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Using ^{137}Cs and $^{210}Pb_{ex}$ and other sediment source fingerprints to quantify fine sediment sources in forested catchments in Chile

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- **Forest export increased by 70% and accounts for ~10% of total export in Chile**

- **Forest companies are involved in certification processes and committed to meet international environmental requirements, adopting management practices to mitigate erosion impacts**

Against this background, a study of the impact of forestry operations on sediment output from forested catchments and the effectiveness of potential mitigation measures is being undertaken in South-Central Chile

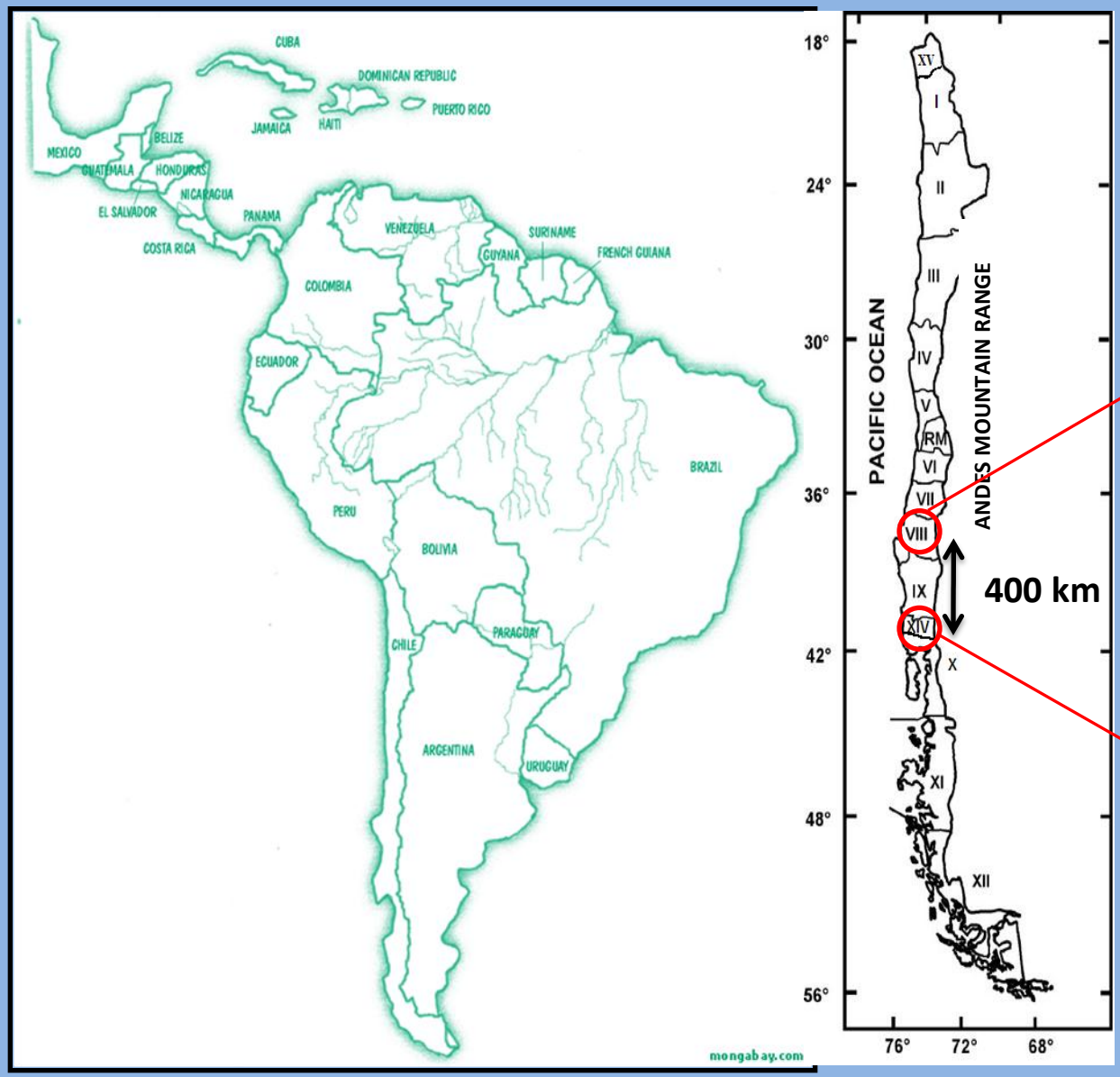
OBJECTIVE

To quantify the relative contribution of fine sediment sources to the total sediment yield measured at the outlet of forest plantation catchments

- **before and after clear-cutting operations**

- **under contrasting rainfall conditions**

STUDY AREAS: Paired forest catchments



Nacimiento NAT & NAC

PP= 1200 mm y^{-1}

Los Ulmos LUT & LUC

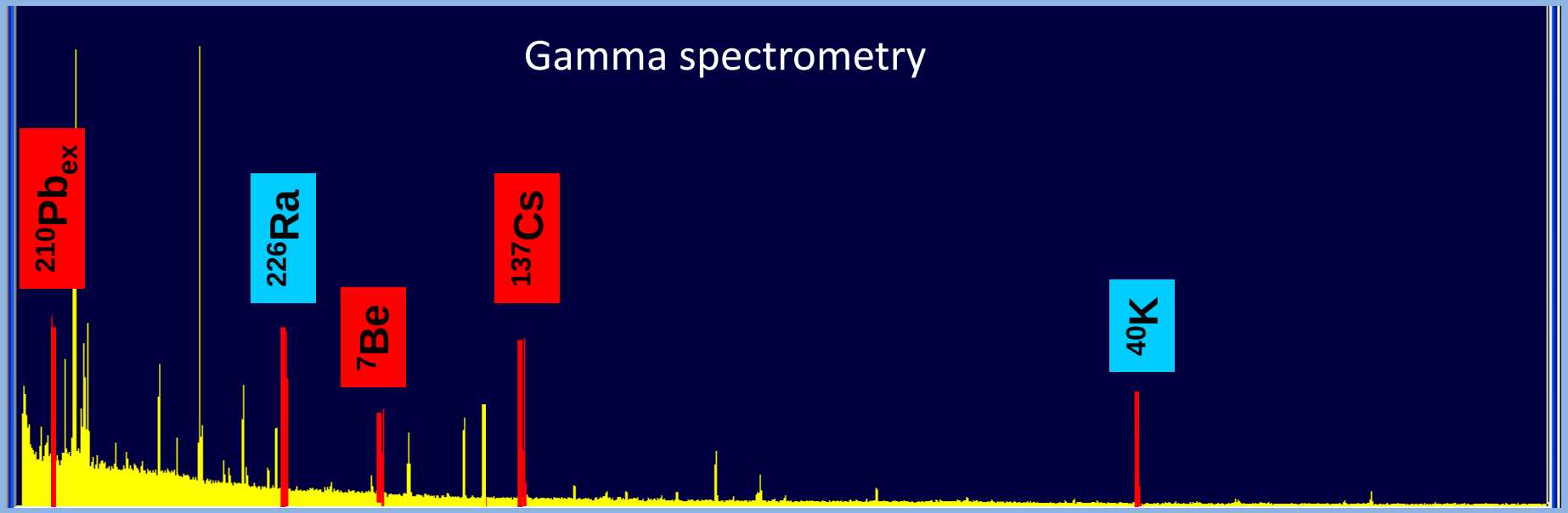
PP= 2500 mm y^{-1}

Sediment source fingerprinting technique based primarily on FRNs

Radioisotopes were tested as fingerprints for this purpose:

FRN ^{137}Cs, $^{210}Pb_{ex}$, (^{7}Be)

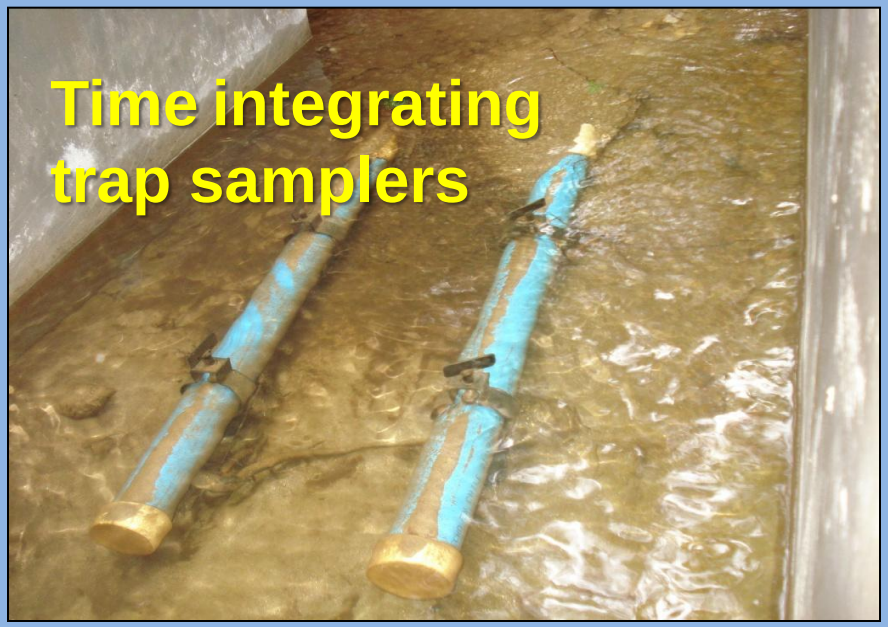
ERN ^{40}K, ^{226}Ra, SOM, N_t were tested to further improve the source discrimination provided by FRN

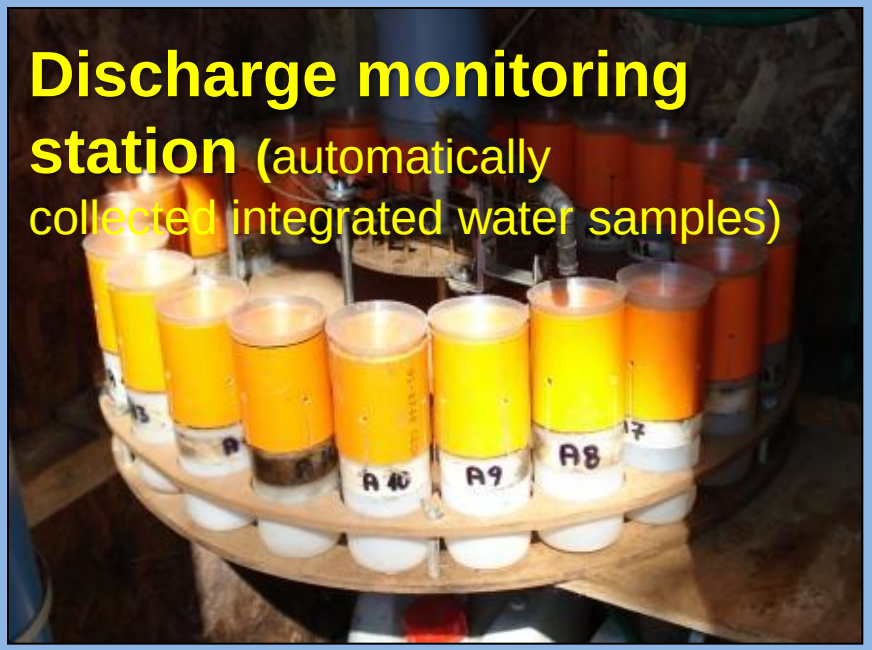


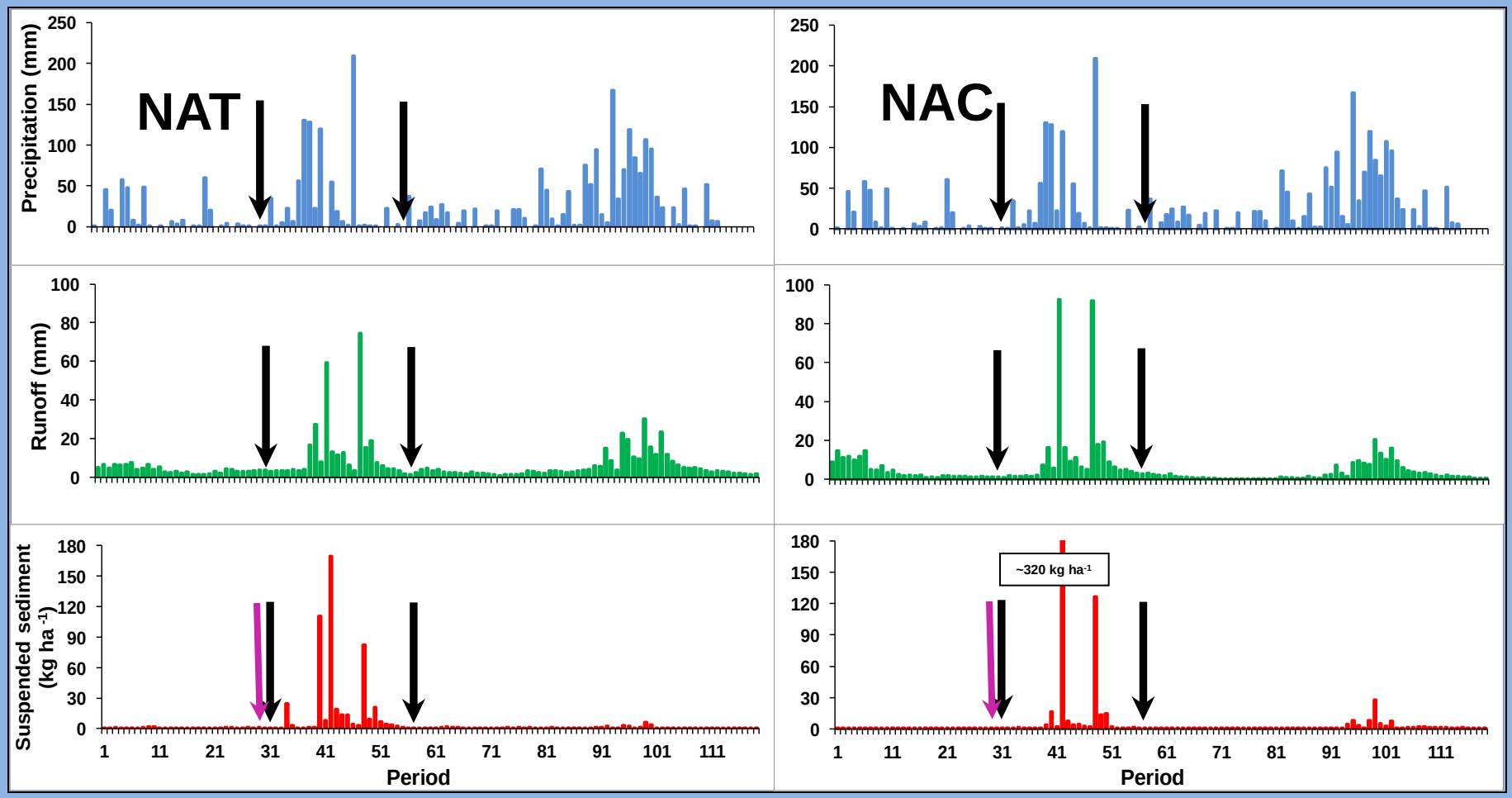
Defined homogeneous landscape zones to identify potential fine sediment sources

TARGET ZONE

Outlet of each catchment

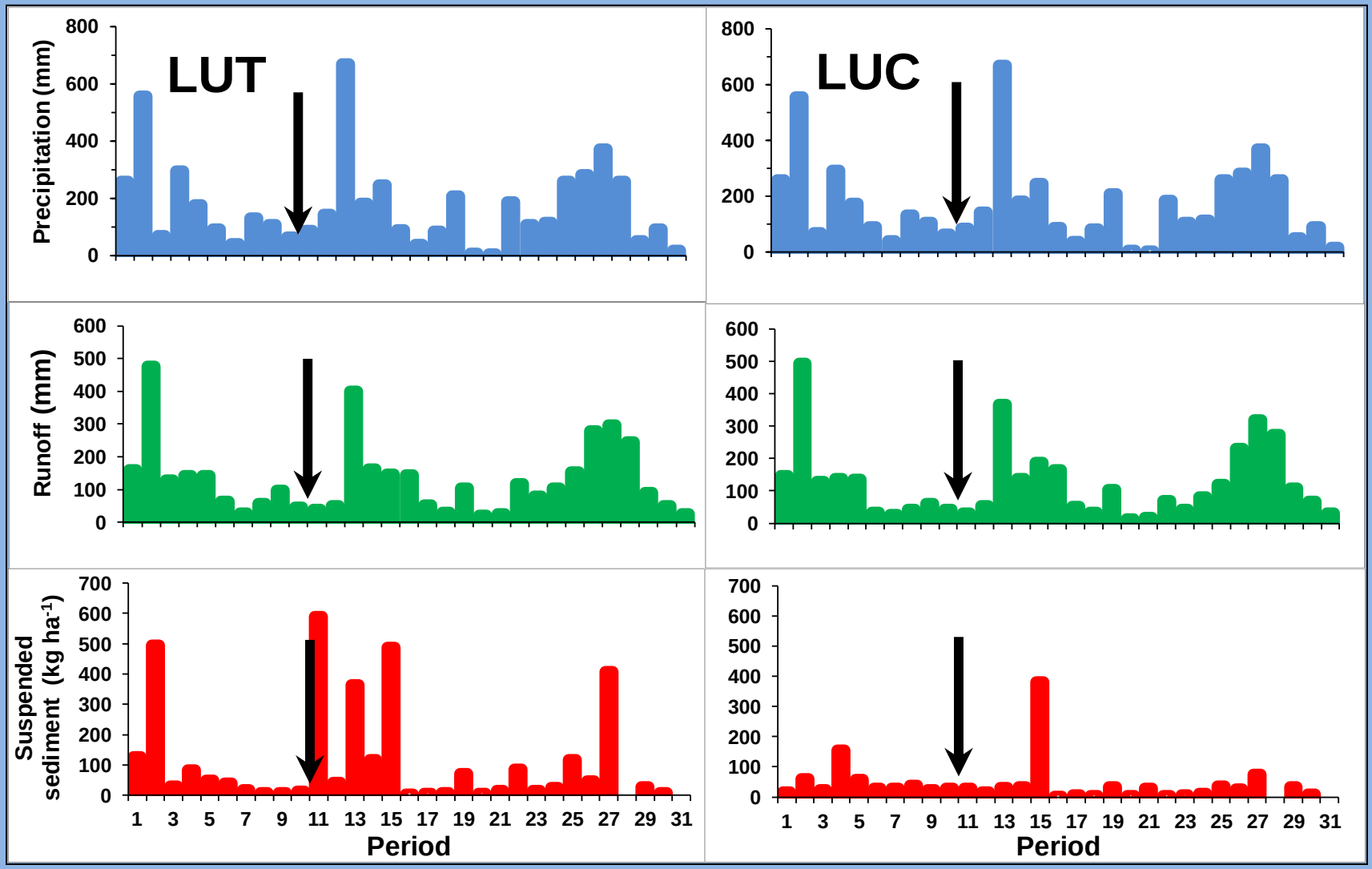






The precipitation (mm), runoff (mm) and suspended sediment load (kg ha^{-1}) recorded at the outlet in Nacimiento catchments during consecutive weekly measurement periods (16-09-2009 to 31-12-2011). The left and right arrows indicate the date of the harvest and reforestation periods, respectively, in NAT.

Earthquake: 27-02-2010, 8.8 magnitude

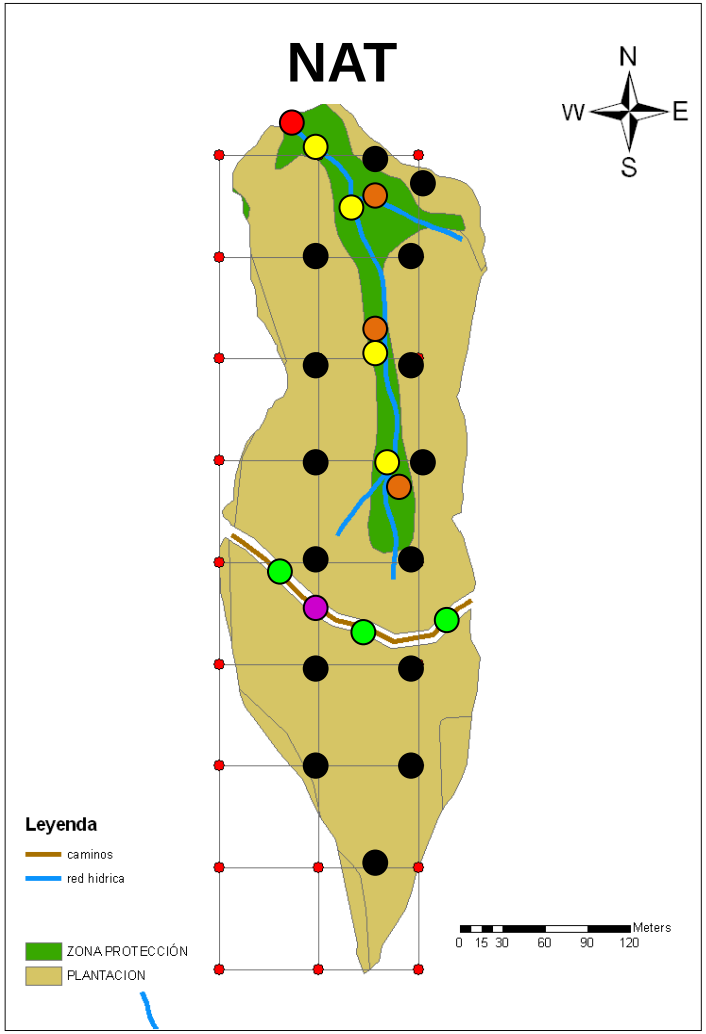


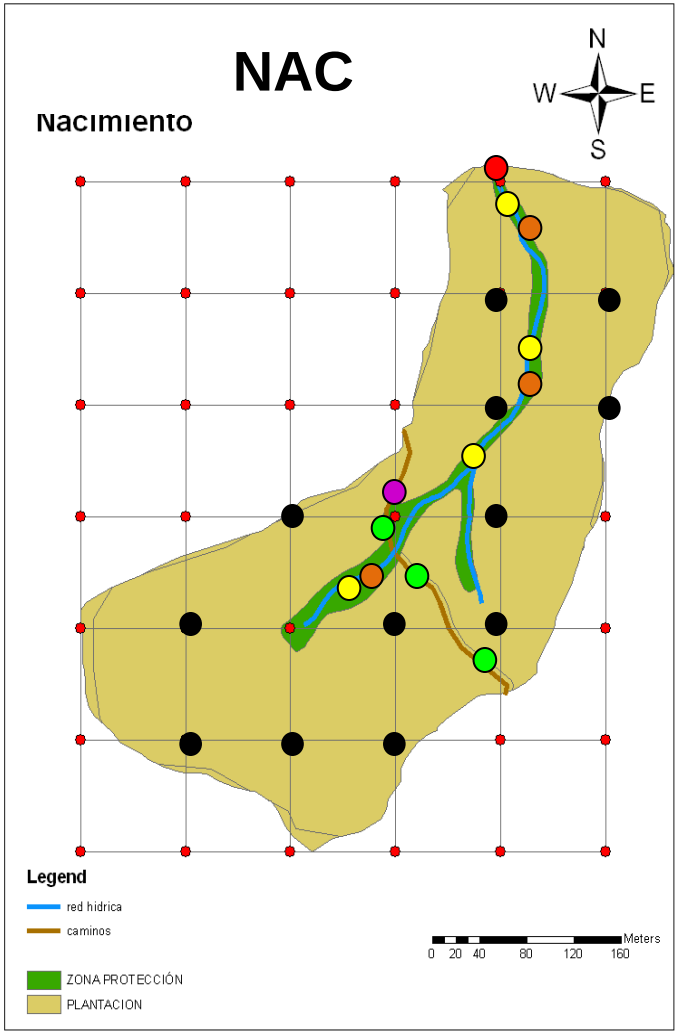
The precipitation (mm), runoff (mm) and suspended sediment load (kg ha^{-1}) recorded at the outlet in Los Ulmos catchments during consecutive monthly periods (17-07-2009 to 31-12-2011). The black arrows indicate the date of the final harvest period in LUT catchment.

SOURCE FINGERPRINTS: To ensure that the results obtained were representative of the sediment sources involved, multiple representative composite samples of different potential source material were collected from the upper 1-cm soil layer in Z1, Z2, Z3, in the control catchments and in the treatment catchment before and after harvest operations

Legend

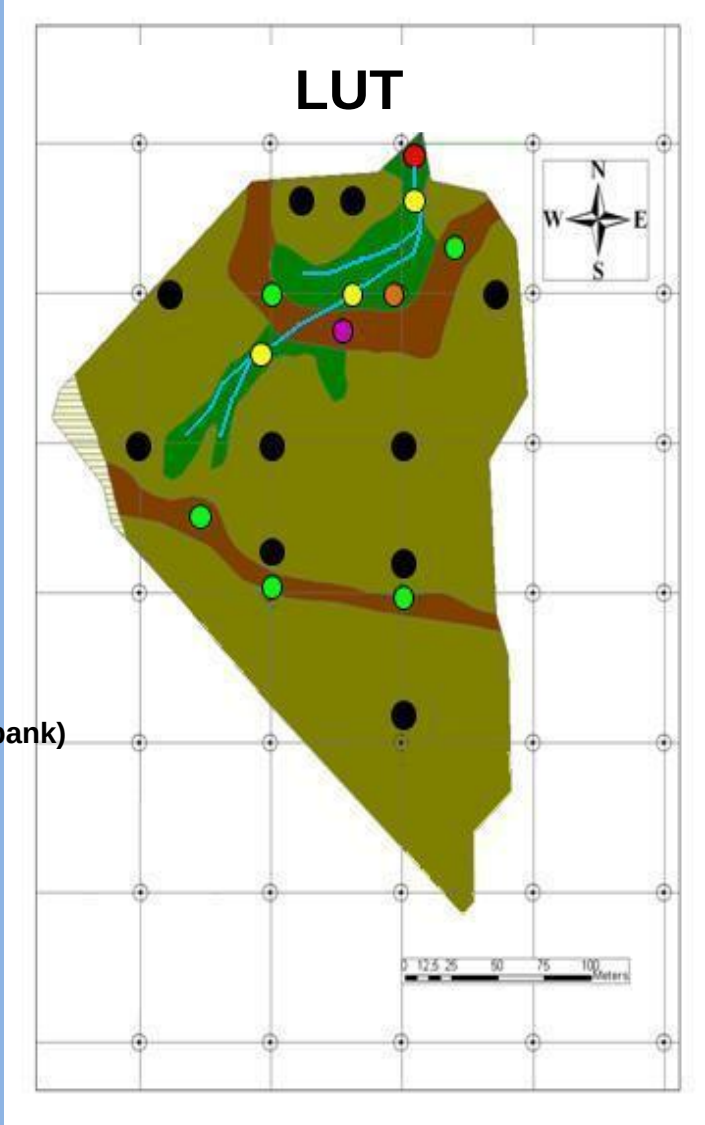
- Streams
- Roads
- ZPC
- Plantation
- Z1 (Forested slopes)
- Z2 (Roads)
- Z3 (Stream bed and bank)
- Weir
- ZPC
- ^{7}Be (Road))

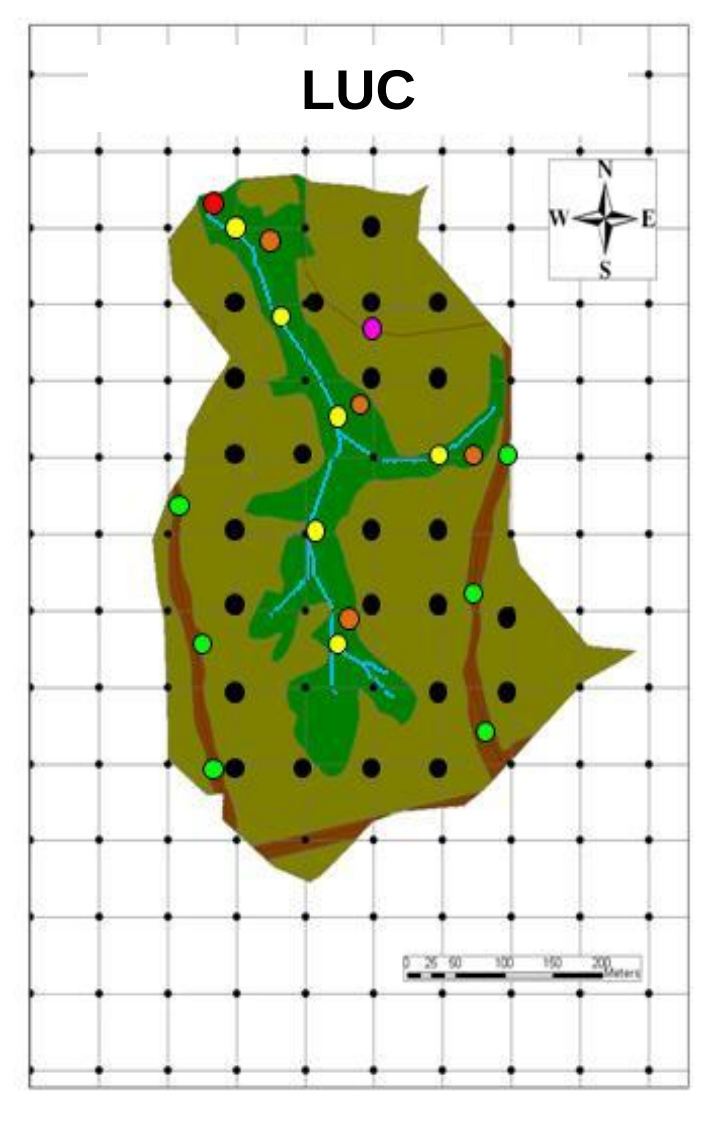




Legend

- Streams
- Roads
- Forest plantation
- ZPC Buffer zone
- Z1 (Forest slopes)
- Z2 (Roads)
- Z3 (Stream bed and bank)
- Weir
- ZPC
- ^{7}Be (Roads))





During all observation periods, monthly samples of fine sediment output were provided by the suspended sediment trap samplers, supplemented by sediment collected from the weir pools

The <63 µm fractions of the source materials and target sediment were used for radionuclide, SOM and N_t assay, to take account of contrasts in grain size composition between source material and target fine sediment

Radionuclide mass activity concentration was determined in 80 mL samples sealed in Petri dishes using an extended range Ge detector of 53% relative efficiency

No particle size correction was performed, because no correlation was found between the fingerprints concentrations and particle size composition

Fingerprints concentration associated with the <63 µm fraction of source material

NAT Pre-harvest

Source zones	Number of analyzed points	^{137}Cs (Bq kg^{-1})	$^{210}Pb_{ex}$ (Bq kg^{-1})	^{40}K (Bq kg^{-1})	SOM (%)
		Mean ± se	Mean ± se	Mean ± se	Mean ± se
Z1	15	6,2 ± 0,8	32 ± 3	390 ± 25	13 ± 1
Z2	3	3 ± 1	18 ± 8	395 ± 24	10 ± 4
Z3	7	1,7 ± 0,2	16 ± 1	539 ± 10	10 ± 1

… ^{226}Ra, N_t

LUT Pre-harvest

Source zones	Number of analyzed points	^{137}Cs (Bq kg^{-1})	$^{210}Pb_{ex}$ (Bq kg^{-1})	^{40}K (Bq kg^{-1})	SOM (%)
		Mean ± se	Mean ± se	Mean ± se	Mean ± se
Z1	10	14 ± 2	76 ± 11	101 ± 20	23 ± 2
Z2	5	3 ± 1	13 ± 4	240 ± 110	9,9 ± 0,5
Z3	6	4,6 ± 0,4	9 ± 3	364 ± 38	11 ± 1

… ^{226}Ra, N_t

Identification of a composite fingerprint set of source material properties capable of discriminating between the potential sources

Two stage procedure:

- **Kruskal–Wallis (KW) test to identify the fingerprint properties which were able to discriminate between the potential sources**

- **Multivariate discriminant function analysis (DFA) to select the optimum sub-set of fingerprint properties from those identified as potential properties in the first stage**

The optimum composite fingerprint for discriminating sediment source types in each catchment during each observation period

Catchment	Period	Fingerprints selected		Correctly classified source samples (%)
NAC	06/08/09 - 18/07/11	^{137}Cs	$^{210}Pb_{ex}$	93,3
NAT pre-harvest	06/08/09 - 24/03/10	$^{210}Pb_{ex}$	^{40}K	80,8
NAT post-harvest	24/03/10 - 09/12/10	^{137}Cs	^{40}K	85,3
NAT post-reforestation	09/12/10 - 18/07/11	^{137}Cs	^{40}K	81,1
LUC	01/10/09 - 20/06/11	^{137}Cs	$^{210}Pb_{ex}$	82,7
LUT pre-harvest	10/09/09 - 19/03/10	^{137}Cs	$^{210}Pb_{ex}$	83,3
LUT post-harvest	19/03/10 - 20/06/11	^{137}Cs	SOM	71,9

Estimating the relative contribution of each potential source to the suspended sediment samples collected at the catchment outlet (*Collins, A.L. et al. 2010*)

A multivariate mixing model was used ➔ minimizing the sum of the squares of relative errors using Monte Carlo analysis

$$\sum_{i=1}^{n}\left\{\left(C_i-\left[\sum_{s=1}^{m}P_sS_{si}\right]\right)/C_i\right\}^2$$

$$\sum_{s=1}^{m}P_s=1$$

C_i = mass concentration of fingerprint property (i) in catchment outlet time-integrated fine sediment sample collected at the outlet

P_s = sediment relative contribution from source zone (s)

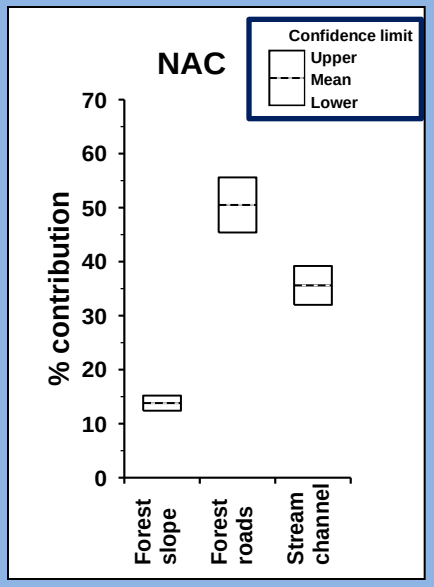
S_{si} = mean mass concentration of fingerprint property (i) in sediment source zone (s)

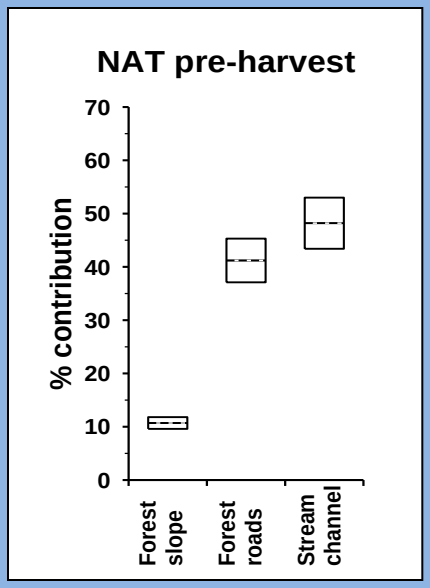
n = number of fingerprint properties comprising the optimum composite fingerprint set (n = 2)

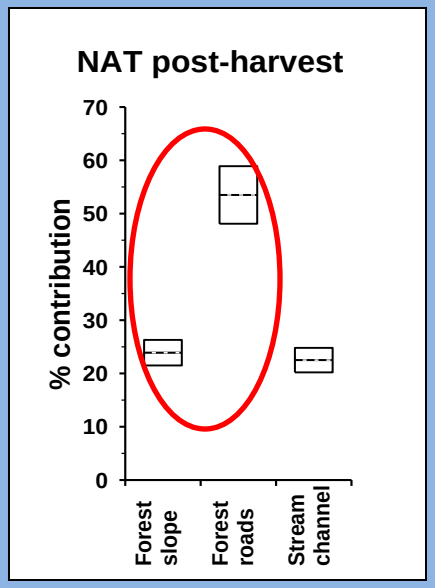
m = number of sediment source zones (m = 3)

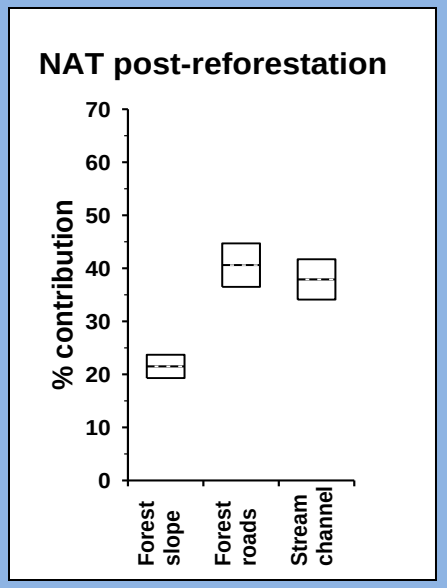
Preliminary results: Relative contribution of the fine sediment source zones to the target sediment, based on load weighted contributions

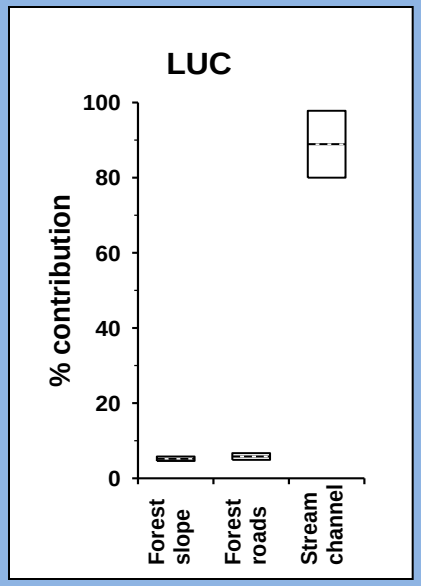
Nacimiento catchments

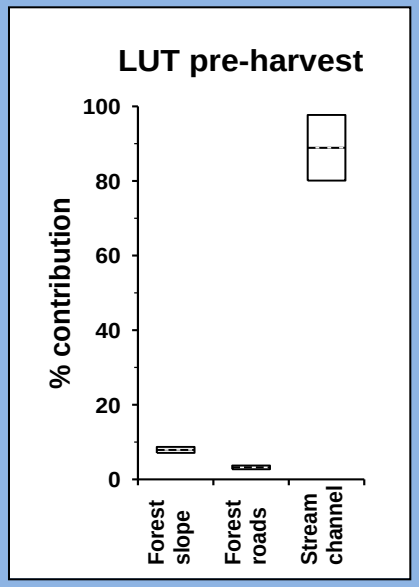


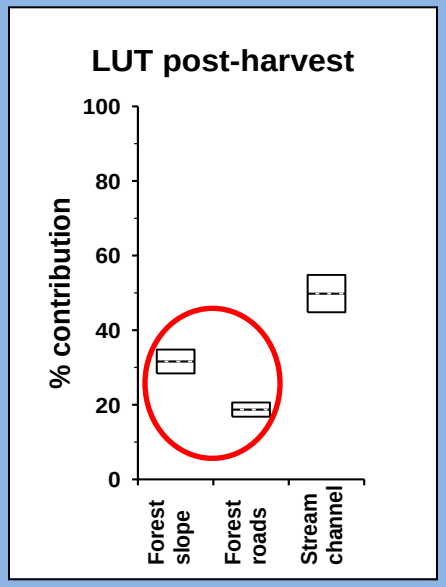








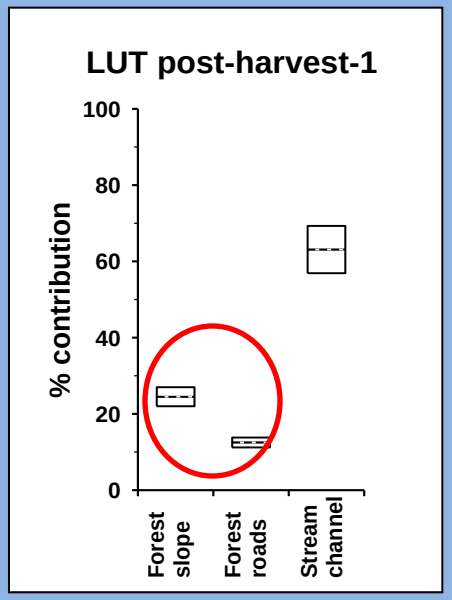


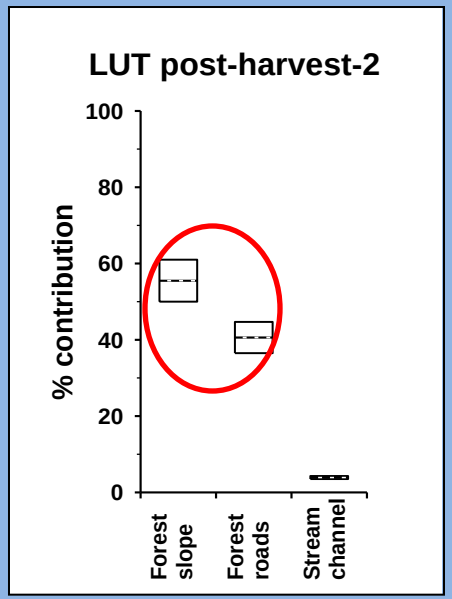


78% SL
Pp 1390 mm

22% SL
Pp 1270 mm

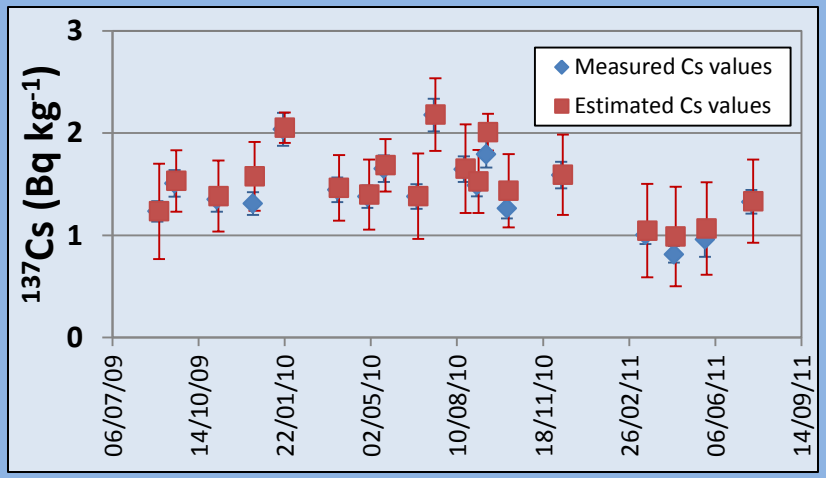
Relative contribution in Los Ulmos catchments

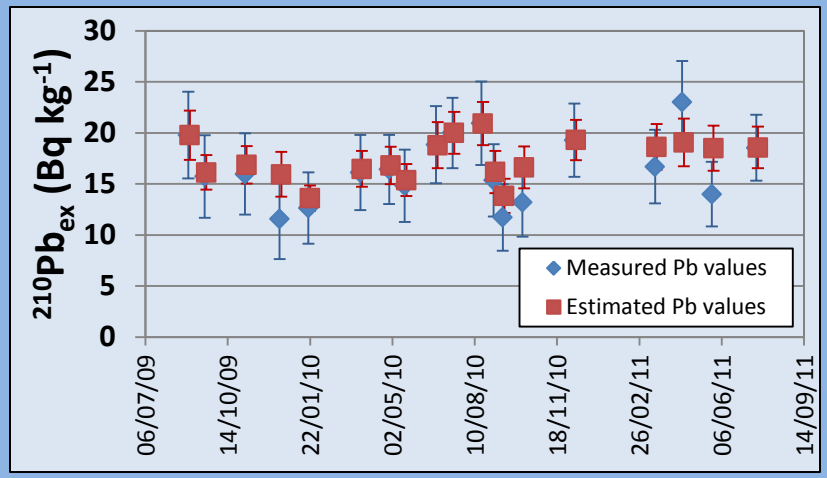




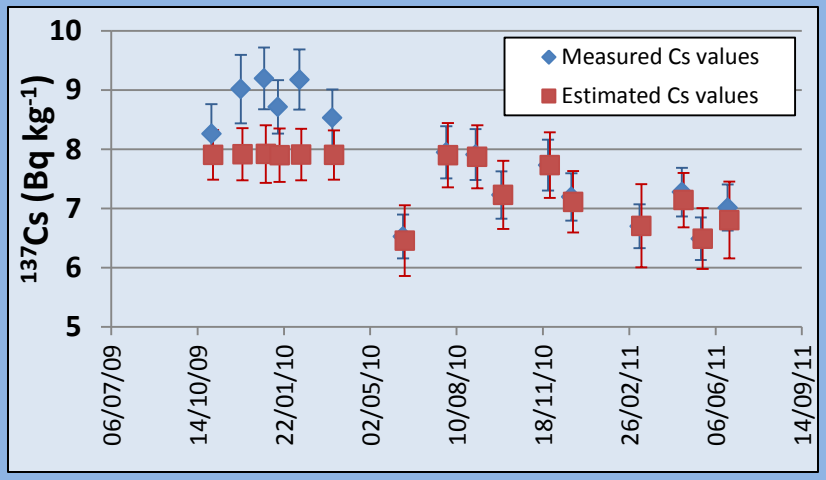
Comparison between fingerprints measured values in target sediment samples and the calculated values using the estimated relative source contributions

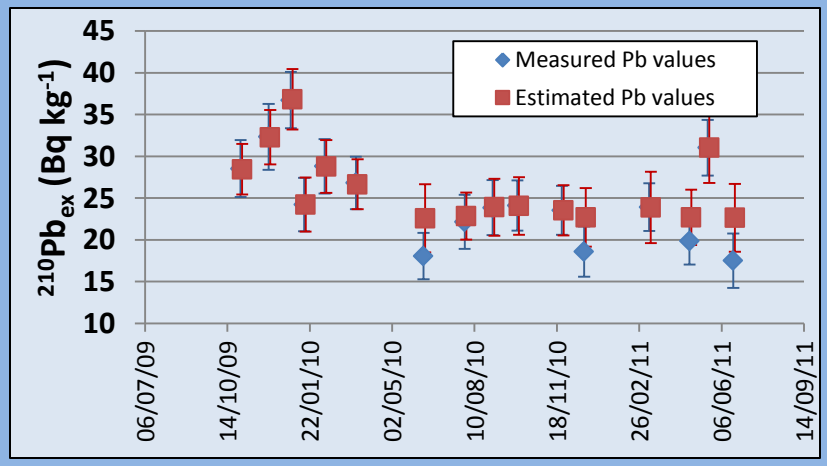
NAC





LUC





This study provides important benefits

- **Demonstrates the application of sediment source fingerprinting procedures in Chile based primarily on FRNs ^{137}Cs and $^{210}Pb_{ex}$**

- **Provides a basis for expanding such work in the future into other regions, agricultural areas and studies linked to other sediment-related environmental problems**

- **Provides improved understanding of sediment source types and their relative contribution to the sediment yields for forested catchments in south-central Chile, particularly during critical periods of disturbance**

- **Contributes to the decision-making process for implementing improved and cost-effective sediment management practices, in order to reduce the impact of plantation forest clearcutting on water quality**

- **Provides important empirical information to support forest certification procedures and plantation sustainability**

Acknowledgements

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