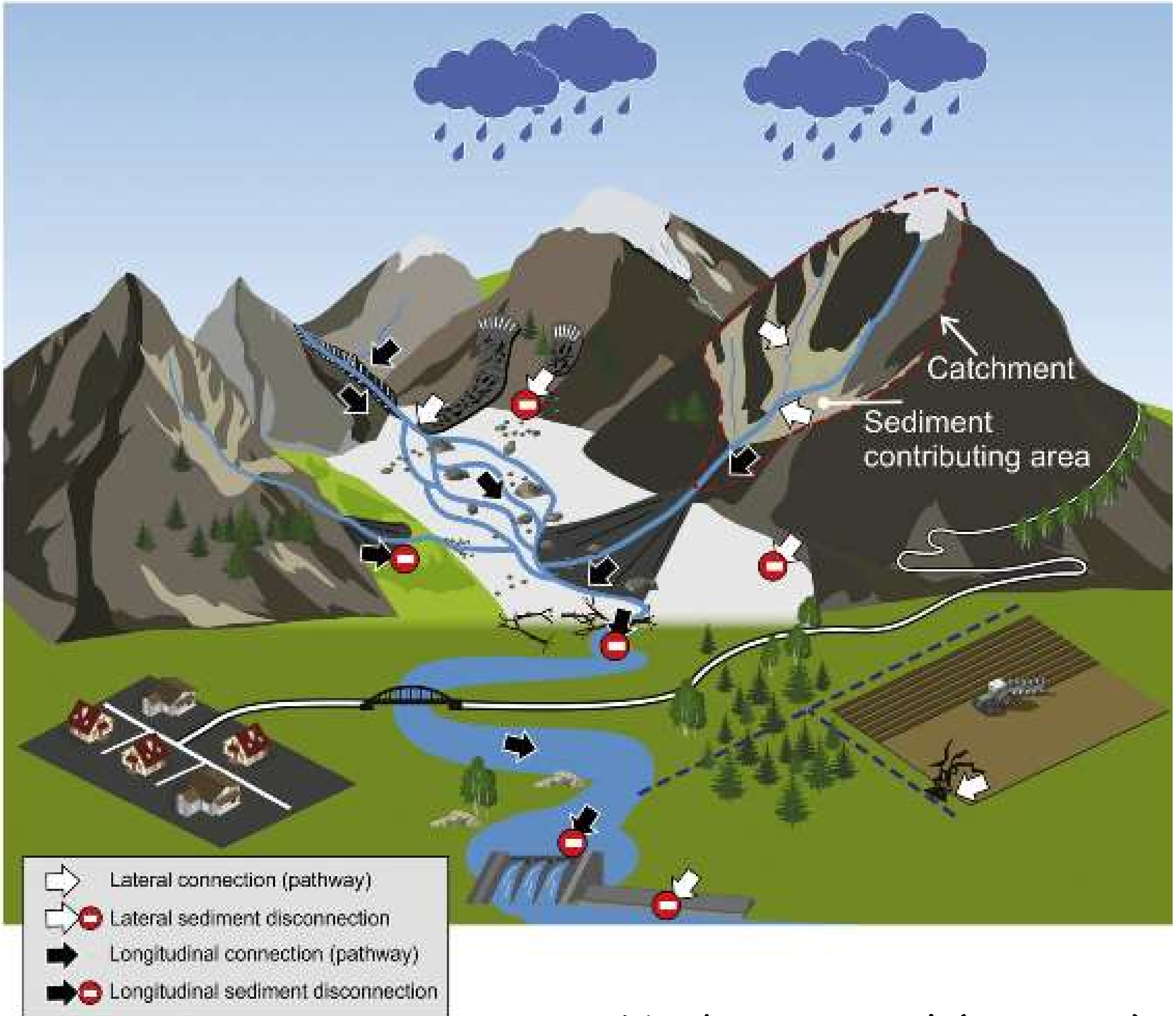
Church (2007)

Sediment sources at the basin scale

Sediment (dis-) connectivity

Depends on

- Forcing factors
- Intrinsic properties
- Geomorphic processes
- Human impacts

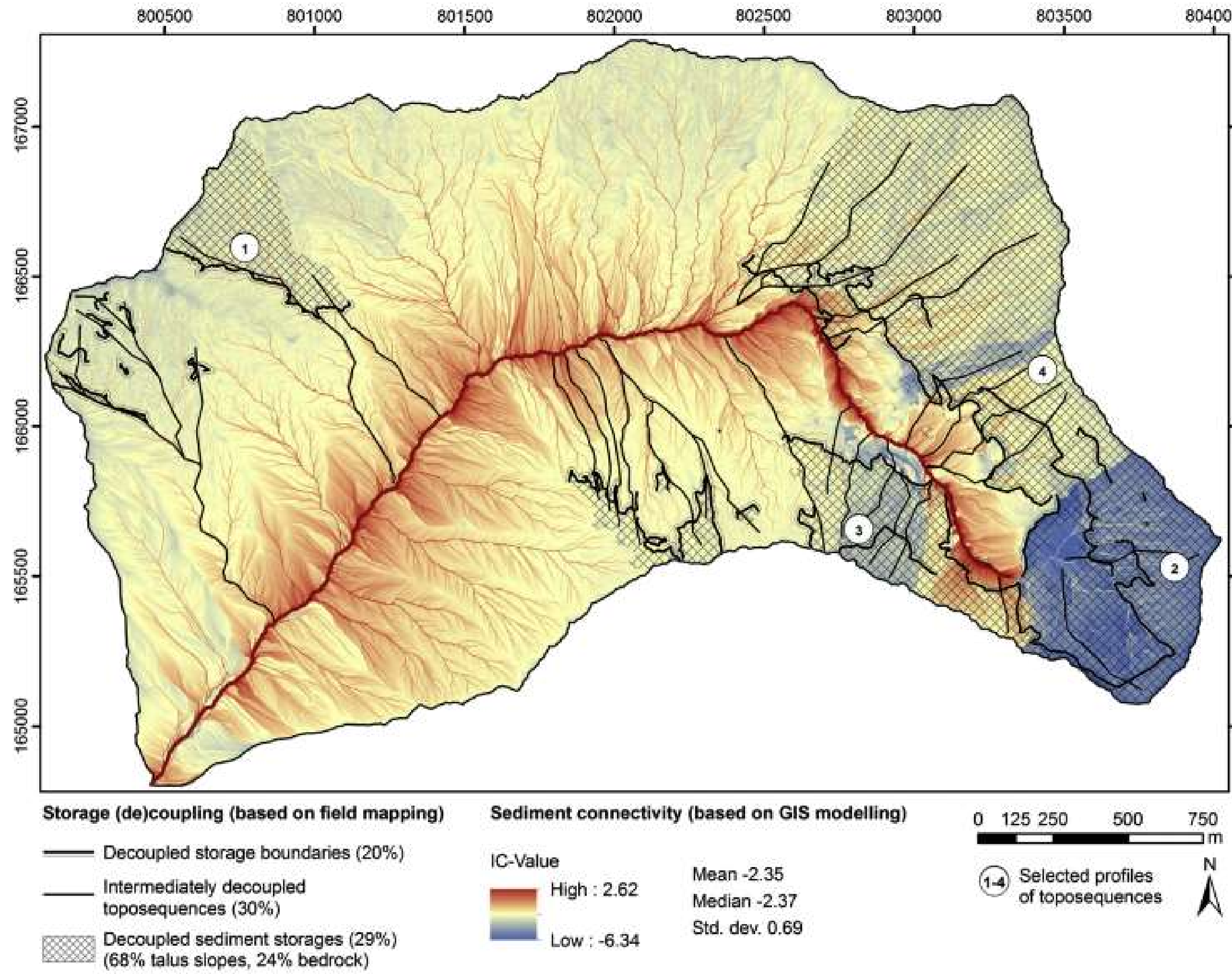


Heckmann et al (in press)

Sediment connectivity

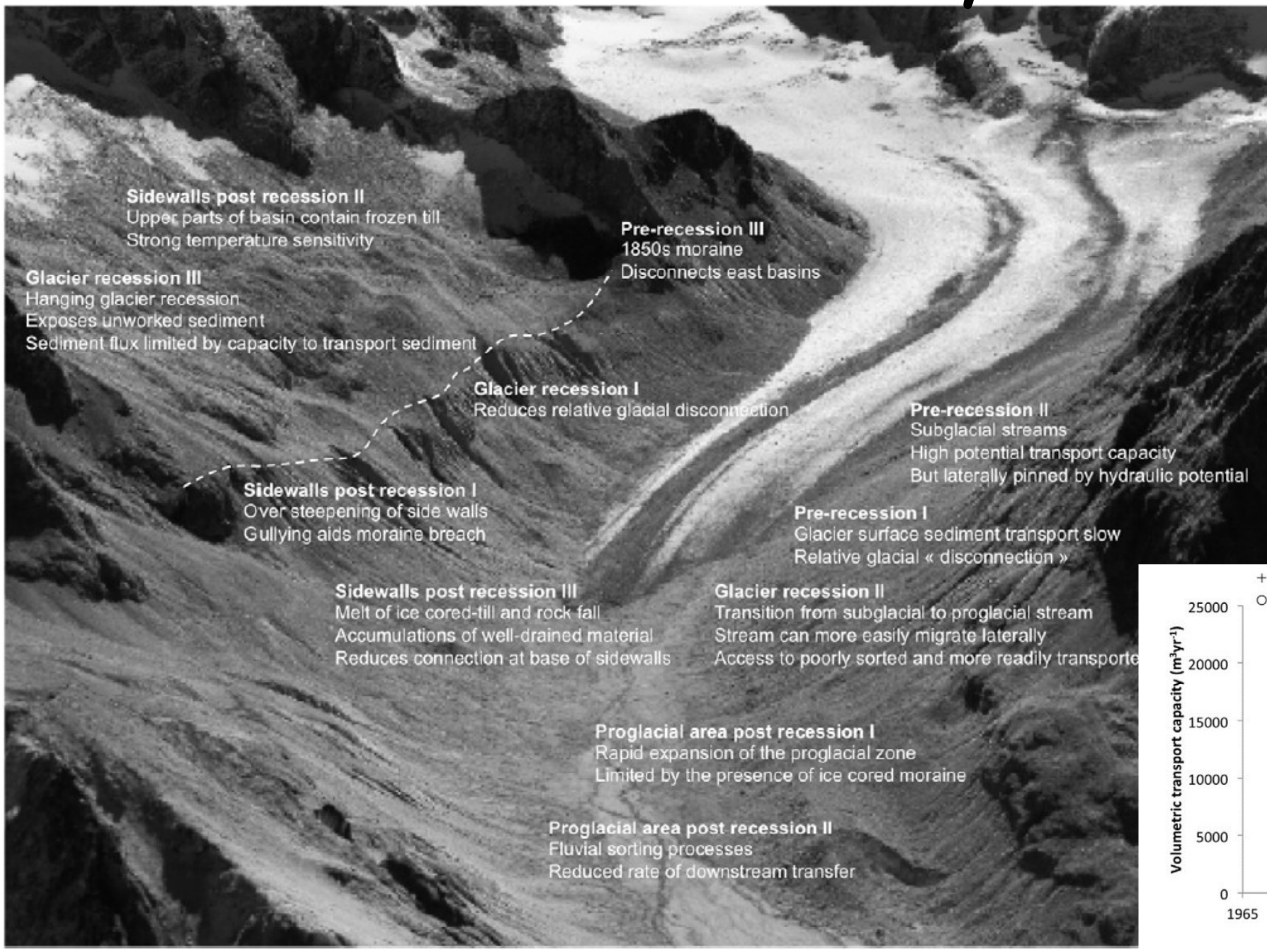
Sediment (dis-) connectivity

Connectivity Index (Cavalli et al., 2013) combined with geomorphic field mapping

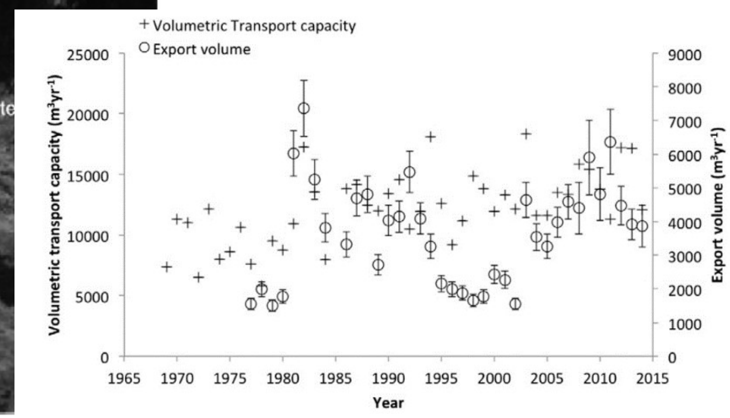


Meßenzehl et al (2014)
Heckmann et al (in press)

Sediment connectivity



Lane et al (2017)

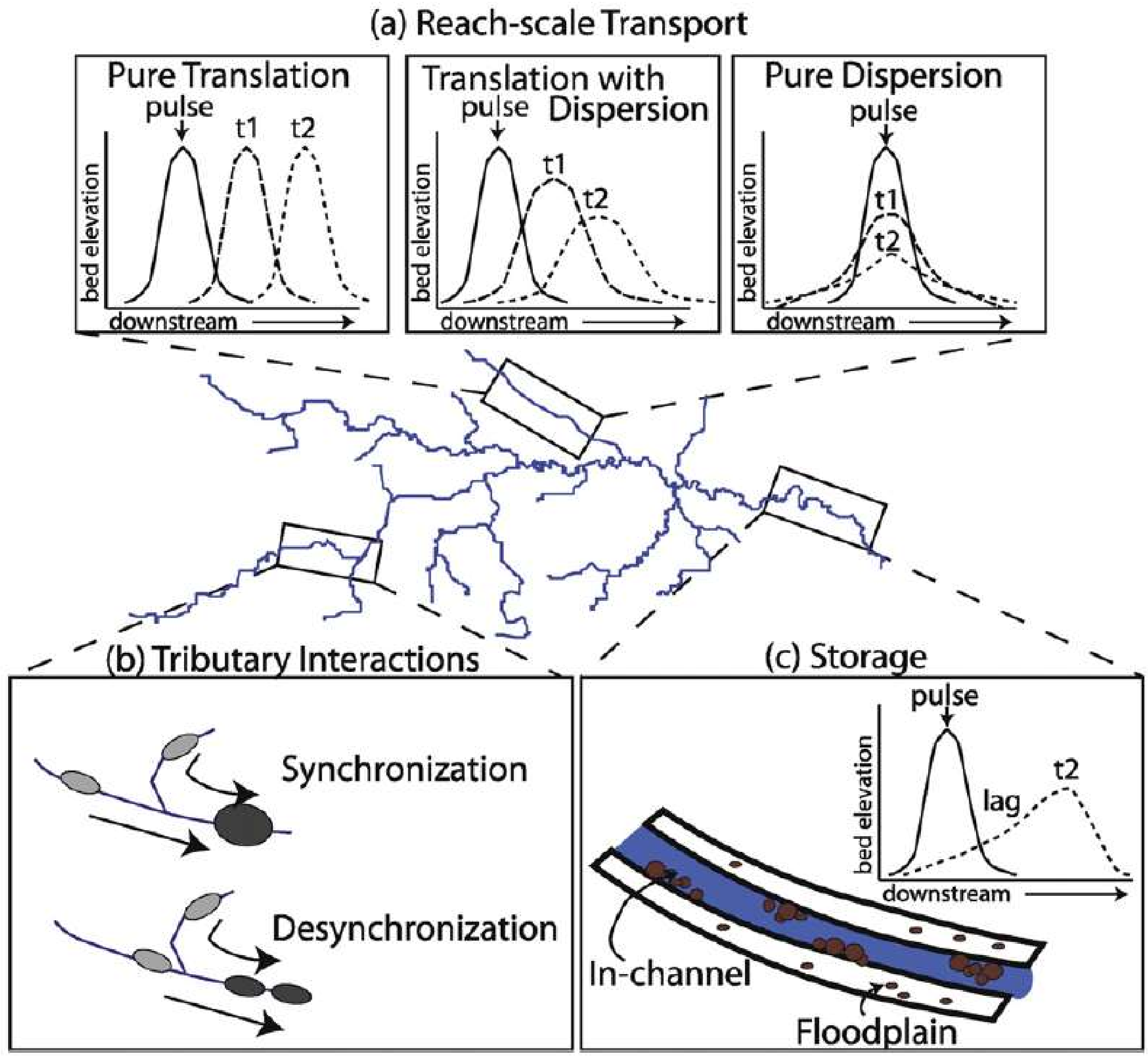


- Retreating glacier does not necessarily increase basin-scale sediment connectivity
- River reworking of glacial till reduces sediment transfer through the proglacial zone.

Patterns of sediment accumulation

Sediment pulse movement

- reach-scale dynamics
- tributary interactions
- in-channel and floodplain storage



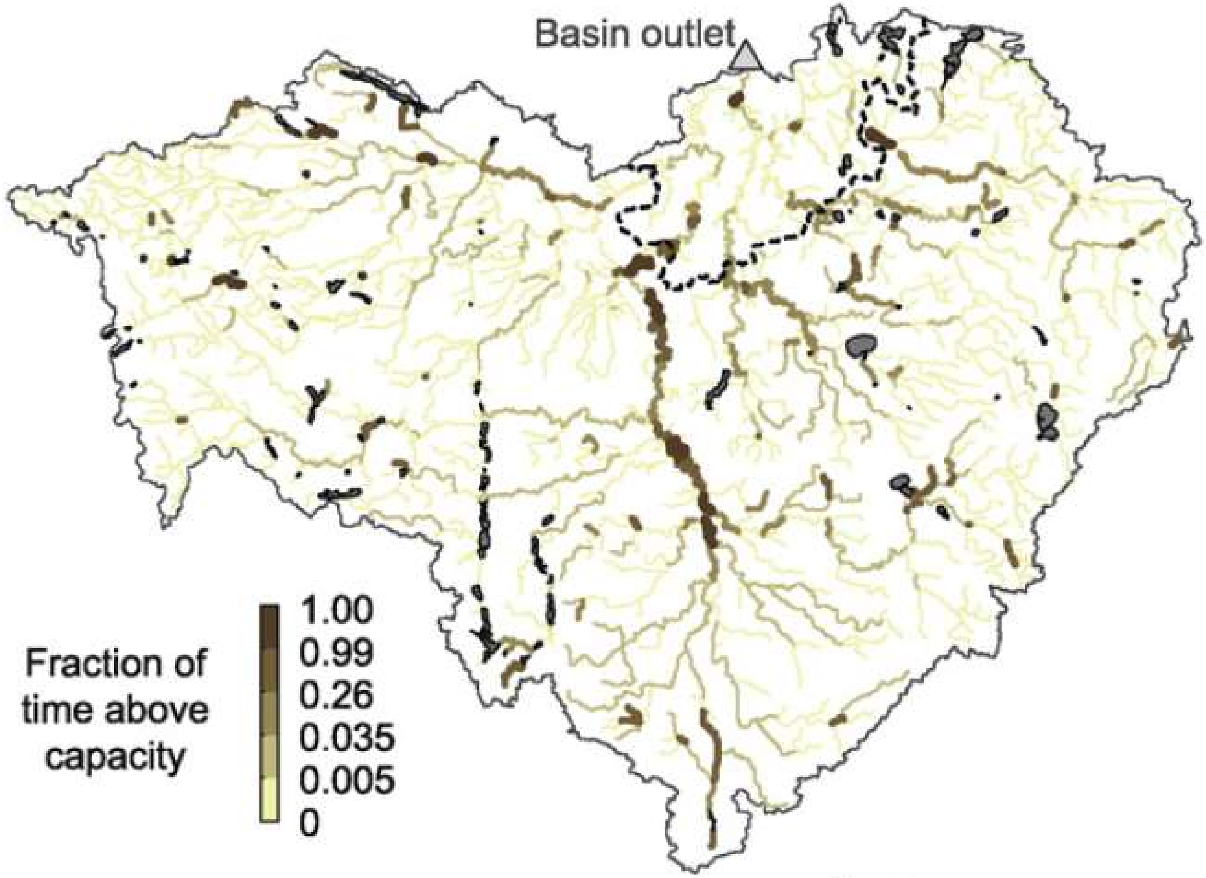
Gran & Czuba (2017)

Patterns of sediment accumulation

Importance of

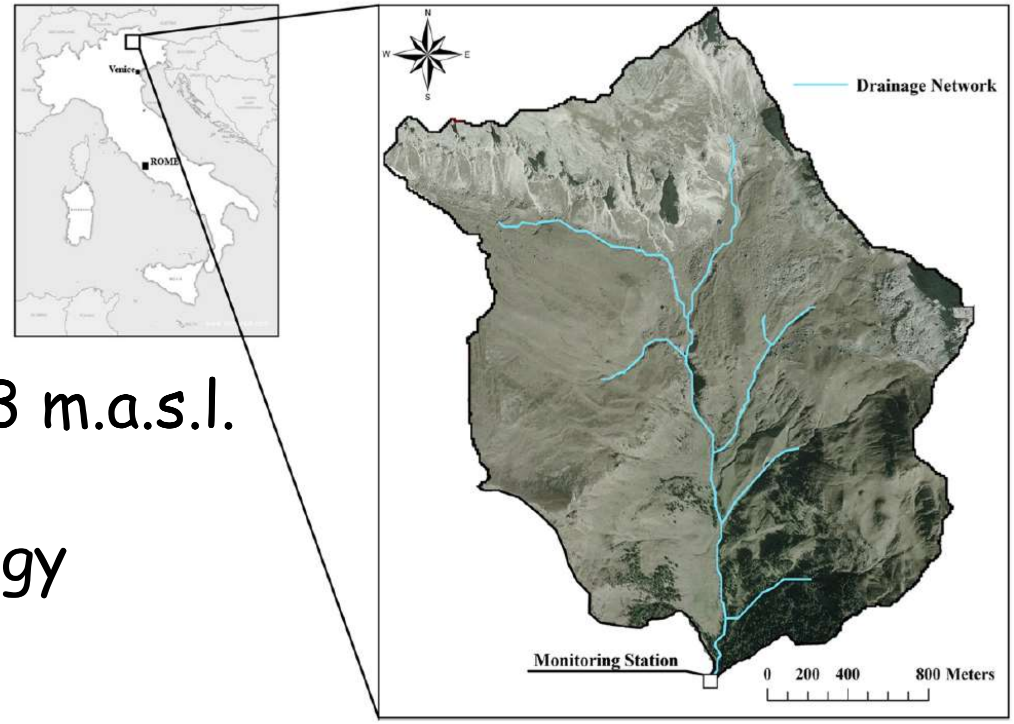
- Network geometry
- spatial pattern of transport capacity
- Location of sediment sources

a) Scenario 4: *Sediment budget inputs, in-channel storage, distributed pulse*

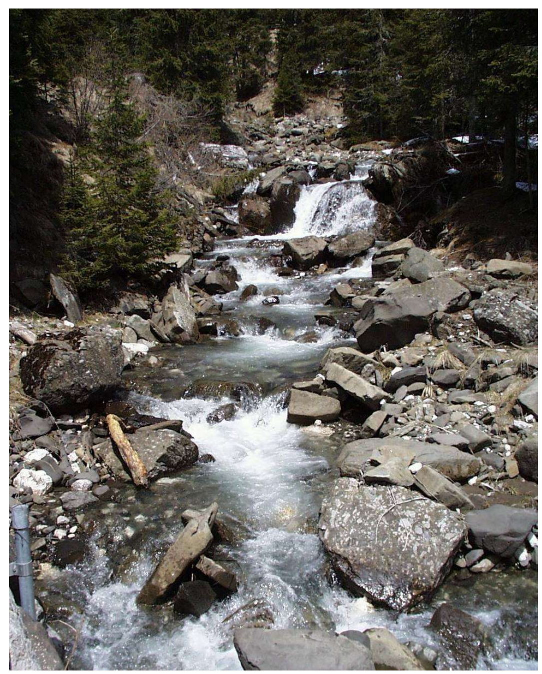


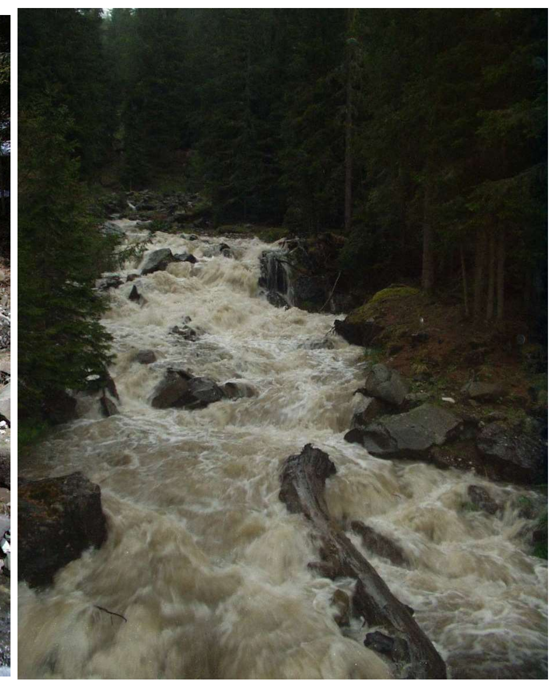
Gran & Czuba (2017)

Rio Cordon (Italy)



Area 5 km^2
Mean slope 0.136
Elevation 1763 – 2763 m.a.s.l.
D_{50} = 90 mm; D_{84} = 260 mm
Step-pool/cascade morphology





Lenzi et al. (2004)

Rio Cordon monitoring facility (since 1987)

- A grid separates coarse (>20mm) from fine sediment and water.
- Bedload is measured by ultrasonic sensors placed above a storage area

arpav

Lenzi et al. (2004)

Rio Cordon monitored events (1987-2017)

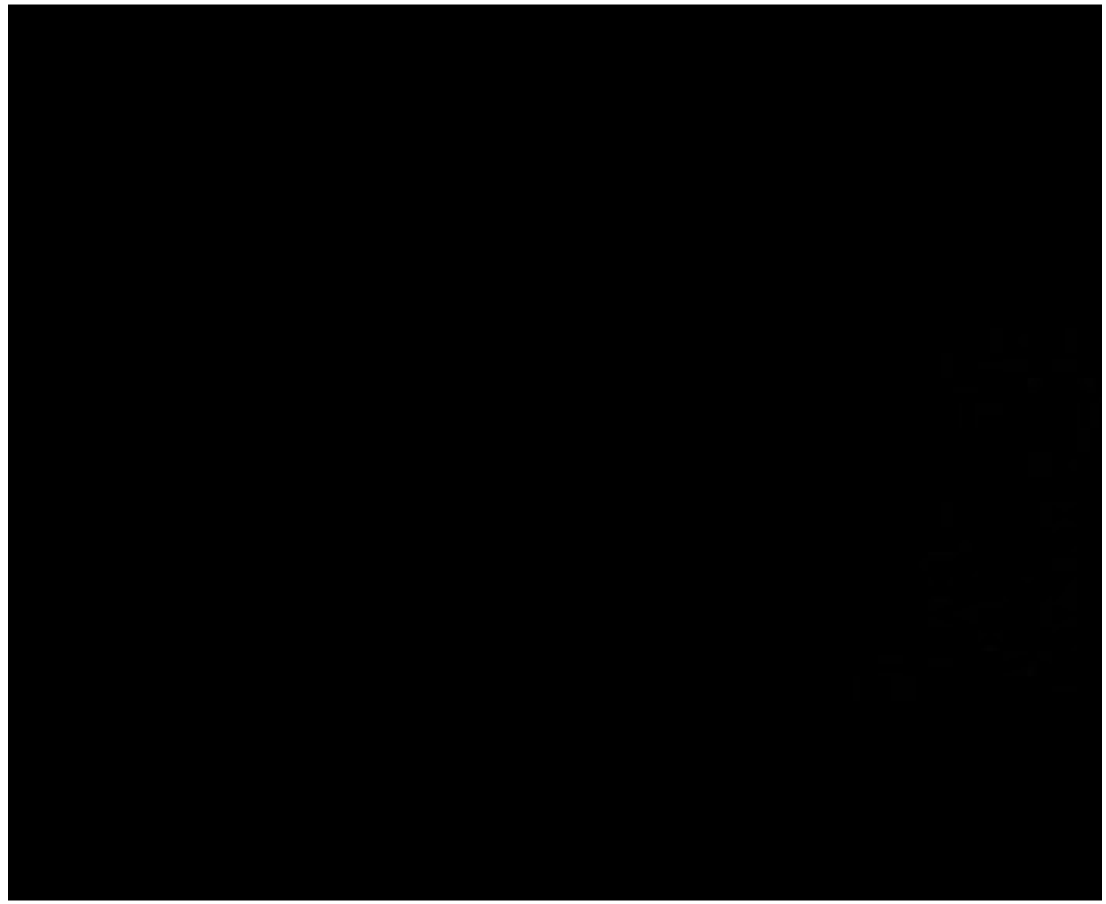
Characteristics of the floods recorded by the Rio Cordon monitoring station, since 1986: Q_{peak} is the peak of water discharge ($m^3 s^{-1}$); RI the recurrence interval (years); *BL* the bedload (tons); *SSL* is the suspended sediment load (tons); *TL* the total load amount (tons), BL_f is the bedload fraction on the total load transported; *ER* is the effective runoff volume ($10^3 m^3$); D_{16}, D_{50} and D_{84} are the percentiles of the grain size distribution concerning the bedload.

	Q_{peak} ($m^3 s^{-1}$)	RI (years)	*BL* (t)	*SSL* (t)	*TL* (t)	BL_f (fraction)	*ER* ($10^3 m^3$)	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)
11 October 1987	5.15	11.5	85.6	131.7	217.3	0.39	79.9	–	–	–
15 July 1988	2.43	2.0	–	–	–	–	–	–	–	–
3 July 1989	4.39	7.1	145.6	223.9	369.5	0.39	103.4	54	103	207
22 May 1990	0.85	1.0	–	–	–	–	–	–	–	–
17 June 1991	4.00	5.5	67.2	68.1	135.3	0.50	57.9	30	51	100
5 October 1992	2.91	2.7	15.5	4.8	20.3	0.76	21.5	22	43	111
2 October 1993	4.28	6.6	17.2	41.1	58.3	0.30	30.7	29	61	135
18 May 1994	1.79	1.4	1.7	2.7	4.4	0.39	5.4	21	33	52
14 September 1994	10.42	>100	1541.7	2435.1	3976.8	0.39	26.6	65	116	226
13 August 1995	2.72	2.4	10.3	98.3	108.6	0.09	1.8	–	–	–
16 October 1996	2.96	2.8	94.7	294.4	389.1	0.24	22.0	40	79	143
27 June 1997	1.46	1.2	–	–	–	–	–	–	–	–
7 October 1998	4.73	8.8	516.8	393.5	910.3	0.57	91.8	40	78	157
20 September 1999	3.65	4.4	32.7	50.9	83.6	0.39	10.4	32	54	98
13 October 2000	3.28	3.5	92.2	142.0	234.2	0.39	110.6	39	61	111
11 May 2001	1.46	1.2	137.8	1017.6	1155.4	0.12	8.5	33	48	69
20 July 2001	1.98	1.6	36.0	119.8	155.8	0.23	15.0	–	–	–
04 May 2002	2.29	1.8	47.2	123.0	170.2	0.28	29.4	39	59	99
16 November 2002	2.35	2.0	17.2	54.3	71.5	0.24	18.9	–	–	–
27 November 2002	2.77	2.5	119.0	373.7	492.7	0.24	70.3	26	44	78
03 May 2003	1.02	1.1	1.7	0.2	1.9	0.89	1.0	–	–	–
01 November 2004	2.05	1.6	7.9	7.6	15.5	0.51	–	25	38	62
6 October 2005	1.68	1.4	1.6	1.2	2.8	0.59	3.3	18	30	55
19 May 2006	1.28	1.1	1.2	5.1	6.3	0.19	1.0	–	–	–
24 May 2009	1.67	1.3	3.1	19.3	22.4	0.14	5.2	–	–	–
5 May 2010	1.82	1.5	1.4	14.2	15.6	0.09	3.7	–	–	–
8 June 2011	1.15	1.1	0.9	0.6	1.5	0.64	0.8	–	–	–
11 November 2012	2.10	1.7	24.4	60.8	85.4	0.29	4.6	23	38	70
17 May 2013	1.96	1.5	3.8	13.7	17.5	0.22	10.2	33	44	90
9 June 2014	2.06	1.7	113.0	76.8	189.8	0.60	16.6	24	41	64
5 November 2014	2.06	1.7	4.6	84.3	88.9	0.05	33.3	25	38	62

Rainato et al. (2017)

Rio Cordon – the 1994 event

14th Septermber 1994
TSL: 4000 t (1500 BL; 2500 SSL)
Qp: 10.4 $m^3\ s^{-1}$
Qs max: 157 kg s^{-1}
RI ≈ 100 years

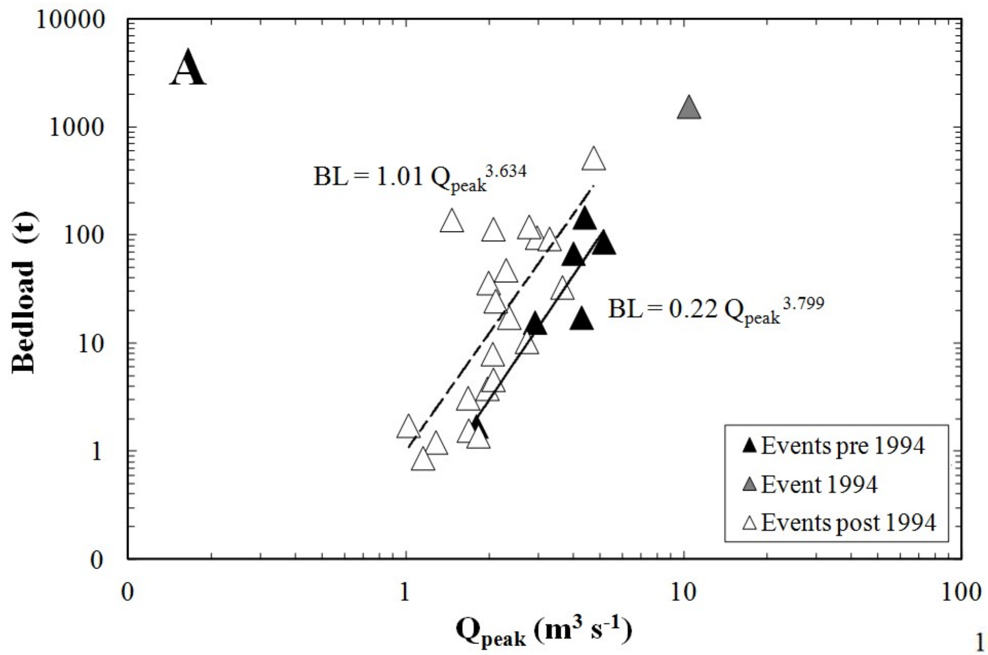


This flood transported 27% of TSL and 50% of BL over 29 years!

The 3 largest floods transported 40% of TSL and 70% of BL

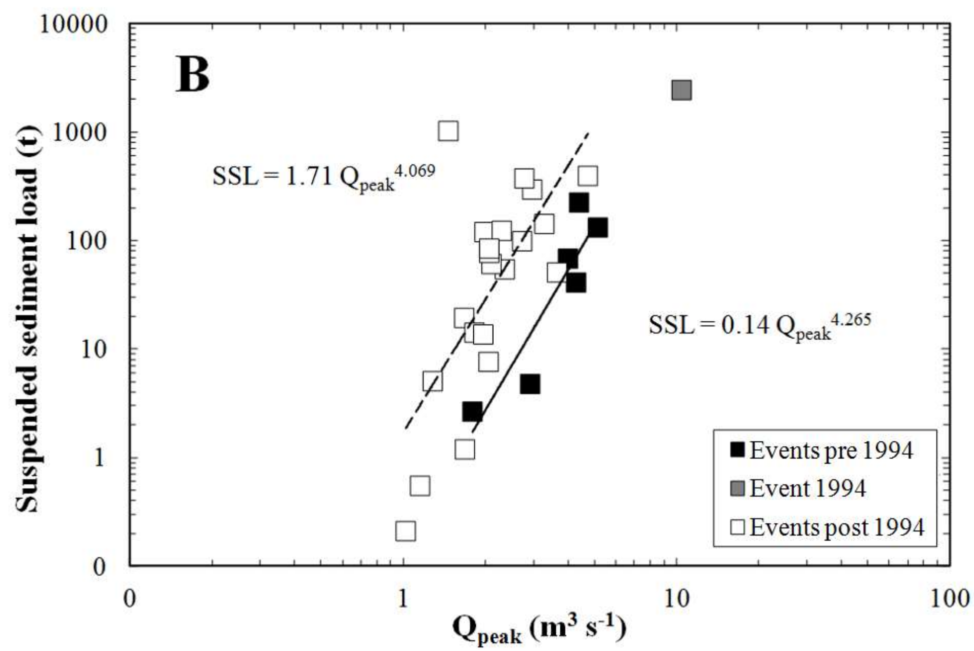
Rainato et al. (2017)

Rio Cordon - the legacy of a “big” event



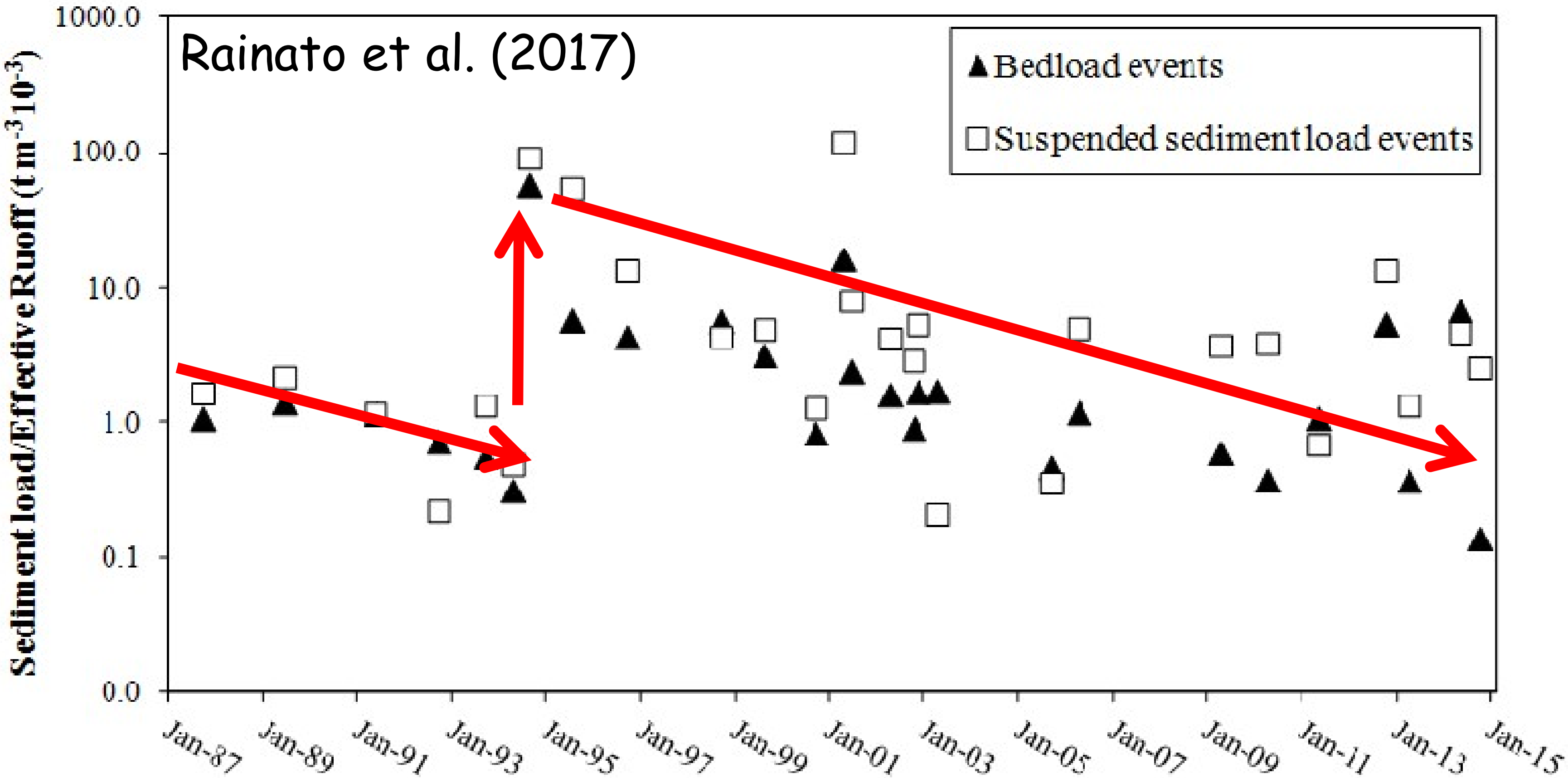
Higher bedload transport after the high-magnitude event

Higher suspended sediment transport after the high-magnitude event



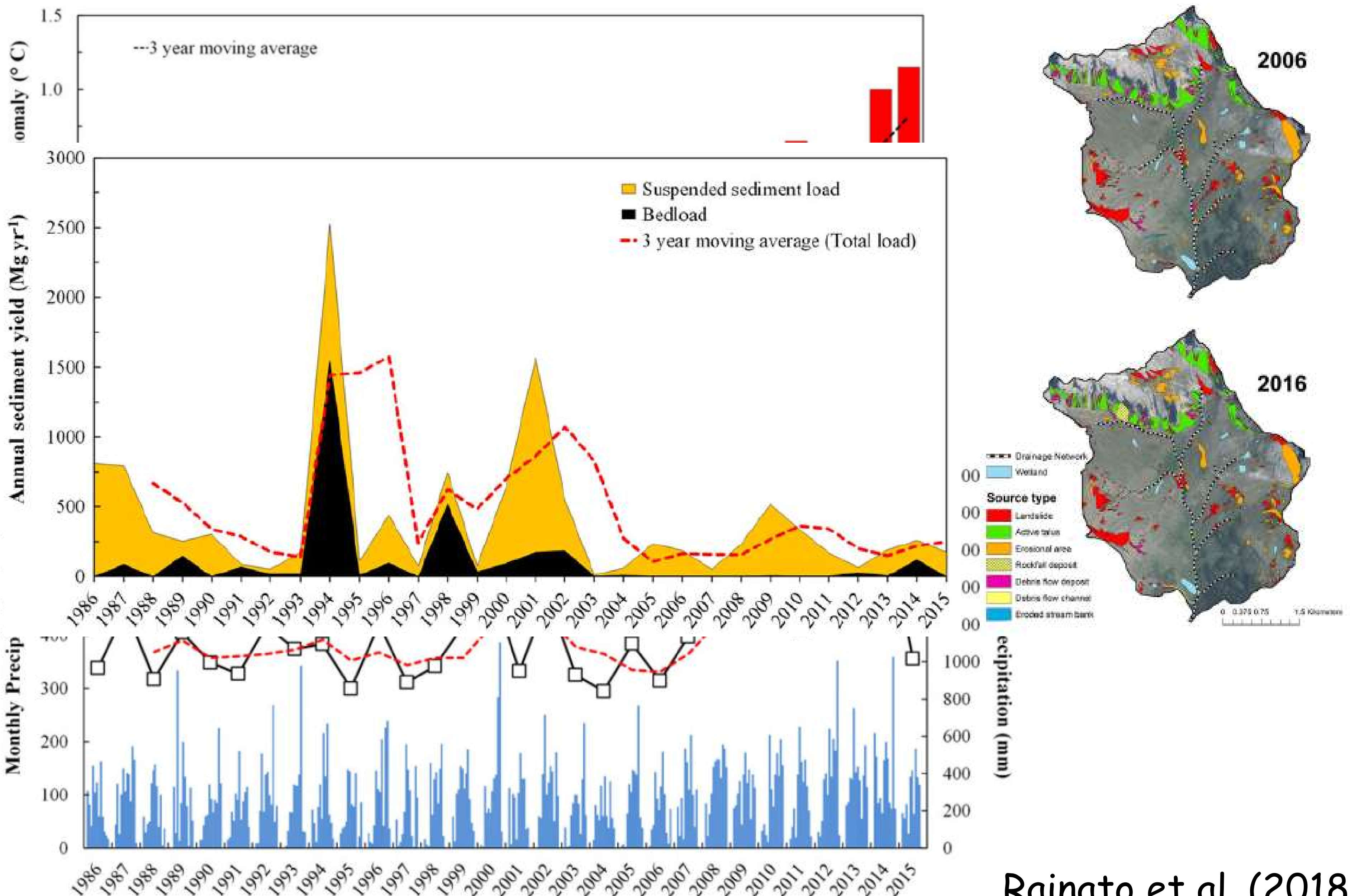
Rainato et al. (2017)

Rio Cordon – the legacy of a "big" event



- Supply-unlimited conditions for the exceptional flood;
- Higher transport efficiency after high magnitude flood
- Decreasing bedload efficiency over time
- Progressive armouring of the bed, stabilization of bedlforms, desactivaton of sediment sources

Rio Cordon – climate and sediment yield

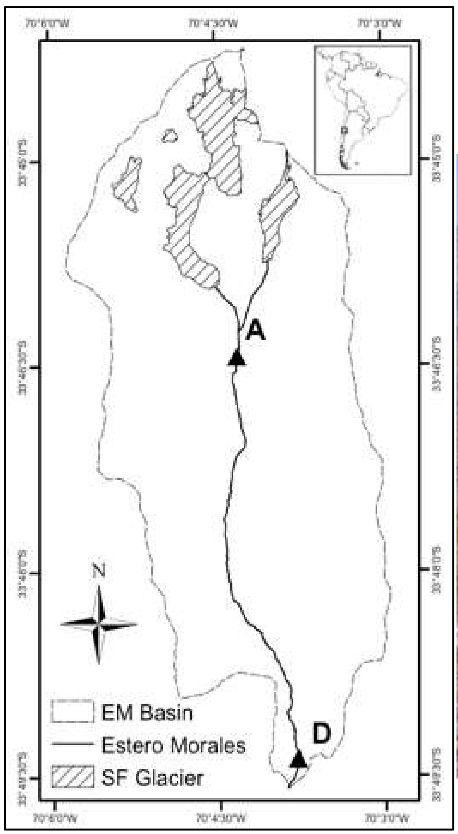


Rainato et al. (2018)


Photo curtesy Daniele Oss-Cazador

Estero Morales (Chilean Andes)

- 27 km^2
- 1850 to 3815 m.a.s.l.
- PP 574 mm; main runoff as snow- and glacier-melting
- San Francisco Glacier 1.8 km^2



Data collection

Continuous monitoring:

- Water stage;
- Turbidity
- Japanese acoustic pipe sensor for bedload

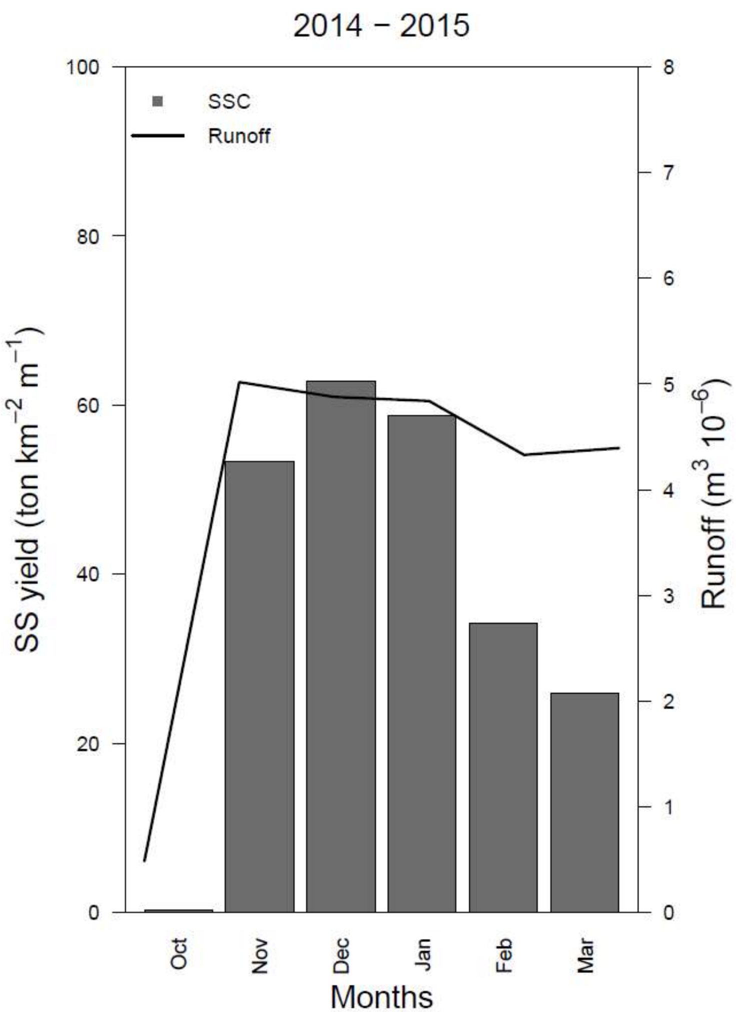
Calibration of the NTU and BL sensor

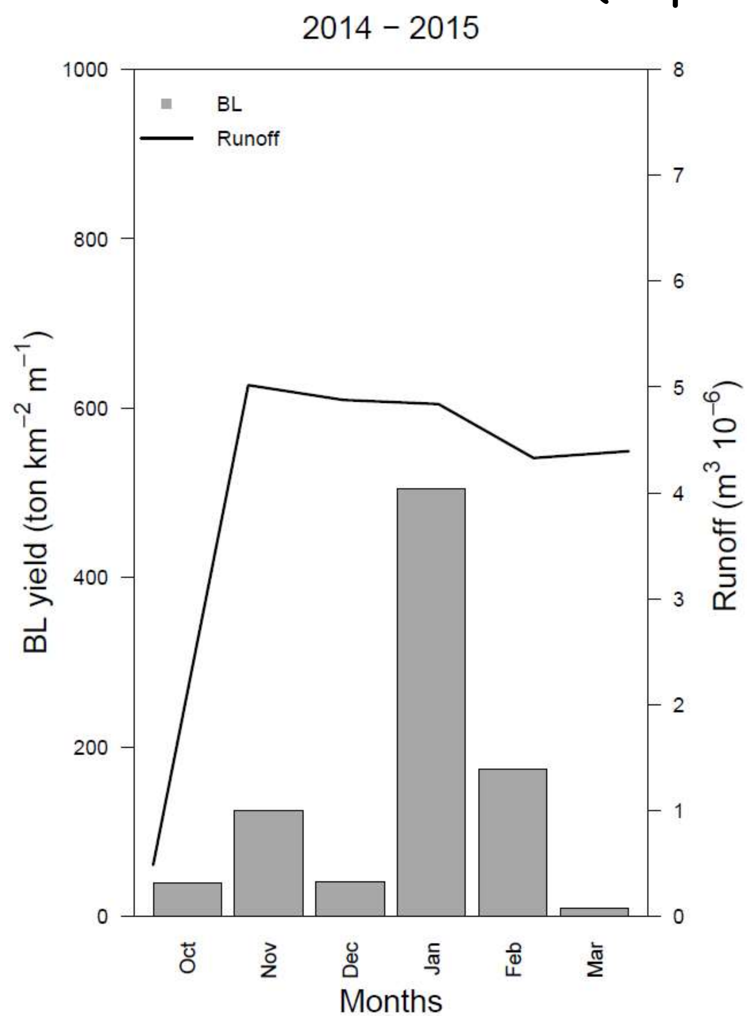
$$gm^{-1}s^{-1} = aI_{s\_c3}{}^{b} I_{s\_c4}{}^{c} I_{s\_c5}{}^{d}$$

Mao et al. (2016)

Monthly sediment yield

Carrillo & Mao
(in prep.)



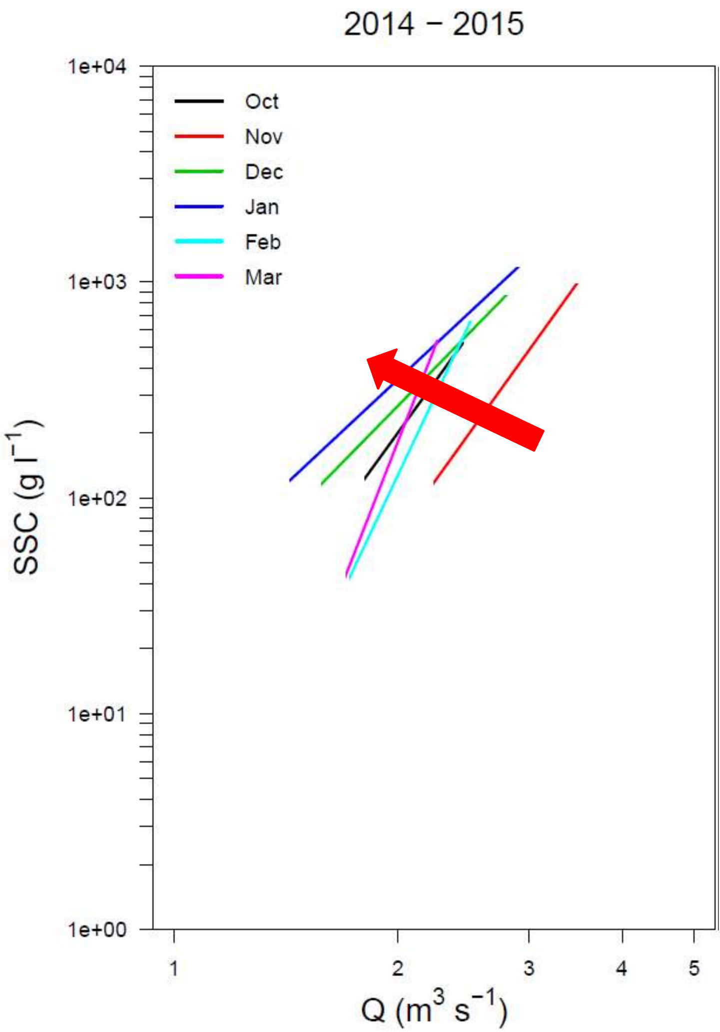


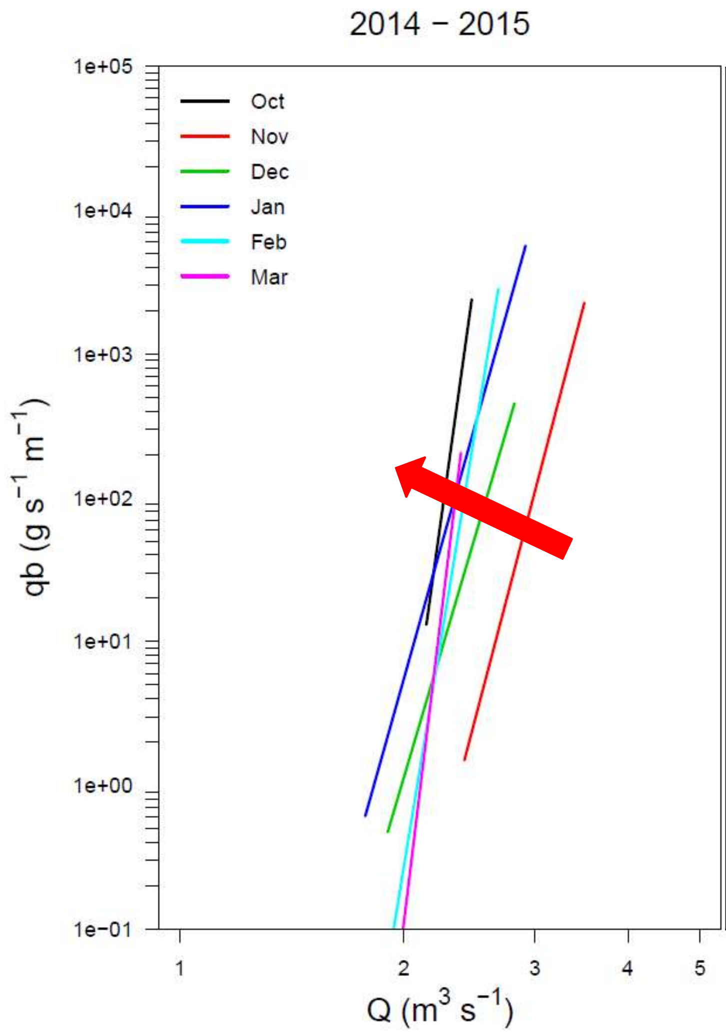
- ≈ 470 t year^{-1} km^{-2}
- Most SSL transported at early glacier melting period

- ≈ 100 t year^{-1} km^{-2} BL
- Most BL yield produced in January

Relationship Q - SSC and Q - BL

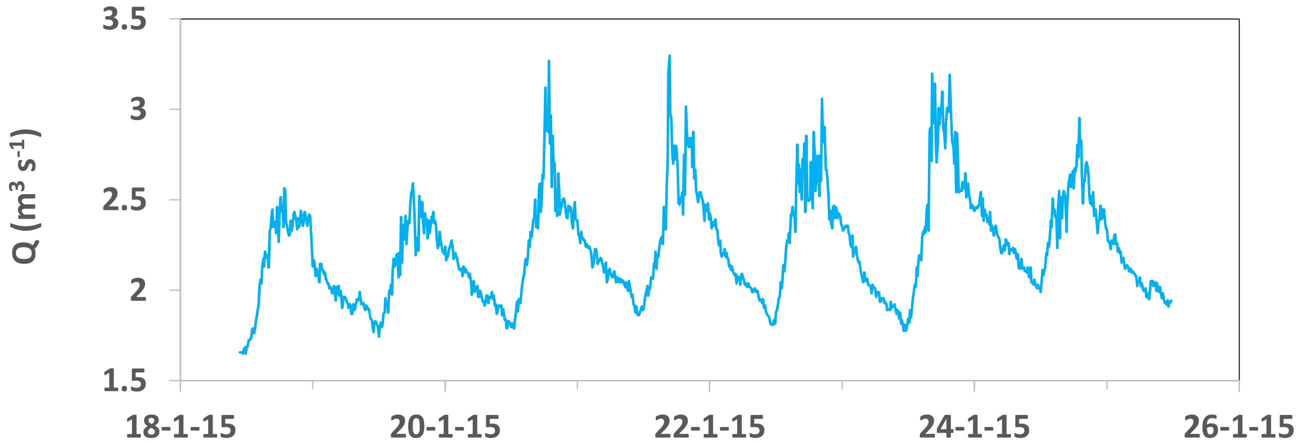
Carrillo & Mao (in prep.)

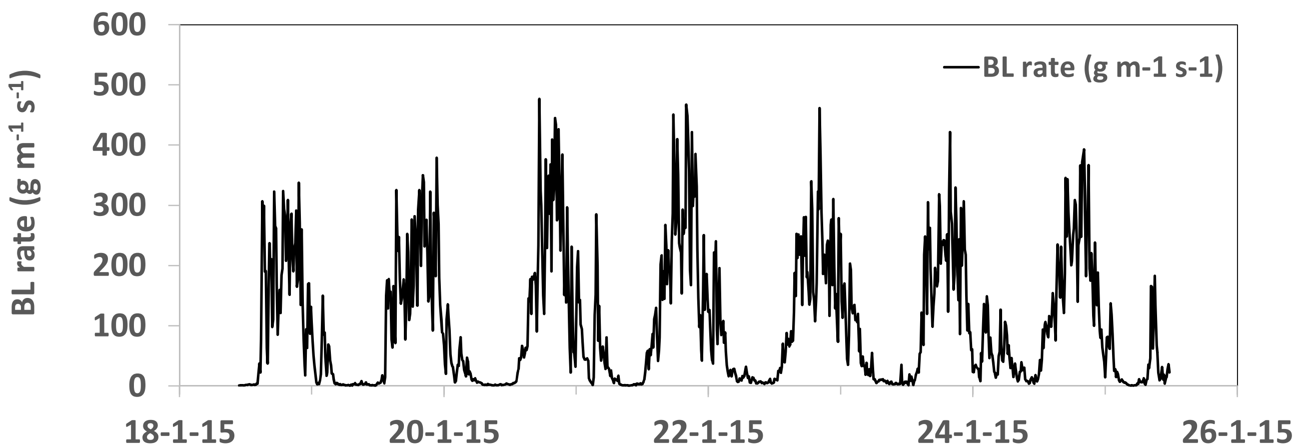




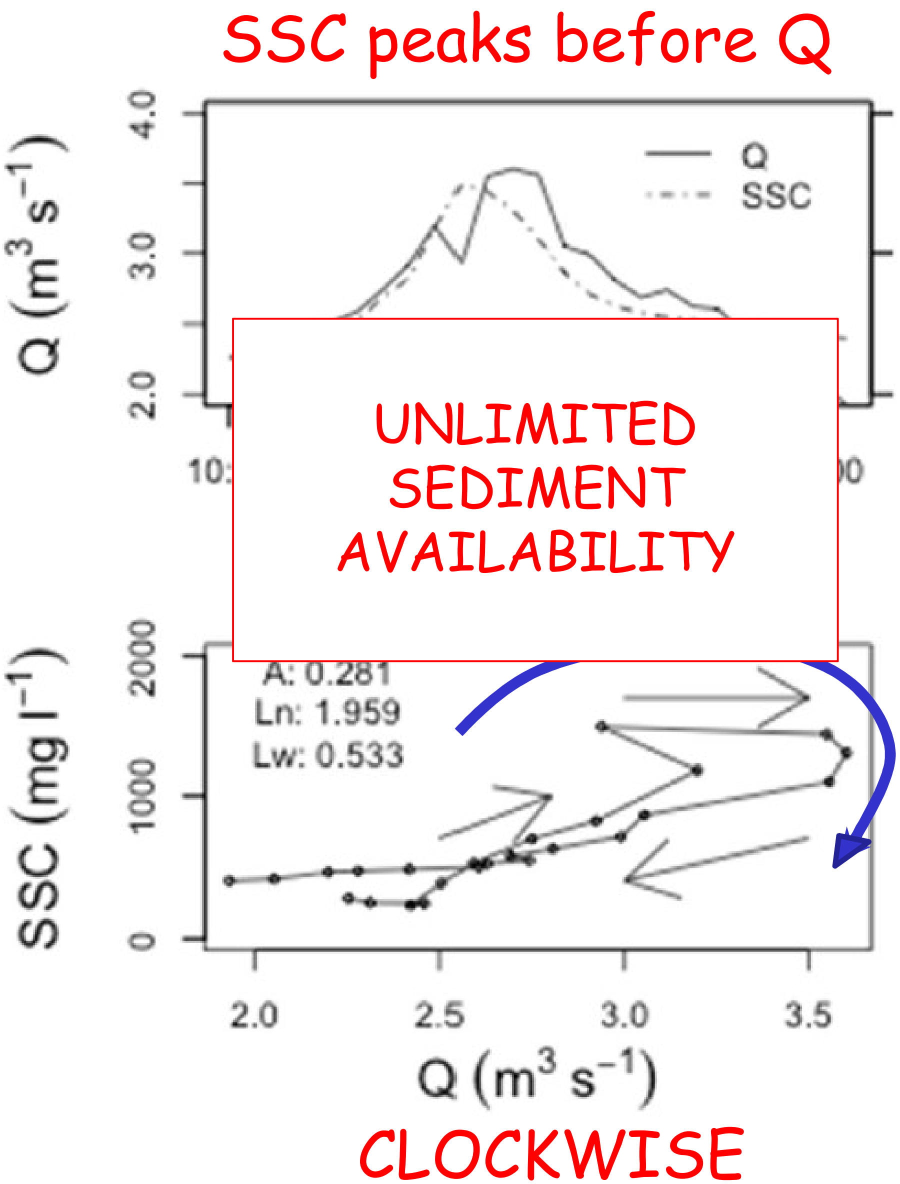
- Increase of sediment transport efficiency, or higher sediment supply (lower Q needed) from snow melting to late glacier melting for suspended and bedload transport

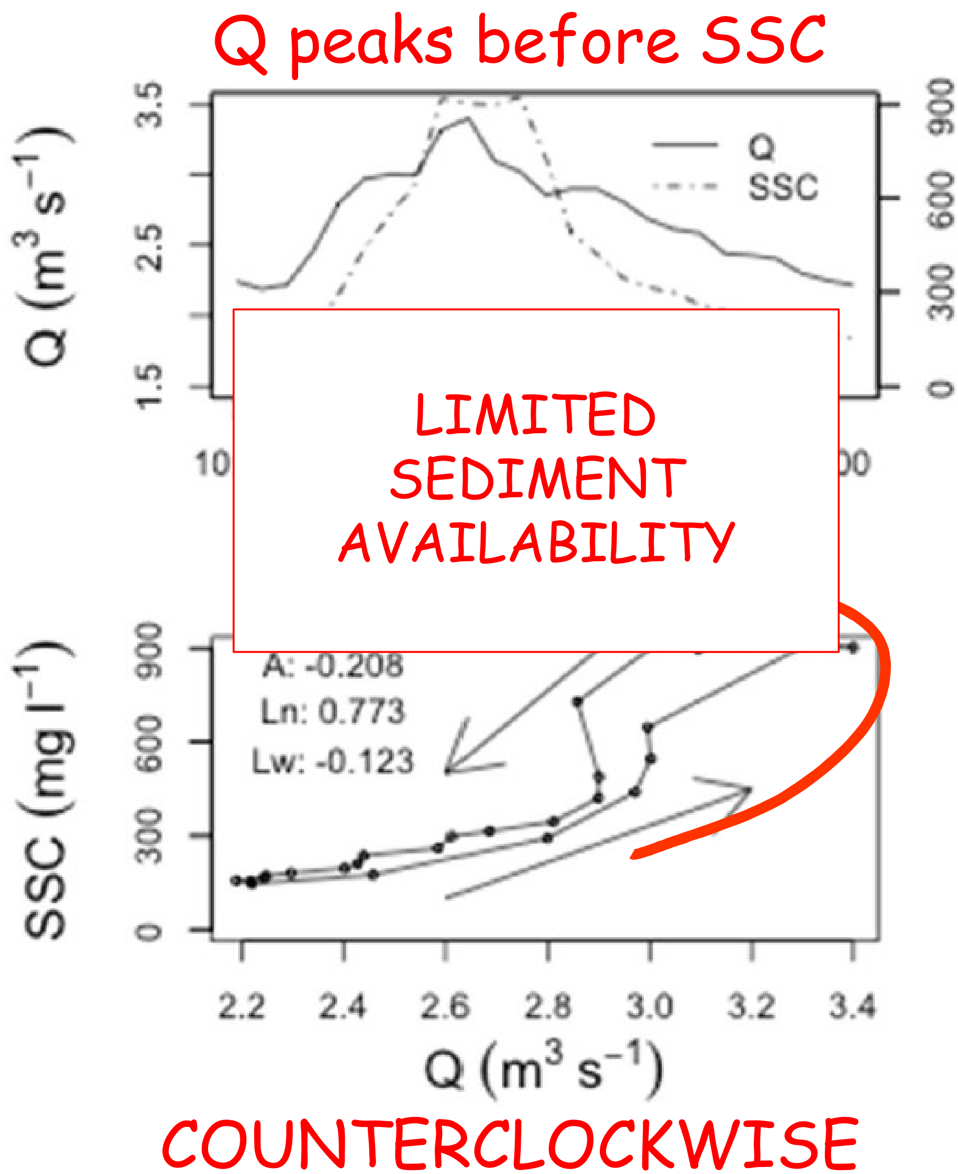
Continuous record of sediment transport





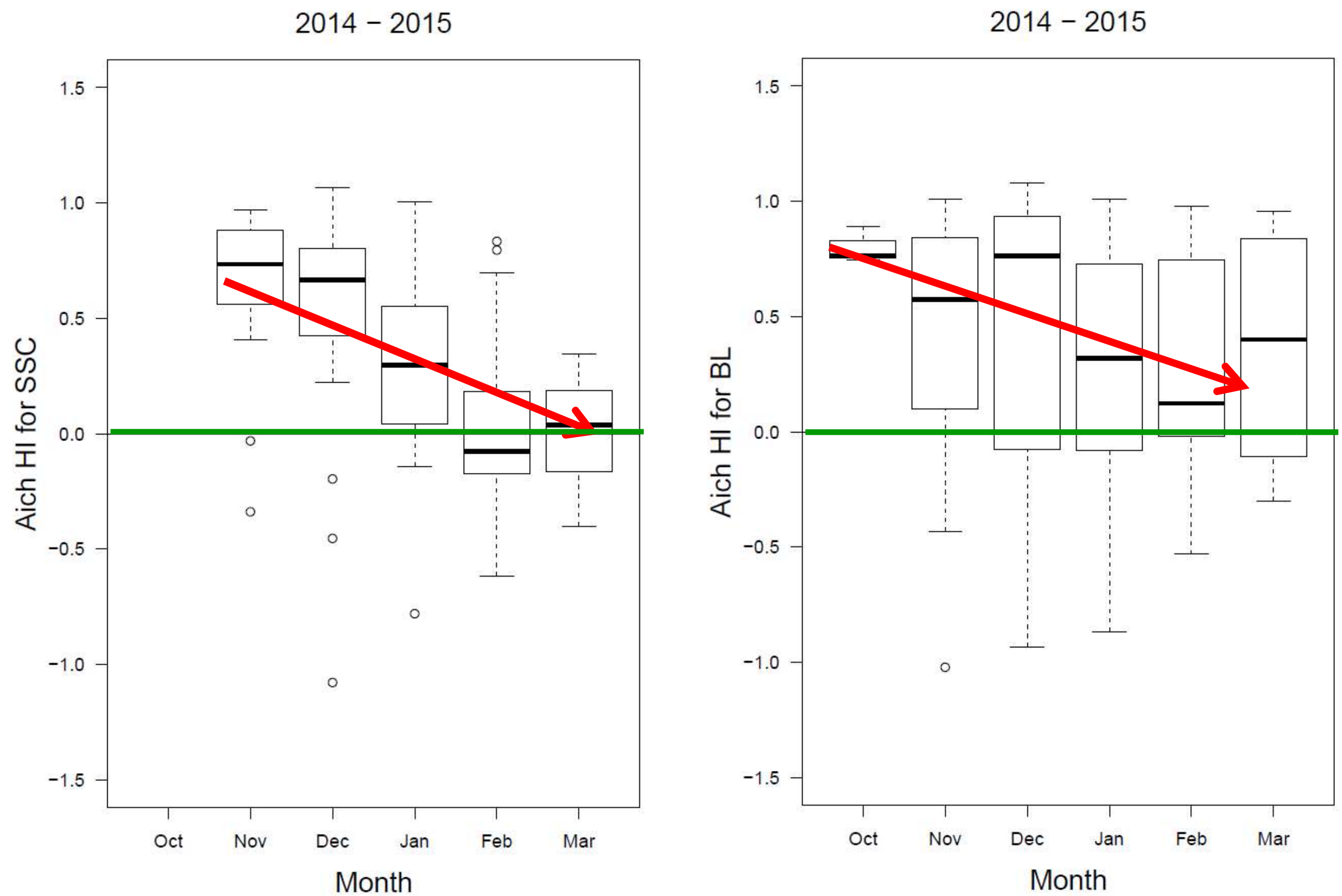
Hysteresis index





Hysteresis Q - SSC and Q - BL

Carrillo & Mao
(in prep.)



Clockwise

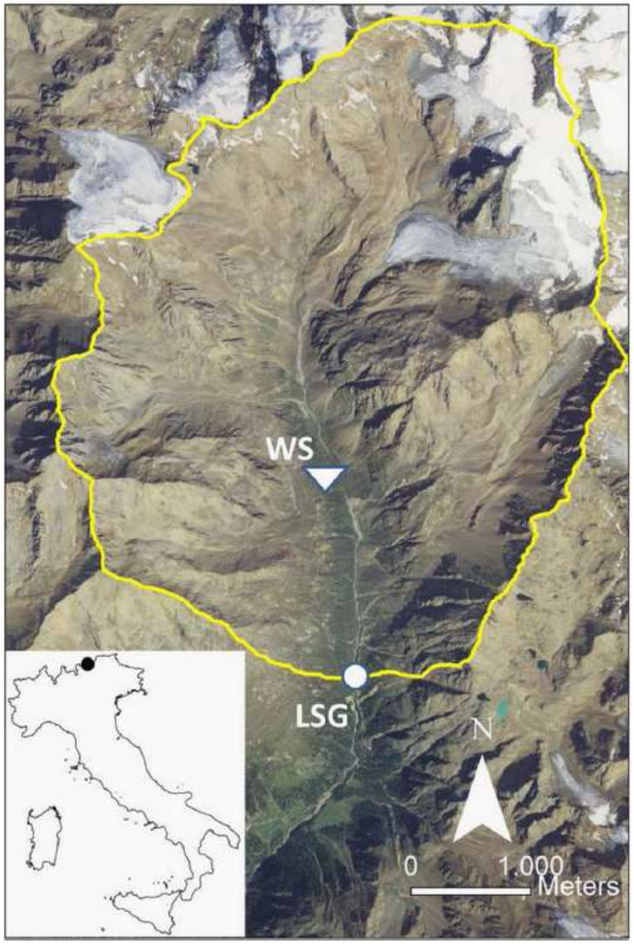
Aich et al (2014)

Counter clockwise

Carrillo & Mao
(in prep.)

- Shift from C to CC from snowmelt to later glacier melting
- From ready available to more distant or less connected sediment sources during the glacier melting season (change in connectivity; sink-release; sediment waves…)

Saldur River

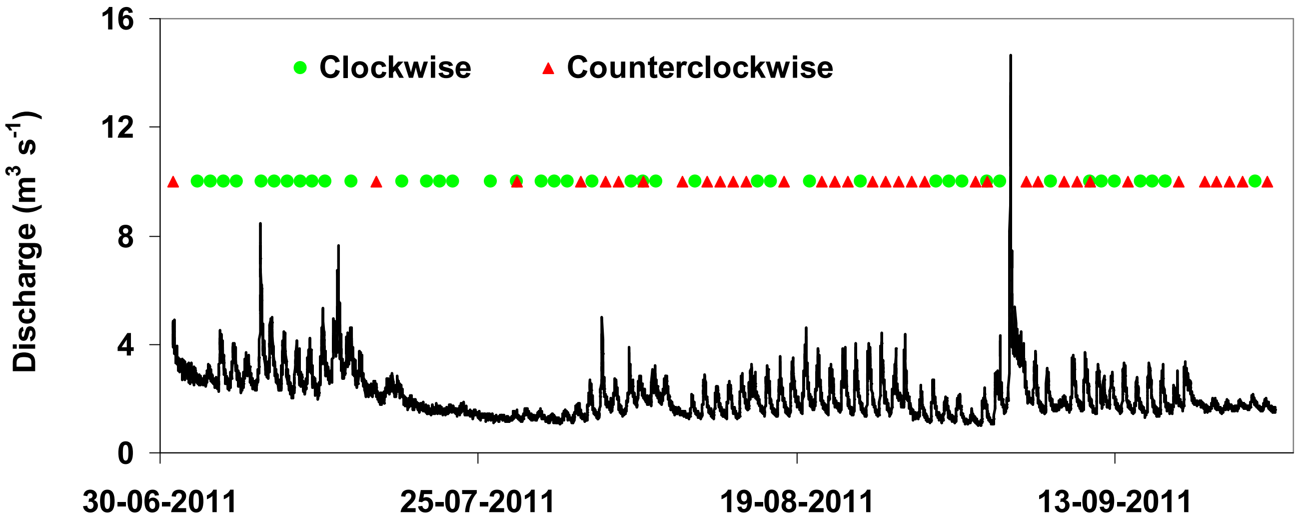


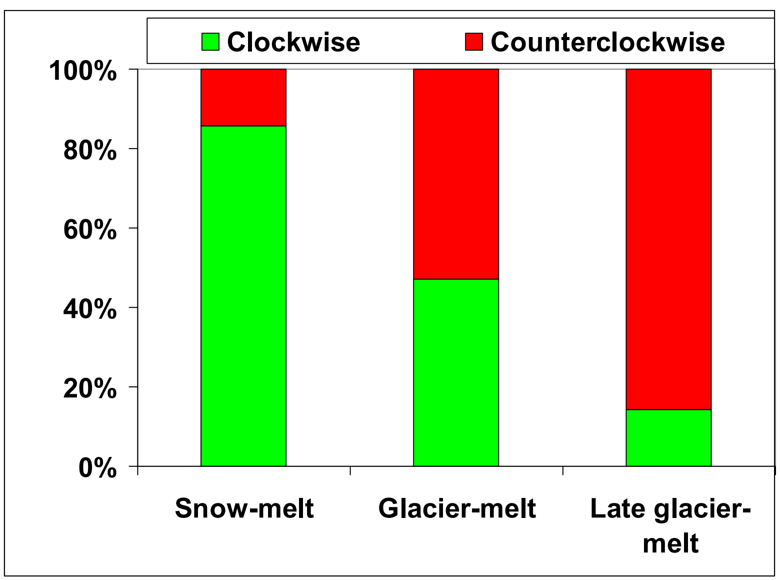
Area: 20 km^2
Small glacier (3.3 km^2)

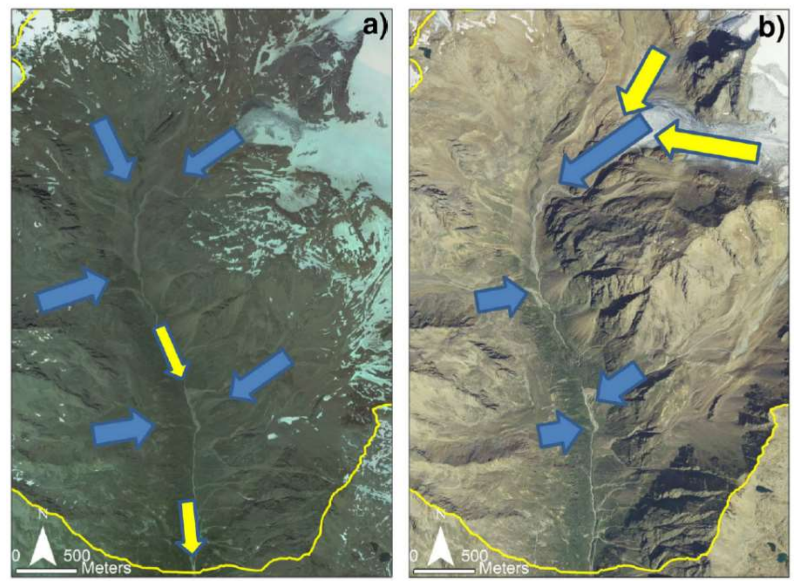
Comiti et al (submitted)

Saldur River

Mao et al (2014)

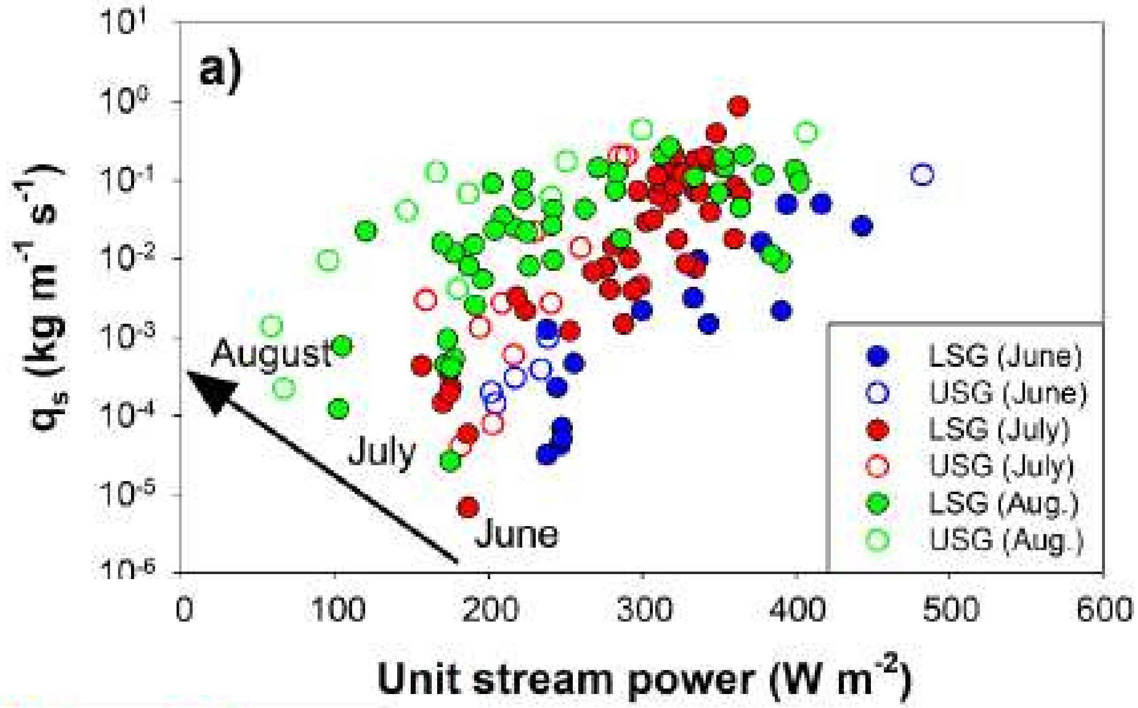


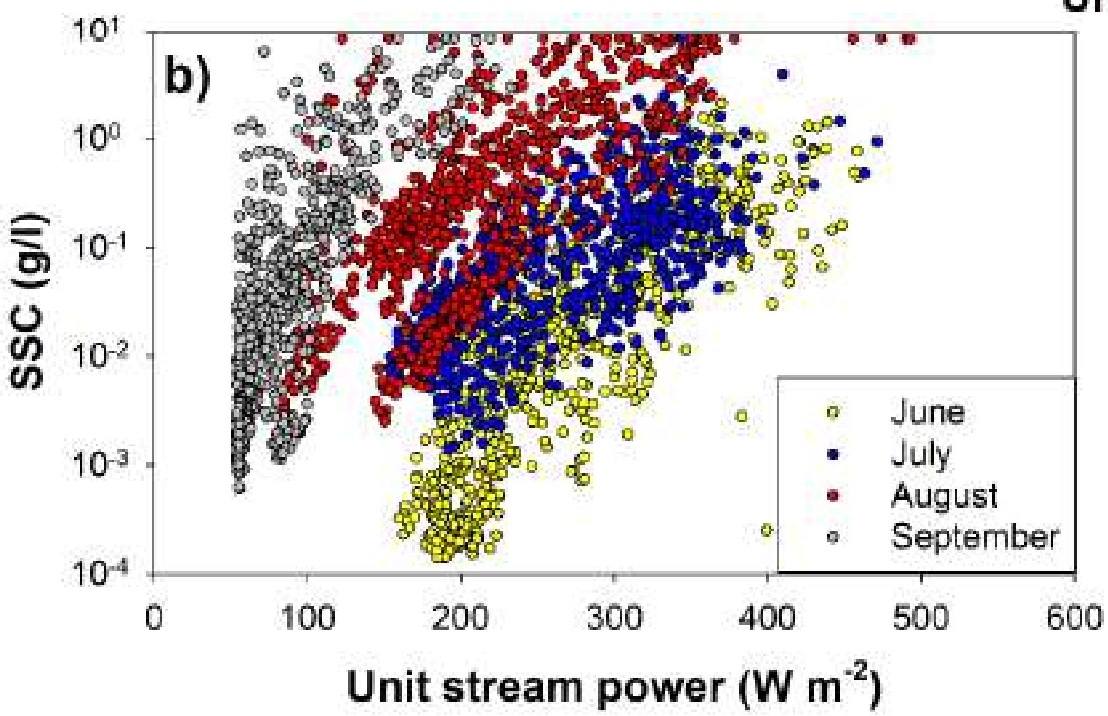




The runoff generation processes play a crucial role on temporal changes in sediment supply in mountain streams

Saldur River



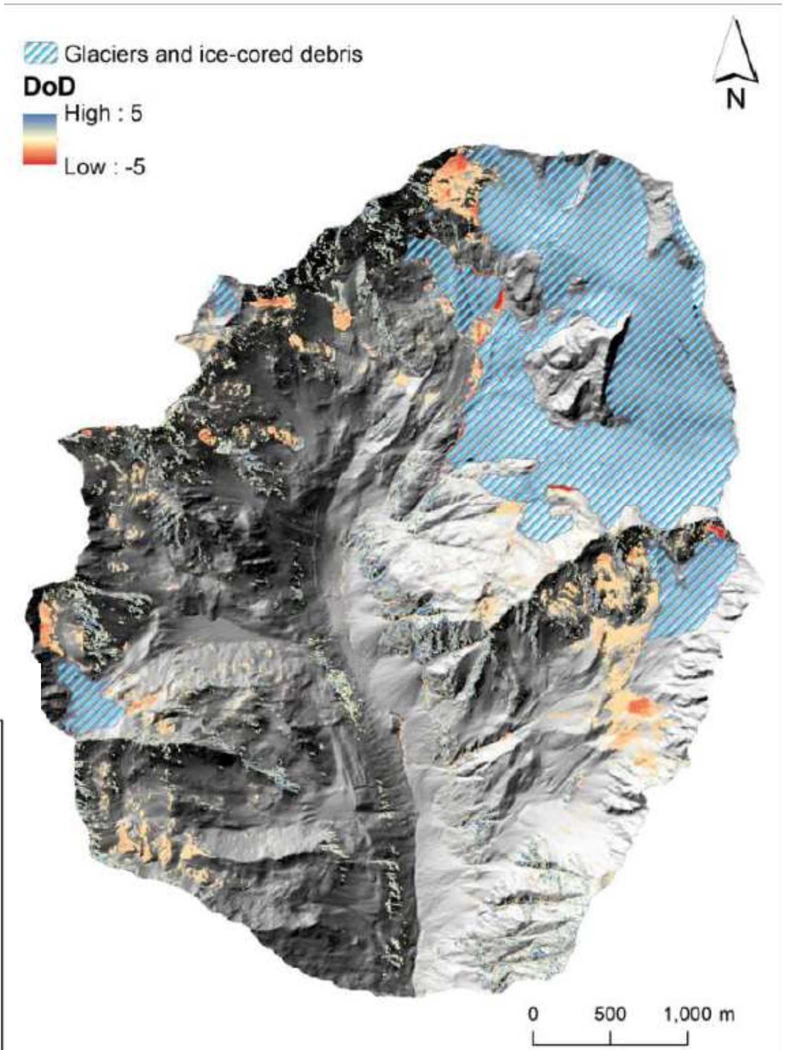


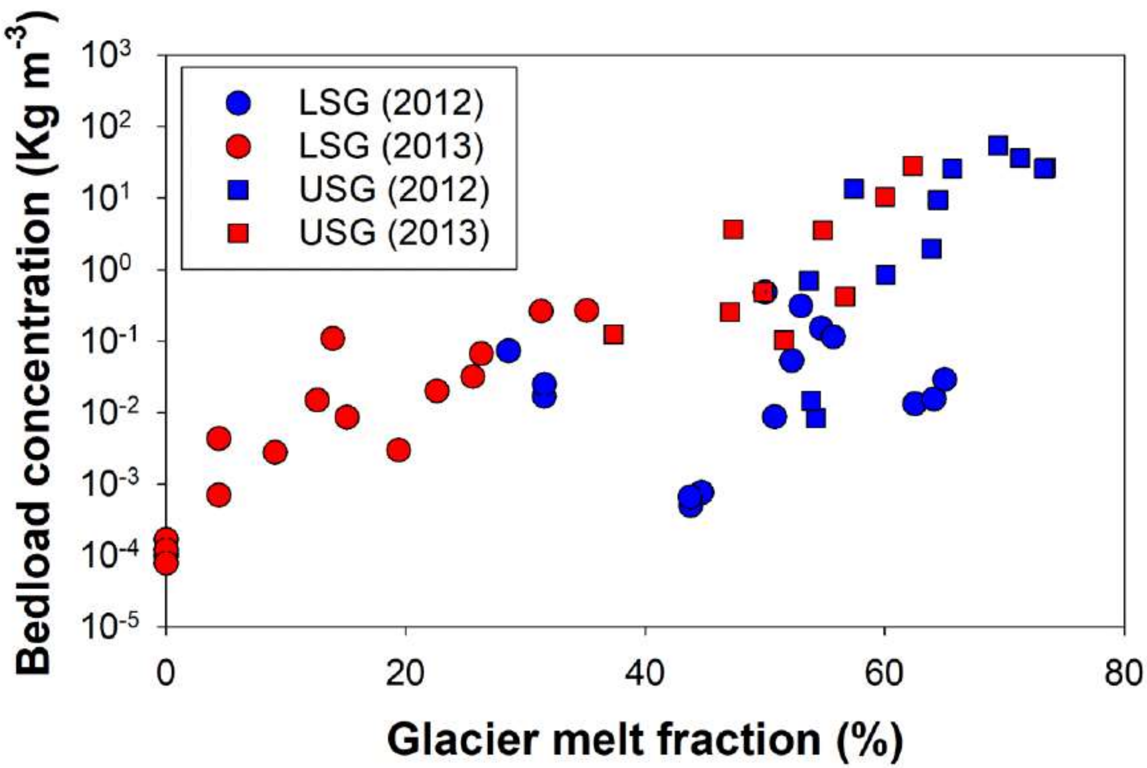
Bedload and suspended transport rates are season-dependent and strongly supply-controlled

Comiti et al (submitted)

Saldur River

Bedload in glacierized catchments originates mostly from glacial areas





Bedload concentration is related to glacier melt runoff fraction

Comiti et al (submitted)

Final remarks

- Importance of sediment connectivity at the basin scale
- The legacy of high-magnitude events (systems may keep a memory of past events in some circumstances)
- Seasonality of sediment transport (changes in sediment availability) depending on the origin of the runoff
- Hysteresis of sediment transport at the scale of single event (can allow to infer dynamics of sediment availability)
- In glacierized basins, bedload transport is related to glacier melt runoff fraction
- Importance of long-term monitoring to capture these complex dynamics (surrogate techniques)