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AGRICULTURAL TERRACED LANDSCAPE DEGRADATION DRIVEN BY HYDROLOGICAL AND GEOMORPHOLOGICAL PROCESSES

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STONEWALLS
DRY-STONE WALLS FOR CLIMATE CHANGE ADAPTATION
Life
PARCO NAZIONALE DELLE CINQUE TERRE
Area Marina Protetta delle Cinque Terre

Presentation layout

- **Overview on agricultural terraces as ancient practice for cultivation on hilly-mountainous landscapes a human-modified environments.**

- **Focus on the hydro-geomorphological functions of agricultural terrace slopes: key elements for soil conservation, water cycle regulation and ecosystems preservation.**

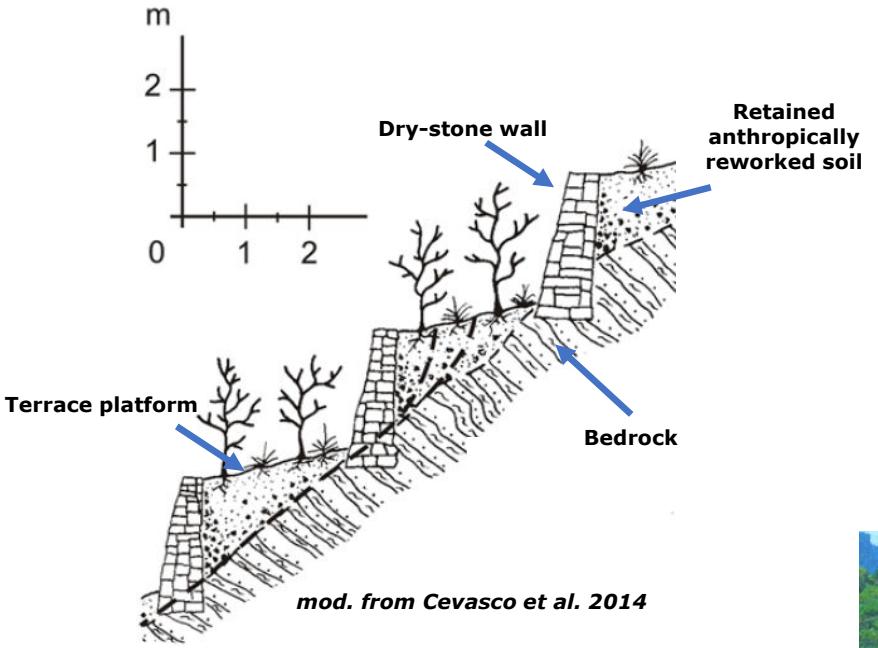
- **The issue of terraced slope degradation in response to land abandonment: implications in terms of rainfall-induced erosion processes and mass movements.**

- **Analysis of the outcomes from research activities performed within the open-air-laboratory of the Cinque Terre National Park (north-western Italy), one of the most worldwide known examples of terraced landscape.**

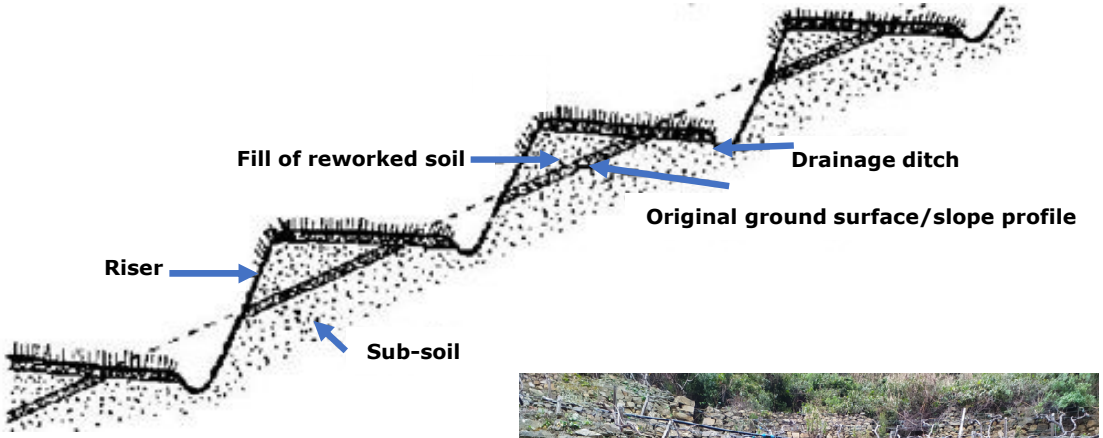
- **Presentation of the project StoneWallsForLife, a LIFE EU-project focused on Climate Change Adaptation which is aimed at investigating how the ancient technique of dry-stone walls can be effectively used to improve the resilience of the territory to climate change.**

Agricultural terraces

Agricultural practice which allows to obtain flat areas for cultivation in hilly-mountainous landscapes



mod. from Cevasco et al. 2014

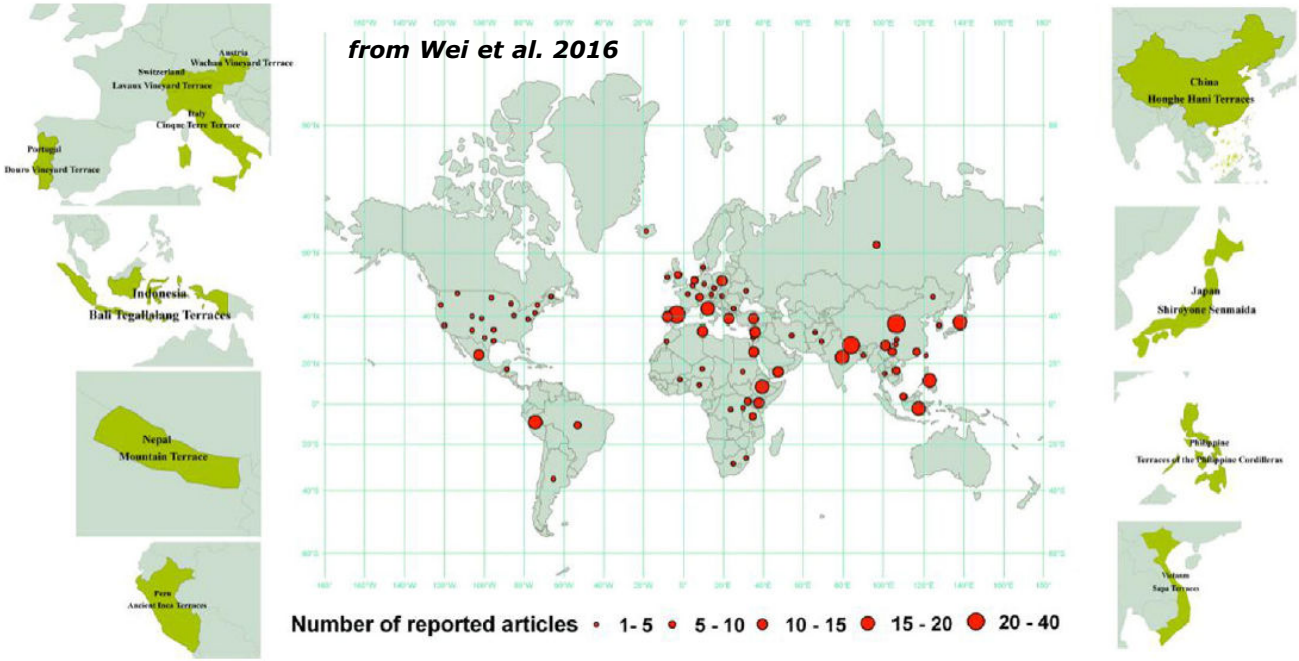


Terraced slopes with terraces sustained by dry-stone walls in Cinque Terre (Italy)

from Terranova et al. 2002

Artificial drainage works

Agricultural terraced landscapes in the world



Most ancient terraced landscapes (UNESCO (United Nations Educational, Scientific and Cultural Organization) and GIAHS (Globally Important Agricultural Heritage Systems)):

- China
- Japan
- Nepal
- Vietnam
- Peru
- Lebanon
- Syria
- Greece
- Italy
- Portugal
- Spain

Agricultural terracing across the globe taking Mediterranean region as an example

Manarola - Cinque Terre (Italy)

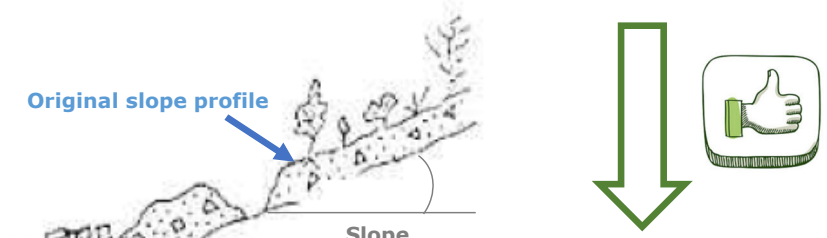
Mallorca (Spain)

Greece

Agricultural terraces

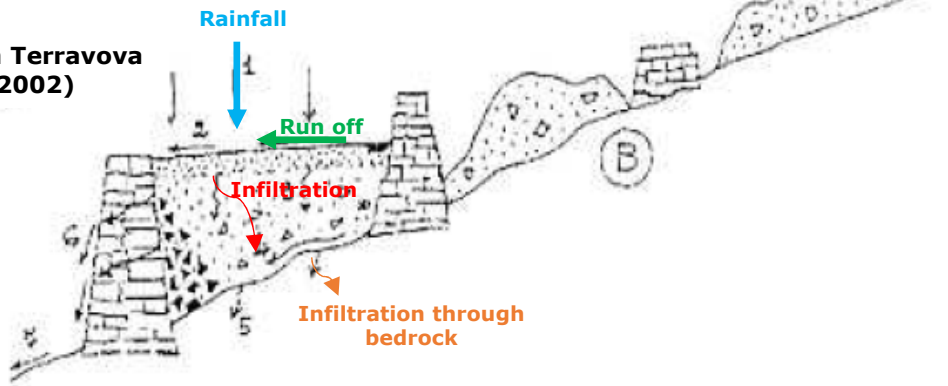
Hydrological & geomorphological functions

- Modification of slope steepness and soil thickness distribution
- Reduction of runoff velocity, hydrological connectivity and of soil erosion
- Increases of rainwater infiltration and of soil moisture
- Modification of surficial water circulation through artificial drainage works (e.g., artificial channels, trenches and ditches)



Building phases of terraces sustained by dry-stone walls

(mod. from Terravova et al. 2002)



- Regulation of the water cycle
- Promotion of soil conservation
- Promotion farmland activities
- Preservation of the ecosystems

Agricultural terraced landscape abandonment

Terraced landscape abandonment: comparison between terraced slopes in 1960 (top) and 2011 (bottom) in Cinque Terre (Italy)

Driving factors

- Socio-economic and demographic changes
- Technological changes
- Political changes

Dynamics

- Population migration towards industrialized cities
- Loss of the economic value of traditional farmland practices
- Difficulties in using of heavy machineries in rugged terrains
- Intense cultivation of croplands located in wide flat areas

Consequences

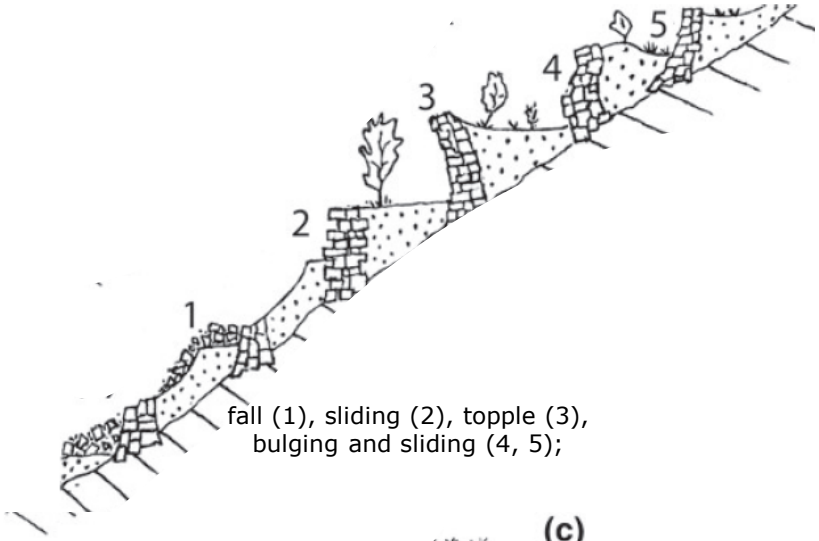
- Farmland activities interruption
- Replacement of agricultural landscapes by scrublands, woods
- Lack of terrace system maintenance

Hydro-geomorphological implications of agricultural terraced landscape abandonment

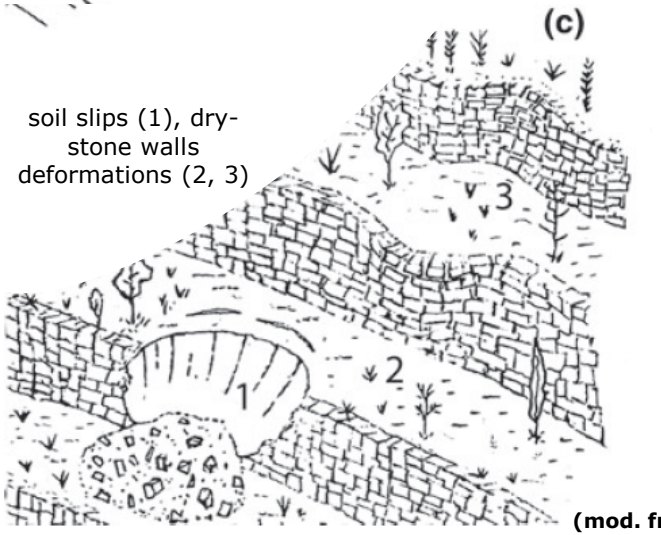
Lack of maintenance: agricultural terraces may gradually lose their hydrological efficiency.

Evolution of slope terracing after farming abandonment

- Progressive collapse of dry-stone walls and terrace risers
- Obstruction of artificial drainage channels



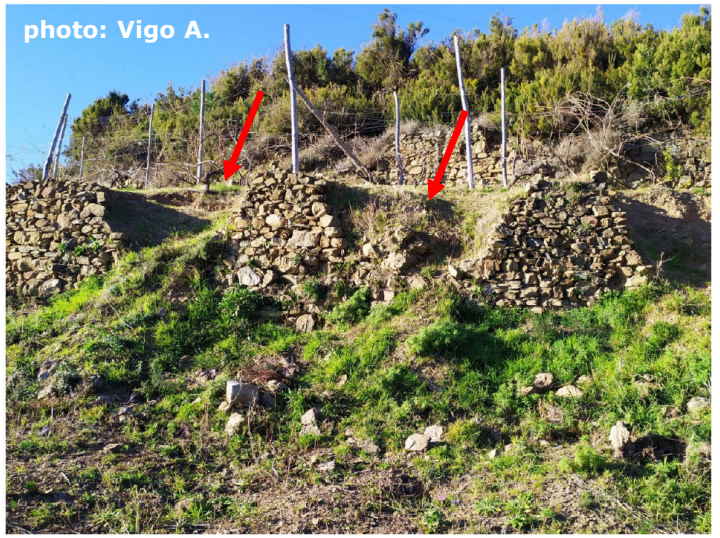
fall (1), sliding (2), topple (3), bulging and sliding (4, 5);



soil slips (1), dry-stone walls deformations (2, 3)

(mod. from Brandolini 2017)

Dry-stone walls deformations & collapses

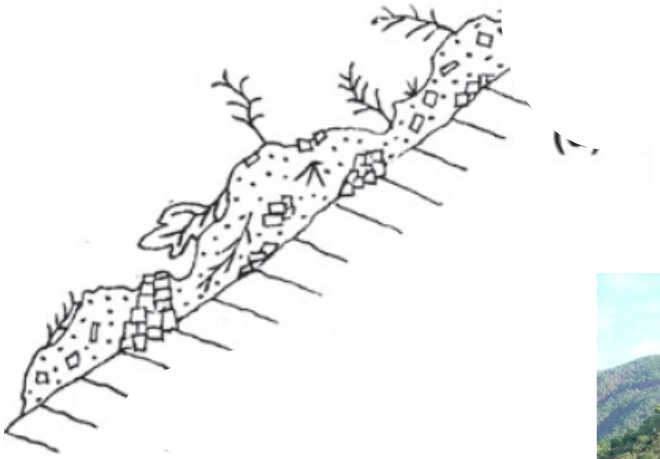


Hydro-geomorphological implications of agricultural terraced landscape abandonment

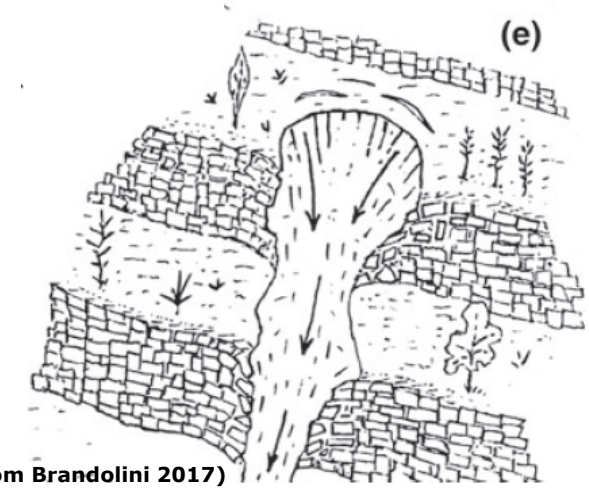
Lack of maintenance: agricultural terraces may gradually lose their hydrological efficiency.

Evolution of slope terracing after farming abandonment

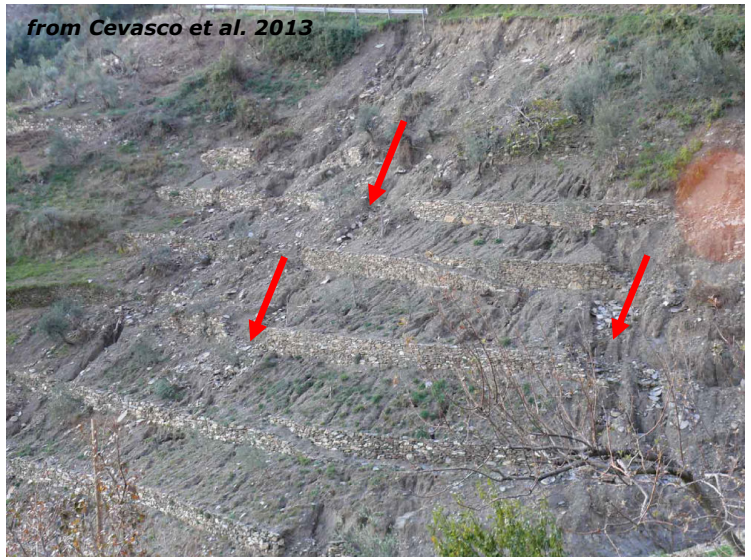
- Development erosion processes (piping and/or gullying phenomena)
- Continuous dry-stone wall disruption



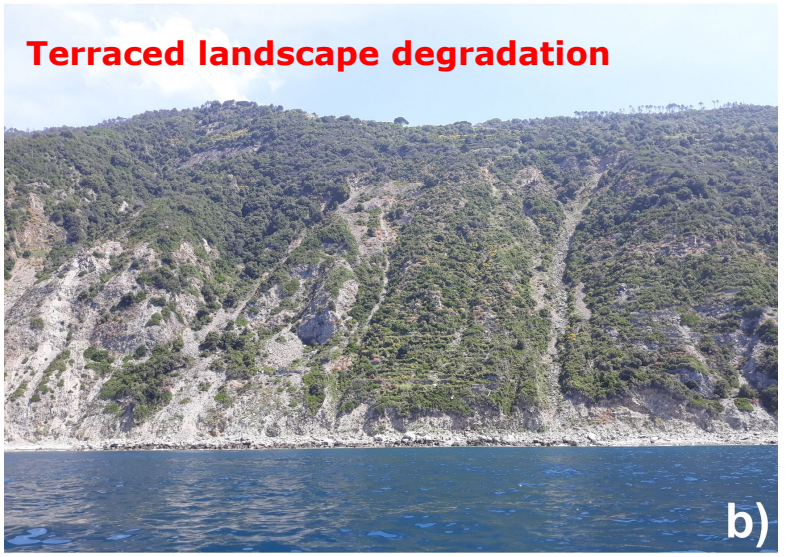
- Development of mass movements



(mod. from Brandolini 2017)



Terraced slope affected by rill erosion



Hydro-geomorphological implications of agricultural terraced landscape abandonment

A wide range of factors can affect the response of terraced landscapes after their abandonment and the interruption of cultivation (e.g., see Moreno-de-las-Heras et al. 2019) .

Geological factors

- Bedrock lithology
- Soil thickness

Climatic factors

- Extreme rainfall
- Antecedent rainfall
- Climate type

Geometrical factors

- Terrace height
- Terrace type

Pedological factors

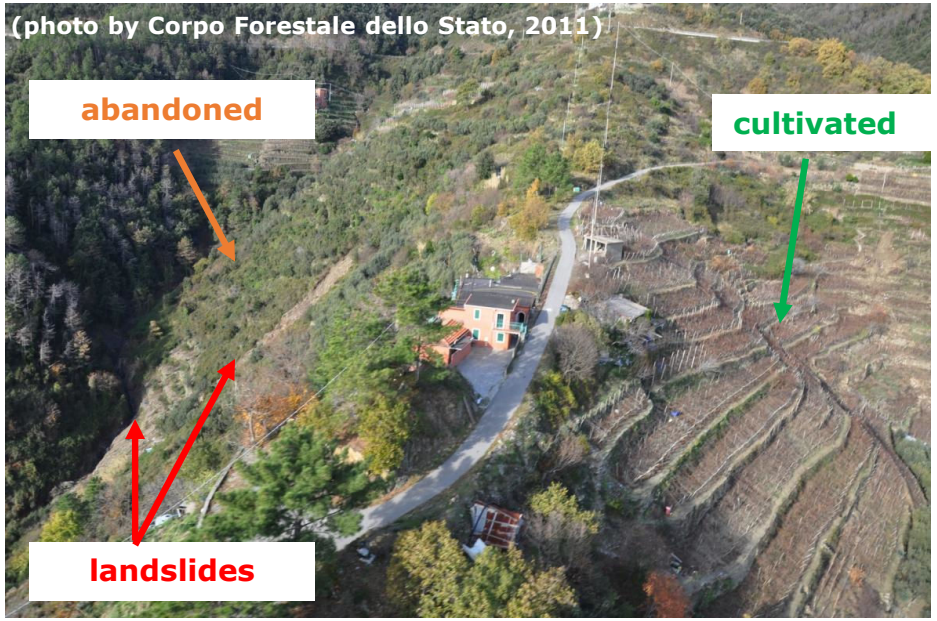
- Organic content
- Soil stoniness

Morphological factors

- Slope gradient
- Slope morphometric features

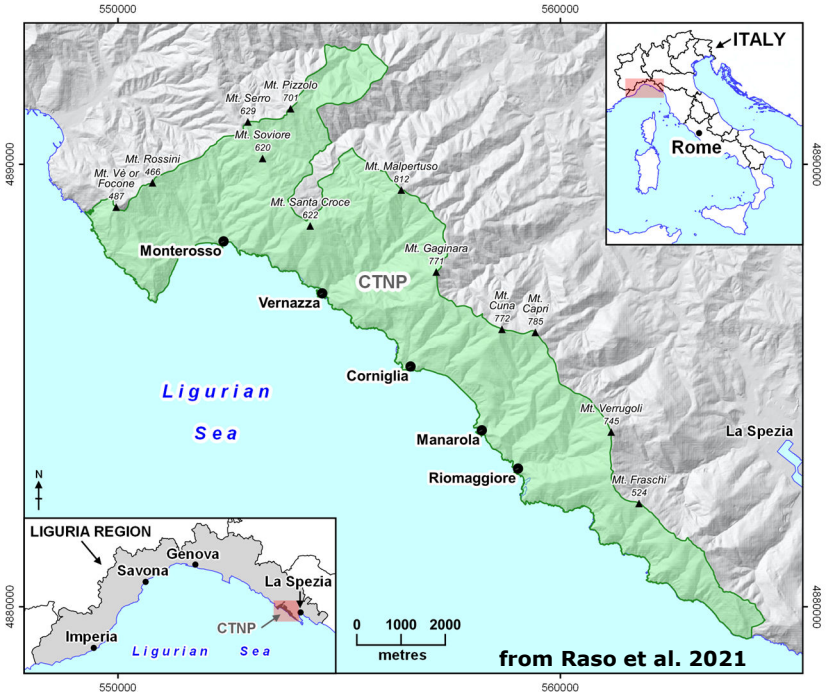
Land use/Land cover (LULC) factors

- Vegetation cover development
- Time after abandonment
- Vegetation disturbance (e.g., grazing & wildfires)



Different response to intense rainfall of slopes in different land use conditions

Experiences from Cinque Terre: what we have learned?



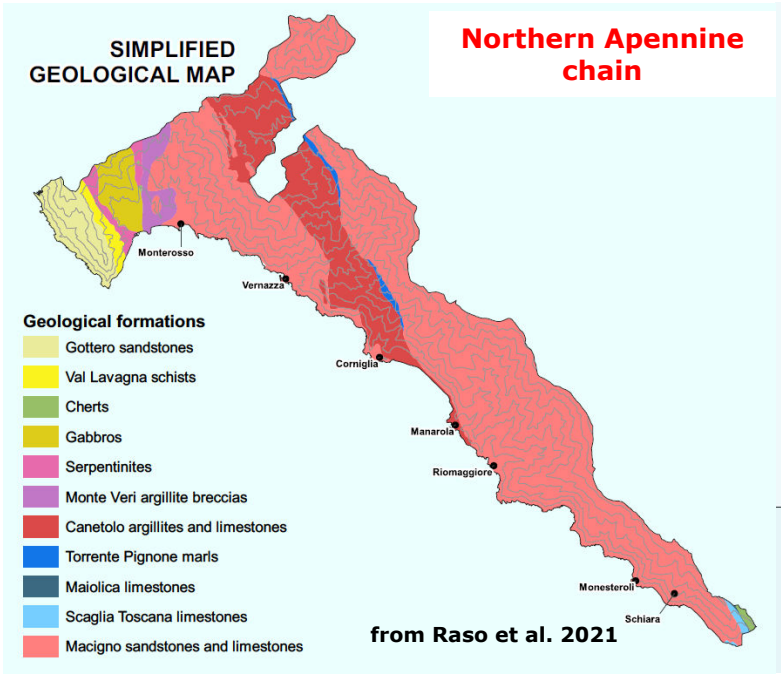
Cinque Terre

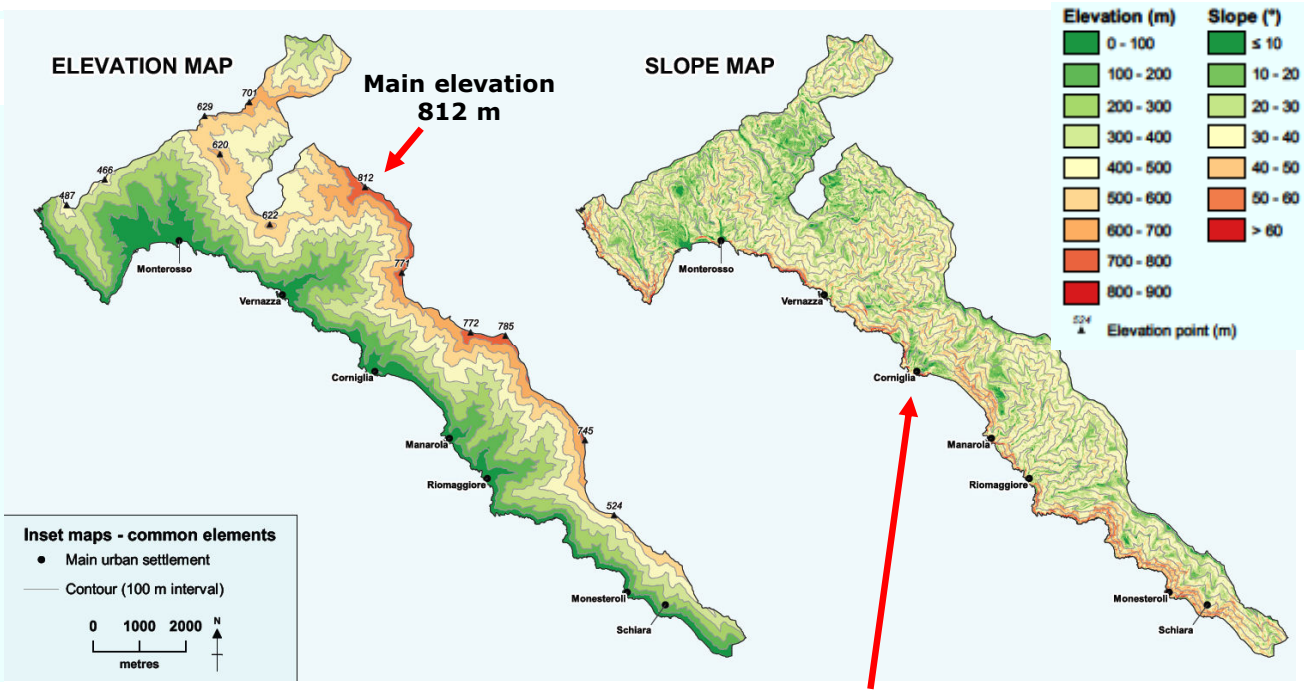
Coastal terraced slopes at Manarola hamlet

Terraced landscape declared since 1997 as '**UNESCO World Heritage**' for its "**high scenic and cultural value**" and since 1999 and as national park due to its environmental and naturalistic relevance

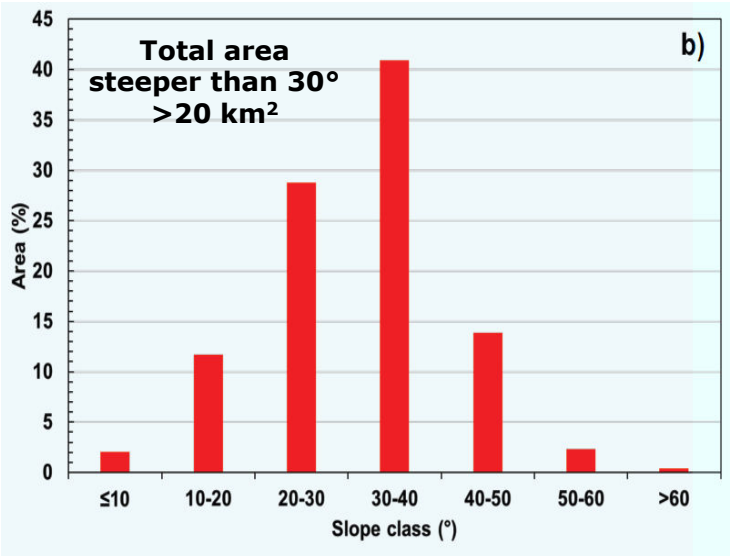
Coastal terraced slopes near the Riomaggiore hamlet

Cinque Terre: geological & geomorphological setting

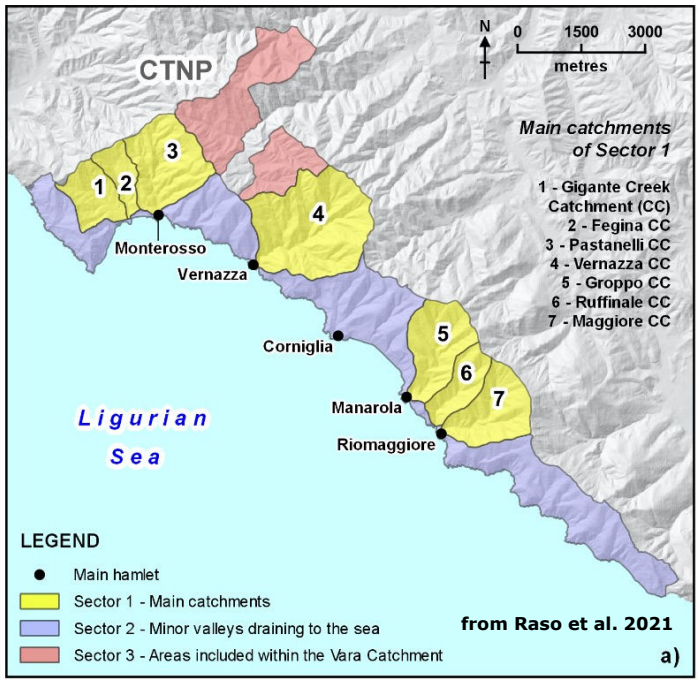




Area extent = 38 km²

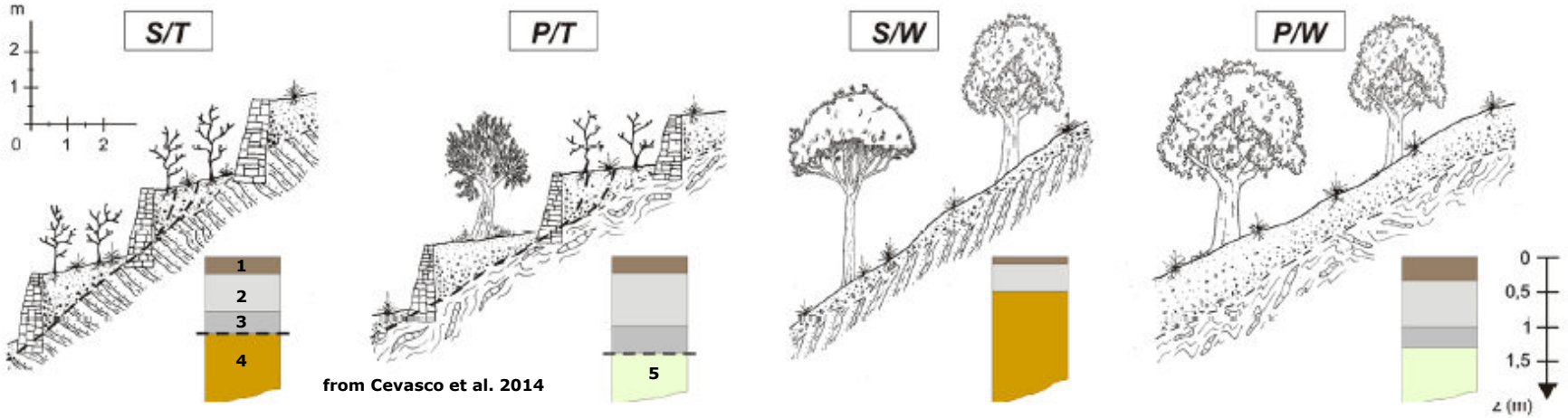


Cinque Terre: geological & geomorphological setting



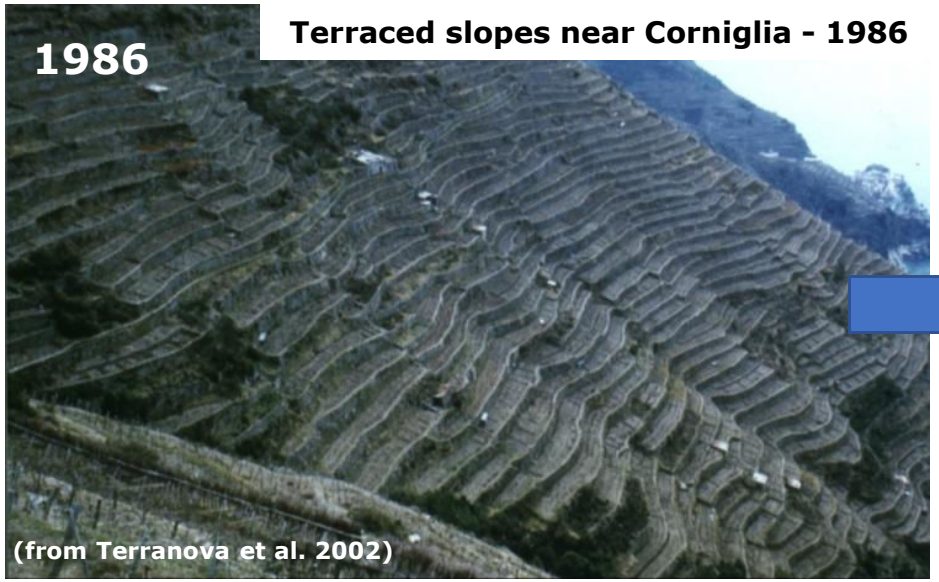
- Small size catchments
- Narrow and deep cut valleys
- Short stream with steep profile
- High erosive & transport power
- Steep coastal slopes & cliffs

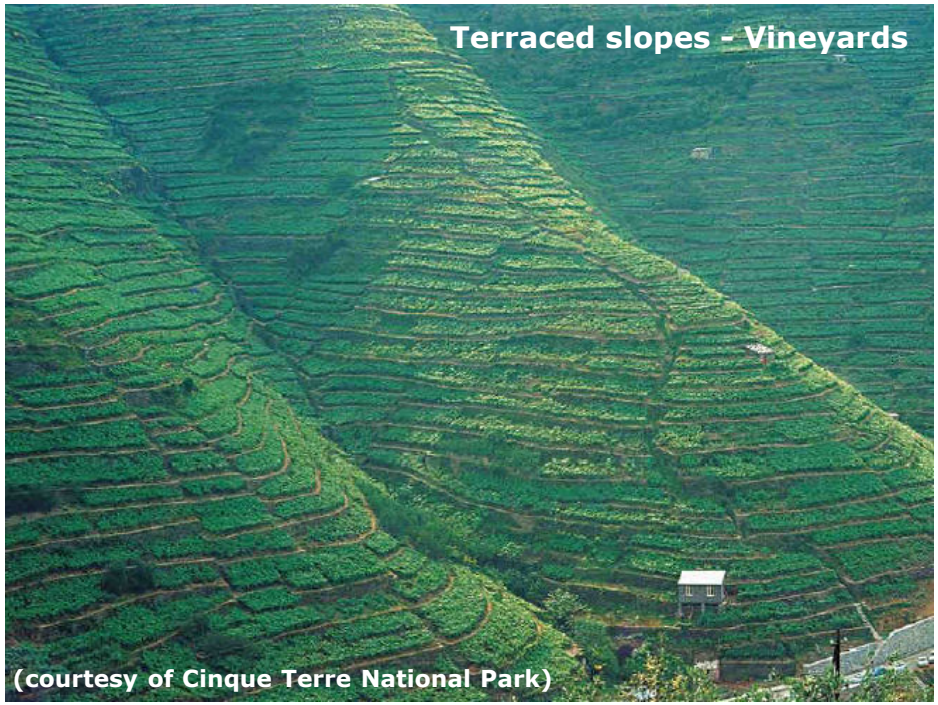
- Slopes mantled by thin covers of eluvial-colluvial deposits, reworked by human activities over the past centuries.



1 humus; 2 loose eluvial-colluvial deposits; 3 dense eluvial-colluvial deposits; 4 predominantly sandstone bedrock; 5 predominantly pelitic bedrock

A human-modified landscape: a history of slope terracing



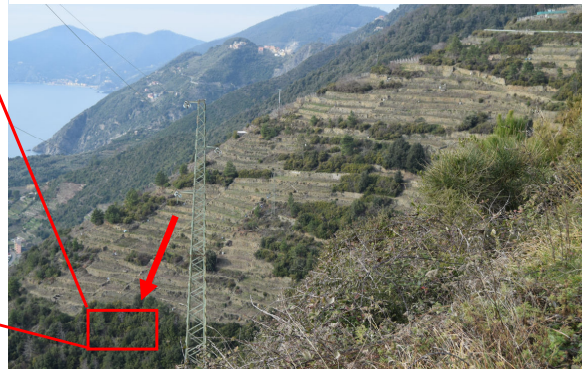


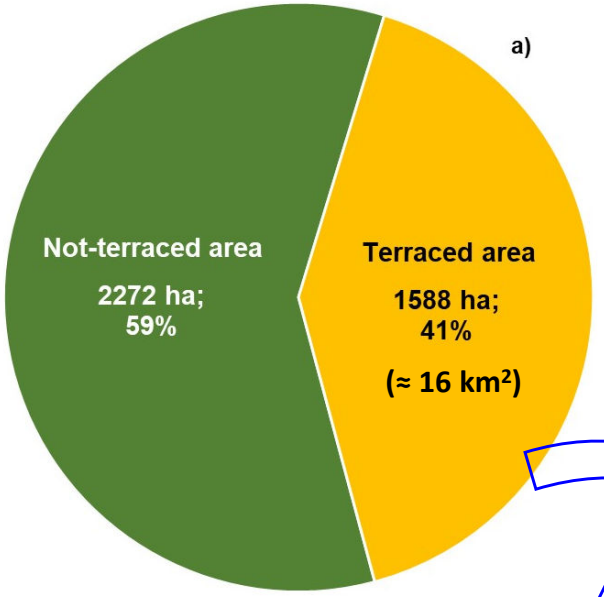
A human-modified landscape: farmland abandonment

Cultivated terraced areas

Terraced areas covered by shrubs

Terraced areas covered by forest

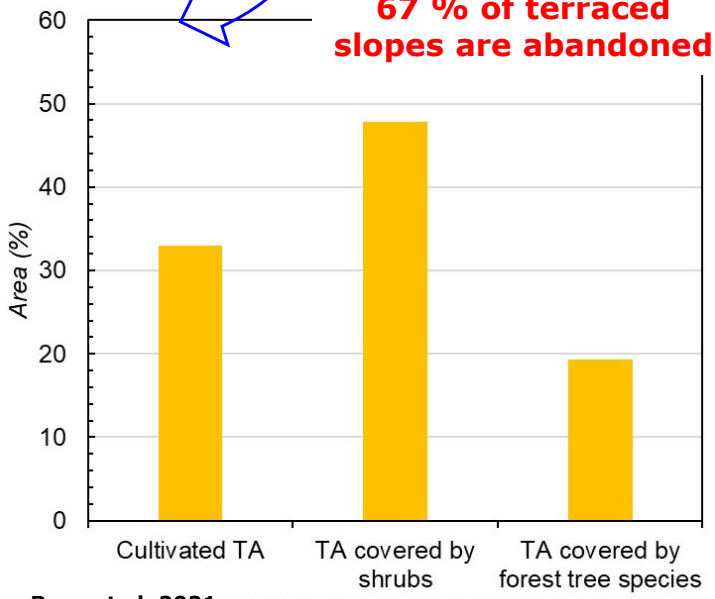




2019

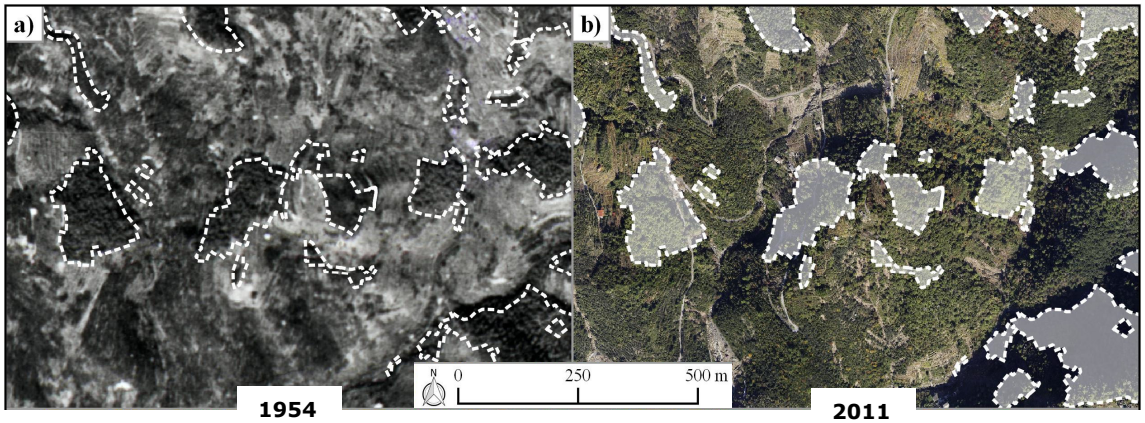
% of park territory occupied by terraced areas (yellow area)

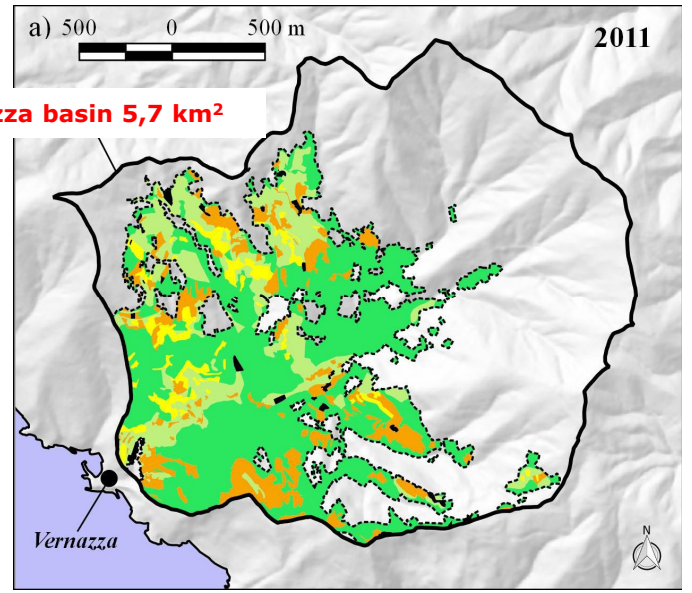
67 % of terraced slopes are abandoned



from Raso et al. 2021

Land use changes: farmland abandonment





LULC setting of the 1954 agricultural area

Data sources	Cadastral data	Aerial photographs	Aerial photographs	Landslides inventory
Period	1950-1952	1954	2011	2011

Phase 1 — LULC mapping

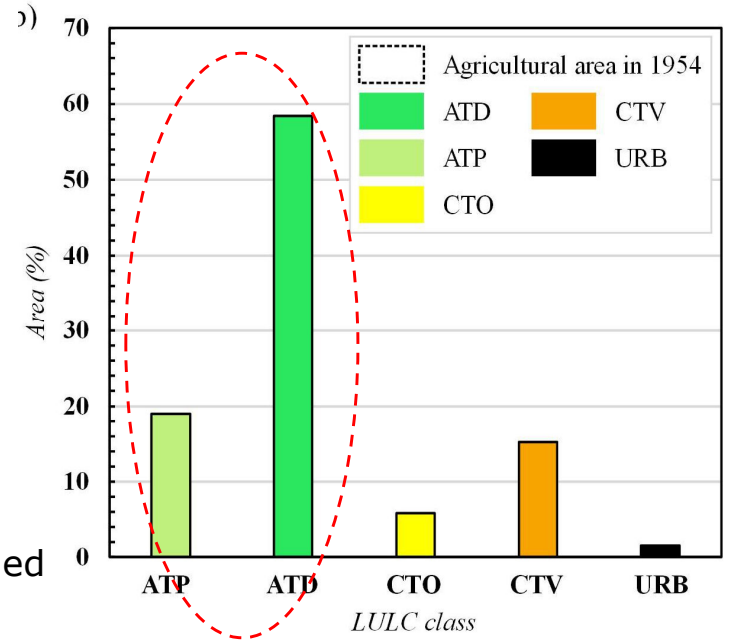
LULC classes for 1950-1952 and 1954:
1) Agricultural area;
2) Natural and semi-natural area;
3) Urban area.

LULC classes for 2011 (within 1954 AGR):
1) Cultivated terraced area;
2) Abandoned terraced area;
3) Urban area.

Phase 2 — LULC analysis

LULC data comparison: 1950-52 VS 1954 *LULC change detection:* 1954 (AGR) VS 2011

from Pepe et al. (2019)

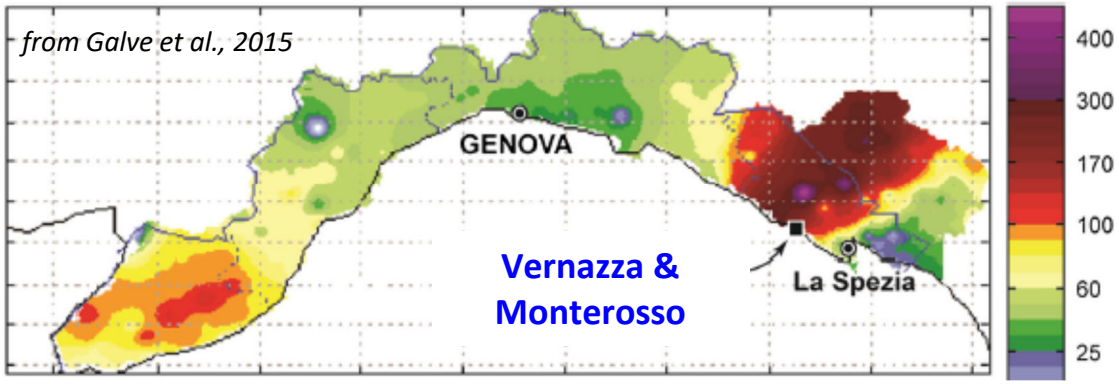


ATD - abandoned terraced slope with dense cover
ATP - abandoned terraced slope with poor cover
CTO - cultivated olive grove
CTV - cultivated vineyard
URB - urban area

Over ≈60 years, 77.4% of agricultural terraced slopes has been abandoned while 21.1% remained cultivated.

The response of terraced slopes to extreme rainfall

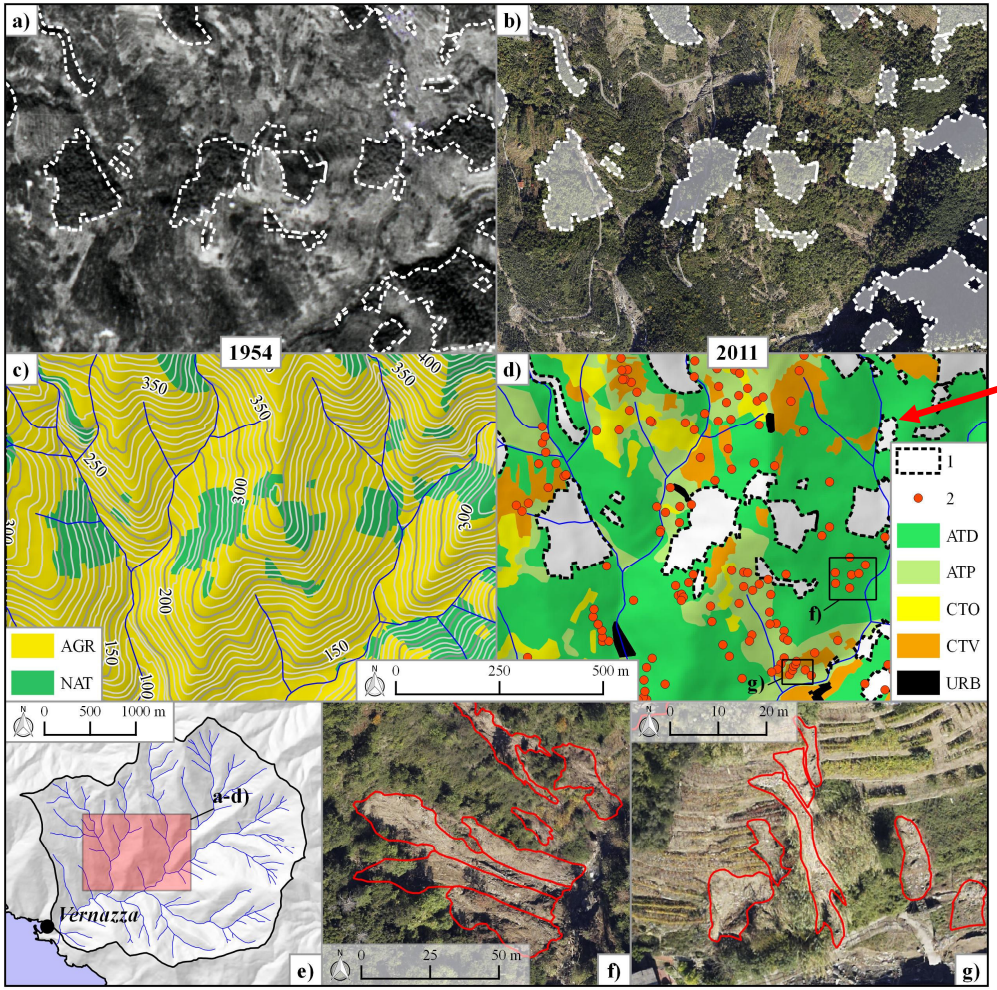
25 October 2011 rainstorm



Rainfall amount: 500 mm in few hours (6 hours), with peaks of about 150 mm/h

- Hundreds (>700) of shallow landslides
- High landslide densities (locally from 40 to 60 landslide/km^2)
- Shallow landslides evolved in debris avalanches and debris flows
- Flooding of the two urban hamlets (i.e., Vernazza & Monterosso)

The role of farmland abandonment on rainfall-induced effects

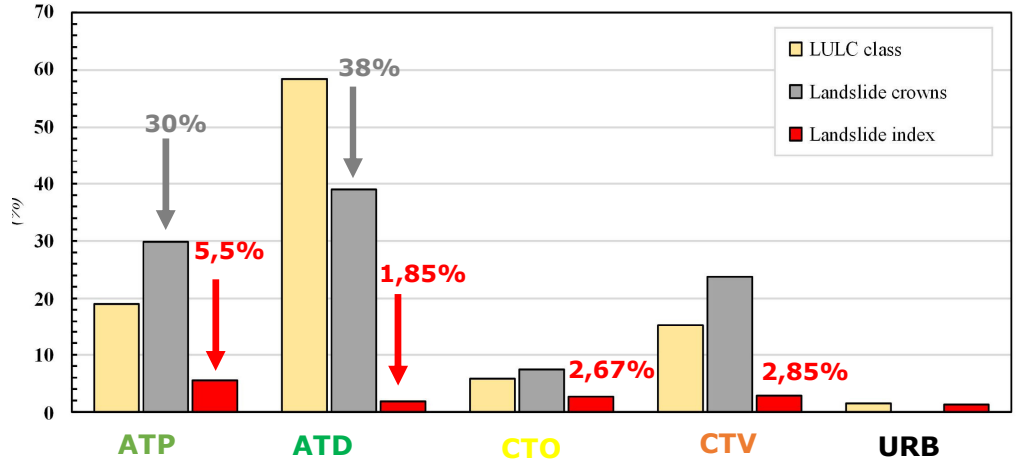


from Pepe et al. (2019)

Landslide sources (red dots) inventory map

$$Landslide\ Index(\%) = \frac{A_{sl}}{A_{LULC}}$$

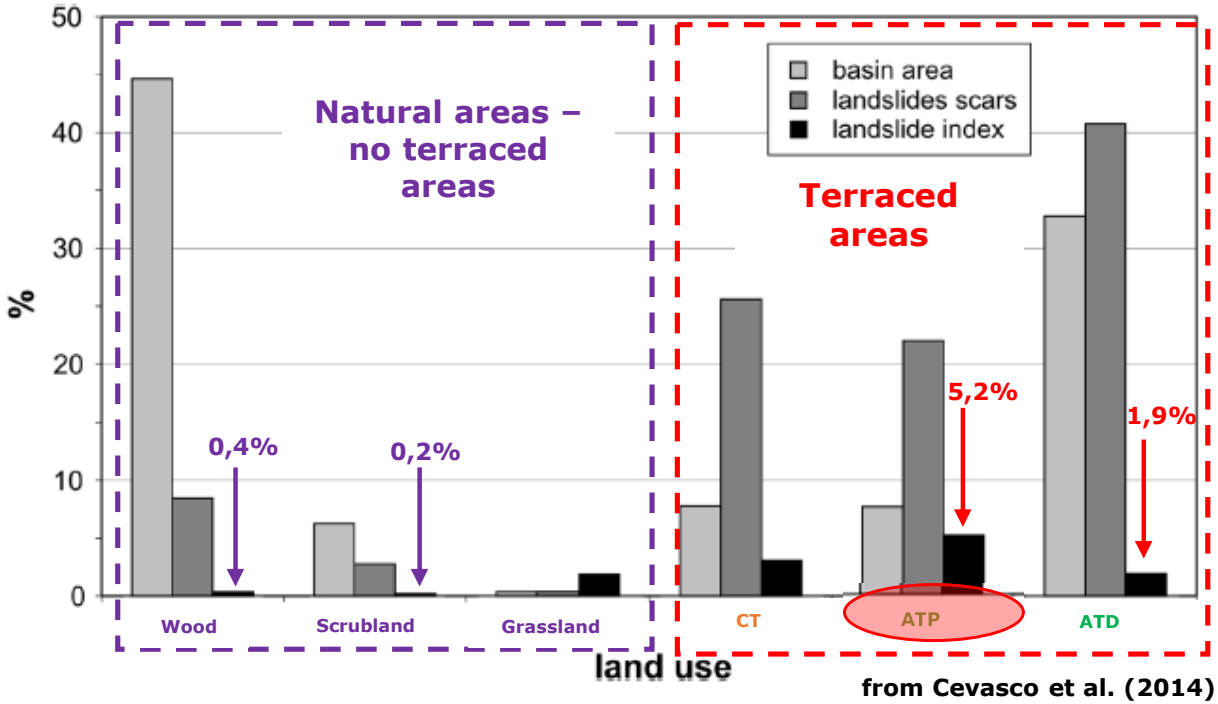
- A_{sl} = area affected by landslides
- A_{LULC} = land use class area



land use class

ATD - abandoned terraced slope with dense cover
ATP - abandoned terraced slope with poor cover
CTO - cultivated olive grove
CTV - cultivated vineyard
URB - urban area

The role of land-use on rainfall-induced effects



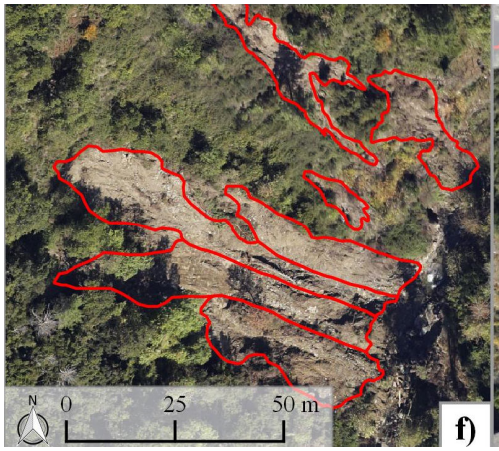
from Cevasco et al. (2014)

Terraced areas vs no terraced areas

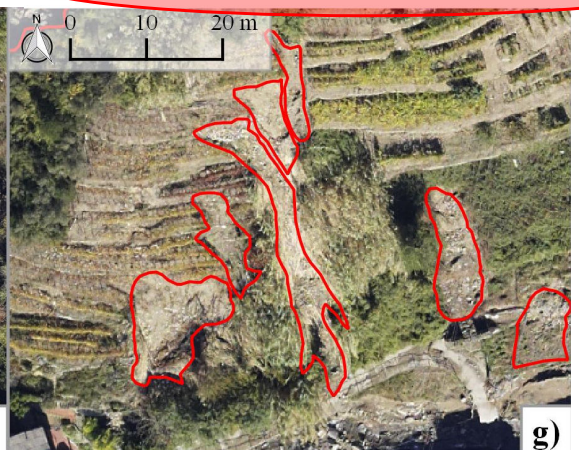
ATD - abandoned terraced slope with dense cover
ATP - abandoned terraced slope with poor cover
CT - cultivated terraced slope

Cultivated terraces

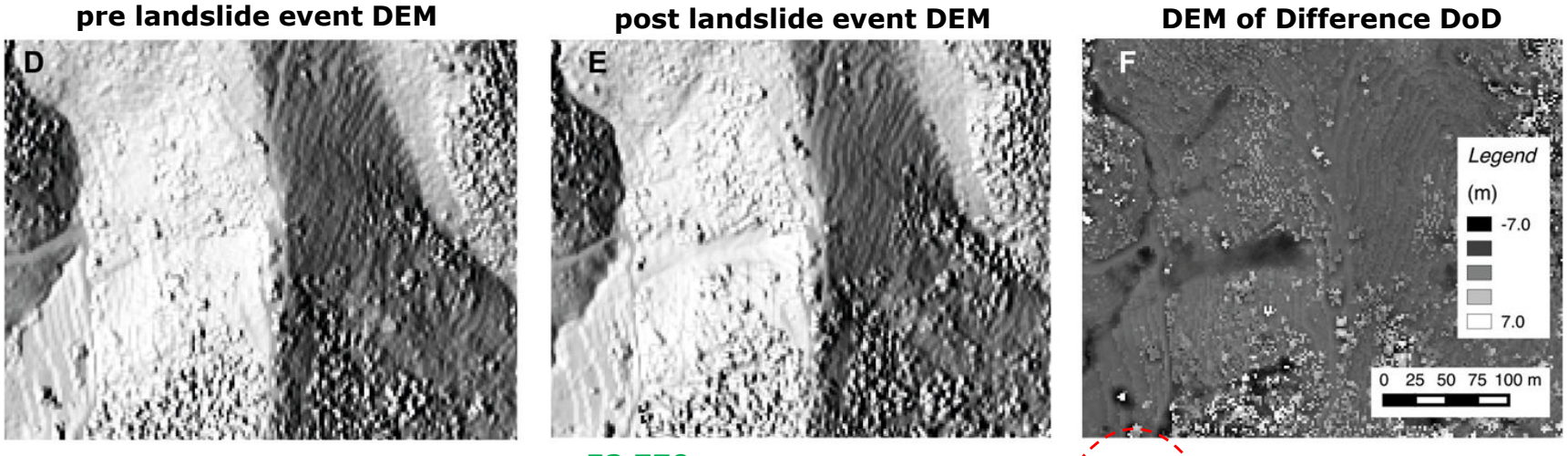
Abandoned terraces with dense cover

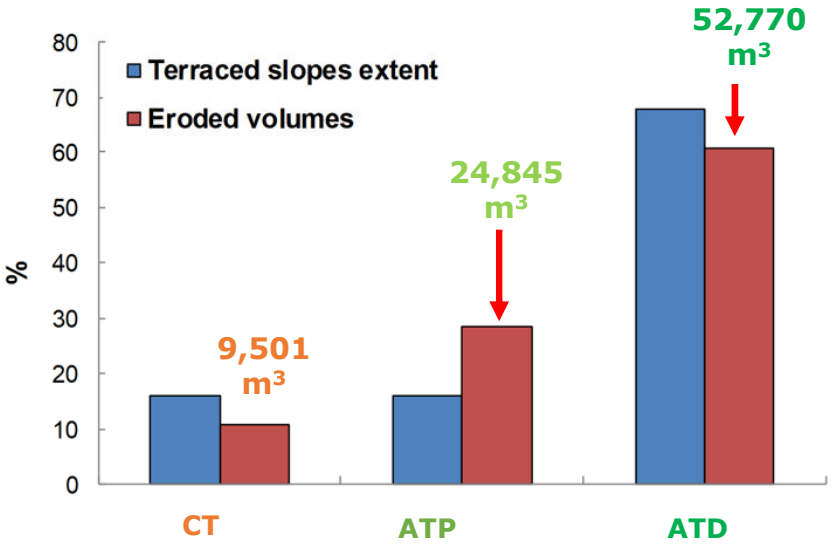


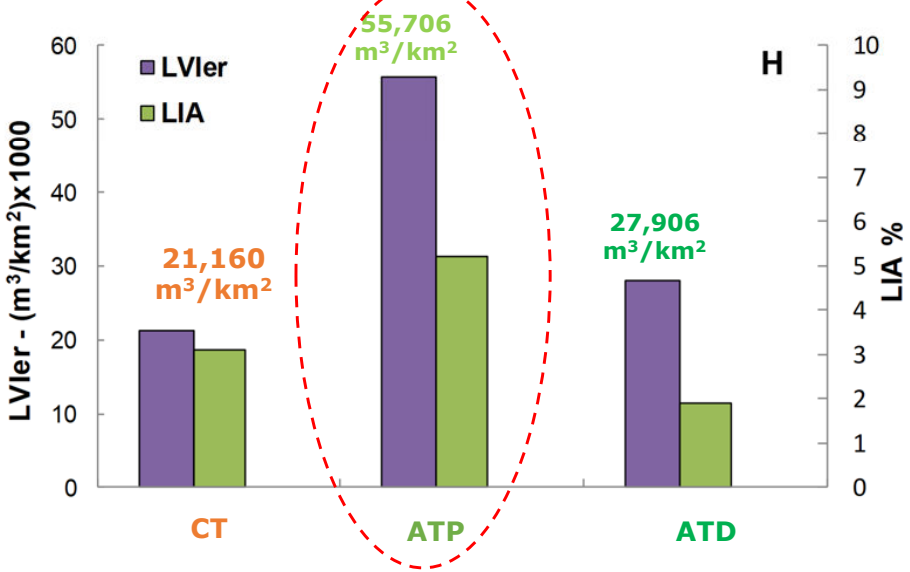
Abandoned terraces with poor cover



Shallow landslide mobilized volumes evaluation







$$LVI_{er,i} = \frac{Vt_{er,i}}{A_i}$$

$$LIA = \frac{A_{landslide,i}}{A_{,i}}$$

LVI$_{er}$: Landslide Volumetric Index

LIA: Landslide Index

i: Land use class

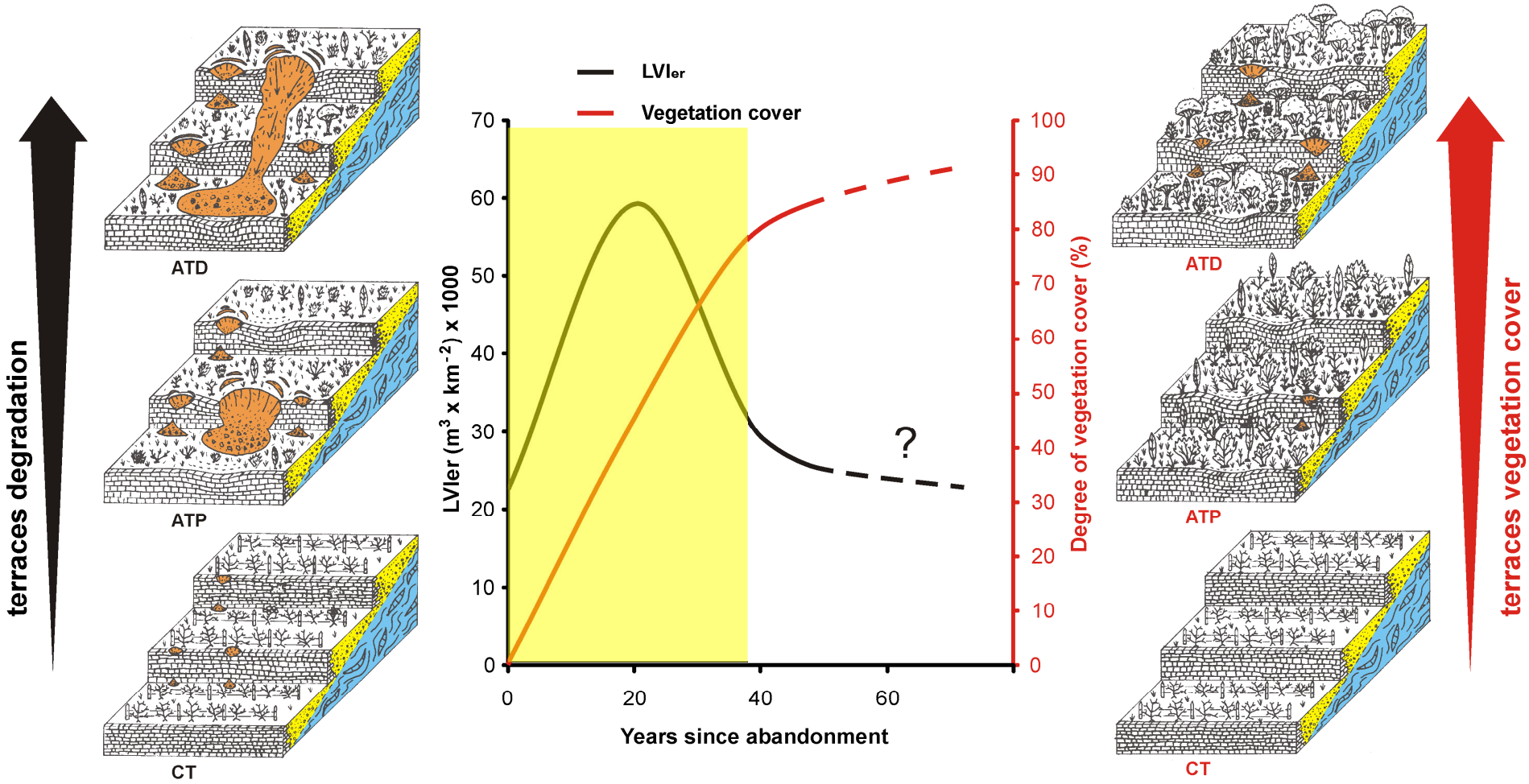
A: Land use class area

Vt$_{er}$: Shallow landslides eroded volumes

A$_{landslide}$: Shallow landslides area

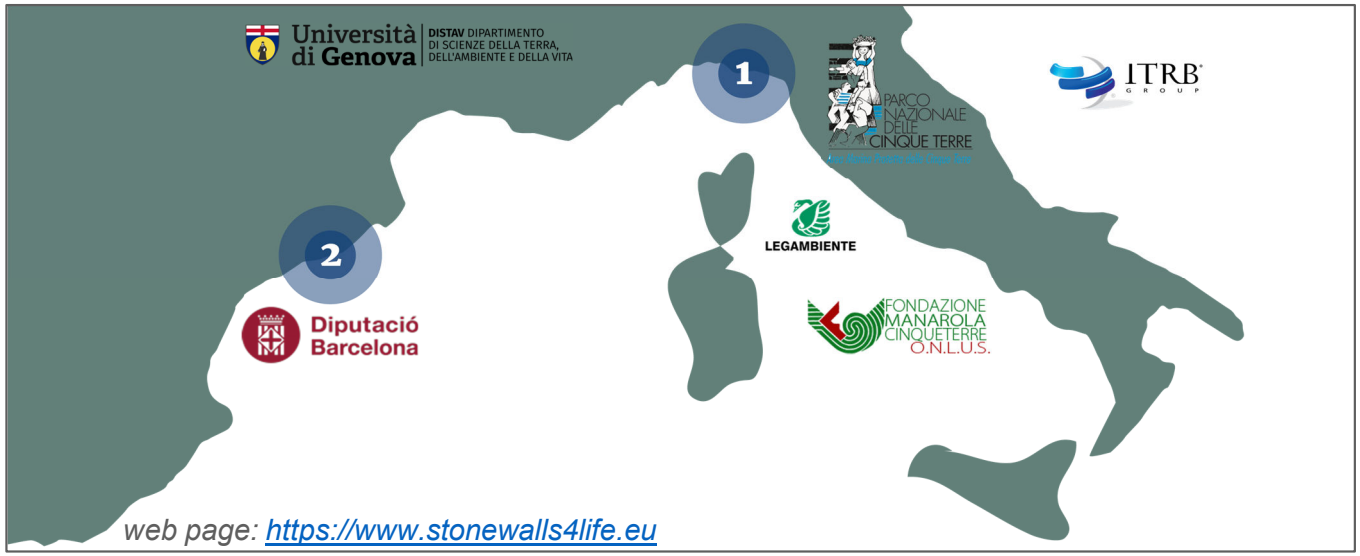
from Brandolini et al. (2018)

Slope degradation vs time since abandonment vs vegetation growth



from Brandolini et al. (2018)

Experiences from Cinque Terre: from what we have learned to new research perspectives

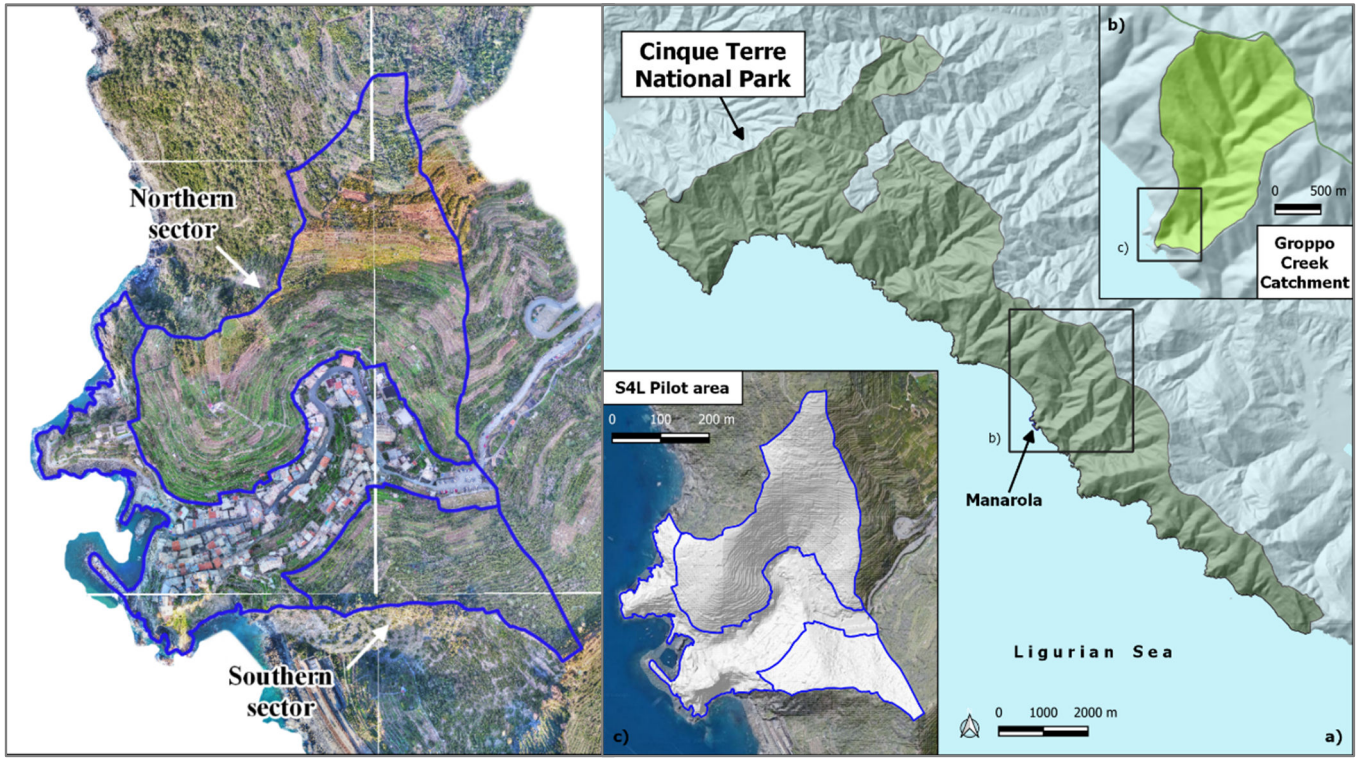


STONEWALLS4LIFE

The Stonewalls4Life Project:

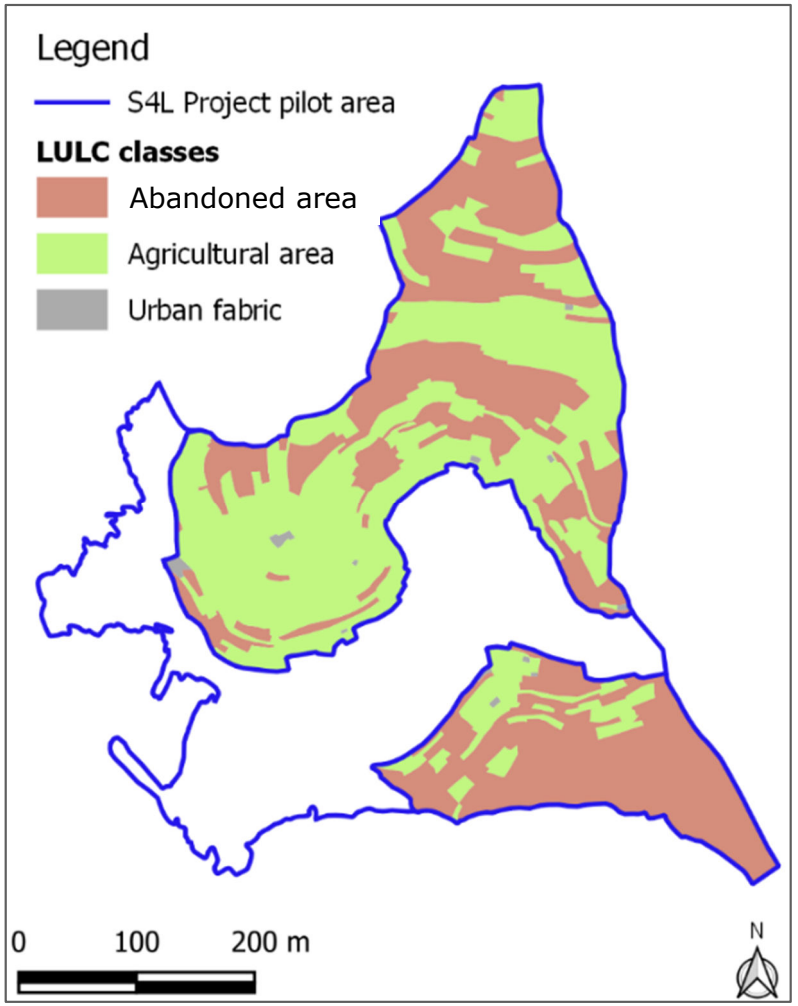
LIFE EU-project focused on Climate Change Adaptation

- **Mission**: investigate how the ancient technique of dry-stone walls can be effectively used to improve the resilience of the territory to climate change
- **Pilot area**: terraced surroundings Manarola hamlet



STONEWALLS4LIFE

Research purposes: understand the hydro-geotechnical response of terraced slopes, in different state of management and in different land use conditions (i.e., cultivated & abandoned**) during rainfall.**



Expected results: Seeking for indications on the **best condition** able to provide best response to extreme rainfall events.

Terraced slopes hydro-geotechnical monitoring

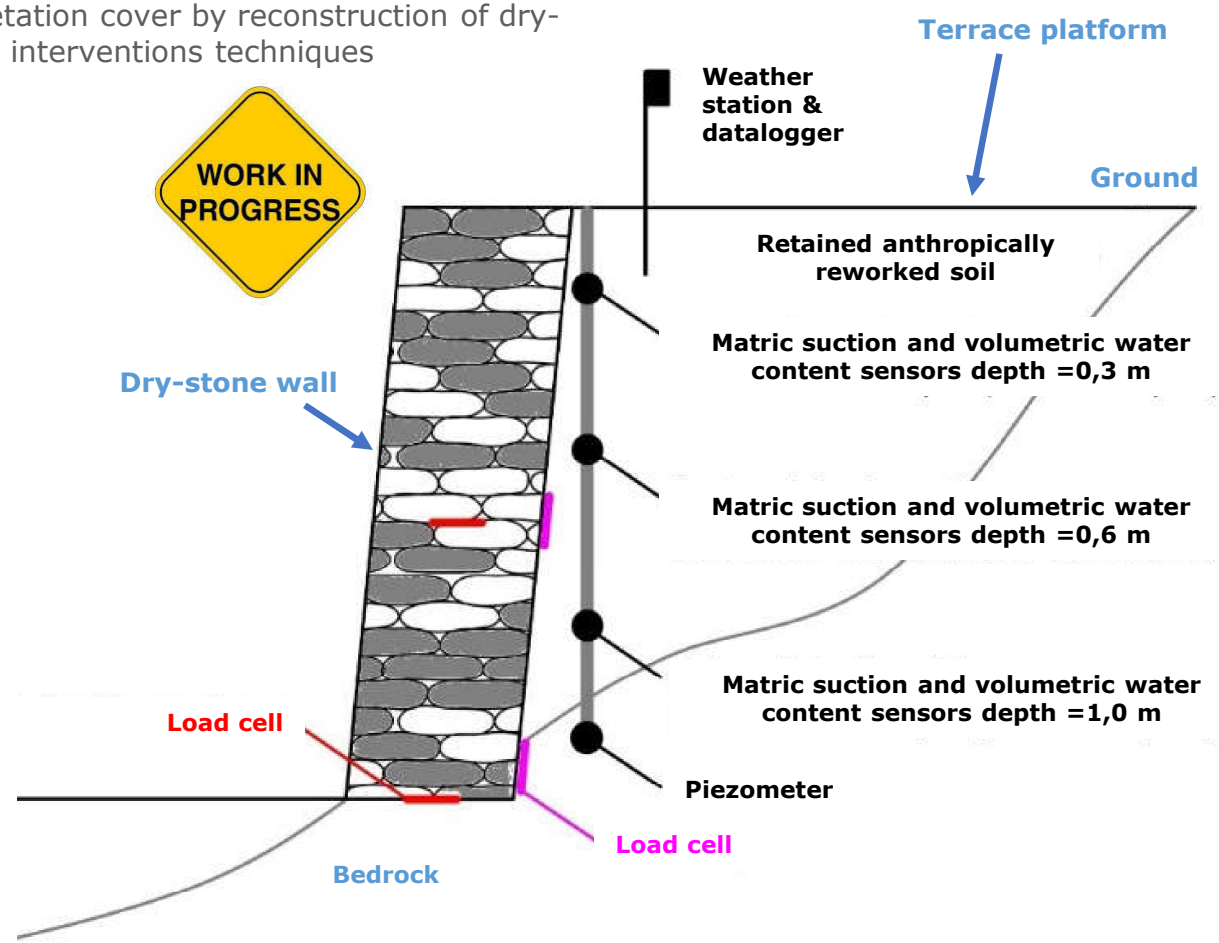
Monitoring scenarios:

1. Currently cultivated terraces
2. Abandoned terraces
3. Restored terraces with scarce vegetation cover by construction of dry-stone walls using traditional building techniques
4. Restored terraces with with scarce vegetation cover by reconstruction of dry-stone walls using innovative/alternative interventions techniques

STONEWALLS4LIFE

Currently cultivated terraces

Abandoned terraces to be restored



THANKS FOR YOUR ATTENTION

To the results showed in this presentation contributed the following working group: Dr. Giacomo Pepe, Prof. Andrea Cevasco, Prof. Pierluigi Brandolini, Prof. Marco Firpo, Prof. Domenico Calcaterra, Dr. Andrea Mandarino, Dr. Emanuele Raso, Dr. Andrea Vigo, Dr. Patrizio Scarpellini & Dr.Francesco Marchese