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E AMBIENTE



Ministero della Giustizia



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GREEN LAB

Progettazione di soluzioni basate sulla natura per la mitigazione del rischio idraulico in ambito urbano e sub-urbano



Green Infrastructures to mitigate flood risks in Urban and sub-urban areas and to improve the quality of rainwater discharges

The choice of plant species for green roofs and rain gardens in the Mediterranean area

Autore: Daniela Romano

Ente: Dipartimento di Agricoltura, Alimentazione e Ambiente – Università degli Studi di Catania

Di3A – Aula G
31 luglio – 1 agosto 2023



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Daniela Romano

Università degli Studi di Catania

Dipartimento di Agricoltura, Alimentazione e Ambiente (Di3A)

The choice of plant species for green roofs and rain gardens in the Mediterranean area

 **Interreg**
Italia-Malta
gifluid

Fondo Europeo di Sviluppo Regionale
European Regional Development Fund



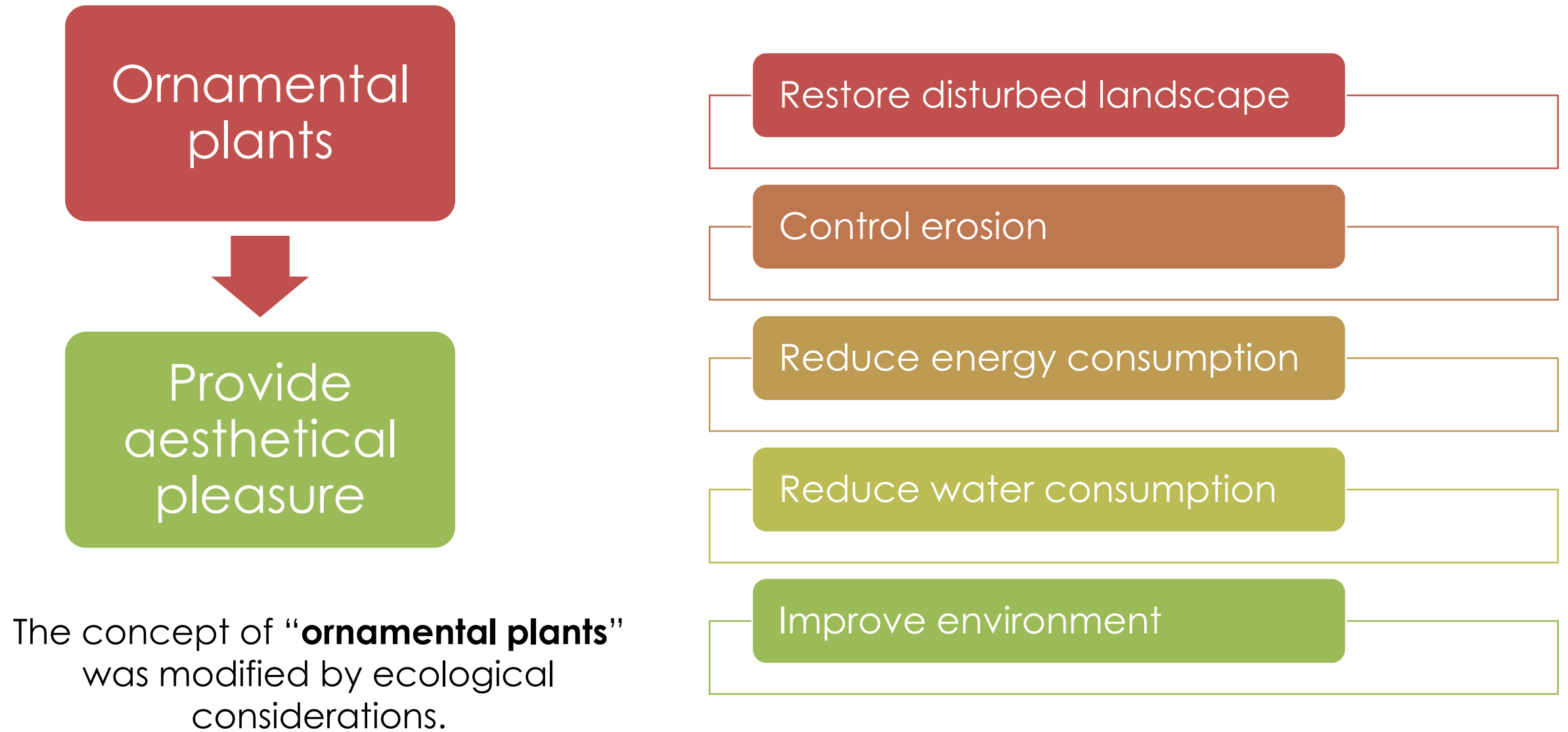
 **CSEI Catania**
Centro Studi di Economia
applicata all'Ingegneria

31 July -1 August 2023



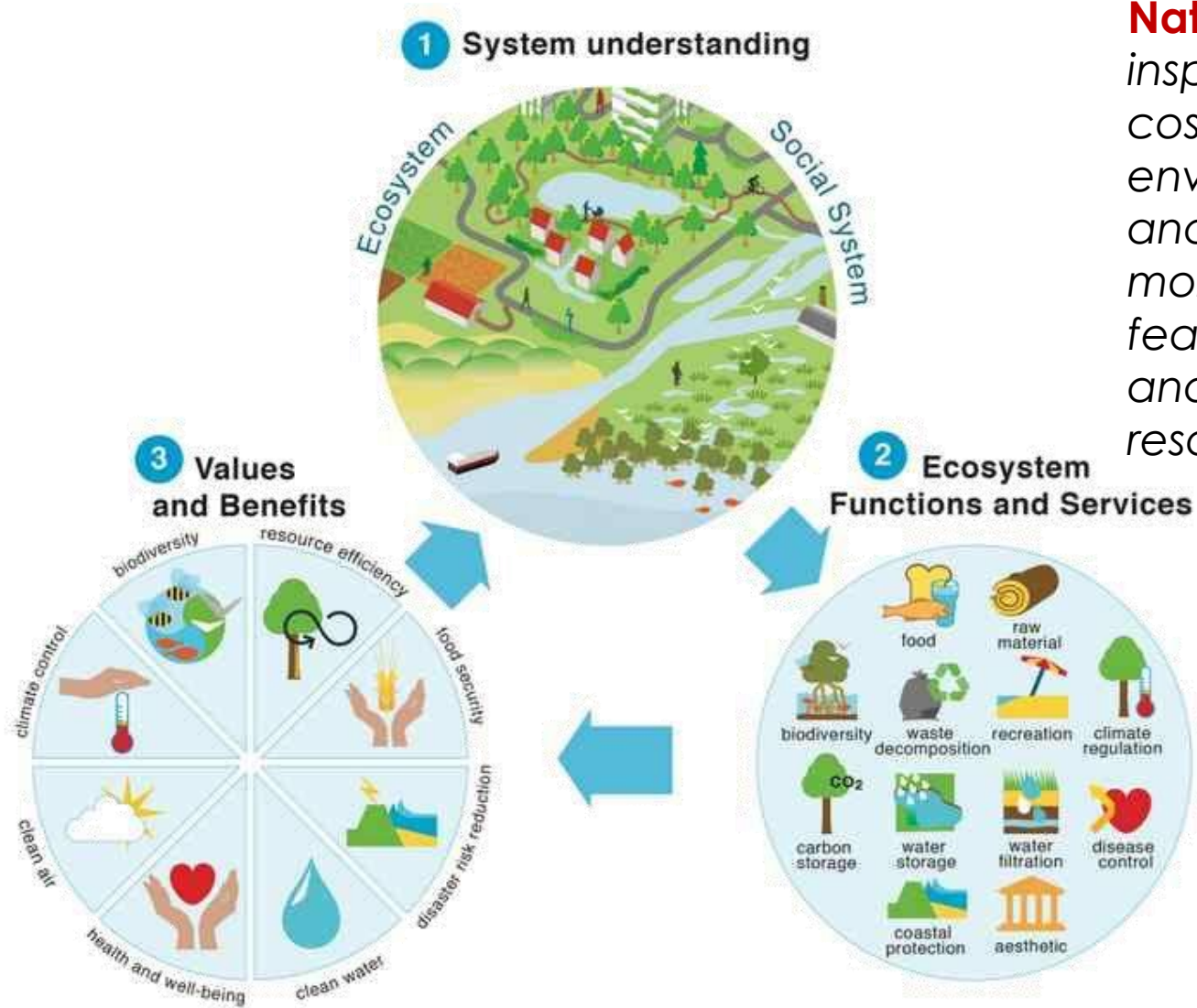
What I want to talk about ...





Savè, 2009



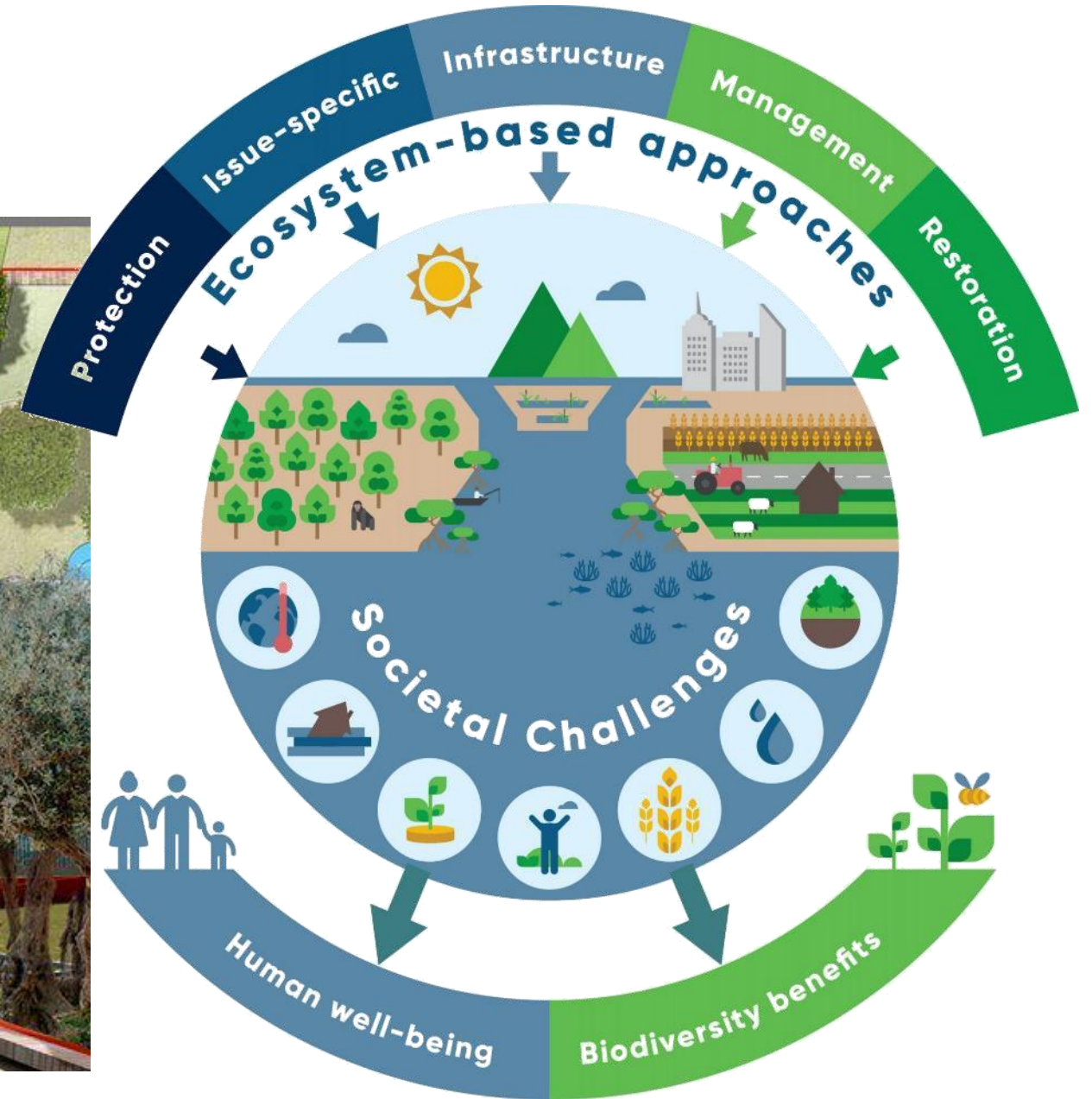
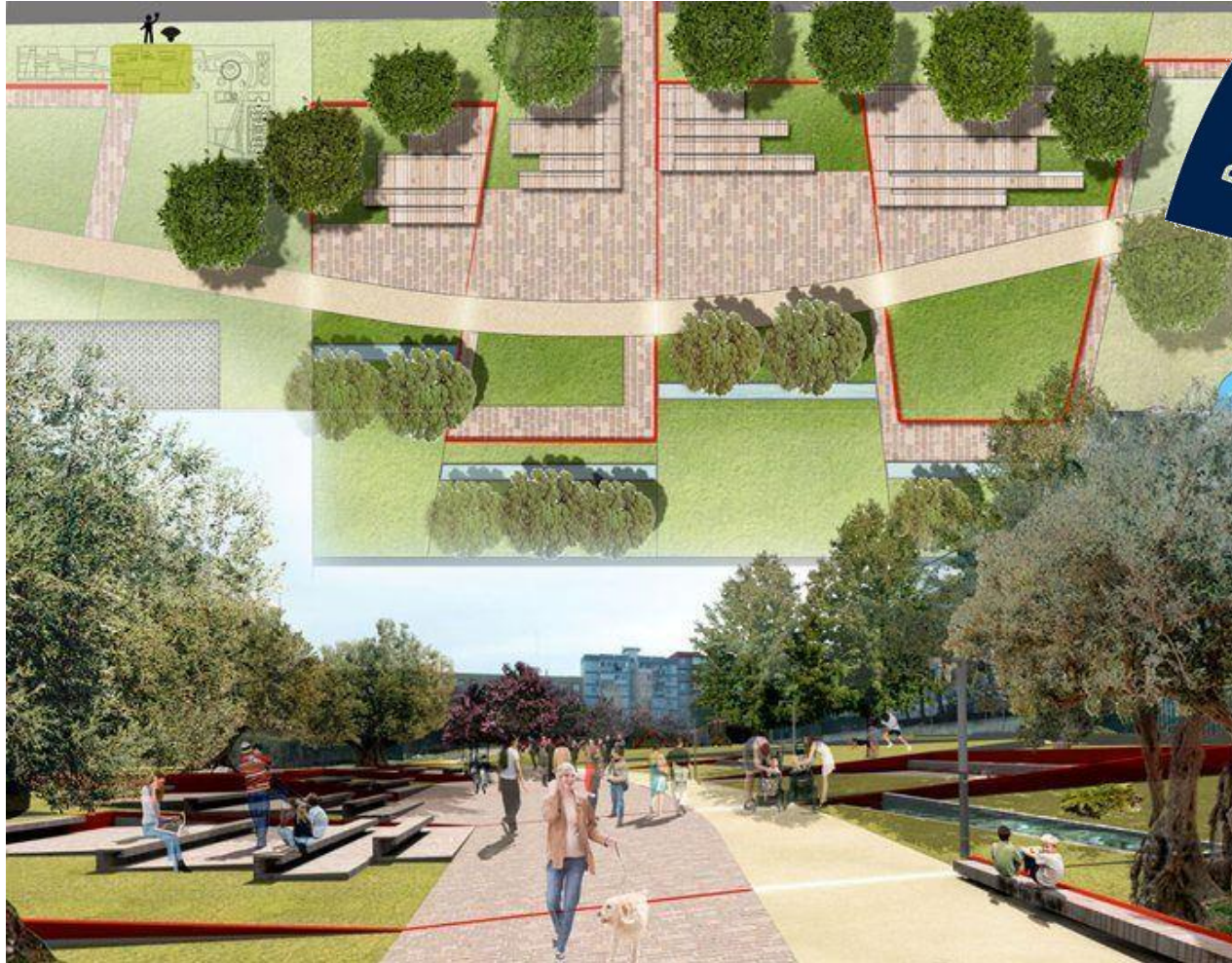


Nature Based Solution = «Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions».

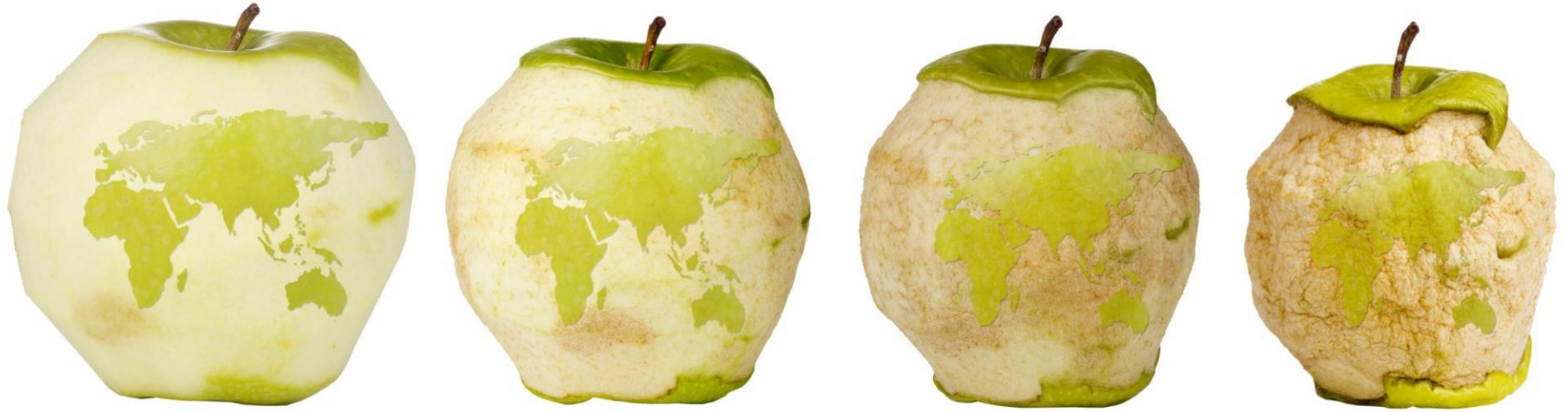


<https://www.greenplanner.it/2018/06/27/nature-based-solutions/>

From the «traditional» green design ...



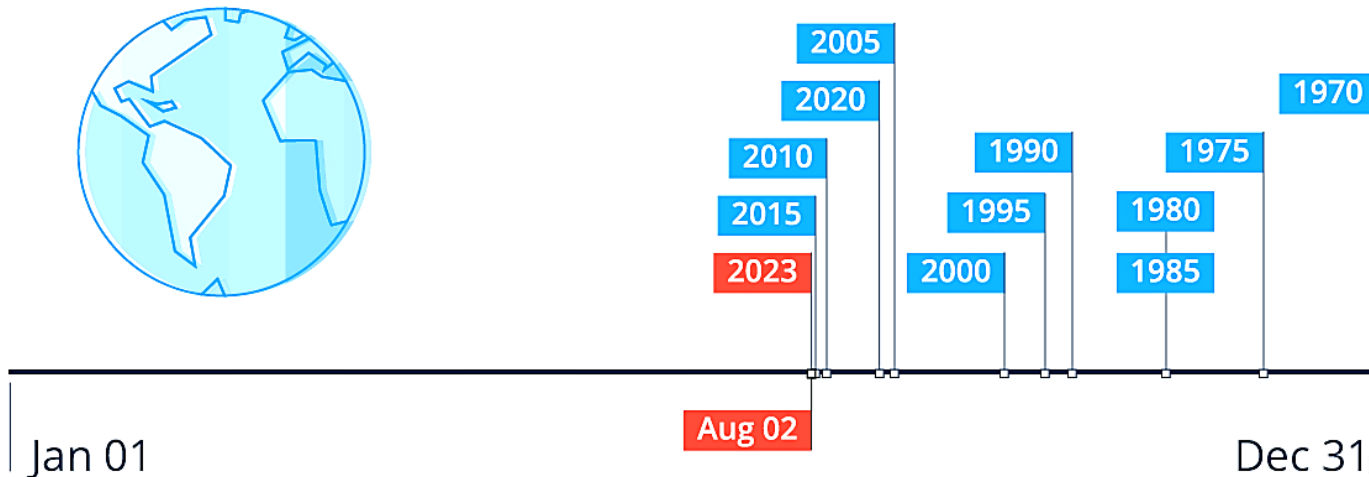




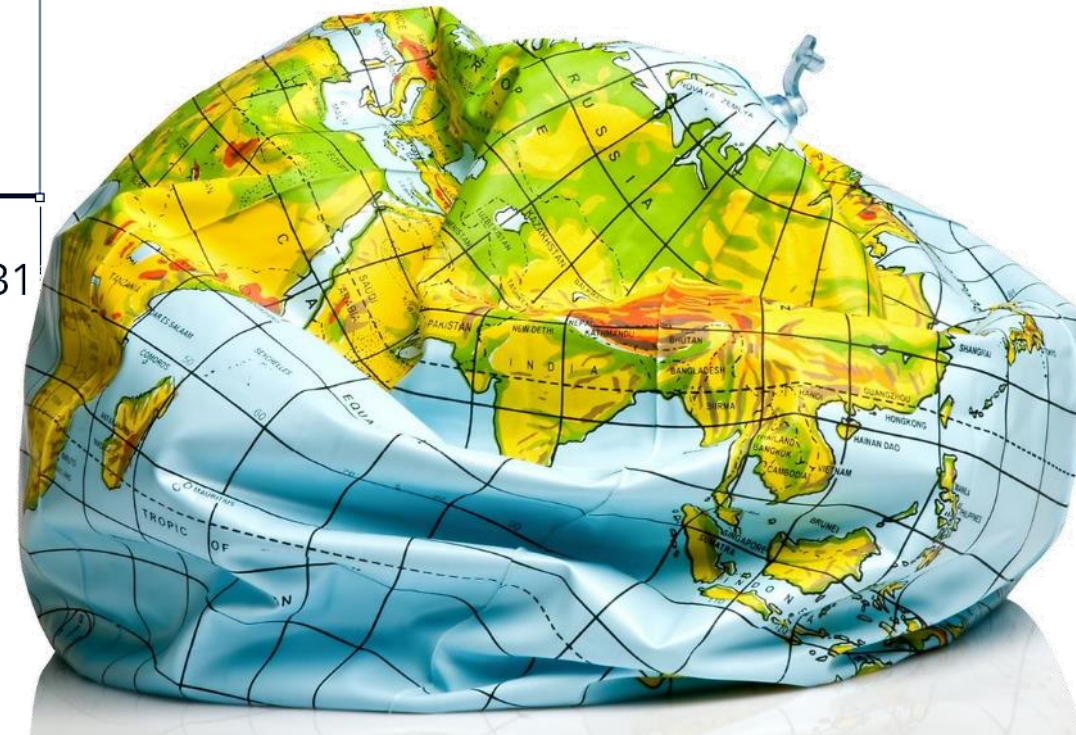
The need to rethink our development models ...

Earth Overshoot Day Is Coming Sooner and Sooner

Historical dates of Earth Overshoot Day



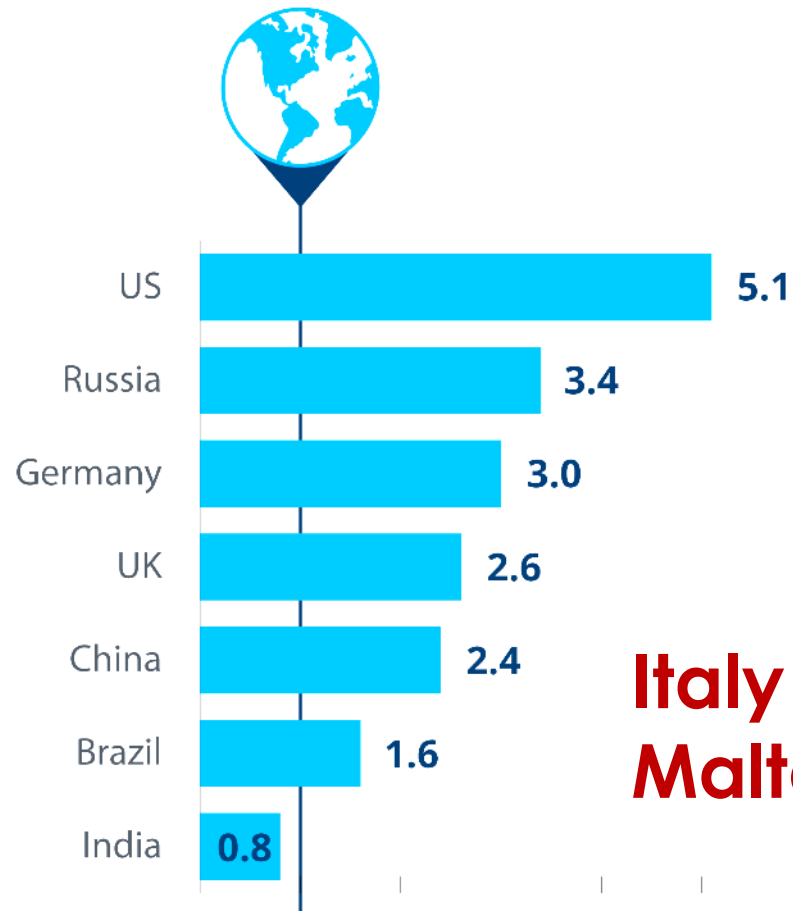
Earth Overshoot Day marks the date when humanity's demand for ecological resources in a given year exceeds what Earth can regenerate in that year.



Source: Earth Overshoot Day

How many Earths would we need

if the world's population lived like...



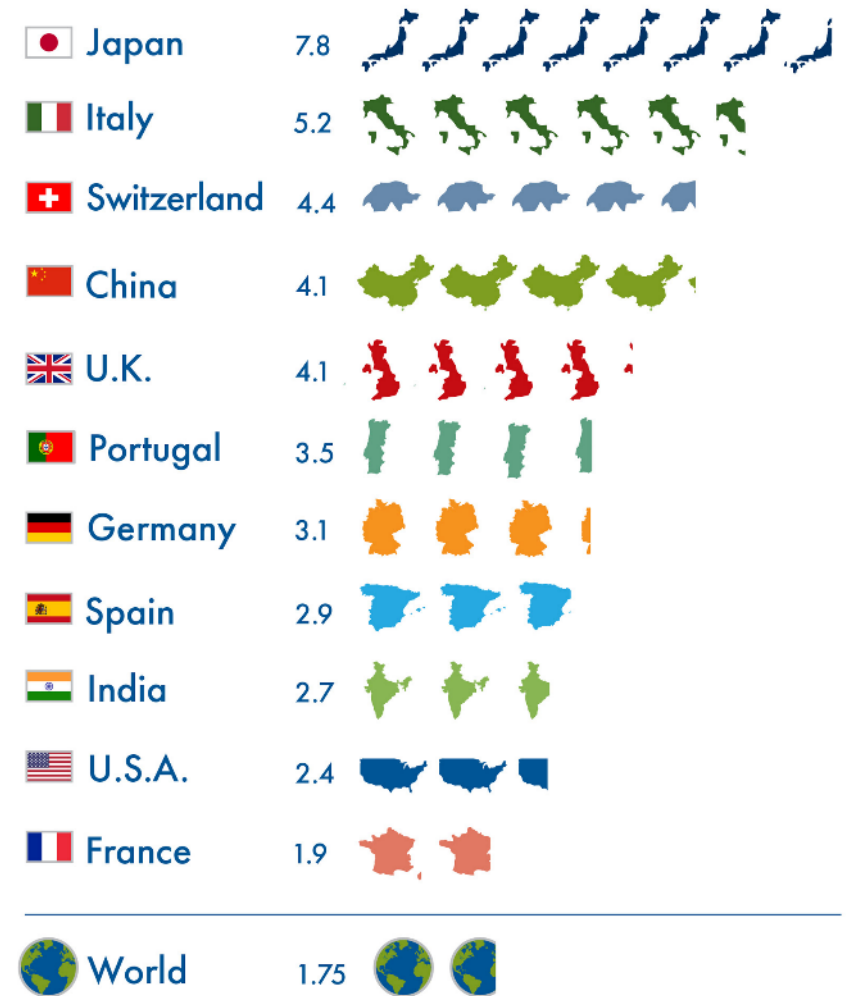
Italy = 15 May 2023
Malta = 16 April 2023



Source: Global Footprint Network and Biocapacity Accounts | 2022

How many Switzerlands does Switzerland need

to meet its residents' demand on nature?



Source: National Footprint and Biocapacity Accounts 2022

Additional countries available at overshootday.org/how-many-countries

We are destroying
the Earth



TIME IS OVER

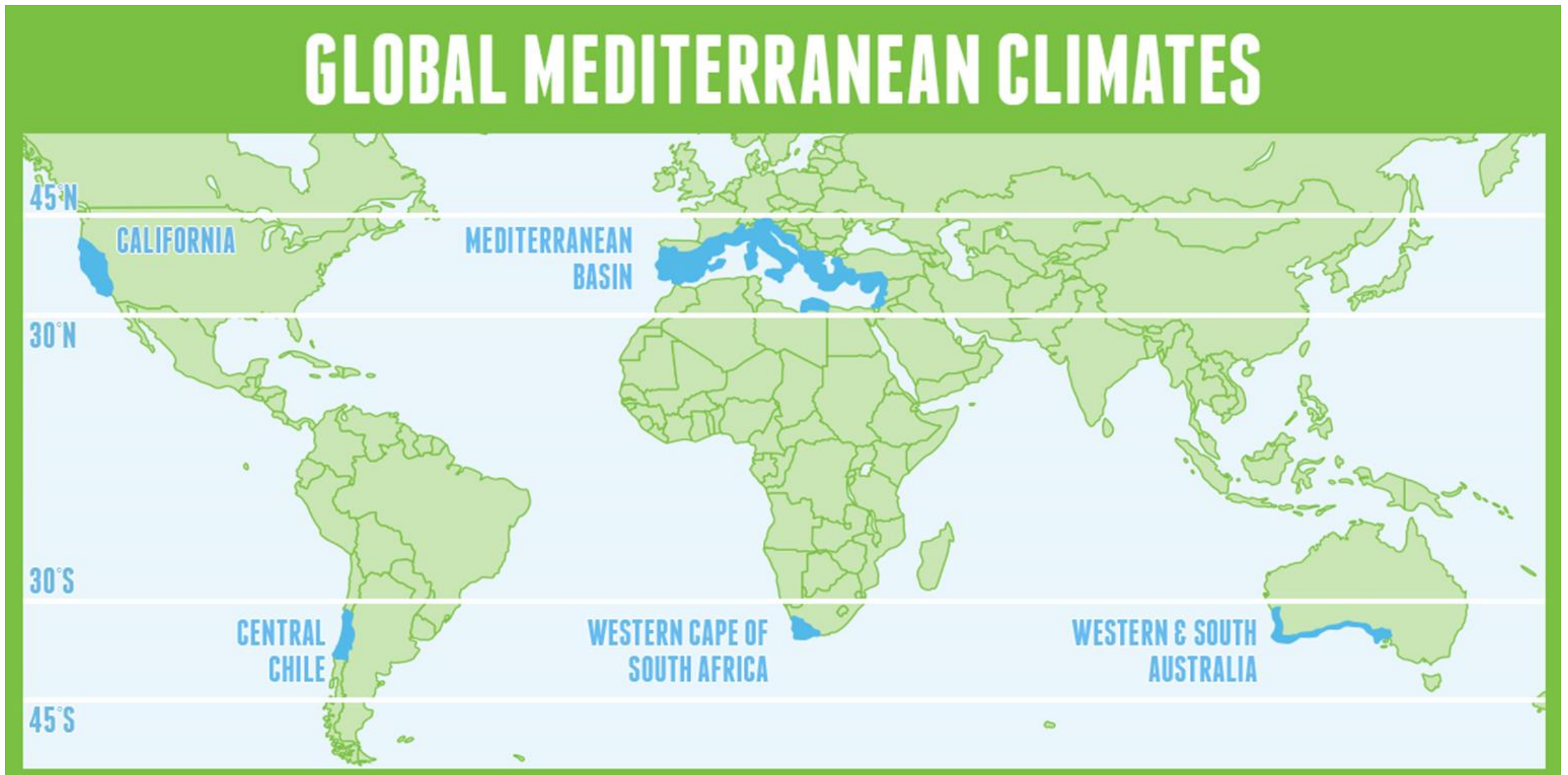


What will we leave for our children?



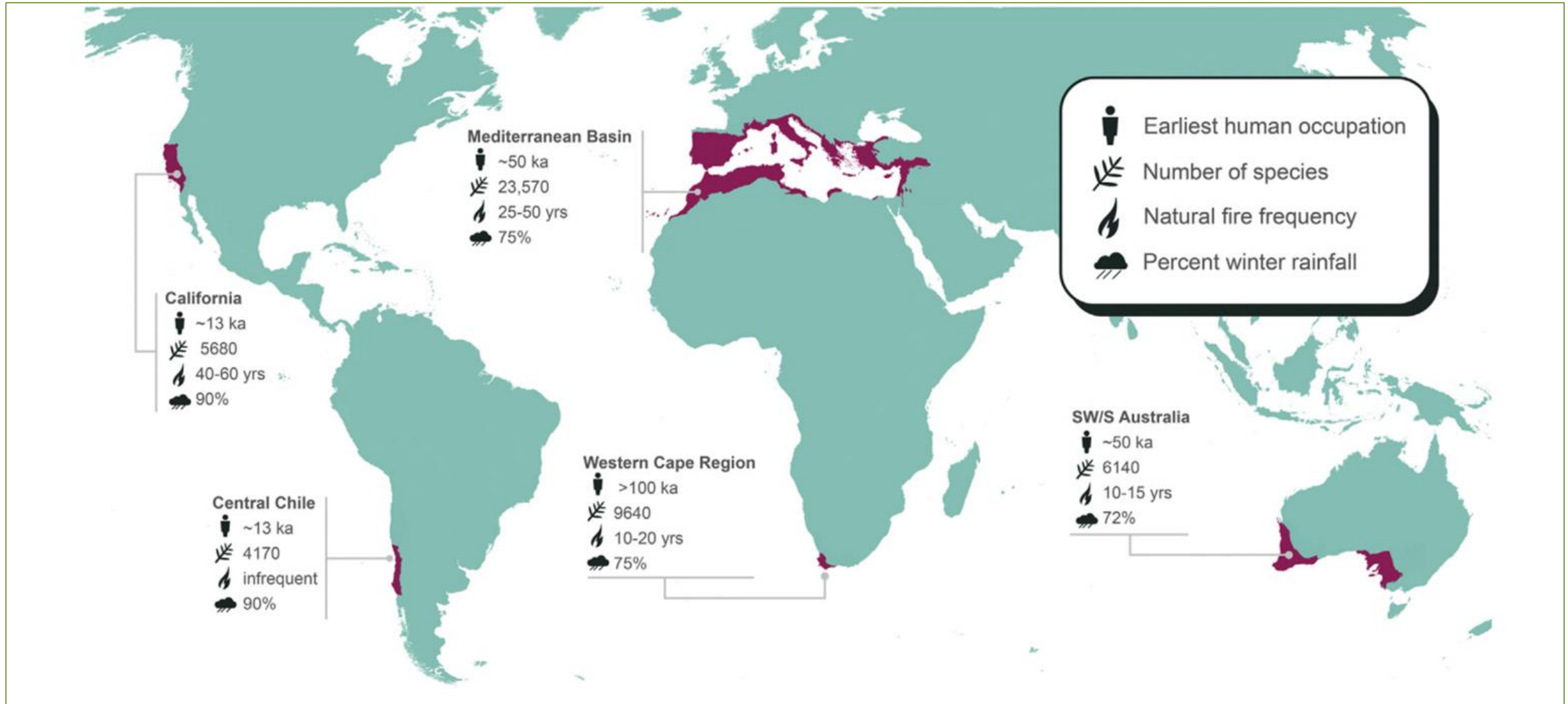
We must stop!





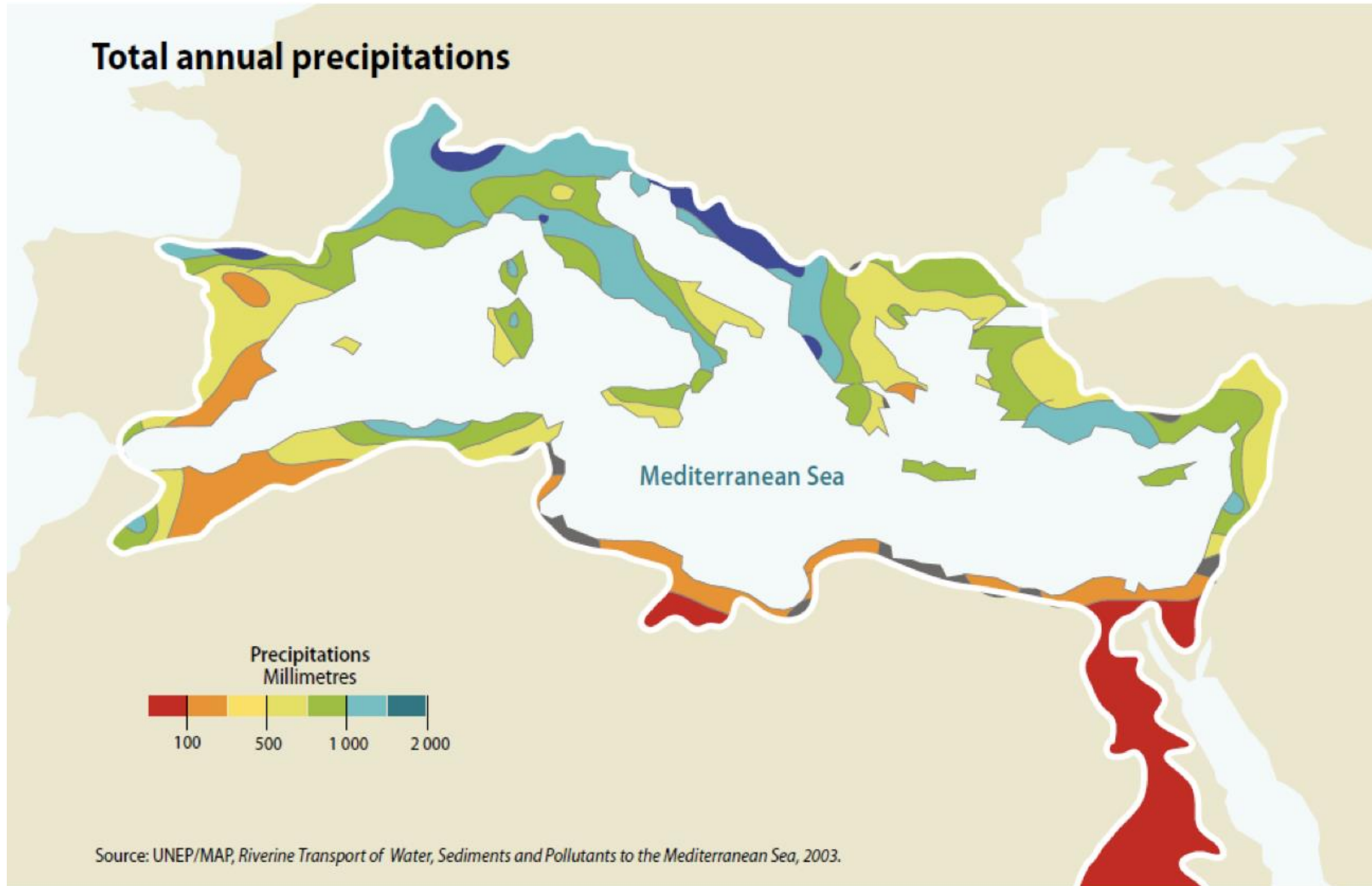
Source: Kottek et al., 2006, *Meteorol.Z.*, 15,259-263.

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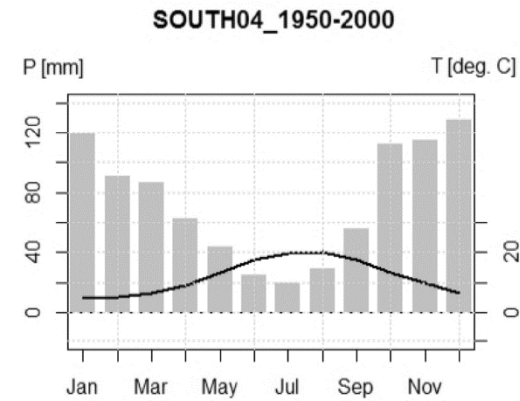
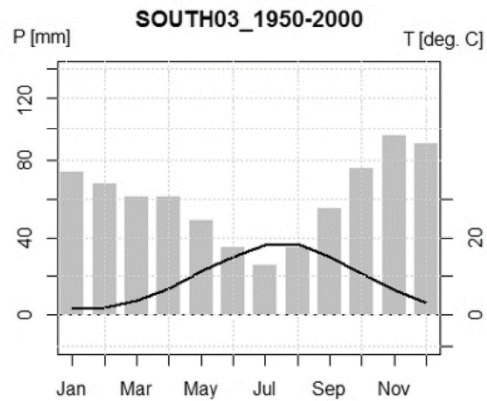
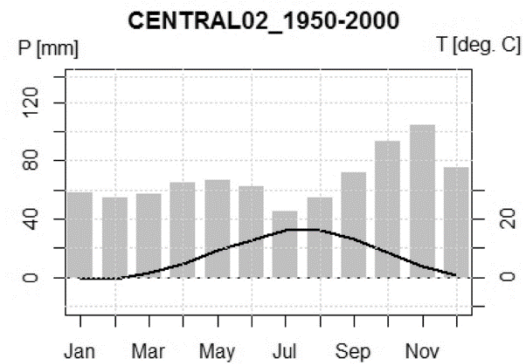
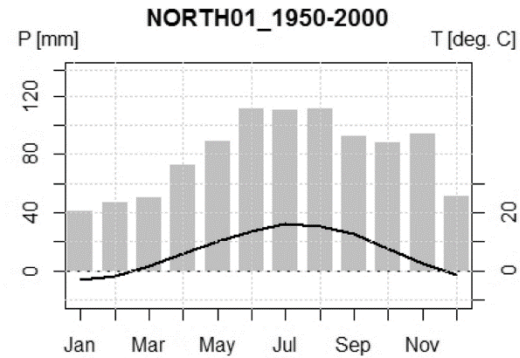
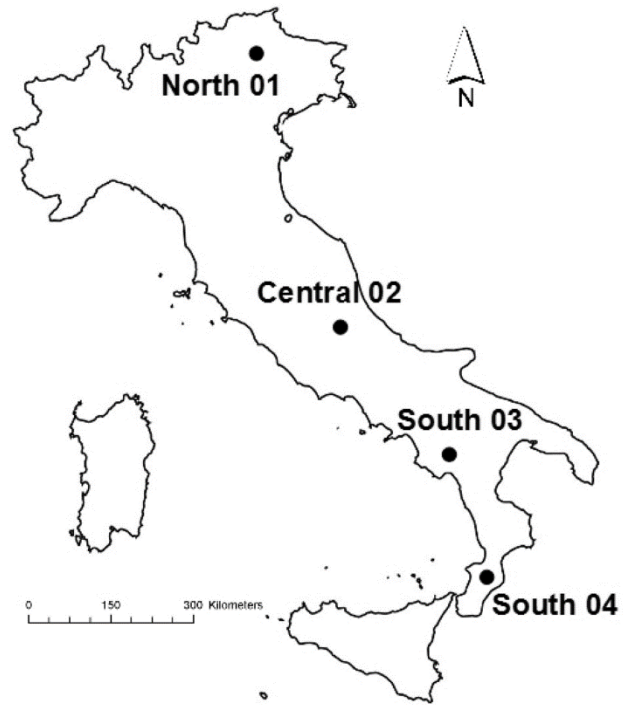
Rick et al., 2020. *Human-environmental interactions in Mediterranean climate regions from the Pleistocene to the Anthropocene*. *Antropocene*, 31, 100253

Romano D. *The choice of plant species for green roofs and rain gardens in the Mediterranean area*

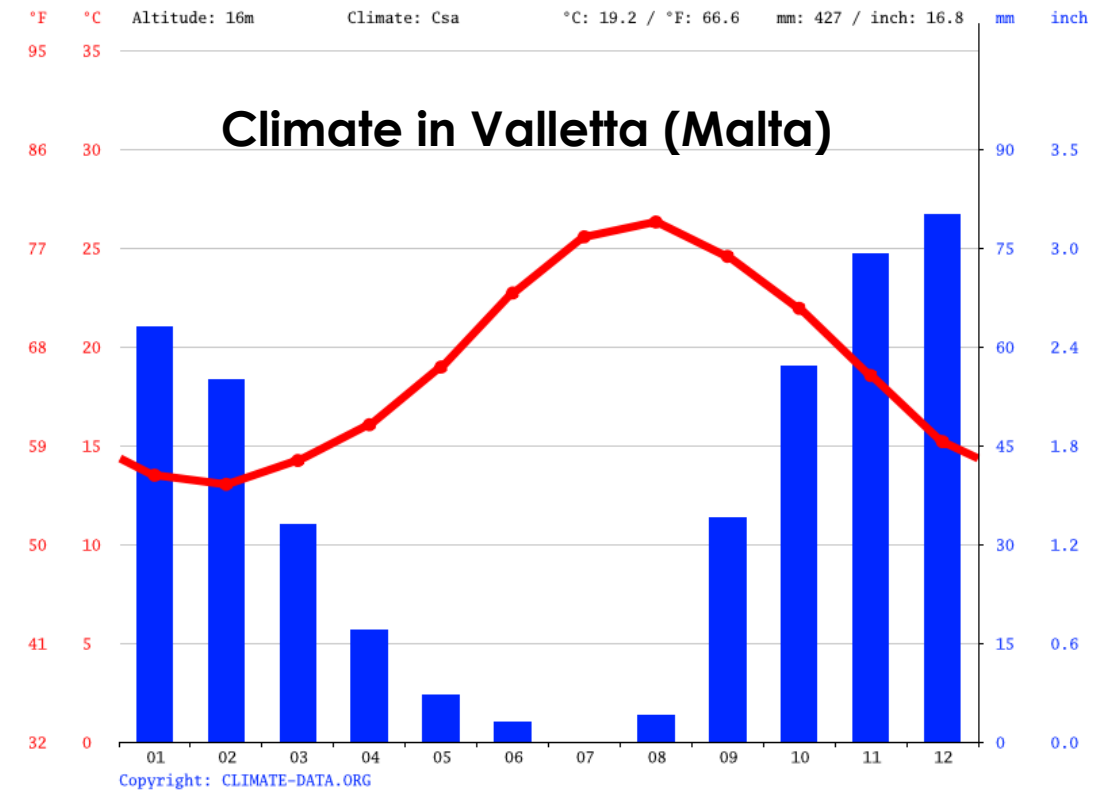


Total Annual
Precipitation
(UNEP/MAP, 2012)

Romano D. The choice of plant species for green roofs and rain gardens in the Mediterranean area



A characteristic aspect of the **Mediterranean climate** is the **long drought summer period**, which influences the presence and physiology of the various plant species.

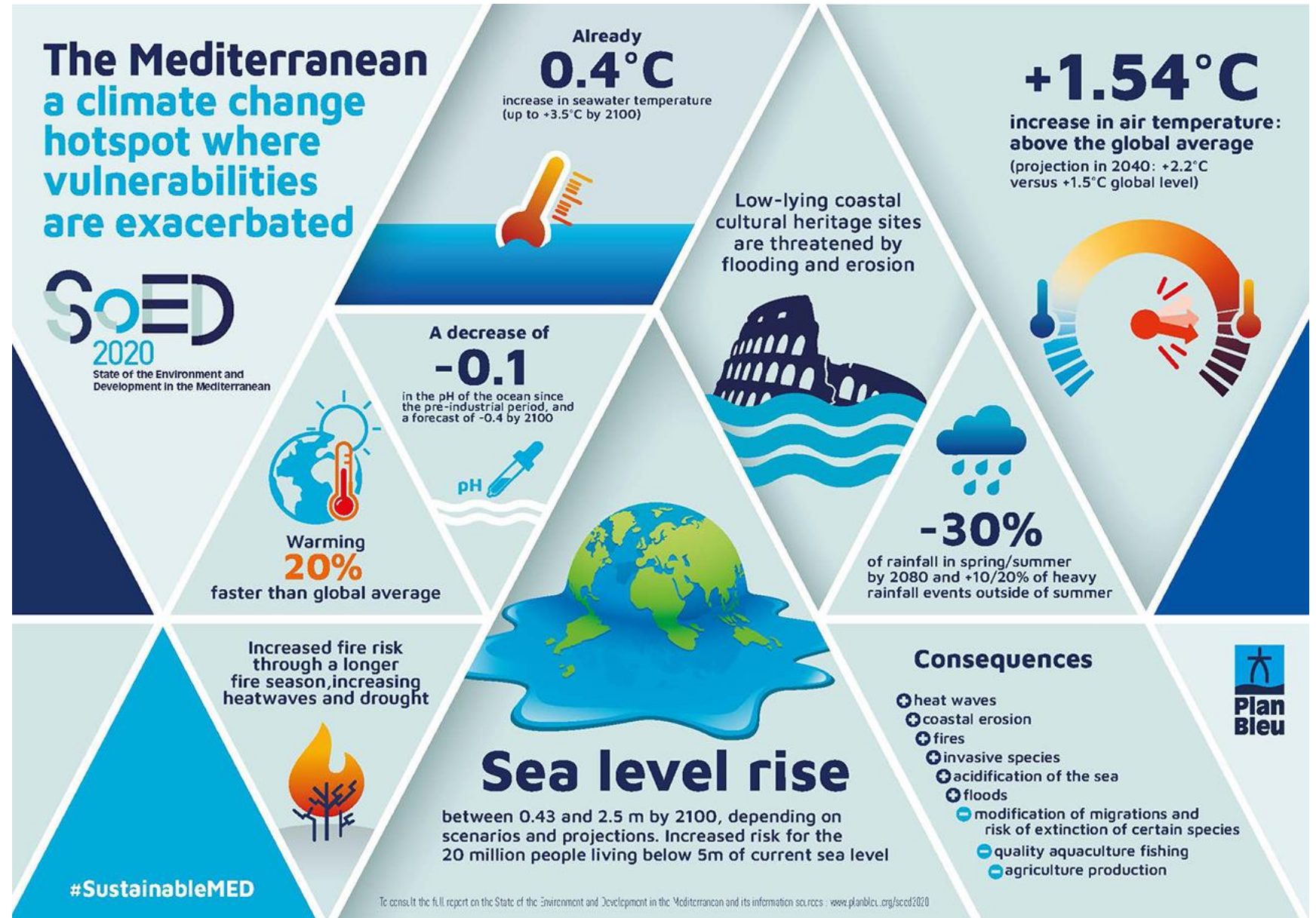


Source: Campetella et al., 2020

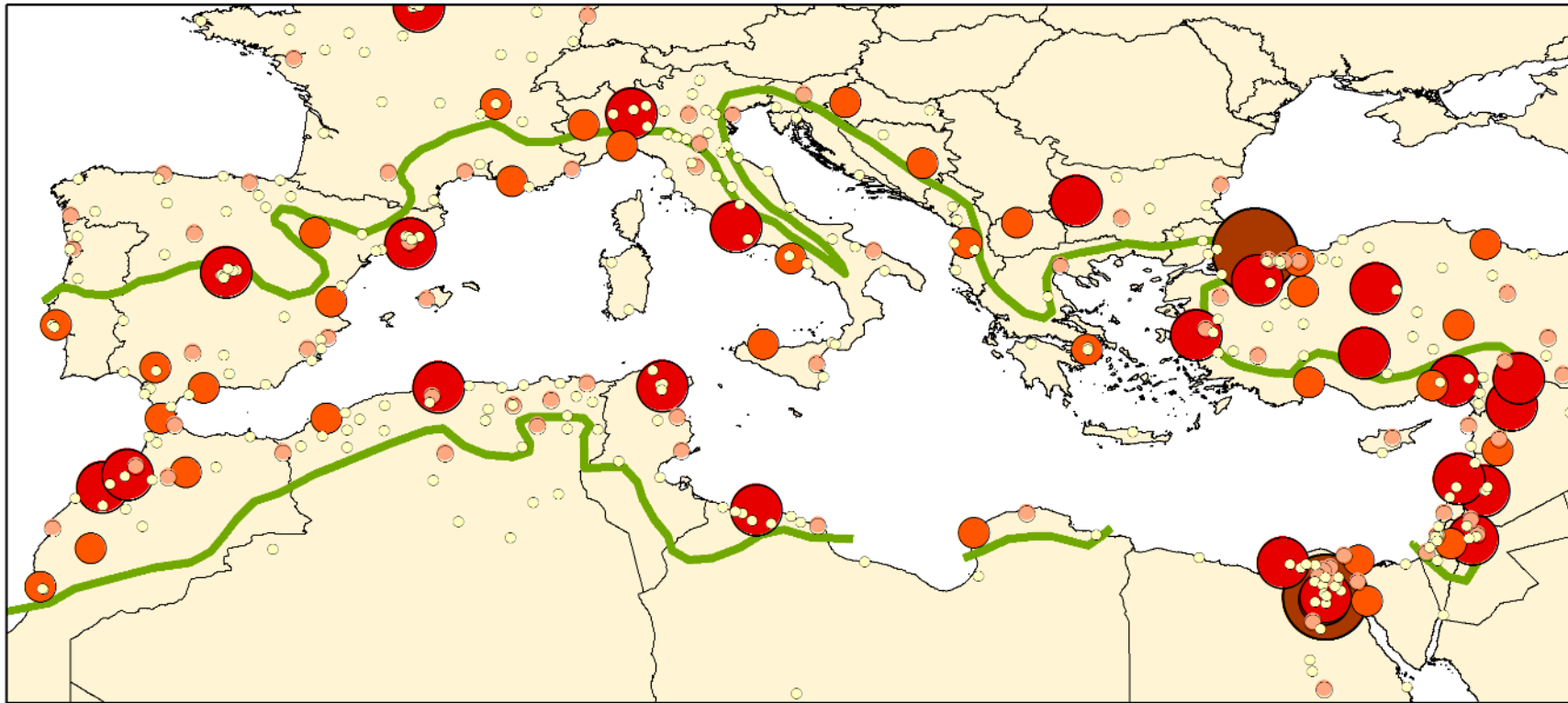
<https://it.climate-data.org/europa/malta/malta/la-valletta-6134/>

The Mediterranean Basin:

- ✓ it is home to more than **510 million people**.
- ✓ it is **warming 20% more** than the world average.
- ✓ **coastal areas** are at **greater risk of disasters**.
- ✓ by **2050**, **demand for water** will double or triple.
- ✓ **2°C** increase will reduce rainfall by **~10-15%**.
- ✓ a **2°C - 4°C** increase would reduce rainfall by up to **30%** in southern Europe.



Population of Cities of the Mediterranean Countries



Cities

Inhabitants

- 100 000 - 250 000
- 250 001 - 500 000
- 500 001 - 1 000 000



1 000 001 - 5 000 000



5 000 001 - 12 829 960

- Limite of the Olive Tree
- Country

WGS1984
ESRI, Delorme Pub. Cie, Inc. 2014
Diverse sources 2012-2014

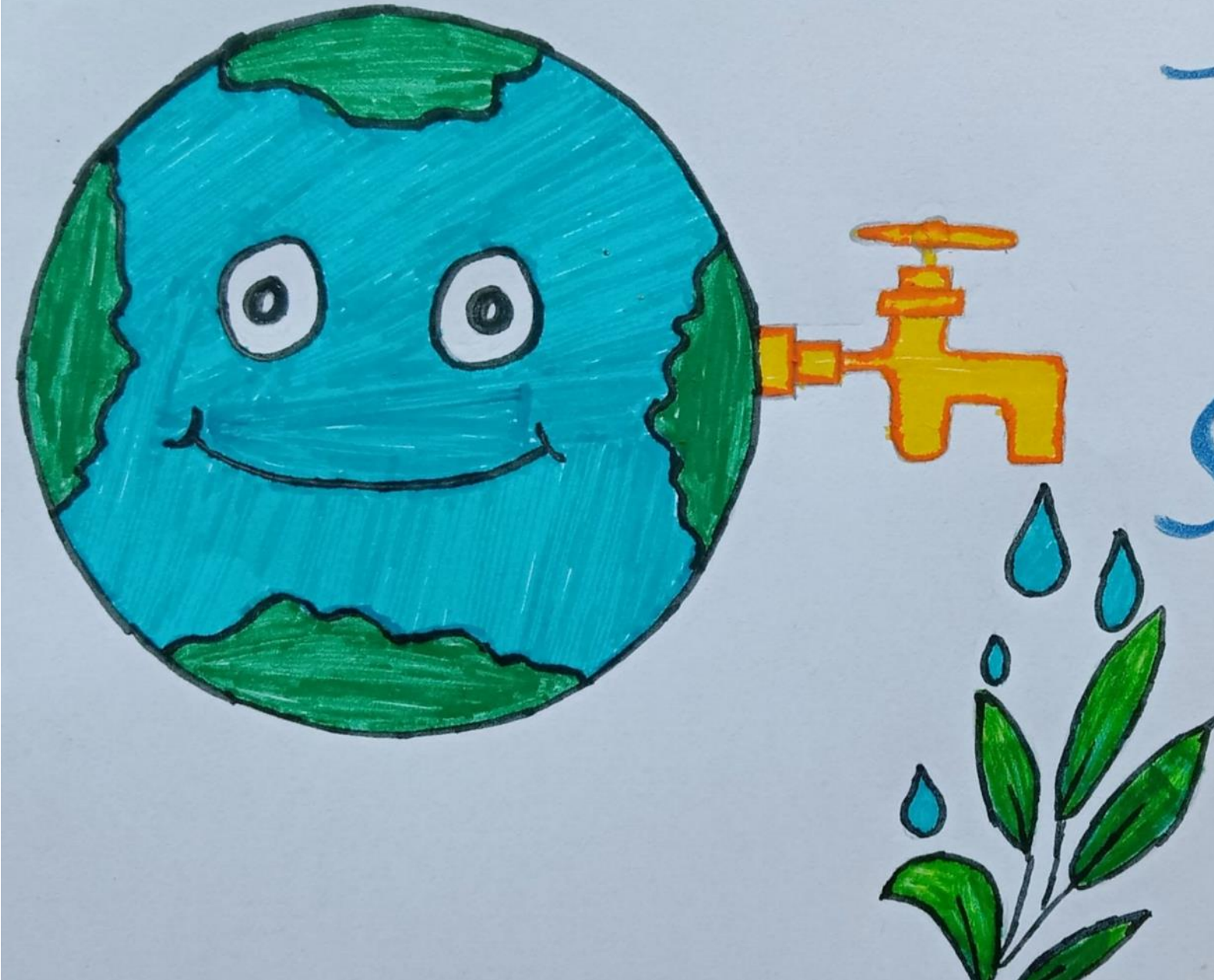
© MC3, 2015

0 125 250 500 750 1 000
Km



In the Mediterranean Basin:

- ✓ **285 cities** have more than 100,000 inhabitants;
- ✓ Together they comprise more than 126 million inhabitants, distributed mainly along the coast.
- ✓ The average size is 442,000 inhabitants (high urban concentration).



SAVE
WATER
SAVE
LIFE

Why give so much importance to the choice of plant species?



Plant
species
choice



Cheapest
cultivation
practice

Plant species
choice



Identify the
plant species
that best meets
our goals

**Meet our goals?
But what are our goals?**



In Phoenix (U.S.),
two models of
green spaces
were compared:



We need to know
what we ask of
plants! And what are
our goals!

- - 30% electric energy
- + 30% water

= cost \$

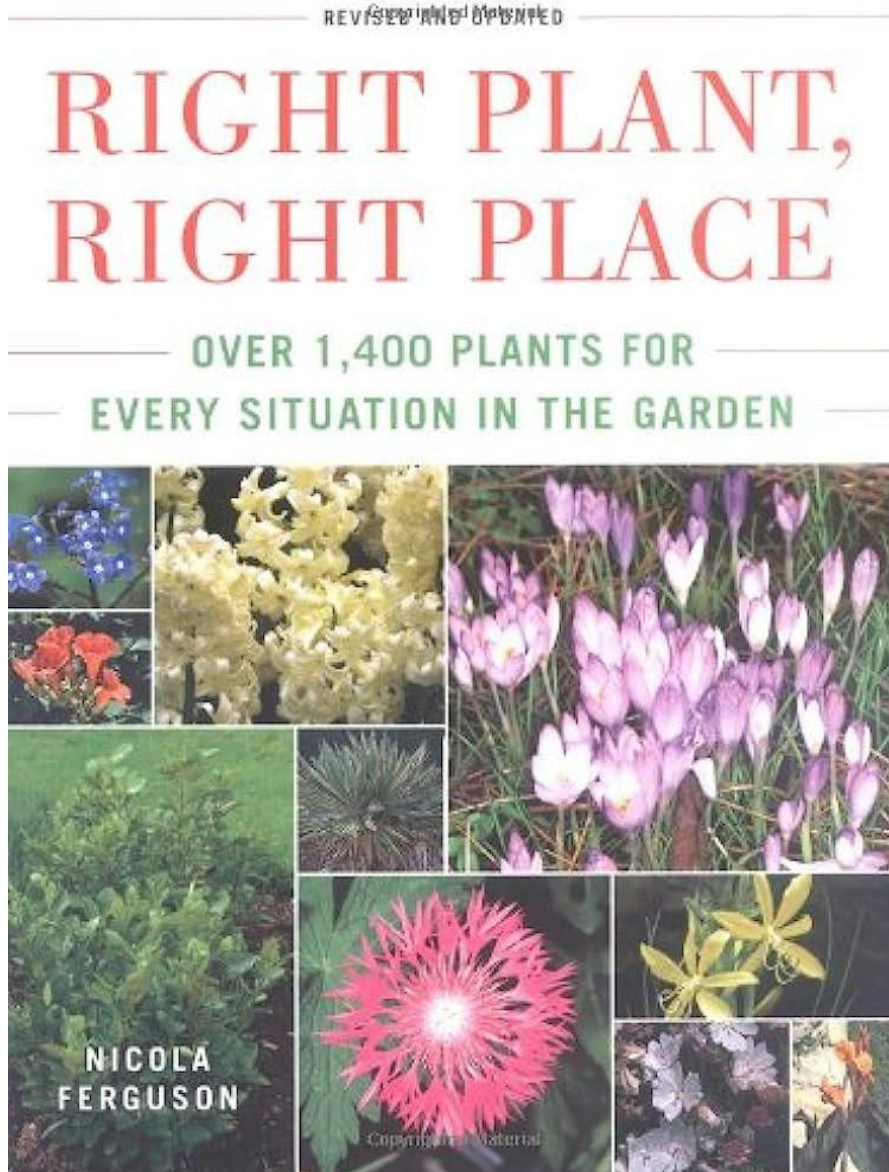
= cost

- + 30% electric energy
- - 30% water

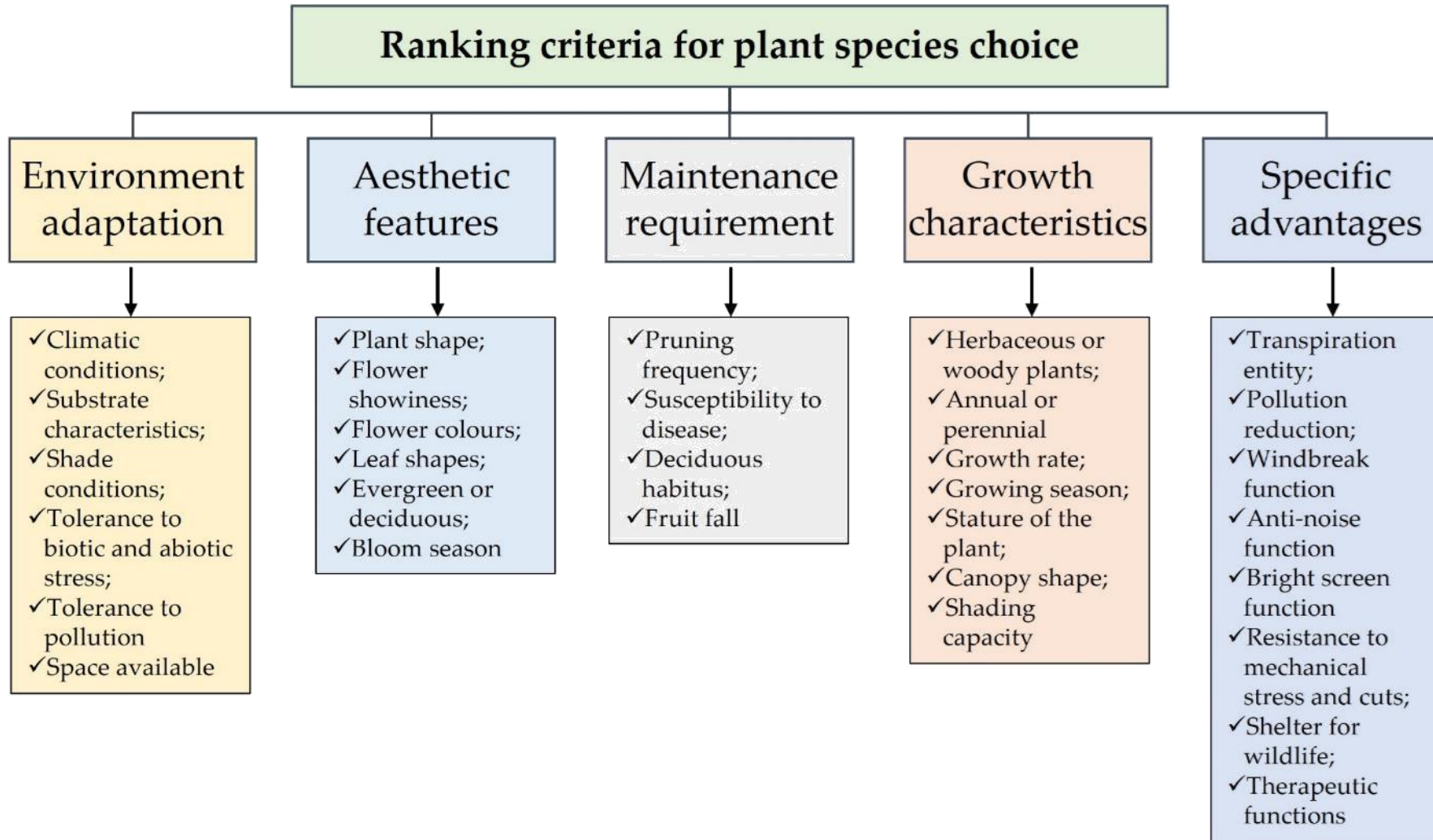


It is essential to put «**the right plant in the right place**»

Capotorti et al., 2020

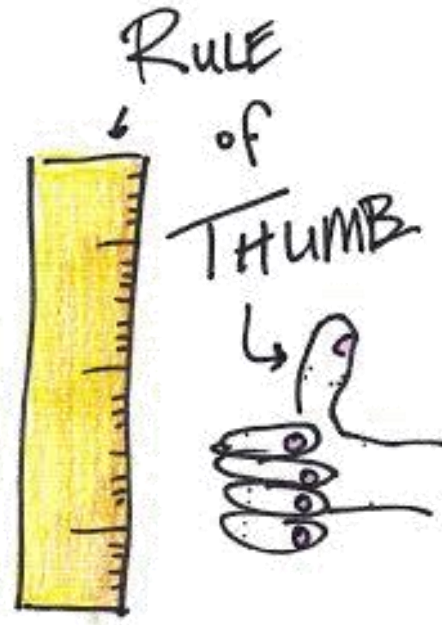


The choice of a **single plant species** can be done on the basis of their adaptability to environmental conditions, their aesthetic and ecological values, their reduced maintenance requirements, and the advantages they can bring (Source: Leotta et al., 2023).



Ranking criteria for plant species choice for **sustainable green areas**.

However, the **biodiversity** of urban green spaces is important as it reduces the risks deriving from pests and diseases and from climate change. To manage and enhance biodiversity, Santamour's proposed 10/20/30 «**rule of thumb**» has been widely accepted, which states that urban forests should comprise no more than **10%** of any particular **plant species**, **20%** of any **genus**, or **30%** of any single **botanical family**.



Plant biodiversity conservation



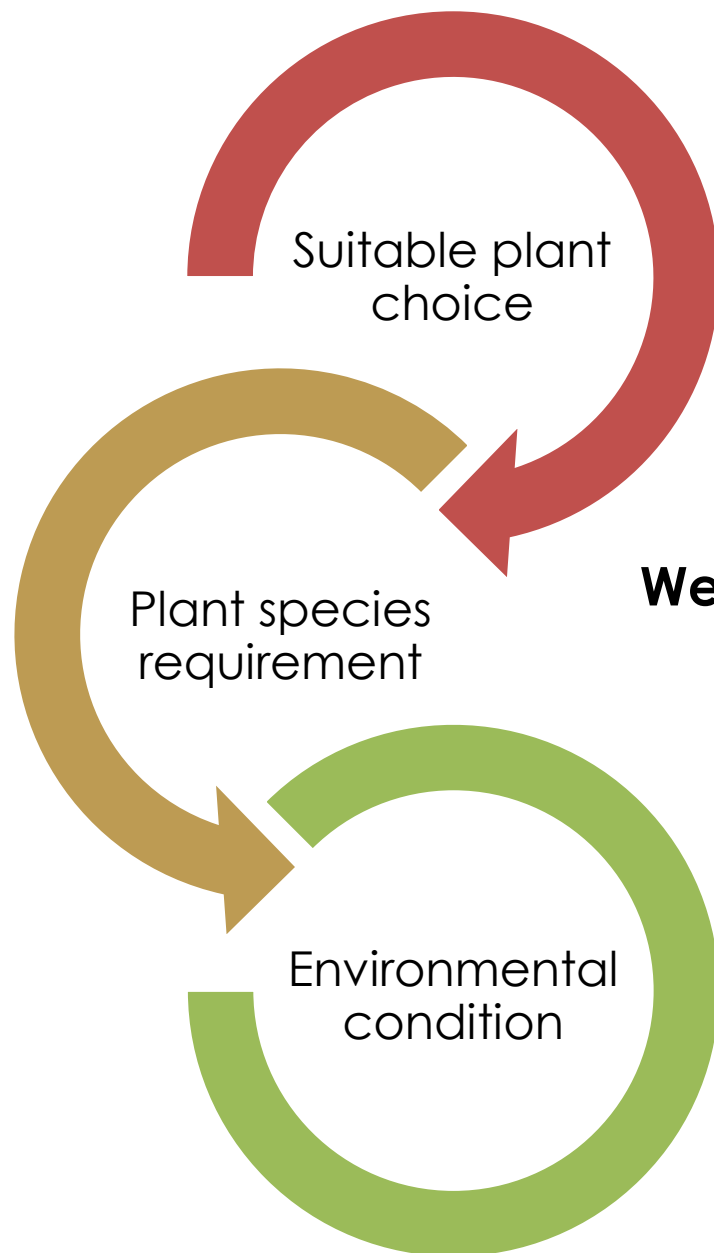
There are an estimated **406.700 plant species** on Earth, and of these, **85.000-99.000 plant species** has **ornamental value** (Chowdhuri & Deka, 2019).

Romano D. *The choice of plant species for green roofs and rain gardens in the Mediterranean area*

Number of **existing** (Exi.) and **threatened** (Thr) higher plant species, **ornamentals** and cultivated plant species worldwide (Source: Khoshbakth and Hammer, 2007)

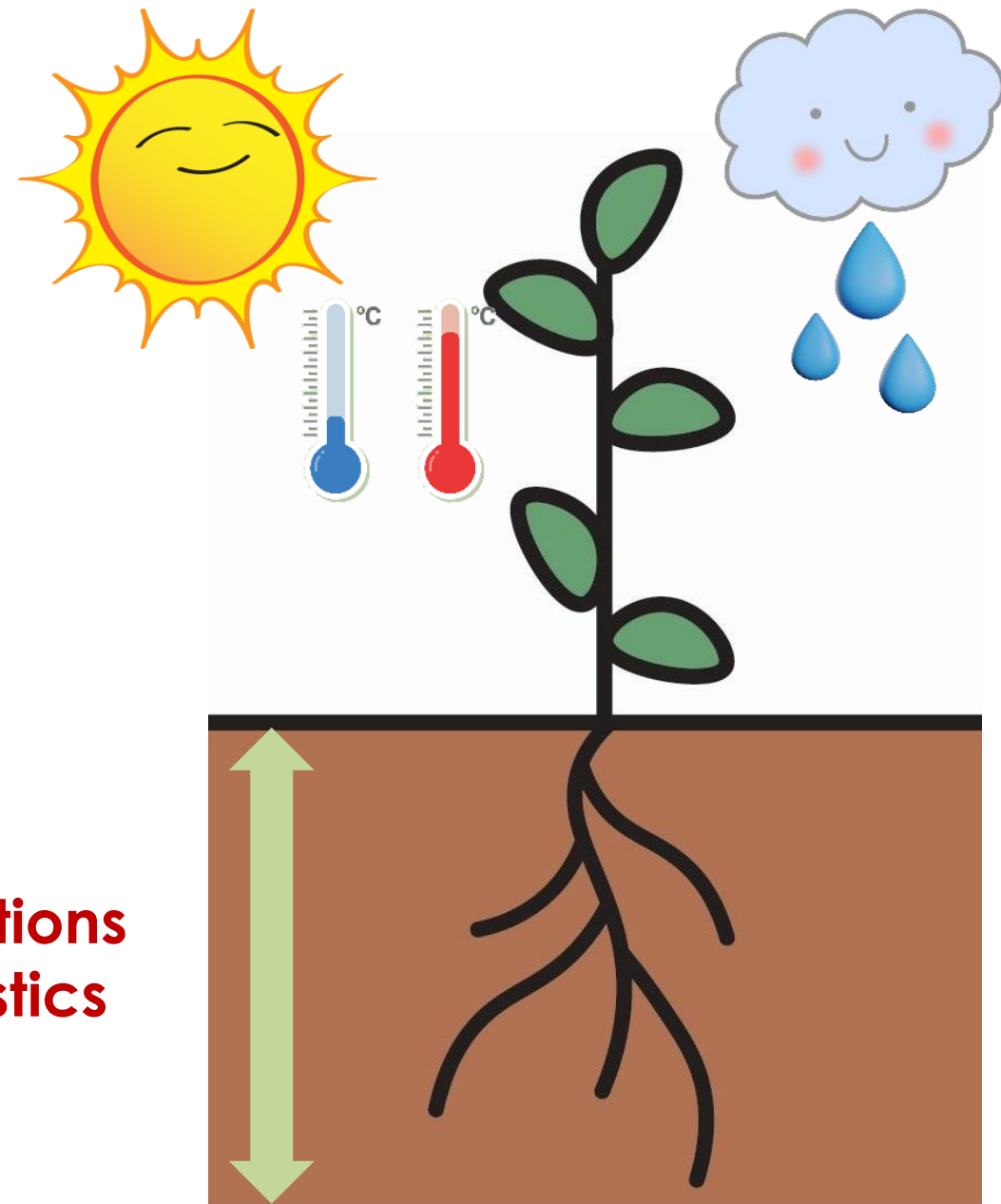
Higher plant species			Ornamental plant species			Crop plant species		
Exi.	Thr.	% Thr.	Exi.	Thr.	% Thr.	Exi.	Thr.	% Thr.
250,000	33,730	13.5	28,000	3,900	13.9	7,000	940	13.4





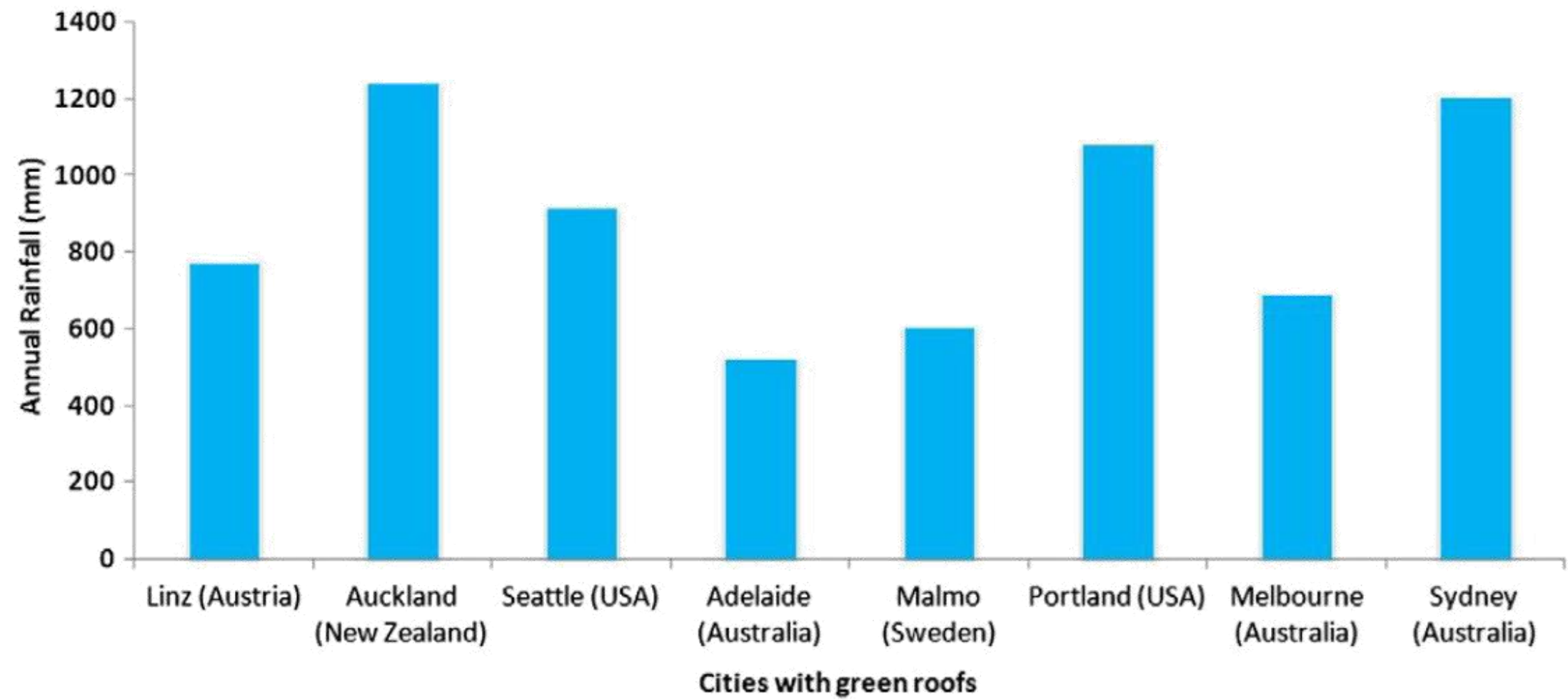
We need to know ...

- 1. Climatic conditions**
- 2. Soil characteristics**
- 3. Site structures**



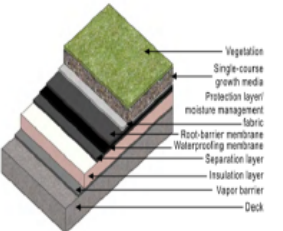


1. Climatic conditions (~)
2. Soil characteristics
3. Site structures



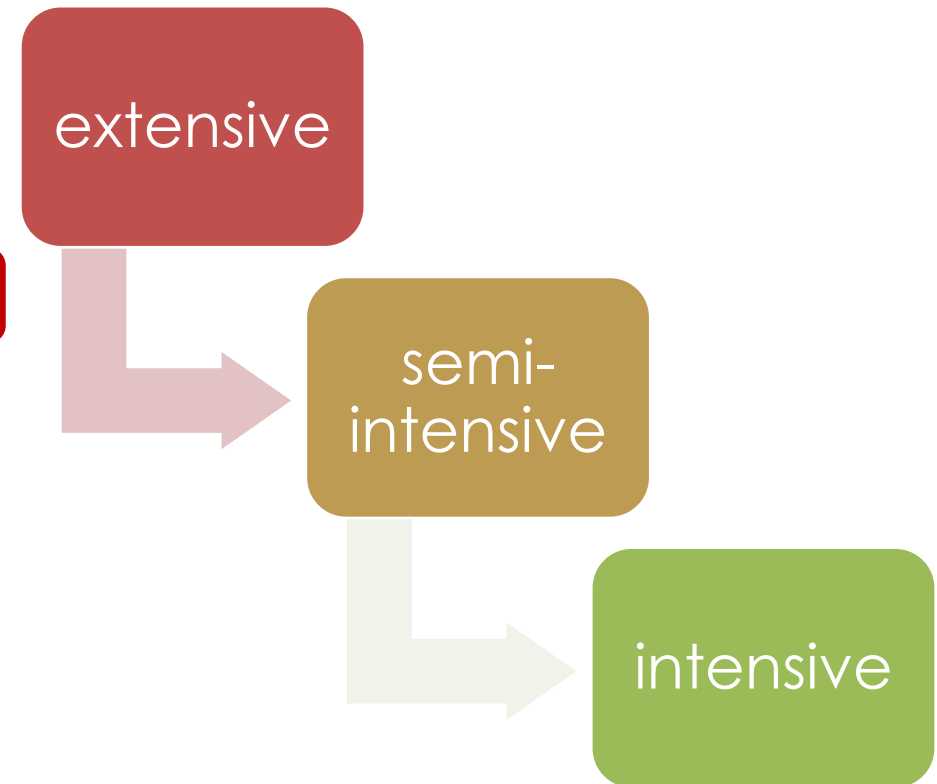


Annual rainfall (mm) of the cities where green roofs are more widespread
(Source: Razzaghmanesh *et al.*, 2014)

Table 1. Types of green roofs according to classification [10] [11].

Green system	Comparison
<p>Single course extensive</p> 	<p>Thickness: 7.6 cm – 10 cm</p> <p>Drainage layer: No separate drainage layer</p> <p>Vegetation layer: Ornamental and Succulents plants</p> <p>Media type: Coarse media</p> <p>Irrigation layer: Not required</p> <p>Prevalence: Used in an area with sufficient precipitation</p> <p>Weight: 60 – 150 kg/m²</p> <p>Cost: 543 – 690 RM/ m²</p>
<p>Semi-intensive</p> 	<p>Thickness: 15 cm – 31 cm</p> <p>Drainage layer: Separate drainage layer</p> <p>Vegetation layer: Ornamental, meadow species, turf grass and woody perennial</p> <p>Media type: Multi-course media</p> <p>Irrigation layer: Required if meadow grass used</p> <p>Prevalence: Common and provide more plants choice</p> <p>Weight: 25% above or below 150 kg/m²</p> <p>Cost: 25% above or below 690 RM/ m²</p>
<p>Intensive</p> 	<p>Thickness: Over 31 cm</p> <p>Drainage layer: Separate drainage system</p> <p>Vegetation layer: Ground-level plants</p> <p>Media type: Intensive growth media layer</p> <p>Irrigation layer: Required</p> <p>Prevalence: Less common due to it is structure and maintenance factor</p> <p>Weight: 200 – 500 kg/m²</p> <p>Cost: 2259 RM/ m²</p>

Abass et al., 2020. A Review of Green Roof: Definition, History, Evolution and Functions

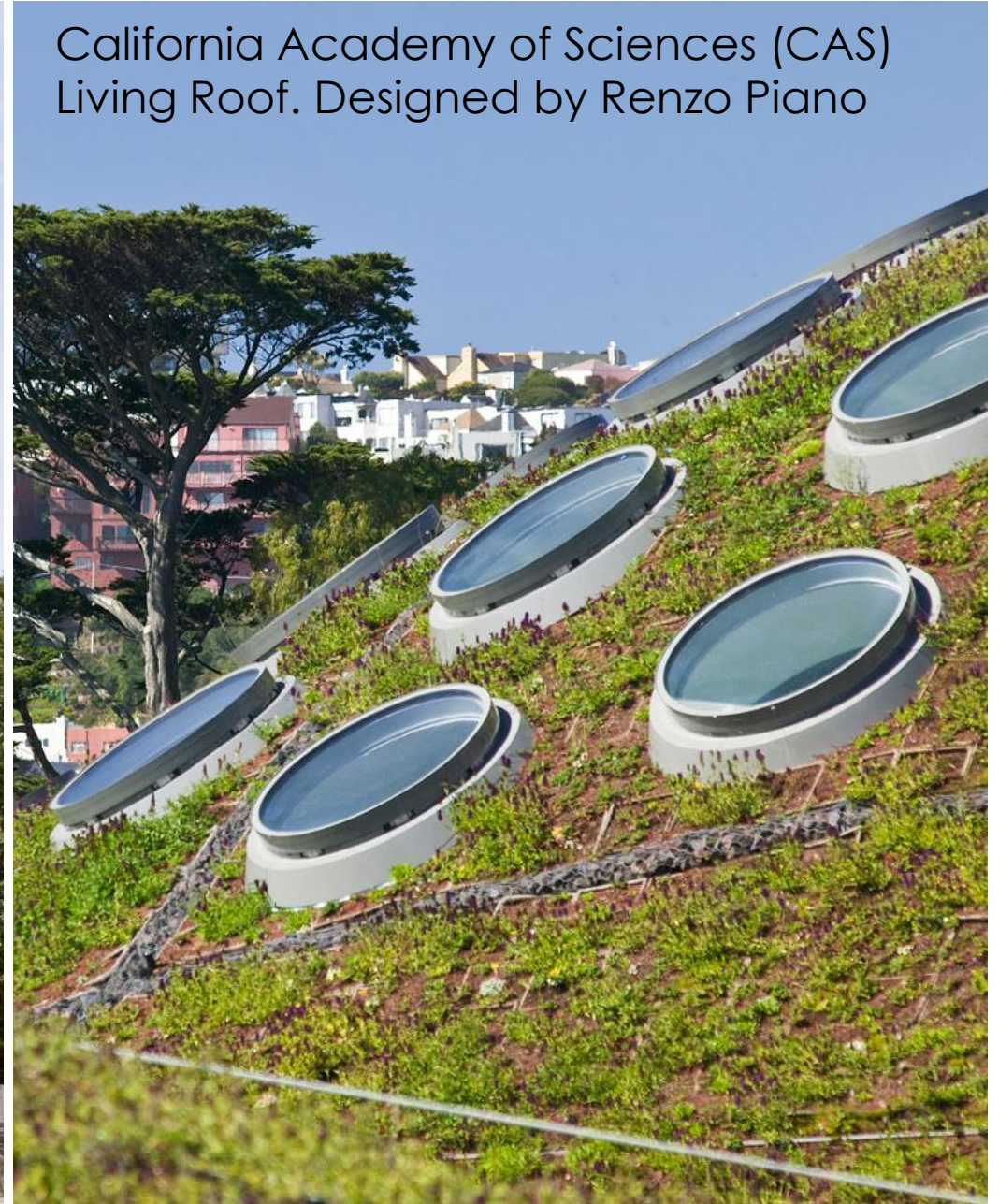


Romano D. *The choice of plant species for green roofs and rain gardens in the Mediterranean area*

Acros building with roof garden, Fukuoka, Japan.
Designed by Emilio Ambasz



California Academy of Sciences (CAS)
Living Roof. Designed by Renzo Piano



Green Roof: California Academy of Sciences (Renzo Piano)



Eschscholtzia californica



Source: <https://www.turfonline.co.uk/product/sedum-flat-roof-kit/>

High Line Park, New York



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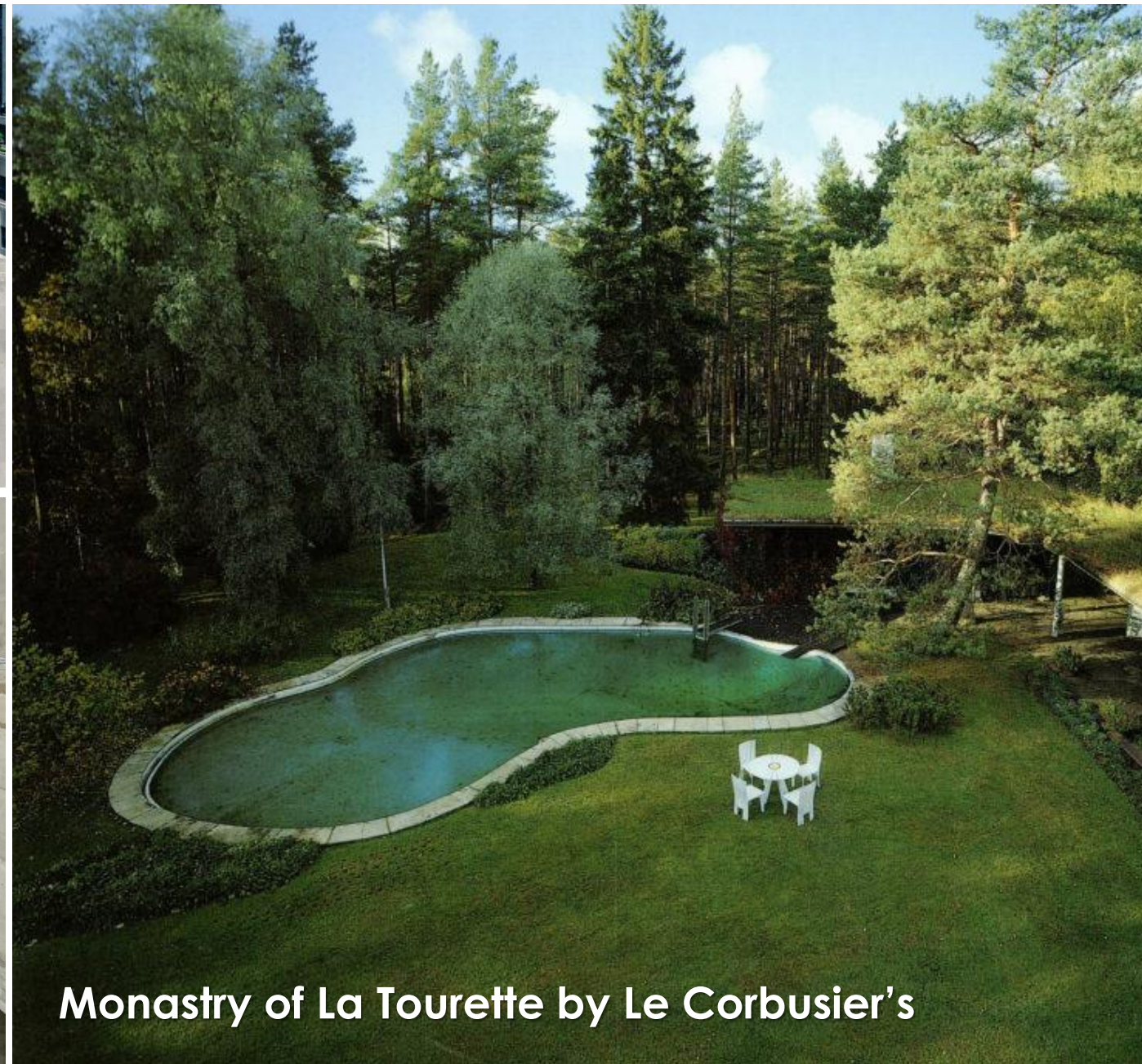


lovebugsandbrooklynbees.wordpress.com

Rockefeller Centre in New York



Villa Mairea by Alvar Aalto



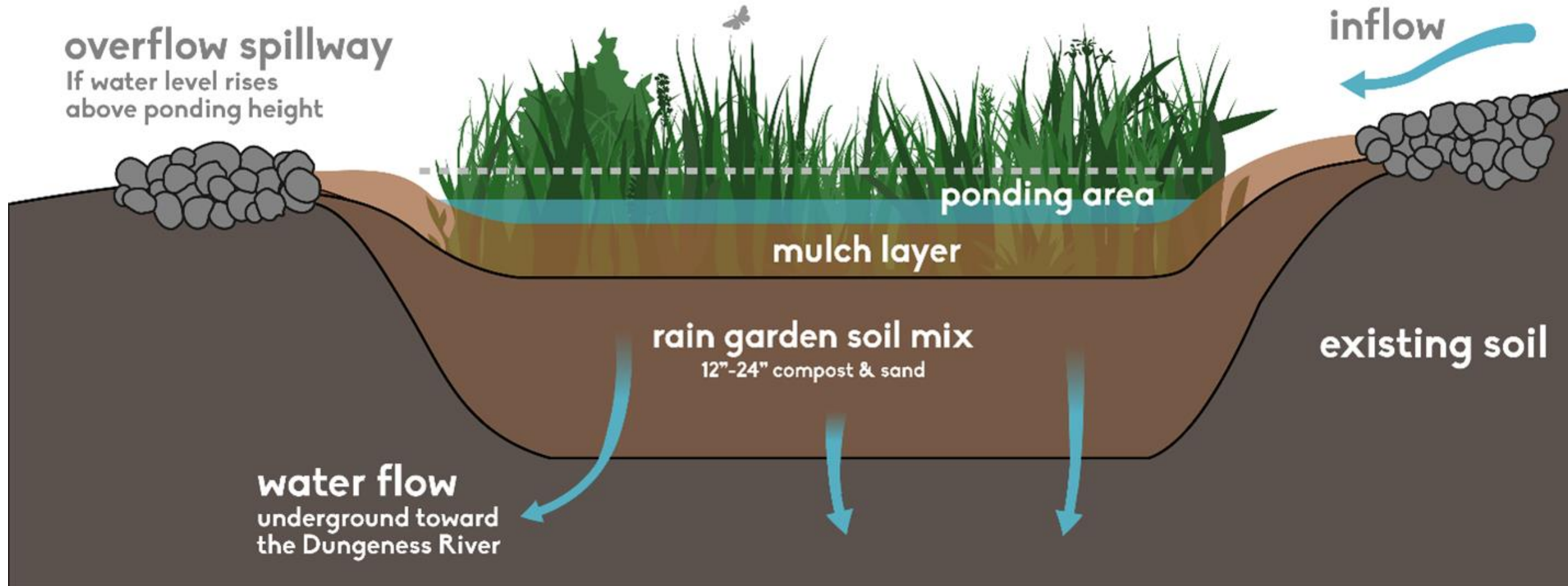
Monastery of La Tourette by Le Corbusier's



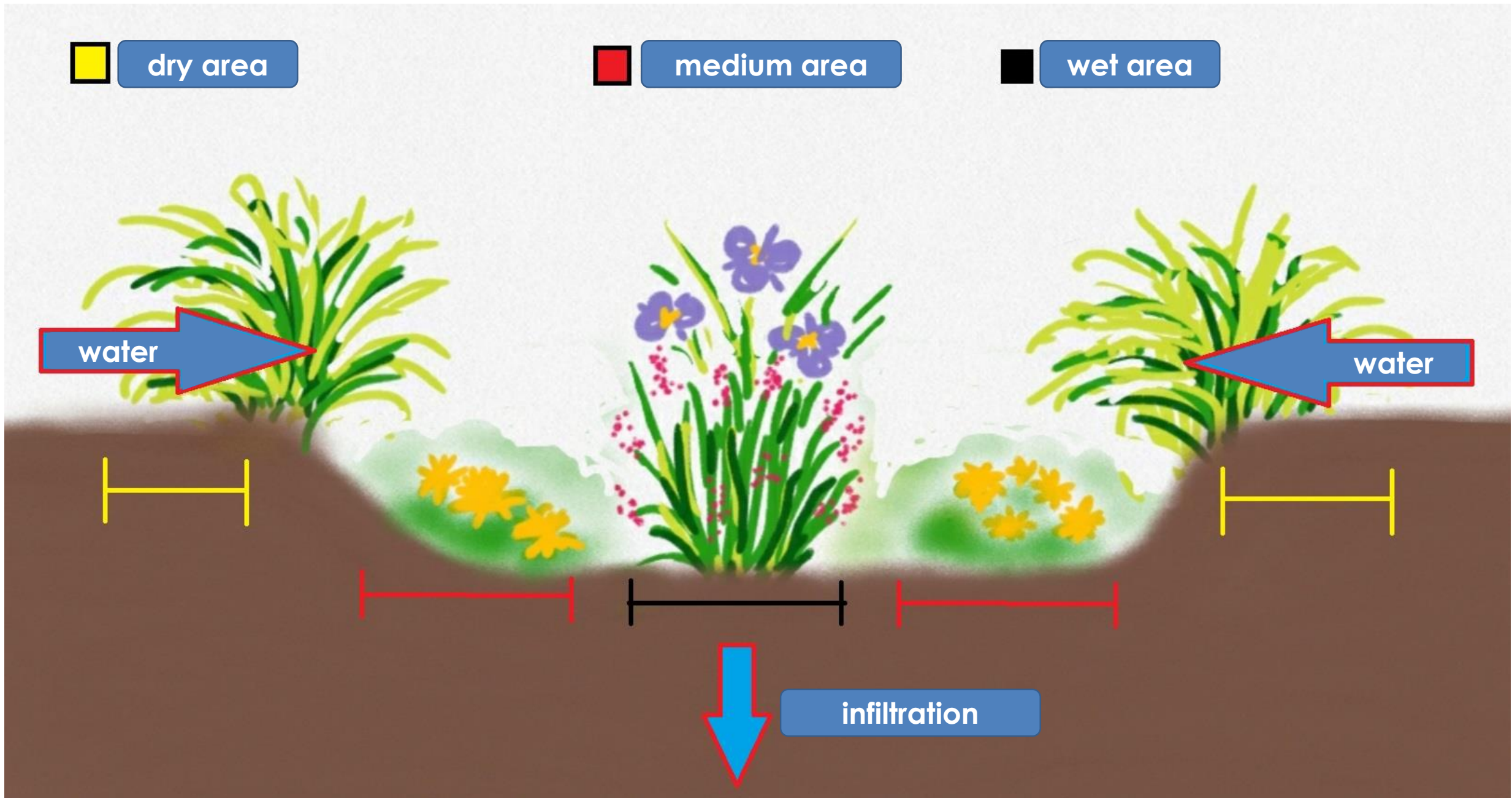
Torre Guinigi (Lucca)



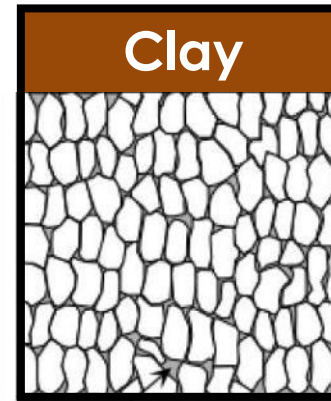
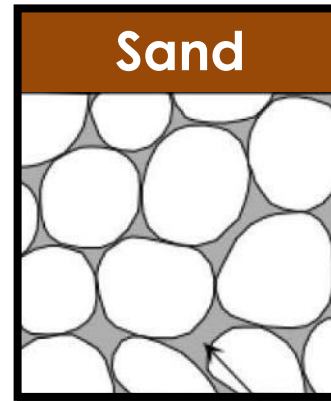
Rain gardens



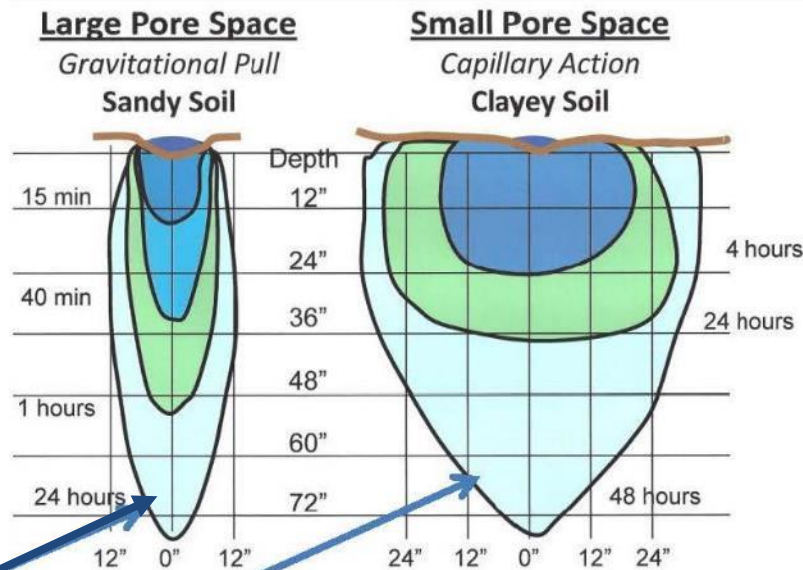
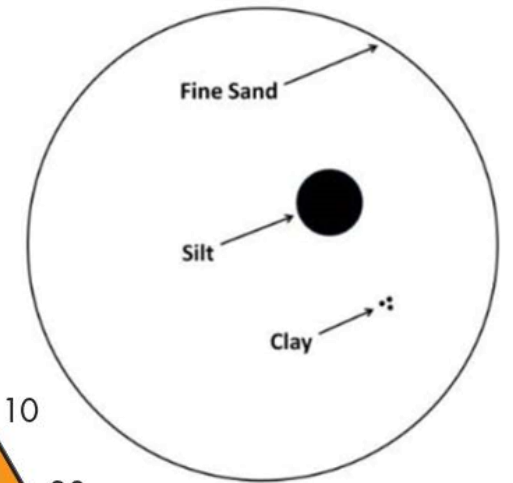
Romano D. *The choice of plant species for green roofs and rain gardens in the Mediterranean area*



Soil texture

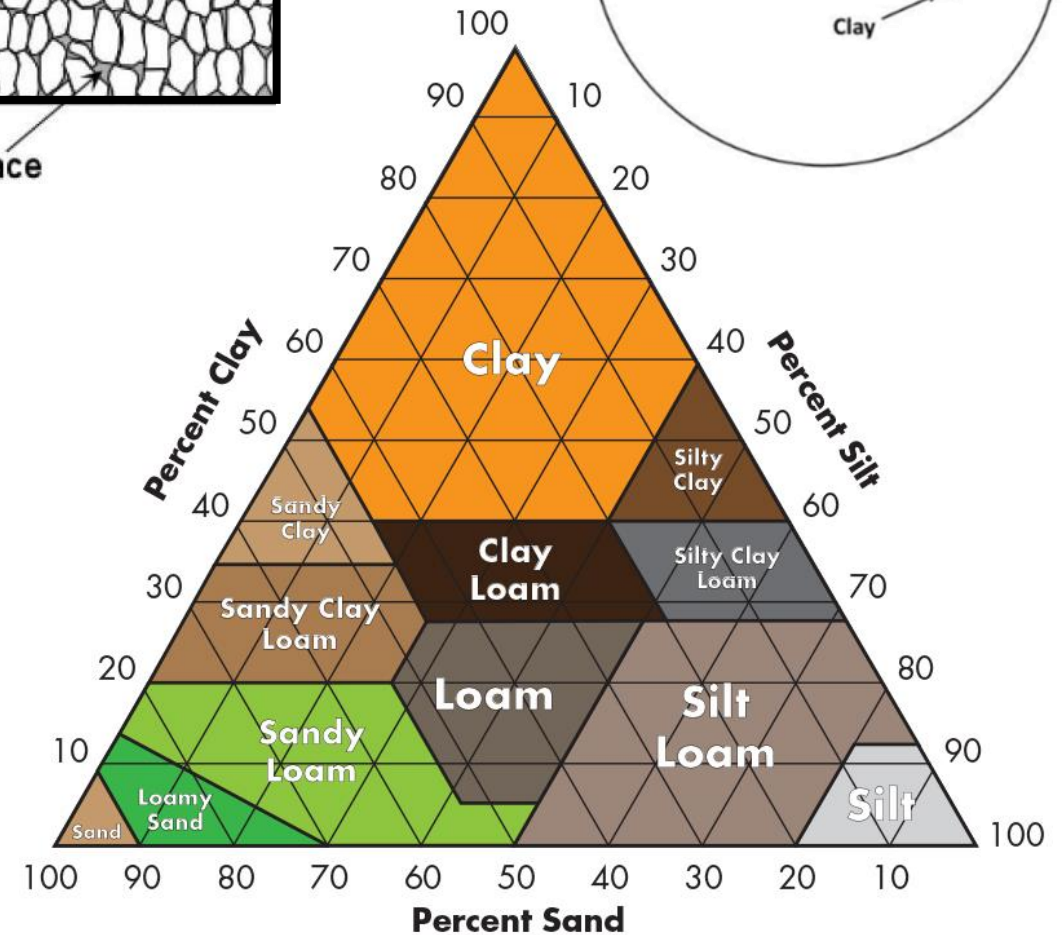


Pore Space



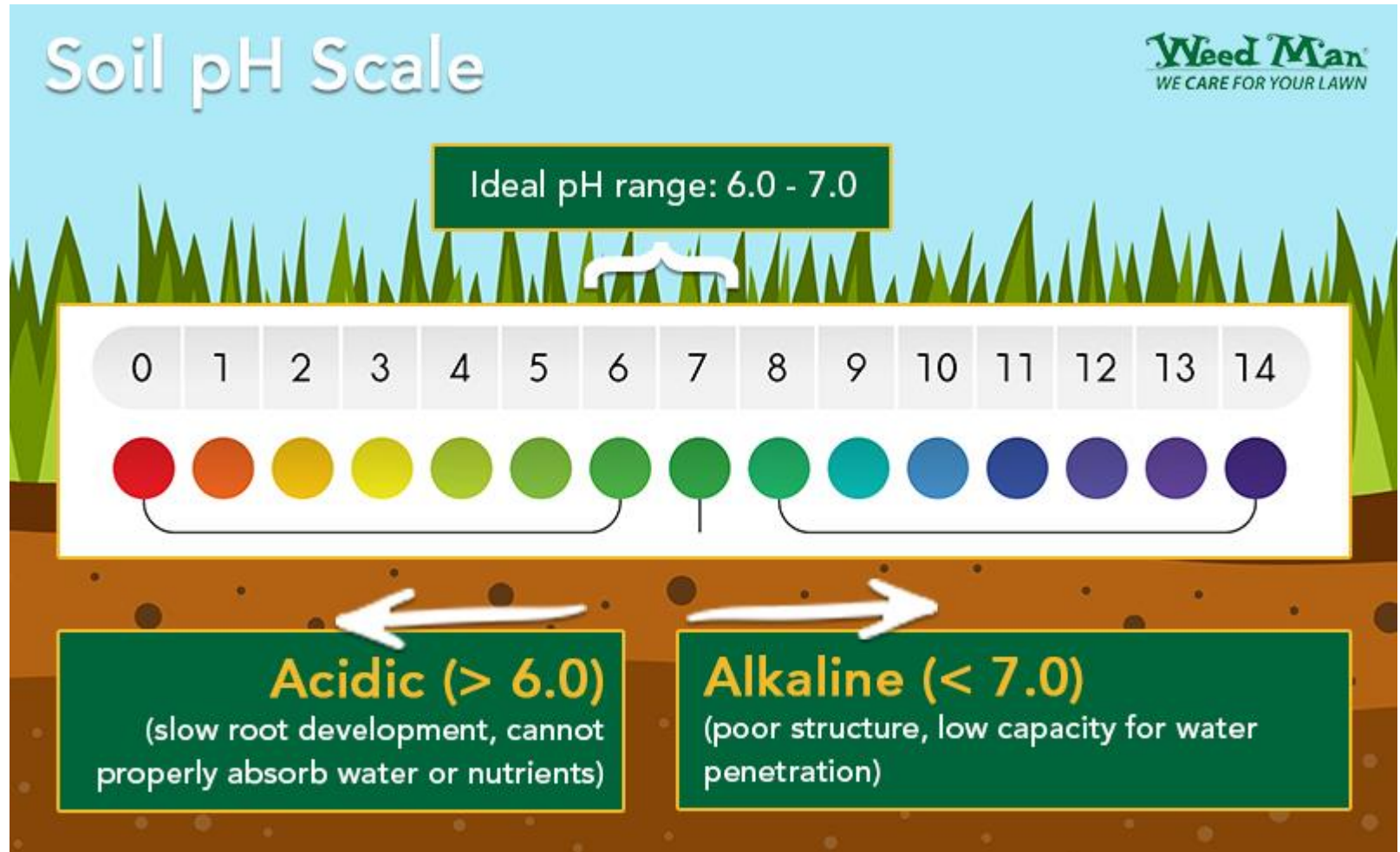
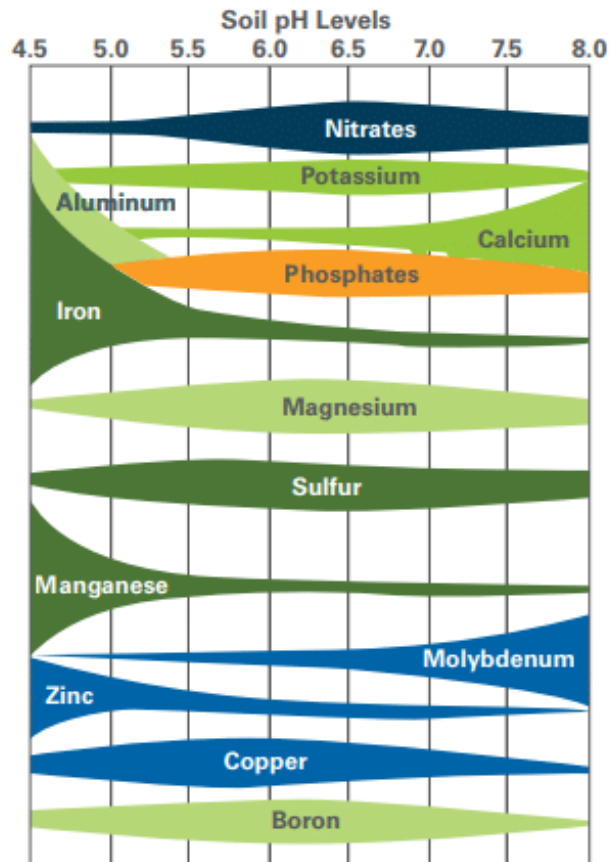
good drainage

poor drainage



Soil pH

- ✓ Changes in pH affect nutrient availability
- ✓ Can limit root growth under extremely acid or alkaline conditions



Plant species choice ...



**Not all plants are the same:
the importance of plant choice
for the delivery of environmental benefits in urban areas**

Dr Tijana Blanus

Principal Horticultural Scientist, RHS

Plant species choice ...



... Not all the plant species are the same

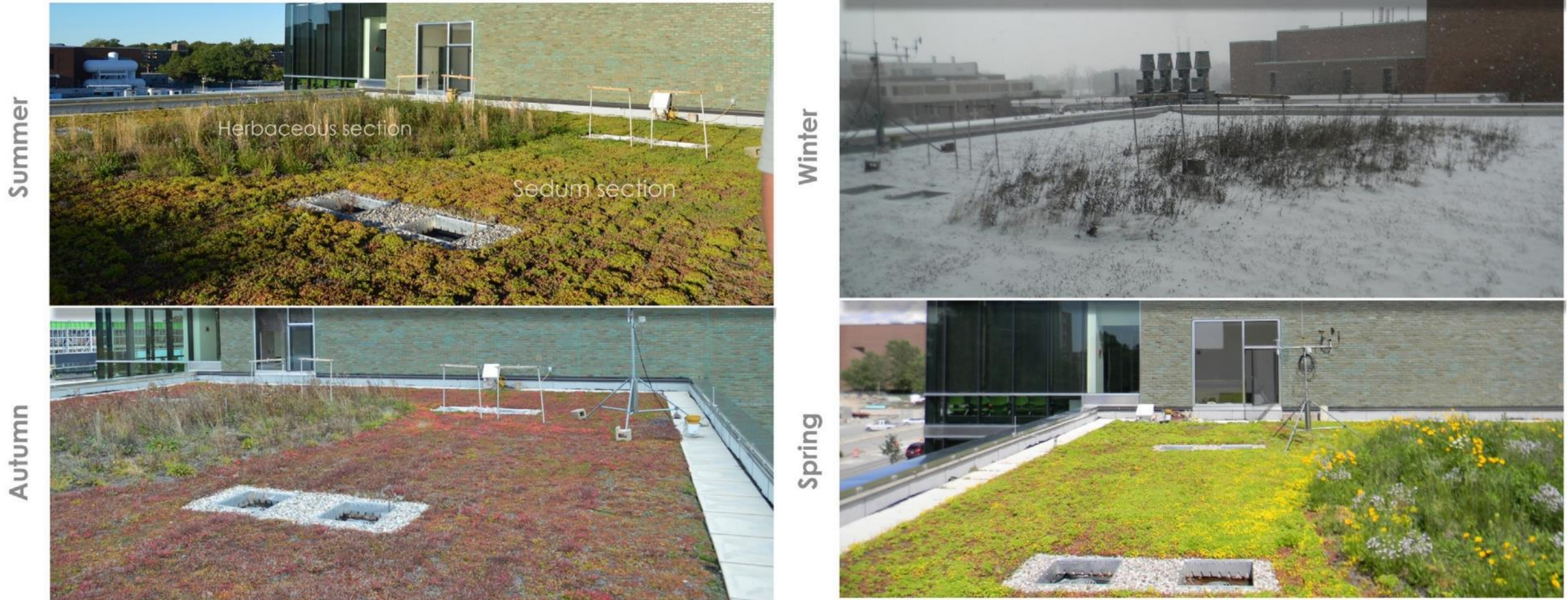


To a suitable choice...
we need to educate the citizens



Olympic Park, London

Vegetation trend over time ...



Green roofs

The required services are numerous...



Biodiversity increasing

Temperature-regulation

Water saving

Hydraulic invariance

Reduction of pollutants

etc.



Little Green Roofs

GIFLUID - Green Infrastructures to mitigate flood risks in Urban and sub-urban areas and to improve the quality of rainwater discharges

Biodiversity increasing

BIOLOGICAL CONSERVATION 141 (2008) 1695–1703



available at www.sciencedirect.com



journal homepage: www.elsevier.com/locate/biocon



The implications of current and future urbanization for global protected areas and biodiversity conservation

Robert I. McDonald^{a,*}, Peter Kareiva^b, Richard T.T. Forman^a

^aHarvard University, Graduate School of Design, 48 Quincy Street, Cambridge, MA 02138, USA

^bThe Nature Conservancy, 4722 Latona Ave NE, Seattle, WA 98105, USA

Journal of Environmental Management 106 (2012) 85–92



Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman



Review

Potential benefits of plant diversity on vegetated roofs: A literature review

Susan C. Cook-Patton^{a,*}, Taryn L. Bauerle^b

^aEcology and Evolutionary Biology, E145 Corson Hall, Cornell University, Ithaca, NY 14853, USA

^bHorticulture, T34A Plant Science Building, Cornell University, Ithaca, NY 14853, USA

The main characteristics of biodiversity green roofs for can be summarized in (Brenneisen, 2006; Baumann, 2006):

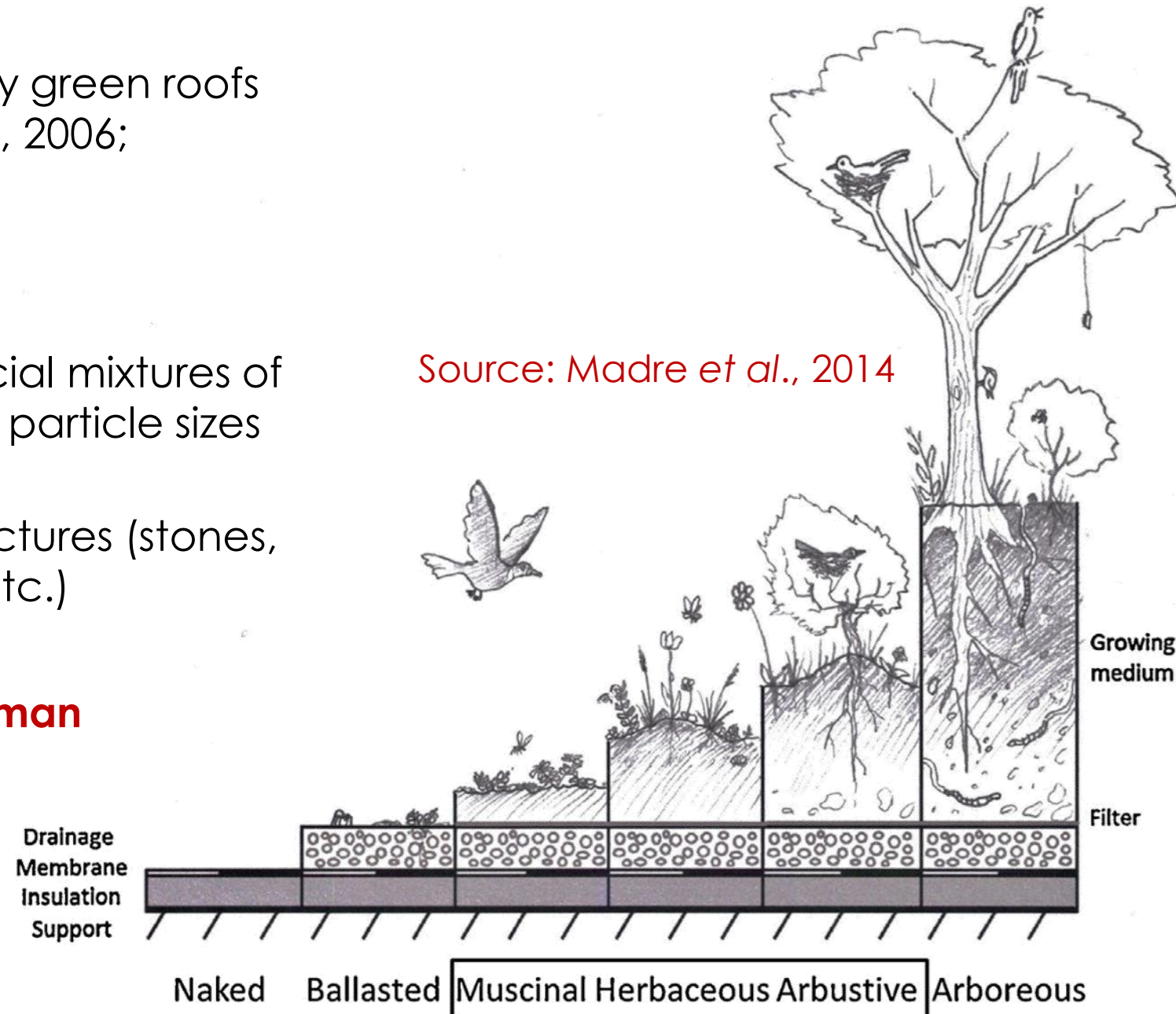
1. Creation of micro-habitats:

- a. Variable thickness of substrate
- b. Different substrate types (commercial mixtures of lightweight aggregates in different particle sizes and organic matter)
- c. Introduction of supplementary structures (stones, stones, tree trunks and branches, etc.)

2. Use of native species

3. Low maintenance and reduced human disturbance.

Source: Madre et al., 2014



Temperature reduction

Source: Blanusa et al., 2013

Table 3

Average soil and air (100 mm above the substrate level, sensor in the centre of the plot) temperatures (°C) associated with different surfaces on the hottest day of the Experiment 3 (4 June 2011, Day 8 of the experiment) between 12 and 16 h. Data are mean of fifty measurements per species/surface and ranked lowest to highest (LSDs are given in the table separately for soil and air temperatures, d.f. = 149). The means followed by a different letter are statistically significantly different.

Species/surface	Soil temperature (°C)	Air temperature (°C) @ 100 mm
<i>Stachys byzantina</i>	22.2 a	24.8 a
<i>Sedum mix</i>	34.2 b	25.1 a
Bare substrate	37.1 c	25.9 b
LSD (d.f.)	1.09 (149)	0.32 (149)

«The **choice of plant species** on green roofs should not be entirely dictated by what **survives** on the shallow substrates of extensive systems, but consideration should be given to supporting those species providing the **greatest eco-system service potential**».

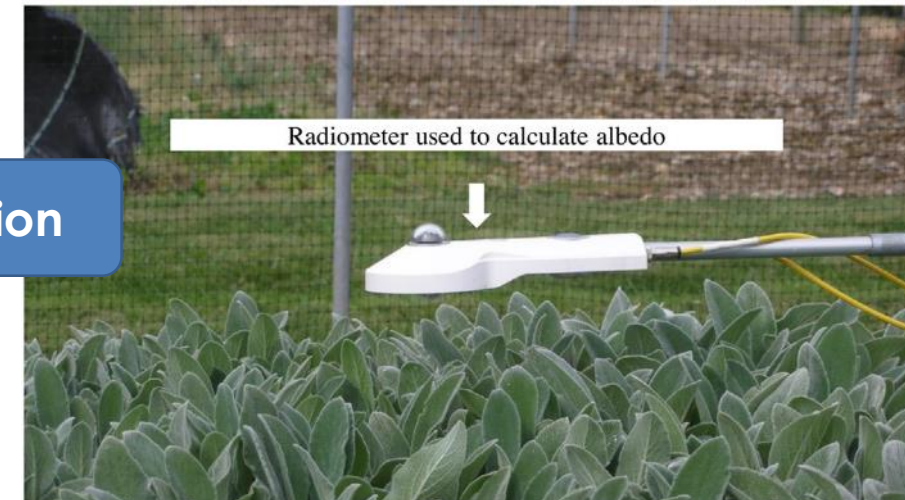
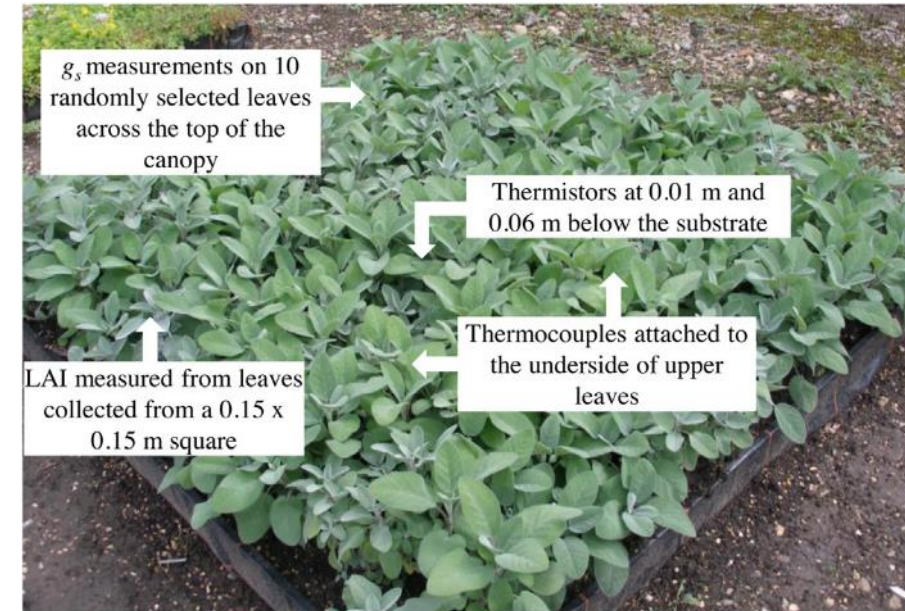


**PLANT
CHOICE**



Romano D. The choice of plant species for green roofs and rain gardens in the Mediterranean area

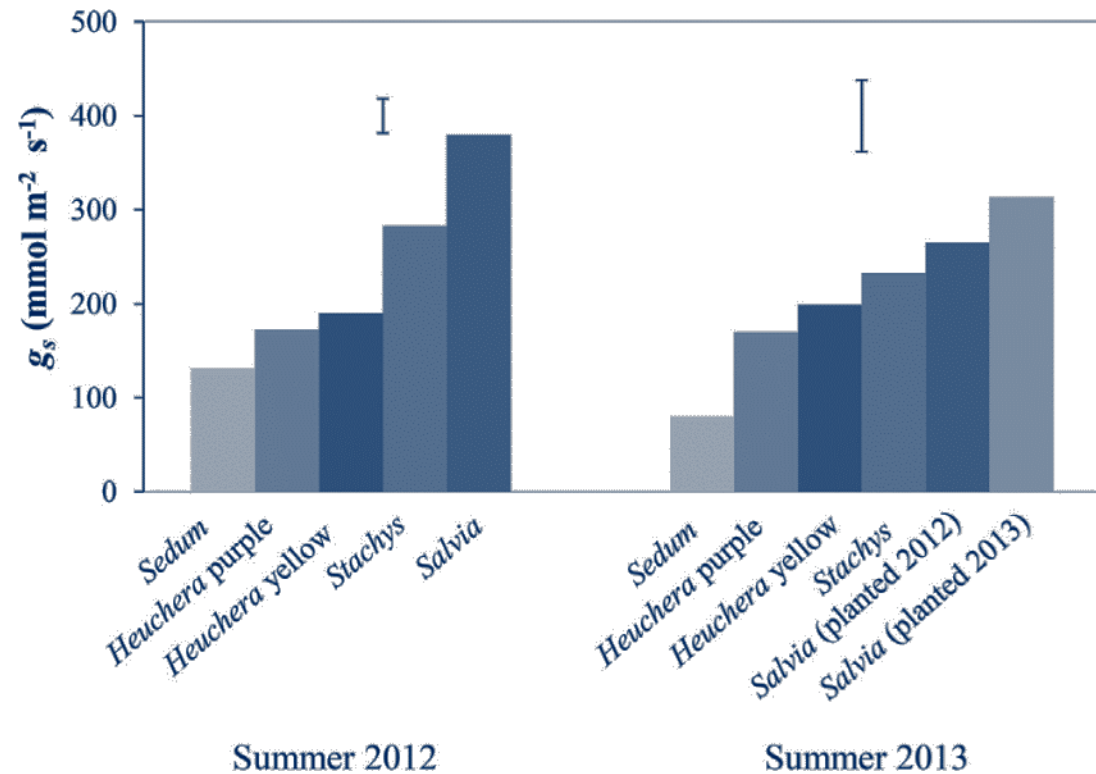
Monteiro et al., 2017



Temperature reduction

Schematic representation exemplifying where measurements were made with in a plot

Romano D. The choice of plant species for green roofs and rain gardens in the Mediterranean area



Mean leaf stomatal conductance (g_s) for all treatments measured; g_s is the average of thirty mean g_s values per treatment in 2012 (degrees of freedom (d.f.)= 149) and twelve g_s values per treatment (or eight for *Heuchera yellow*) in 2013 (d.f. = 67). LSDs are shown at the top of the figure.

Temperature reduction



Functional green roofs: Importance of plant choice in maximising summertime environmental cooling and substrate insulation potential

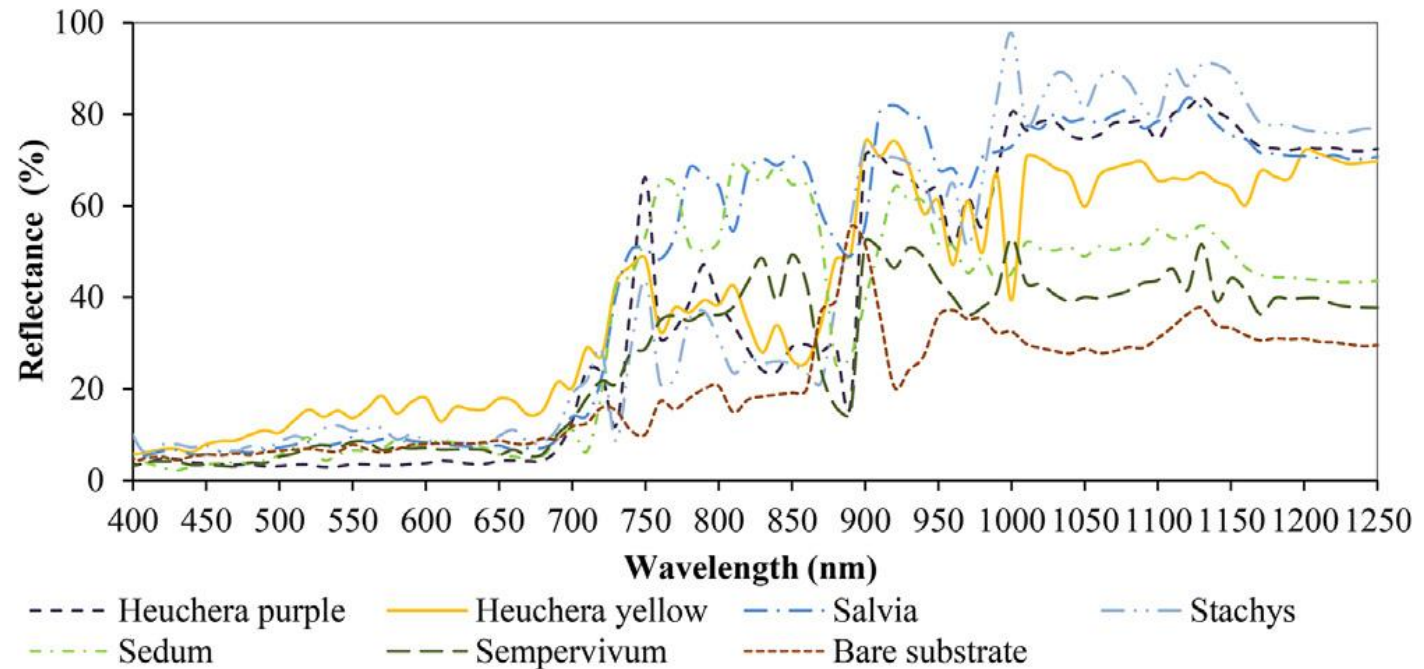
M. Vaz Monteiro^{a,1}, T. Blanuša^{a,b,*}, A. Verhoef^c, M. Richardson^a, P. Hadley^a, R.W.F. Cameron^d

^a School of Agriculture, Policy and Development, University of Reading, RG6 6AR, UK

^b Royal Horticultural Society, Plant Sciences Department, Garden Wisley, Woking GU23 7QB, UK

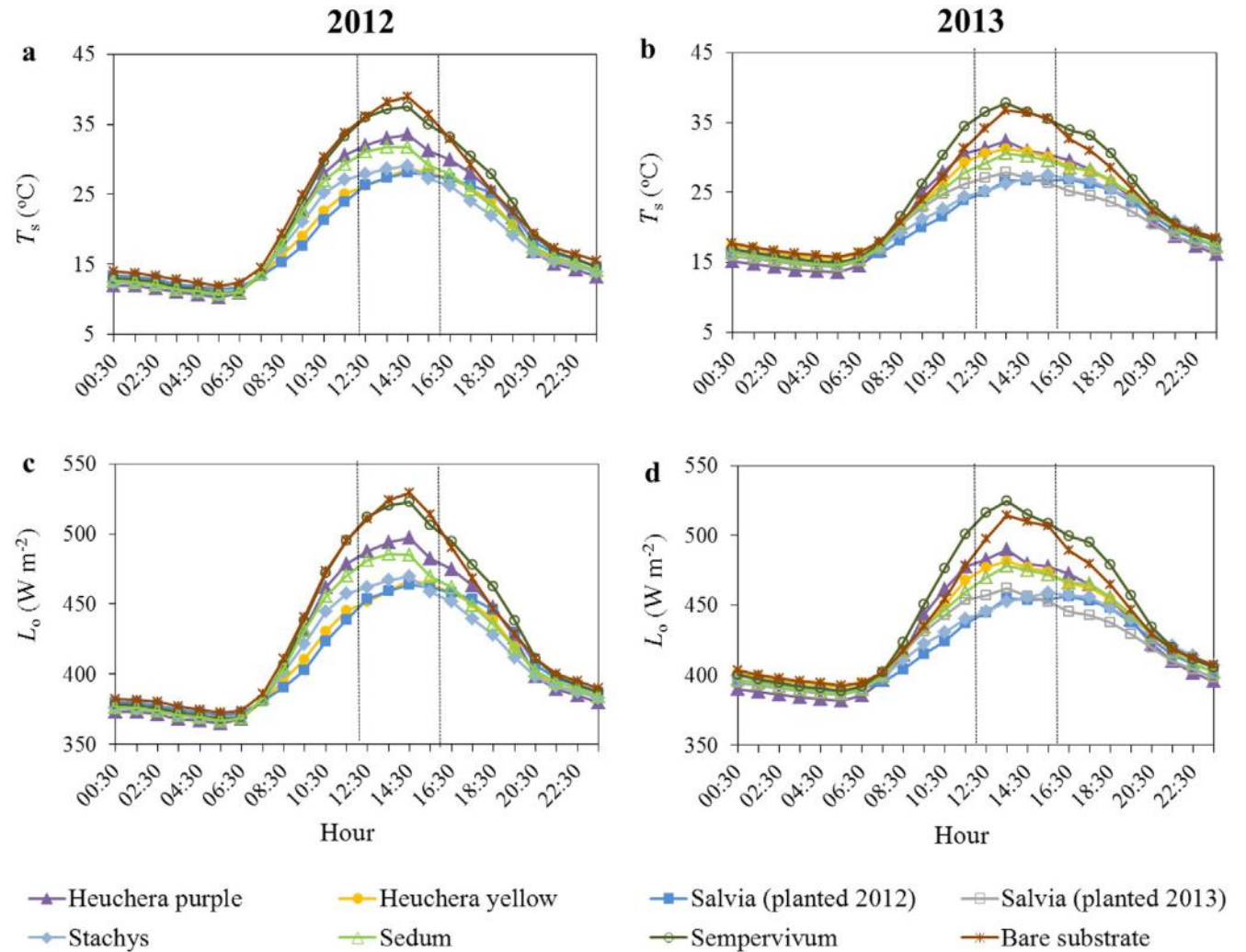
^c Department of Geography and Environmental Science, School of Archaeology, Geography and Environmental Science, University of Reading, Whiteknights, RG6 6AB, UK

^d Department of Landscape, University of Sheffield, S10 2TN, UK



Mean spectral reflectance within the short- wave spectrum for all treatments analysed in 2012, measured during a day in August with $T_{max} = 18^{\circ}\text{C}$.

Mean diurnal cycle of estimated surface temperature (T_s) and outgoing long-wave radiation (L_o) for treatments evaluated in 2012 and 2013. Data presented are a mean of 10 days with $T_{max} > 24^\circ\text{C}$. LSDs associated with the REML analysis for the periods delimited by the vertical lines were: a. 4.19 and b. 2.81°C, c. 25.84 and d. 17.07 W m^{-2} .



Functional green roofs: Importance of plant choice in maximising summertime environmental cooling and substrate insulation potential

M. Vaz Monteiro^{a,1}, T. Blanuša^{a,b,4}, A. Verhoef^c, M. Richardson^a, P. Hadley^a, R.W.F. Cameron^d

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^b Royal Horticultural Society, Plant Sciences Department, Garden Wisley, Woking GU23 6QB, UK

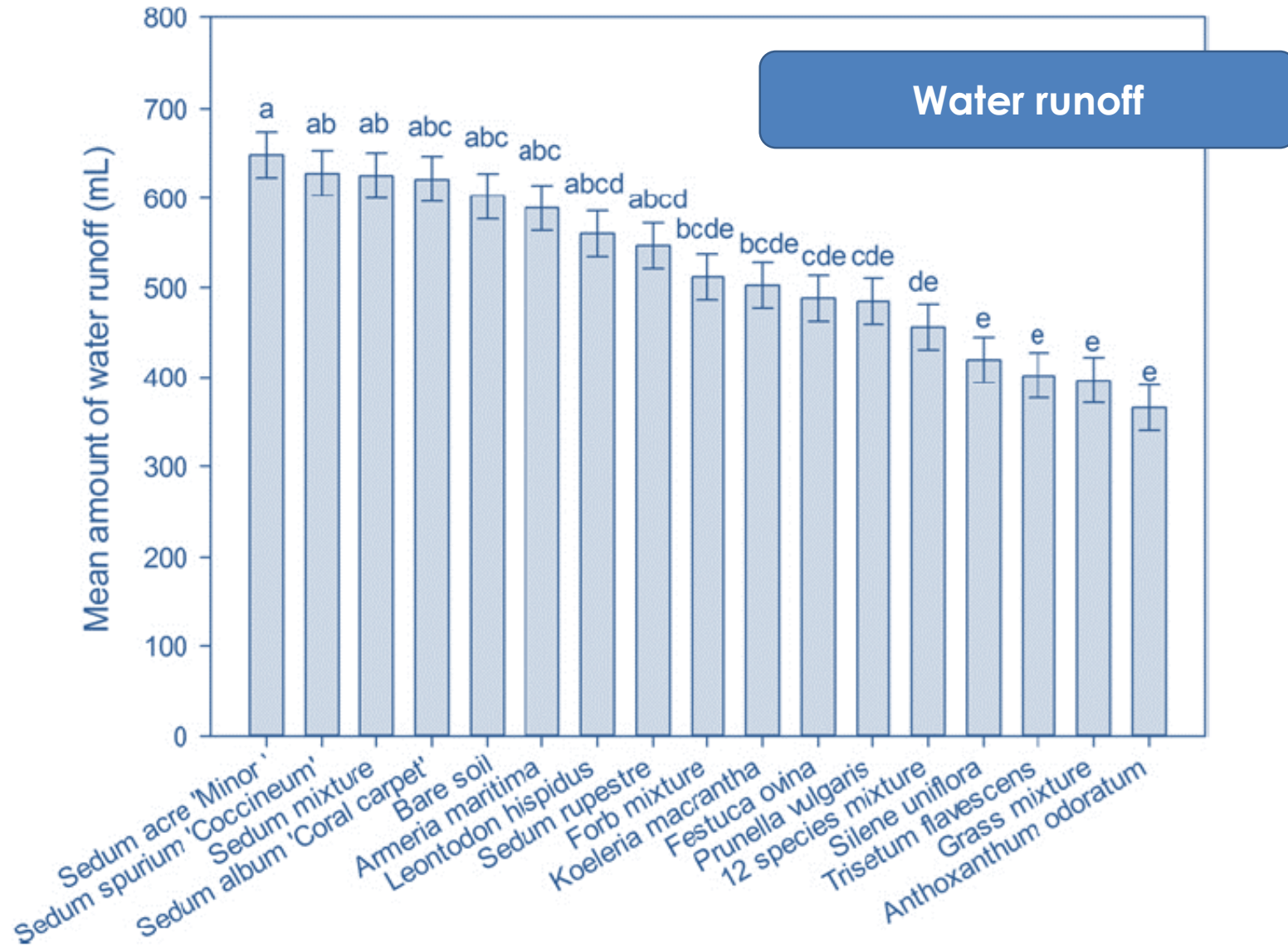
^c Department of Geography and Environmental Science, School of Archaeology, Geography and Environmental Science, University of Reading, Whiteknights, RG6 6AR, UK

^d Department of Landscape, University of Sheffield, S10 2TN, UK



«Based on the evidence we collected, we argue that new urban planning policies should take much greater consideration of **plant choice**, when attempting to **maximise ecosystem services provision**. Not all components of green infrastructure provide the same benefits, and plant genotype choice within this infrastructure, can strongly determine the type and level of benefits provided».

Romano D. The choice of plant species for green roofs and rain gardens in the Mediterranean area

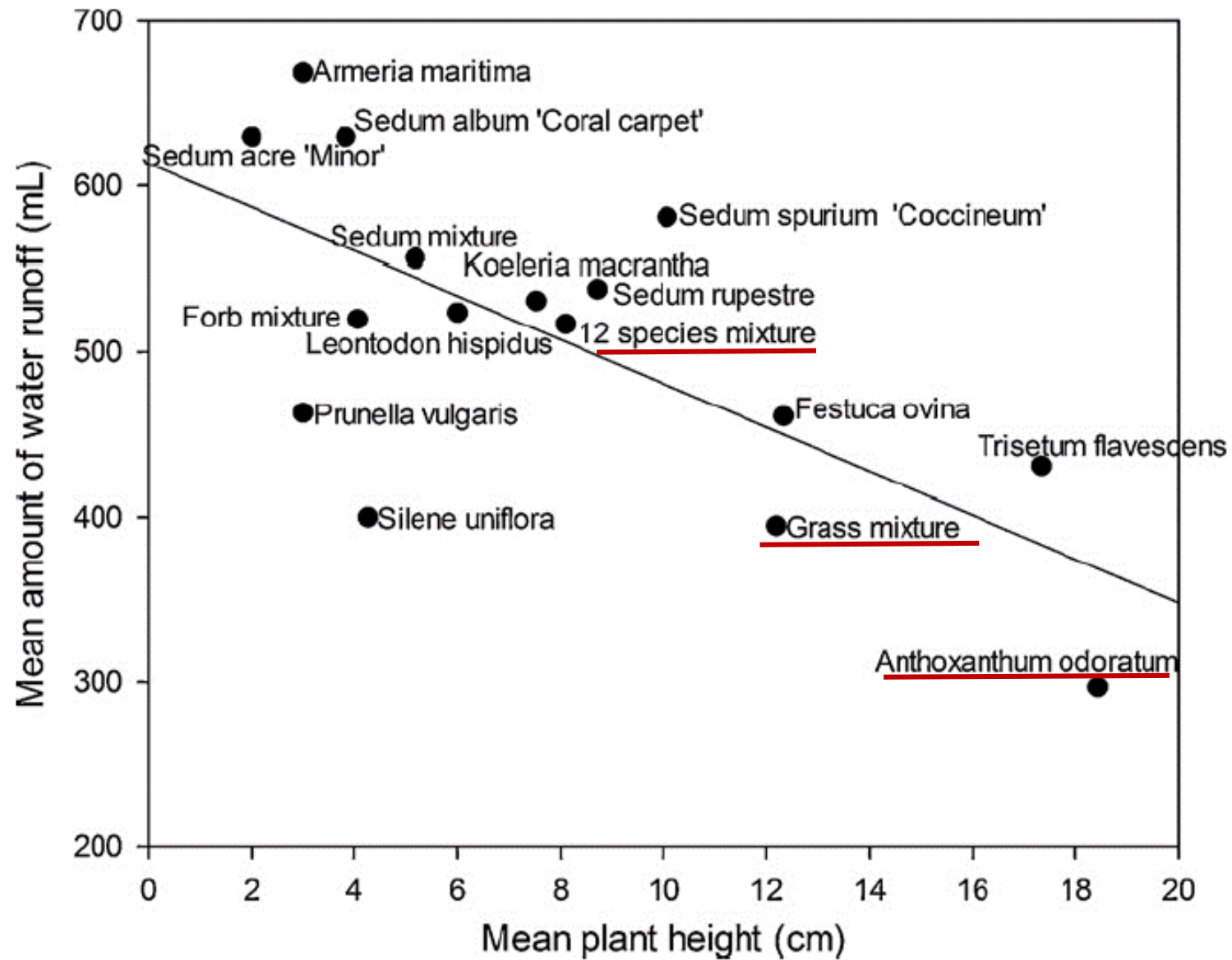


grasses > forbs > *Sedum*



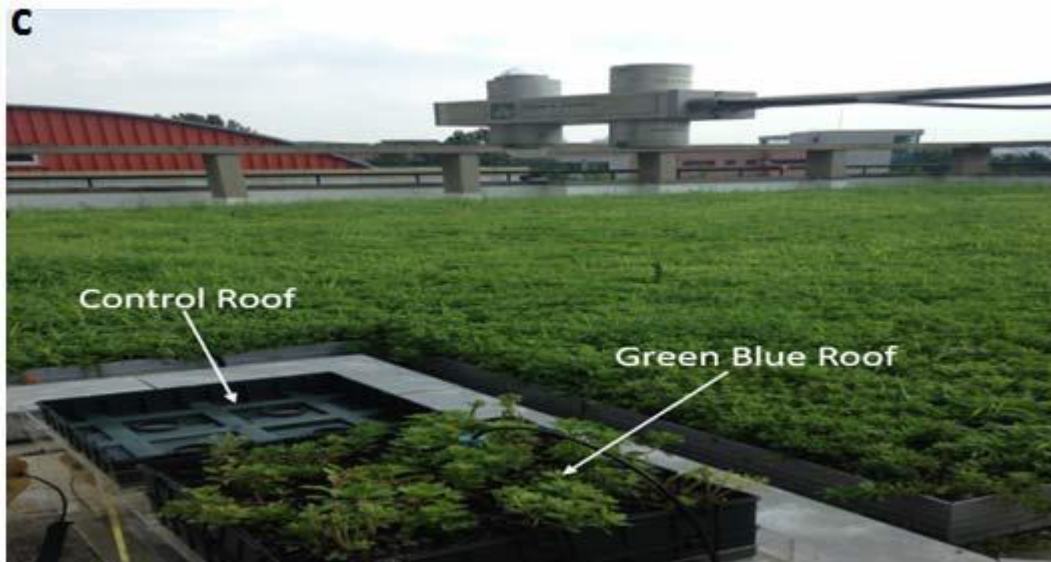
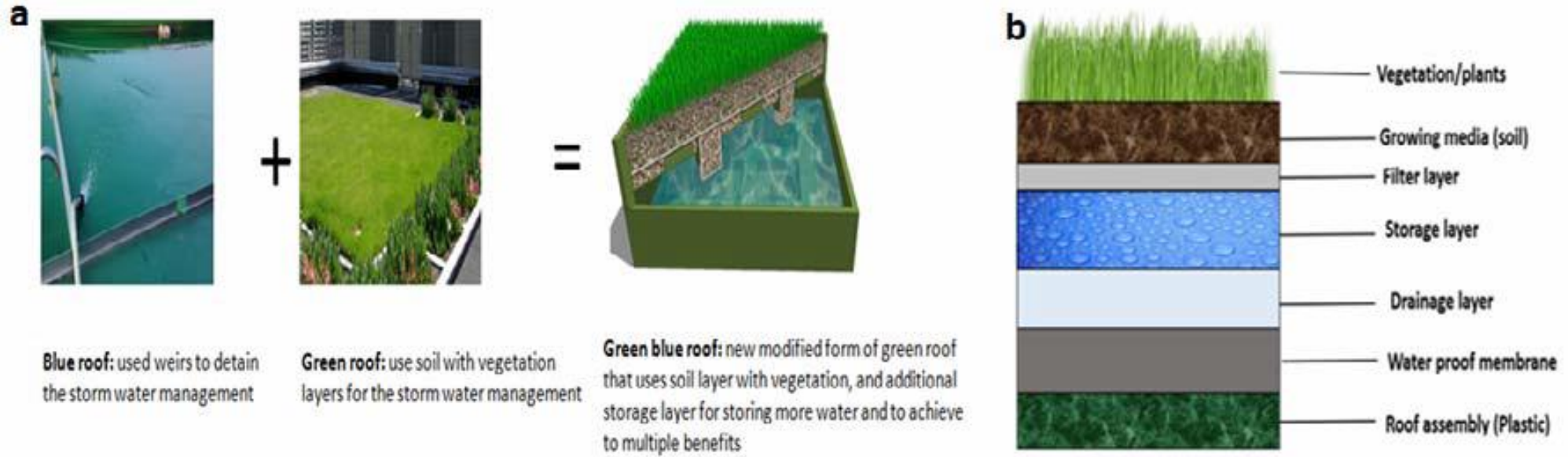
Mean amount of water runoff from different vegetation types. Error bars represent standard error. Means with the same letter do not differ significantly from each other (d.f. = 15,238, $F = 12.88$, $P < 0.01$).

Source: Nagase & Dunnet, 2012



Source: Nagase & Dunnet, 2012

Romano D. The choice of plant species for green roofs and rain gardens in the Mediterranean area



Green blue roof:

- a) green blue roof concept
- b) structure of a green blue roof
- c) green blue roof located in Seoul, Korea

Source: Shafique & Kim, 2017

Drought tolerant

Heat tolerant

Able to survive in extreme conditions

Low maintenance

etc.


What kind of plant are we looking for?



Plants selection in green roofs has many criteria which are interrelated:

- Climate and **micro-climate and environmental factors**
- The project purpose and the favourite roof appearance
- The canopy structure of plant species
- Depth of growing medium
- Rate of plant growth, nutrient needs, and sensitivity to pollution

Source: Arabi et al., 2015, modified

- 
- ✓ Roof orientation and slope may affect the intensity of the solar radiation and growing medium humidity
 - ✓ adjacent buildings may shade a part of the roof
 - ✓ air vents from air conditioning and heating units may dry the soil out
 - ✓ industrial chimneys may stunt the plant growth by chemical pollution
 - ✓ installation technique may impact plant choice

Romano D. *The choice of plant species for green roofs and rain gardens in the Mediterranean area*

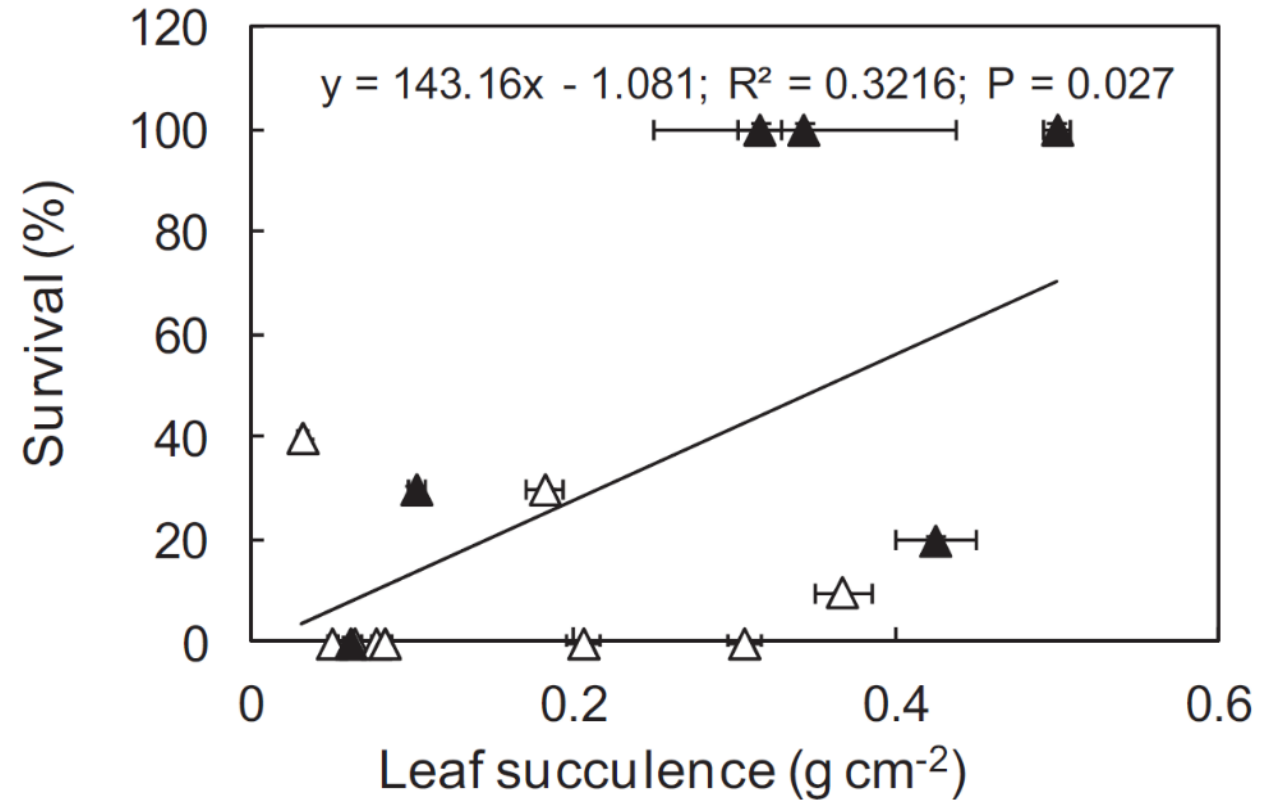
No	Plant type	Positive aspects	Negative aspects
1	Sedum mats or pre-grown vegetation blankets	Instant established and neat vegetation carpet	High cost Low diversity potential
2	Plug planting – planted at densities of 15 m ²	Can influence plant selection and desired seeds Cost effective	May take time to establish
3	Sowing seeds or cutting	Selection and sowing of desired seeds Cost effective	Takes 1-3 years to establish vegetation cover Sowing can only take place in spring or autumn
4	Natural colonization	High biodiversity Minimal cost	Take time to establish Aesthetically not to everyone's taste

Plant species in extensive green roofs have to survive drought, intense wind exposure, solar radiation, low nutrient supply, extreme temperatures, and limited root area (MacIvor & Lundholm, 2011).

Determining parameters in plant selection for green roofs.

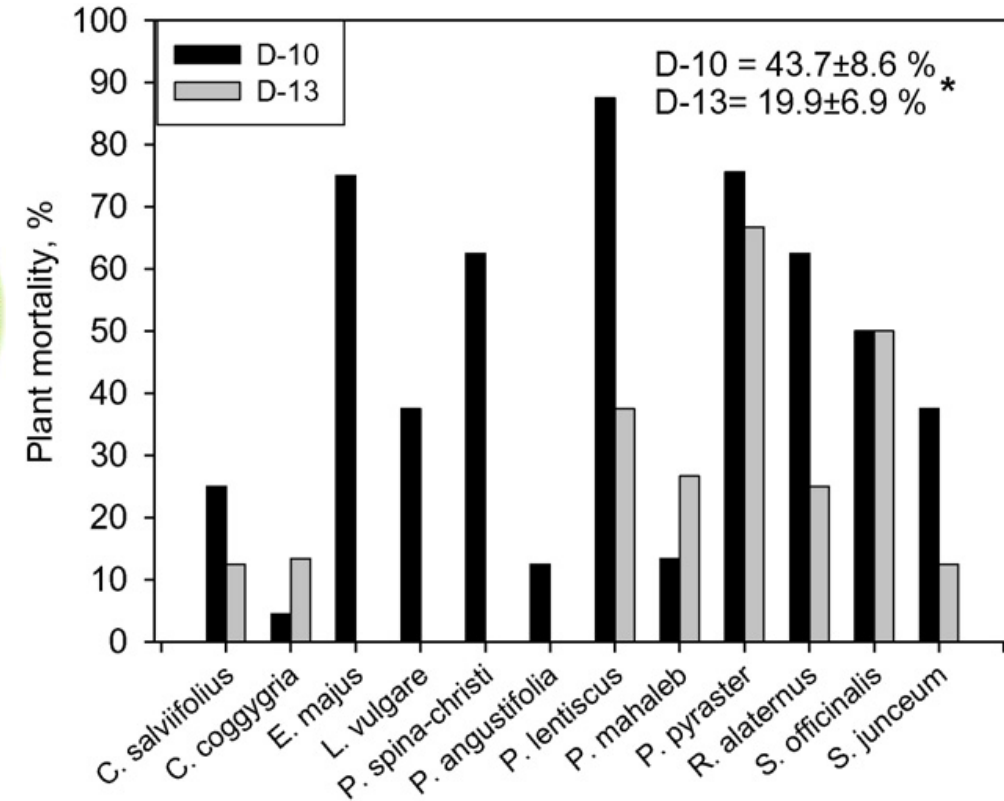
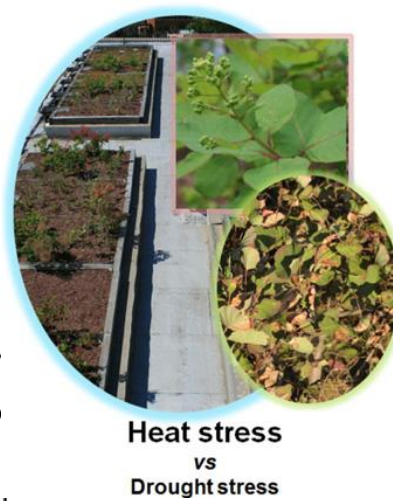
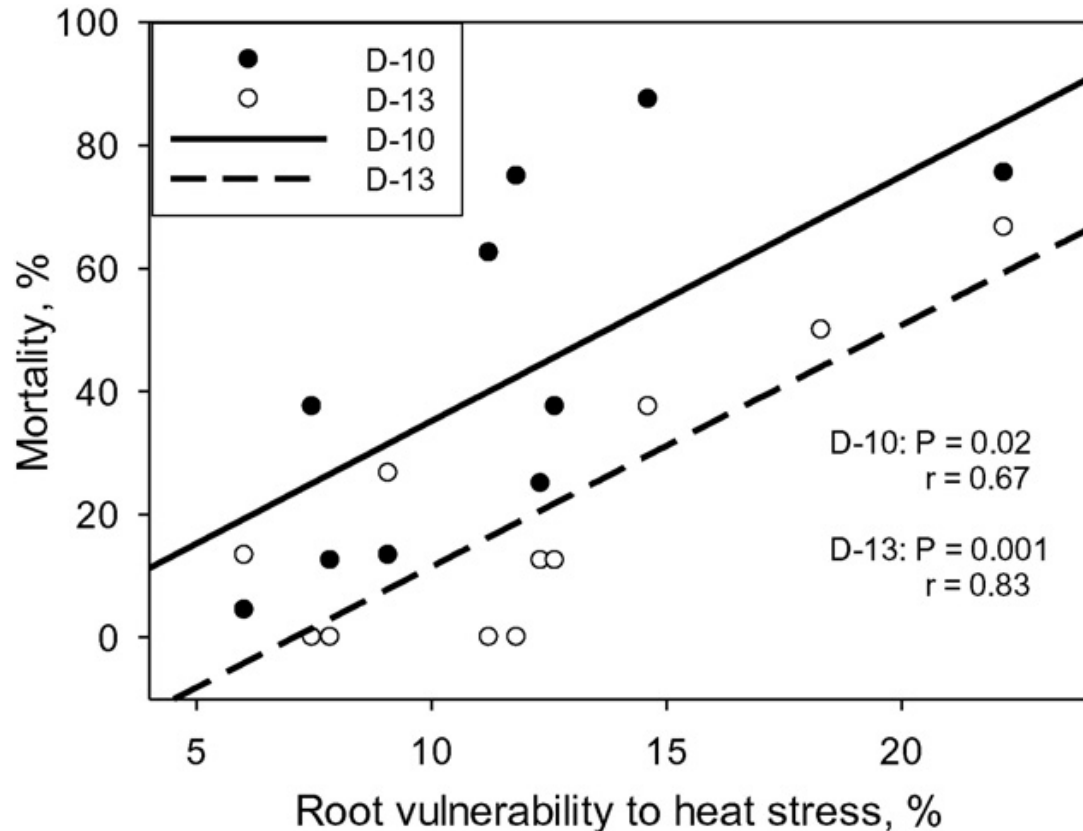
Determining factors		
Climate condition	Maintenance requirements	Visual appearance
Temperature	Irrigation	-
Solar radiation	Weeding	-
Humidity	Fertilization	-
Precipitation	Replanting	-
Drought	Pruning	-
Frost	Weed control	-

Source: Arabi et al., 2015, modified



Relationship between leaf succulence and species survival (%) of upright succulents (**closed triangles**) and prostrate succulents (**open triangles**) at the end of a 42 week green roof experiment. Overall species with greater leaf succulence ($\text{g H}_2\text{O leaf area cm}^{-2}$) had greater survival but this relationship was not significant within life-forms.

Drought-tolerant species exhibit **lower water requirements and growth rates**, but the **ability to survive** in harsh microclimate conditions is significantly related to the **resistance of the root system** to heat stress.



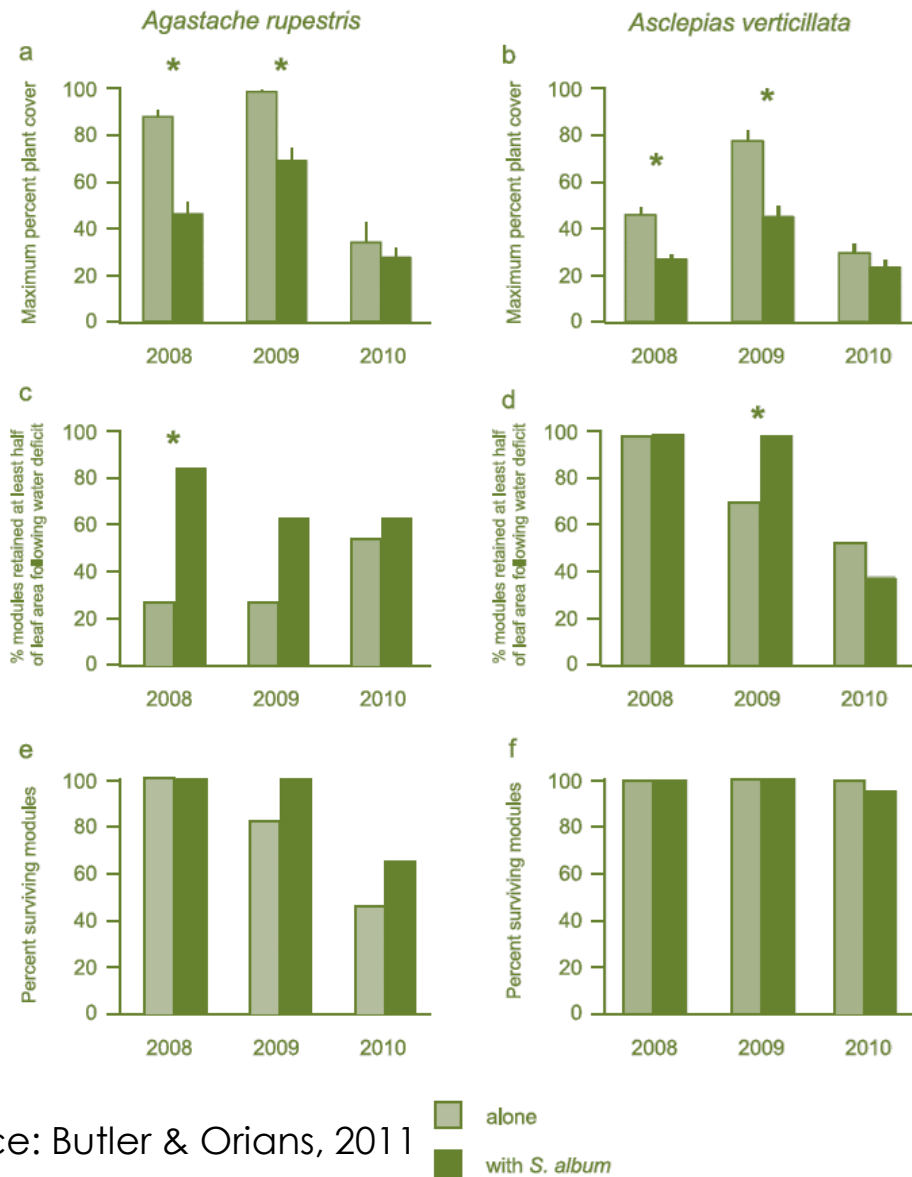
One of the main goals in green roof research is the **reduction of substrate depth**, to limit installation weight and costs (Cao *et al.*, 2014). However, this strategy could contrast with **the need to minimize temperature extremes** in the substrate and ensure plant survival.

Savi *et al.*, 2016

Is it possible to do
something to
improve plant
performance?



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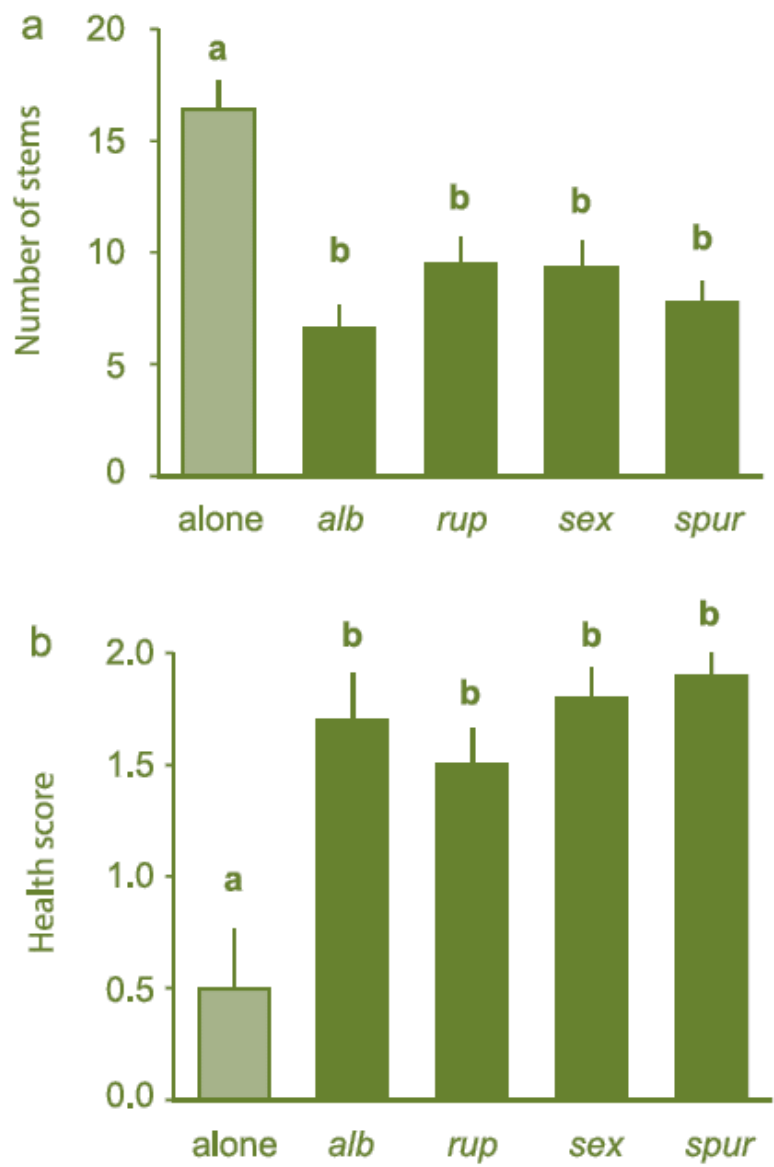


Take advantage of the «group» effect



Source: Butler & Orians, 2011

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Agastache 'Black Adder'



Sedum album



S. rupestre



S. sexangulare



S. spurium

Source: Butler & Orians, 2011

Romano D. *The choice of plant species for green roofs and rain gardens in the Mediterranean area*

Plant traits to drought tolerance and auto-sustainability, two key criteria for survival on **extensive green roofs**. (a) Traits and criteria used to exclude unsuitable species before scoring; (b) Plant traits used for scoring. Plant traits were derived from TRY initiative (Kattge *et al.*, 2001). (Source: Van Mechelen *et al.*, 2014)

a) Plant traits for species exclusion	Exlusion criteria	Reference
Raunkier life form	Phanerophyte	Julve, 1998
Typical plant height	Tall plant (> 1 m)	Cornelissen, 1996; Diaz <i>et al.</i> , 2004; Garnier <i>et al.</i> , 2007; Paula <i>et al.</i> , 2009
Root depth	Deep rooting system (> 20 cm)	Green, 2009; Paula <i>et al.</i> , 2009
Tolerance to drought	No drought tolerance	Green,, 2009
Grime strategy	No stress tolerance	Kühn <i>et al.</i> , 2004
b) Plant traits for scoring step	Preferable condition	Reference
Raunkier life form	Chamae-, geo- and therophytes preferred	Julve, 1998
Typical plant height	Small plants (< 1 m)	Kleyer <i>et al.</i> , 2008; Diaz <i>et al.</i> , 2004; Garnier <i>et al.</i> , 2007; Green, 2009; Paula <i>et al.</i> , 2009
Root depth	Shallow rooting system (< 20 cm)	Green, 2009; Paula <i>et al.</i> , 2009
Tolerance to drought	Medium or high drought tolerance	Green, 2009
Grime strategy	Ruderality and/or stress tolerance	Kühn <i>et al.</i> , 2004
Leaf phenology	Evergreenness	Cornelissen, 1996; Cornwell <i>et al.</i> , 2008; Kattge <i>et al.</i> , 2009; Paula <i>et al.</i> , 2009
Leaf shape	Small, acicular, needle-like leaves	Kühn <i>et al.</i> , 2004; Paula <i>et al.</i> , 2009
Maximum plant longevity	Annual or perennial plants	Diaz <i>et al.</i> , 2004; Green, 2009; Kühn <i>et al.</i> , 2004; Moles <i>et al.</i> , 2004
Metamorphosis for storage	Succulence	Kühn <i>et al.</i> , 2004
Photosynthetic pathway	(Facultative) CAM metabolism	Cornelissen, 1996; Cornwell <i>et al.</i> , 2008; Diaz <i>et al.</i> , 2004; Wright <i>et al.</i> , 2004

But then, what is
the **ideotype of
plant?**



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Table 5 Synthesis of key results categorising species according to: (1) water use strategy under well watered (WW) conditions (daily transpiration rate), (2) rate of water use under water

deficit (WD), i.e. time taken to effectively deplete soil moisture content and (3) water status (predawn water potential; Ψ_{PD}) under water deficit at the end of the experiment

Characteristic	Category 1	Category 2	Category 3
Water use strategy when well-watered (WW)	High water users (>70 g H ₂ O pot ⁻¹ d ⁻¹) <i>D. admixta</i> (M) <i>S. glauca</i> (M) <i>D. perfoliata</i> (H) <i>I. axillaris</i> (H)	Moderate water users (30-50 g H ₂ O pot ⁻¹ d ⁻¹) <i>A. milleflorum</i> (M) <i>L. longifolia</i> (M) <i>B. multifida</i> (H) <i>C. semipapposum</i> (H) <i>C. reflexa</i> (S) <i>C. tetragona</i> (S)	Low water users (<20 g H ₂ O pot ⁻¹ d ⁻¹) <i>G. alpina</i> (S) <i>H. obtusifolia</i> (S) <i>S. pachyphyllum</i> (Su)
Water use strategy under water deficit (WD)	High water users (>20 g H ₂ O pot ⁻¹ d ⁻¹) <i>S. glauca</i> (M) <i>D. perfoliata</i> (H) <i>I. axillaris</i> (H)	Moderate water users (10-20 g H ₂ O pot ⁻¹ d ⁻¹) <i>A. milleflorum</i> (M) <i>D. admixta</i> (M) <i>L. longifolia</i> (M) <i>B. multifida</i> (H) <i>C. semipapposum</i> (H) <i>C. reflexa</i> (S) <i>C. tetragona</i> (S)	Low water users (<10 g H ₂ O pot ⁻¹ d ⁻¹) <i>G. alpina</i> (S) <i>H. obtusifolia</i> (S) <i>S. pachyphyllum</i> (Su)
Water status (Ψ_{PD}) under water deficit (WD)	High water status (Ψ_{PD} < -1.5 MPa) <i>A. milleflorum</i> (M) <i>D. admixta</i> (M) <i>L. longifolia</i> (M) <i>S. glauca</i> (M) <i>I. axillaris</i> (H) <i>*S. pachyphyllum</i> (Su)	Moderate water status (Ψ_{PD} -1.5 to -3.0 MPa) <i>D. perfoliata</i> (H) <i>C. tetragona</i> (S)	Low water status (Ψ_{PD} > -3.0 MPa) <i>B. multifida</i> (H) <i>C. semipapposum</i> (H) <i>G. alpina</i> (S) <i>H. obtusifolia</i> (S) <i>C. reflexa</i> (S)

Life-form indicated in parentheses with *M* monocot, *H* herb, *S* shrub and *Su* succulent. Categories are arbitrarily assigned and shading represents desirable characteristics for green roof plant species. "*" indicates that although Ψ_{PD} was not measured for *Sedum pachyphyllum*, leaf relative water content data (see Table 3) suggests it maintained a high water status under water deficit



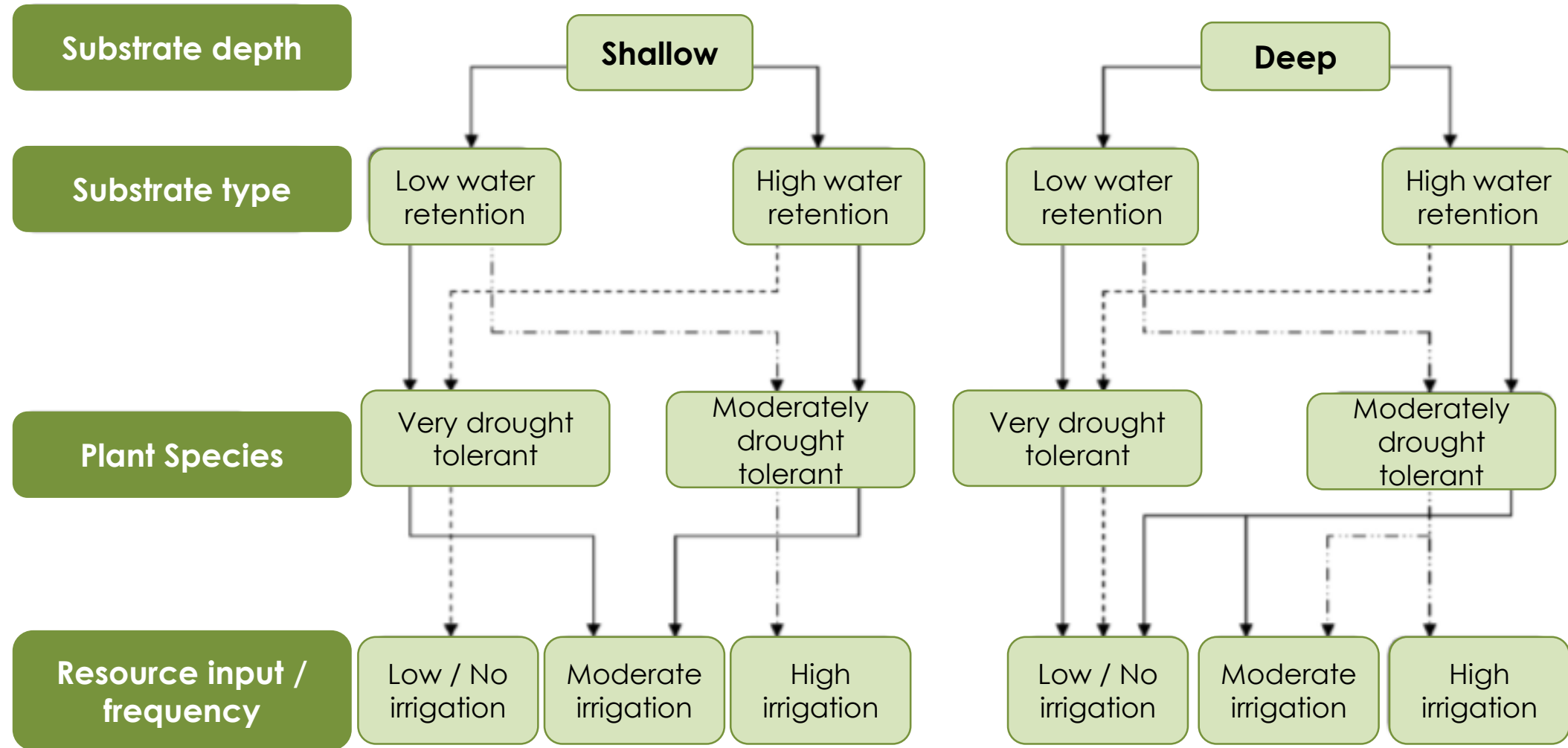
Isotoma axillaris



Dianella admixta

(Source: Farrel *et al.*, 2013)

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Interaction between the four major factors (substrate depth, substrate type, plant species selection and resources input/frequency) that, according to the adaptive approach, contribute to successful and sustainable extensive green roofs. Different line types indicate independent flow (Source: Ntoulas *et al.*, 2013).

Finally, let's not
forget the aesthetic
aspect of plants ...



Table 1
Family name, life form, natural habitat and season of propagule collection of the plant species included in this study.

Species	Family	Life form	Natural habitat	Seed or propagule collection season
<i>Asteriscus maritimus</i>	Compositae	Chamaephyte	Bare coastal and rocky areas near the sea	July to November
<i>Brachypodium phoenicoides</i>	Poaceae	Hemicryptophyte	Dry grasslands and pine forest margins	July and August
<i>Crithmum maritimum</i>	Umbelliferae	Chamaephyte	Coastal zones	September and October
<i>Limonium virgatum</i>	Plumbaginaceae	Chamaephyte	Coastal salty soils	September to November
<i>Sporobolus pungens</i>	Poaceae	Geophyte	Coastal sandy soils	July
<i>Sedum sediforme</i>	Crassulaceae	Chamaephyte	Rock crevices	August to October

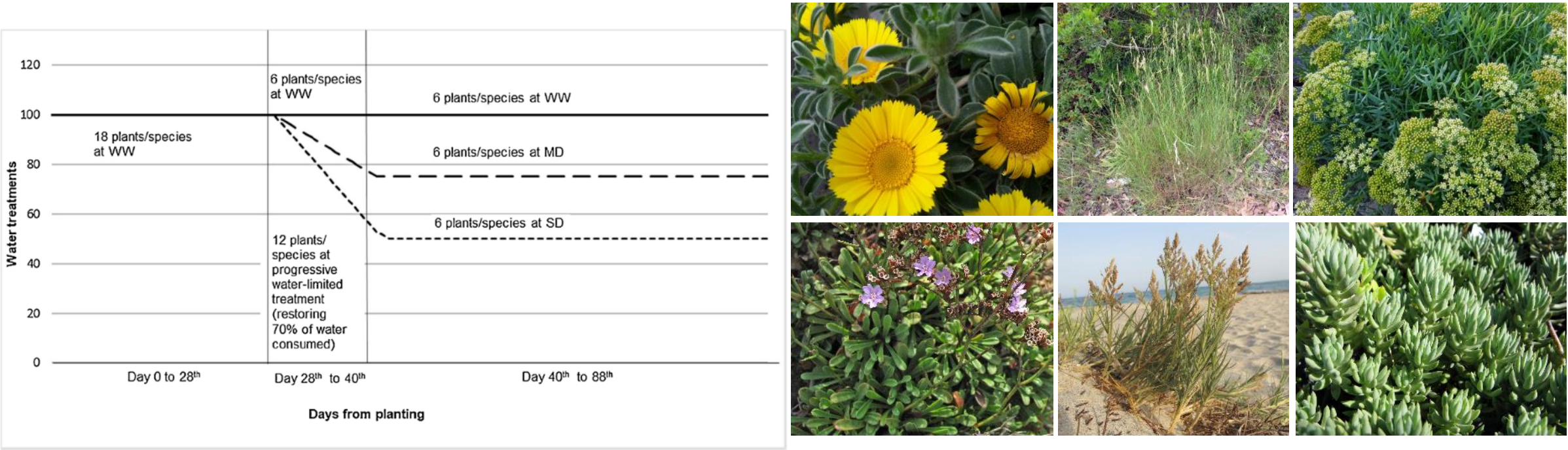
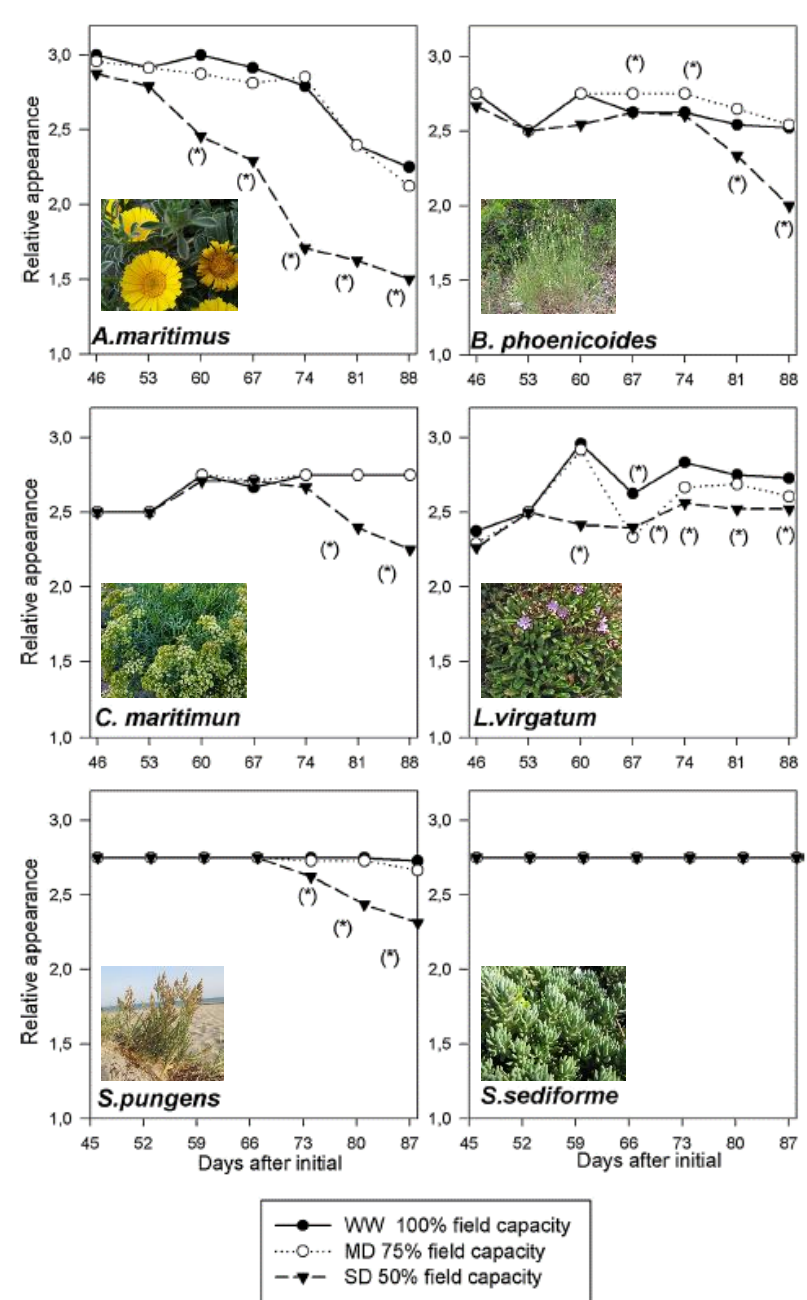


Fig. 2. Water treatments (as % of soil field capacity) of each treatment: Well-Watered (WW, 100% of soil field capacity), solid line; Mild Drought (MD, 75% of field capacity), dashed line; and Severe Drought (SD, 50% of field capacity), dotted line, according to experimental design and experiment period. The substrate water content was kept at the % of field capacity indicated after each irrigation event (every 2–3 days) by restoring 100% or 80% (during the substrate water content depletion in 75% and 50% treatments) of consumed water.

Azeñas et al., 2019

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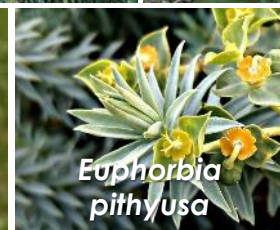
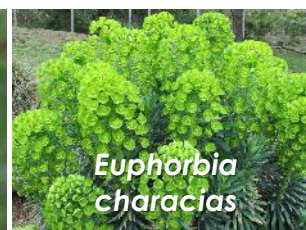
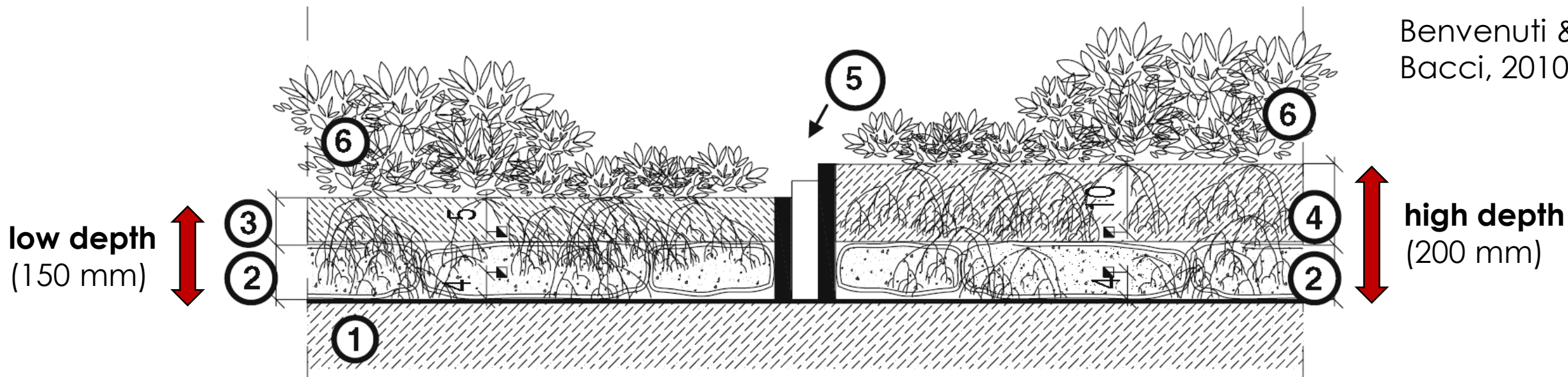
Plant Color		
3 Optimal color richness	2 Acceptable color richness	1 Senescent (brown leaves)
Flowering		
3 High density	2 Low density -Absence	1 Senescent (brown flowers)

Azeñas et al., 2019

Plant Vigor		
3 Optimal (turgid leaves)	2 Adequate (seldom dehydrated leaves)	1 Inadequate (several dehydrated leaves)
Plant Shape		
3 Optimal (compact)	2 Adequate (partially open)	1 Inadequate (formless)

Romano D. The choice of plant species for green roofs and rain gardens in the Mediterranean area

Benvenuti & Bacci, 2010



Post-transplant survival (%) = n.s.

Plant cover (%) Biomass growth (g^{-plant})



Table 2 Biometric measurements of the tested species in the two types of green roofs (high and low substrate depths: 200 mm and 150 mm respectively): % of post-transplant survival (1 month after transplant), % of plant cover (3 months after transplant) and biomass growth (6 months after transplant). Means followed by one of two asterisks differ statistically at $p < 0.05$ and $p < 0.01$ respectively

Plant species	Post-transplant survival (%)			Plant cover (%)			Biomass growth (g ^{-plant})		
	high	low	significance	high	low	significance	high	low	significance
<i>Anthemis maritima</i>	100	100	n.s.	100	100	n.s.	69.4	69.1	n.s.
<i>Armeria pungens</i>	100	94	n.s.	40	27	**	17.3	14.8	*
<i>Calamintha nepeta</i>	100	100	n.s.	93	71	*	31.3	19.8	*
<i>Centranthus ruber</i>	97	93	n.s.	100	62	**	45.2	33.7	**
<i>Crithmum maritimum</i>	100	100	n.s.	15	17	n.s.	25.8	25.7	n.s.
<i>Dianthus carthusianorum</i>	100	94	n.s.	33	30	n.s.	22.7	21.5	n.s.
<i>Euphorbia characias</i>	100	100	n.s.	60	40	**	32.2	19.9	*
<i>Euphorbia pithyusa</i>	100	92	n.s.	48	28	**	23.0	16.3	*
<i>Glaucium flavum</i>	100	100	n.s.	100	100	n.s.	67.0	47.3	**
<i>H. italicum</i> subsp. <i>microphyllum</i>	100	100	n.s.	66	59	n.s.	26.2	23.7	n.s.
<i>Helichrysum italicum</i>	100	100	n.s.	68	56	*	38.1	32.4	*
<i>Helichrysum stoechas</i>	100	100	n.s.	67	52	*	39.5	33.6	*
<i>Lavandula stoechas</i>	100	92	n.s.	55	53	*	33.2	25.2	*
<i>Leontodon tuberosus</i>	100	100	n.s.	15	12	n.s.	18.0	16.3	n.s.
<i>Otanthus maritimus</i>	100	100	n.s.	44	31	*	22.1	19.3	n.s.
<i>Satureja montana</i>	100	100	n.s.	24	17	n.s.	45.0	44.9	n.s.
<i>Scabiosa columbaria</i>	95	91	n.s.	100	66	**	57.3	45.1	*
<i>Scrophularia canina</i>	100	100	n.s.	100	87	*	44.8	42.3	n.s.
<i>Sedum rupestre</i>	100	100	n.s.	19	16	n.s.	10.2	9.7	n.s.
<i>Verbascum thapsus</i>	100	100	n.s.	100	69	**	80.8	59.7	**

Flowering periods: longer with high depth substrate



Table 3 Flowering periods of the tested species in the two different green roofs: high depth (200 mm) and low depth (150 mm). The number of points (1–3) indicate the flowering period in 10 day periods of the relative months

Plant species	Grren roof	Flowering periods								
		March	April	May	June	July	August	Sept.	Octob.	Nov.
<i>Anthemis maritima</i>	hight			••	•••	••			••	
	low			•	•••	••			•	
<i>Armeria pungens</i>	hight				•	•••				
	low					•••				
<i>Calamintha nepeta</i>	hight				••	•••				
	low				•	•••				
<i>Centranthus ruber</i>	hight			••	•••				••	
	low			•	•••				••	
<i>Critonum maritimum</i>	hight					••	•••			
	low					•	•••			
<i>Dianthus carthusianorum</i>	hight			•	•••	•••	•		•	
	low				•••	•••			•	
<i>Euphorbia characias</i>	hight	No flowering during the first growing season								
	low									
<i>Euphorbia pithyusa</i>	hight	No flowering during the first growing season								
	low									
<i>Glauicum flavum</i>	hight			•	•••	••				
	low				•••	••				
<i>H. italicum subsp. microphyllum</i>	hight			•	•••					
	low				•••					
<i>Helichrysum italicum</i>	hight			•	•••					
	low				•••					
<i>Helichrysum stoechas</i>	hight			•	•••					
	low				•••					
<i>Lavandula stoechas</i>	hight			••	•••					
	low			•	•••					
<i>Leontodon tuberosus</i>	hight			••	•••	•			••	
	low			•	•••	•			••	
<i>Otanthus maritimus</i>	hight					•	•••			
	low						•••			
<i>Satureja montana</i>	hight					••	•••	•		
	low					•	•••	•		
<i>Scabiosa columbaria</i>	hight				••	•••	•		••	•
	low				•	•••	•		••	•
<i>Scrophularia canina</i>	hight			••	•••					
	low			•	•••					
<i>Sedum rupestre</i>	hight			•	•••	•				
	low			•	•••	•				
<i>Verbascum thapsus</i>	hight					••	•••			
	low					•	•••			

What happens
instead with the
rain gardens?



Romano D. The choice of plant species for green roofs and rain gardens in the Mediterranean area

4. ENTRY AND OVER FLOW SYSTEM (Often combined as a Kerb Cutdown)

An overflow bypass for excess flows when rain garden ponding area is full. Sometimes an internal overflow sump is required.

Stormwater entry choice impacts on maintenance regime and costs. Ideally a grassed filter strip or grassed swale included before entry as first stage filtration removing larger particles. Sedimentation bays should be used in high silt load risk areas.

1. RAIN GARDEN MEDIA MIX

Most important component. The filter media layer filters pollutants.

2. PONDING AREA

Holds stormwater runoff until it seeps through the media mix and into the under drain system. Ideally 300mm lower than the surrounding hard surfaces. Ponding depth ideally 300mm deep except if trees are in the garden.

3. PLANTS (PREFERABLY NATIVE)

Helps filter pollutants and looks attractive. Native plants are usually better suited to extreme/dry conditions such as ponding for 24hrs or no rain for a month.

5. GRAVEL MULCH LAYER

Prevents weeds and helps prevent soil drying out. Sometimes a sacrificial photo degradable weed mat is introduced under the mulch in active construction zones with high sediment loads. Bark mulch is inappropriate as it floats.

8. EDGE SUPPORT

Measures to protect carriageway subgrade from saturation and failure during media replacement. Struts may be needed between deep walls.

7. DRAINAGE LAYER

Collects and transports filtered water towards the stormwater collection system. Some very permeable soils may not require a drainage layer or piped collection system.

6. FILTER SAND TRANSITION LAYER

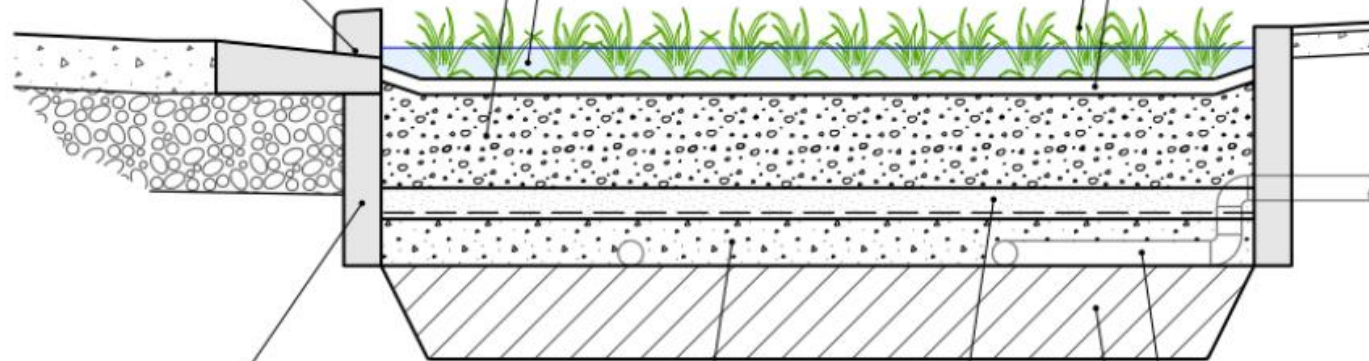
An additional filter layer which helps retain media within the rain garden.

9. UNDER DRAIN SYSTEM

Piped system collecting filtered water.
- If trees in rain garden, solid pipe and 300mmø vertical standpipes needed.
- If planting only, drilled collection pipes and 100mmø standpipes used.
- Where a shallow stormwater outfall exists, some of the lower rain garden may be saturated and up turned elbows are necessary.

10. RAIN GARDEN BASE

Loosened to 300mm below surface to assist in partial soakage.

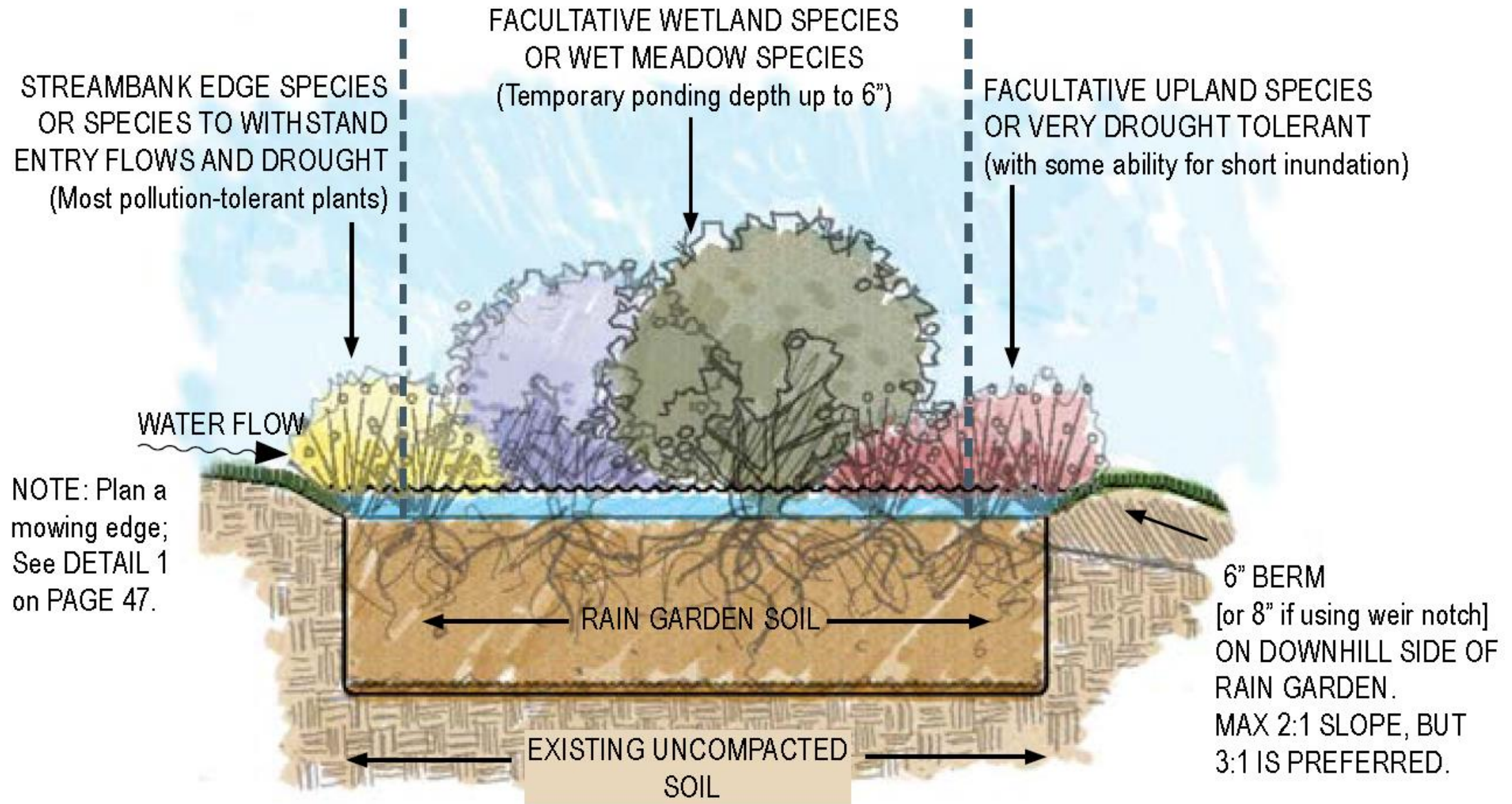


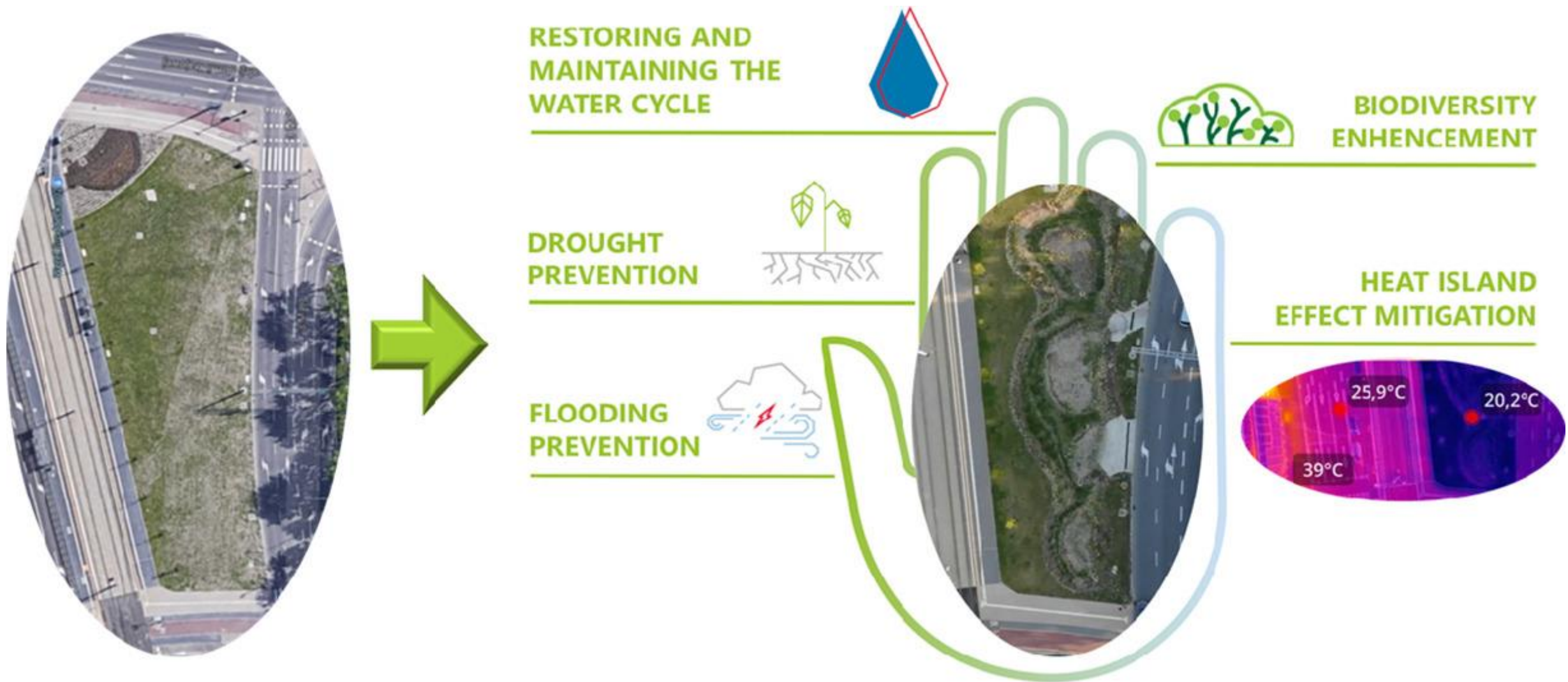
Key components of a rain garden

TYPICAL CROSS SECTION

Christchurch City
Council, 2016

Figure 6. Planting plan moisture and pollution zones





Kasprzyk et al., 2022

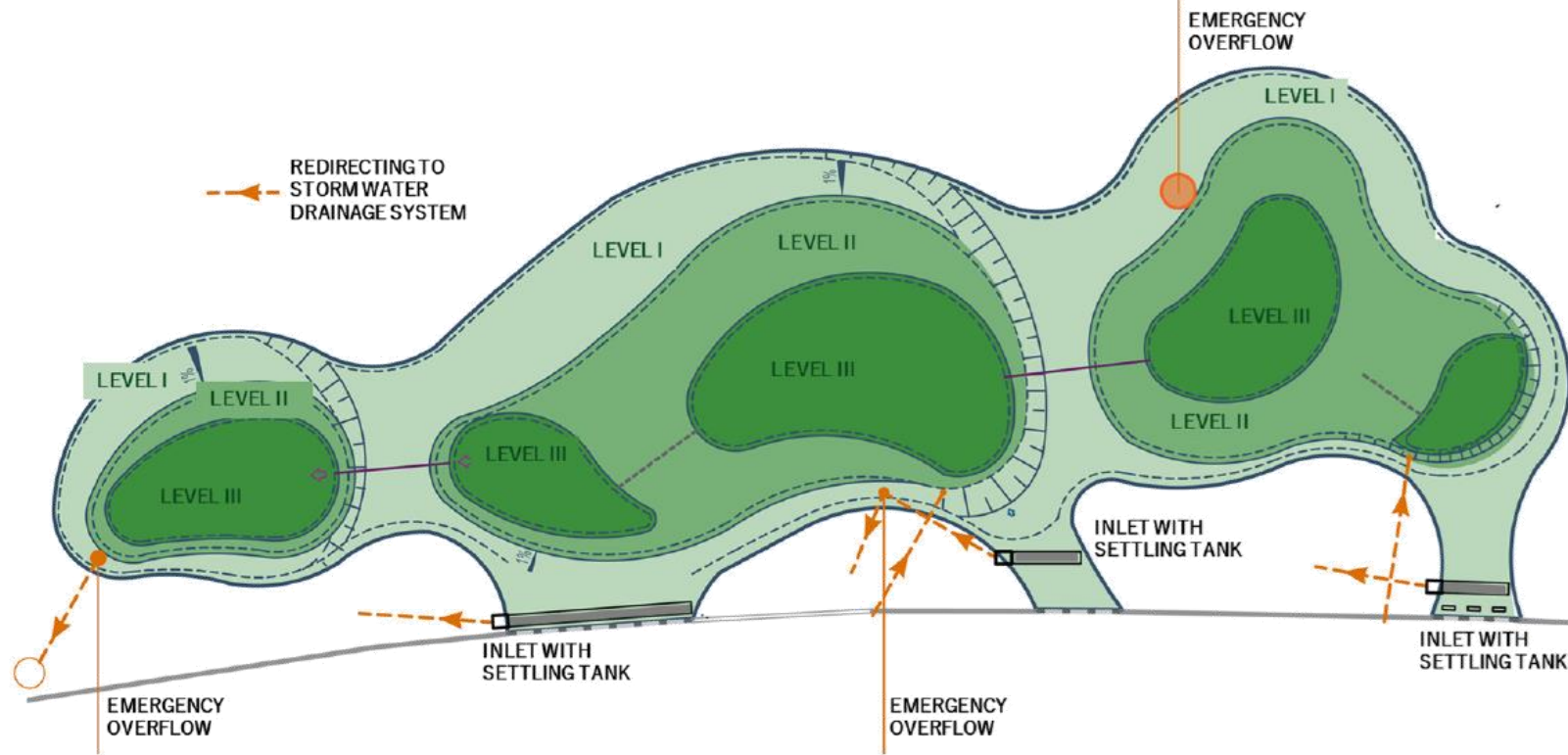
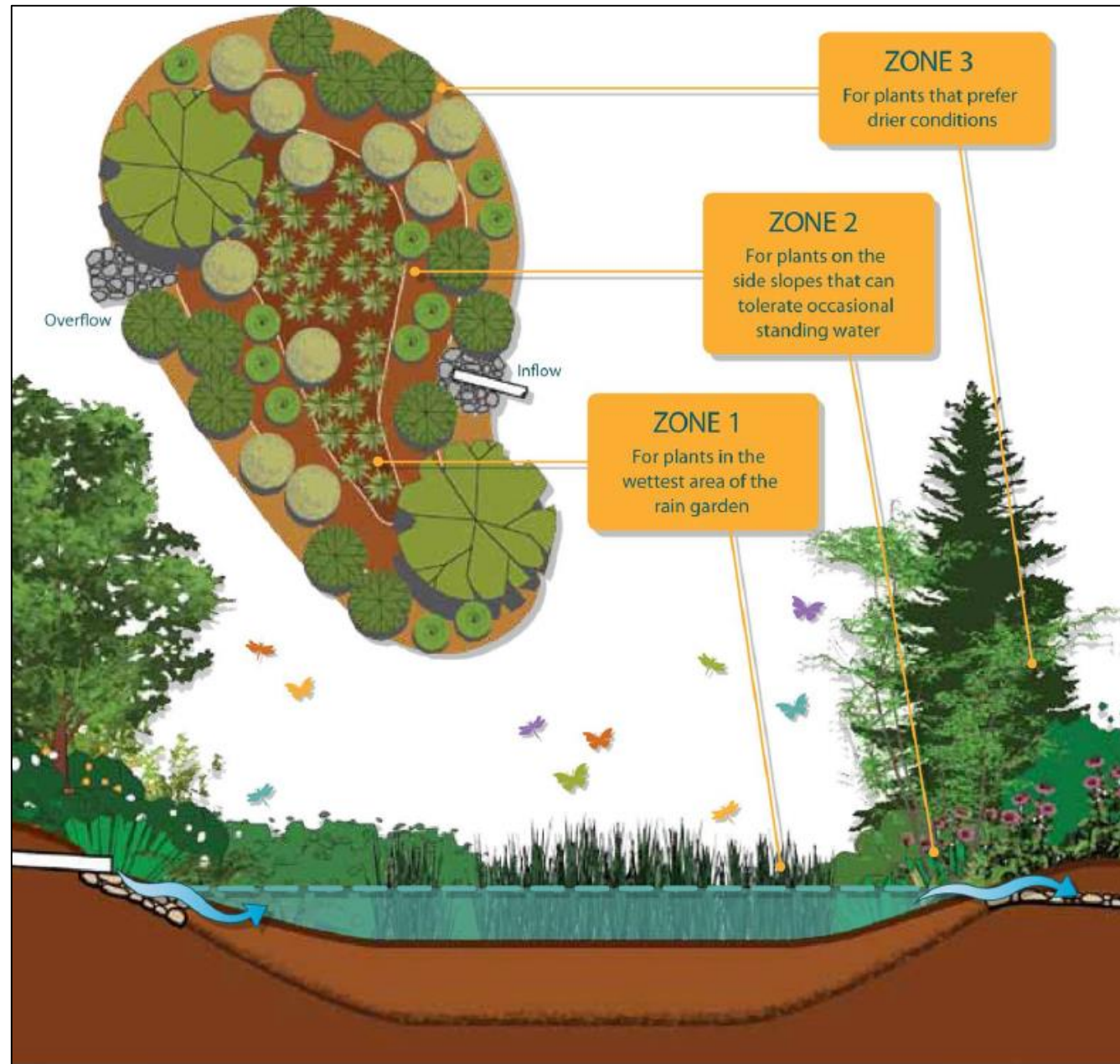


Fig. 7. The general concept of the triple-level storm water retention system.

- i) the lowest basins designed to receive precipitation – **LEVEL III**; most humid area, where all basins have been landscaped with **hydrophytic plants** tolerating permanently stagnant water;
- ii) designed to retain excess water during excessive precipitation – **LEVEL II**; most often this level will be **free of damp**; therefore, it has been designed with a grassy surface for **recreational purposes** (accessible greenery);
- iii) a part of the terrain that regulates the water level of each basin – **LEVEL I**; these levels are connected with dikes dividing each basin and equipped with emergency overflows (with diameters of 450 mm to 600 mm), one for each basin.

Inundation zones



Rain garden Handbook for
Western Washington,
Washington State
Department of Ecology,
June 2013

Rain garden plant function

- ✓ Nutrient and some heavy metal uptake
- ✓ Transpiration
- ✓ Enhance infiltration
- ✓ Soil stabilization
- ✓ Provide wildlife habitat – pollinators and beneficial insects
- ✓ Provide aesthetic appeal



General guidelines should apply to planting:

Christchurch City Council, 2016

- Choose appropriate plant species that can withstand prolonged **periods of ponding and drought**;
- Lay out plants randomly to suit soil depth, orientation of the plant bed, and overall site location. Ensure plants do not overhang pedestrian or movement corridors;
- **Do not locate woody vegetation** (shrubs and trees) near **inflow locations**;
- Consider wind, sun and exposure when choosing varieties for planting;
- Do not plant noxious weeds;
- **Aim for aesthetics and visual characteristics** – it should look good;
- Consider traffic visual requirements (no tall plants in line-of-sight from a vehicle) and safety issues;
- Pay particular attention to watering plants as they establish because the use of free draining media requires that plants and trees need more frequent inspection and watering during the first two years. Once established, rain garden plants not typically require watering;
- Plants placed near the inlet structure will receive more water and higher sediment loads so they need to be suitable in these growing conditions. Plants placed away from the inlet will receive less water and therefore need to be more drought tolerant.

Romano D. The choice of plant species for green roofs and rain gardens in the Mediterranean area

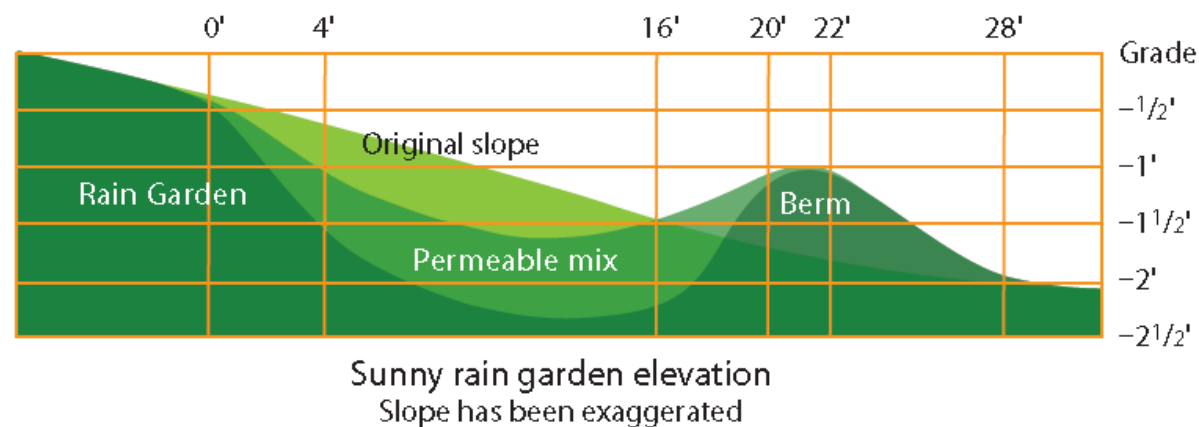
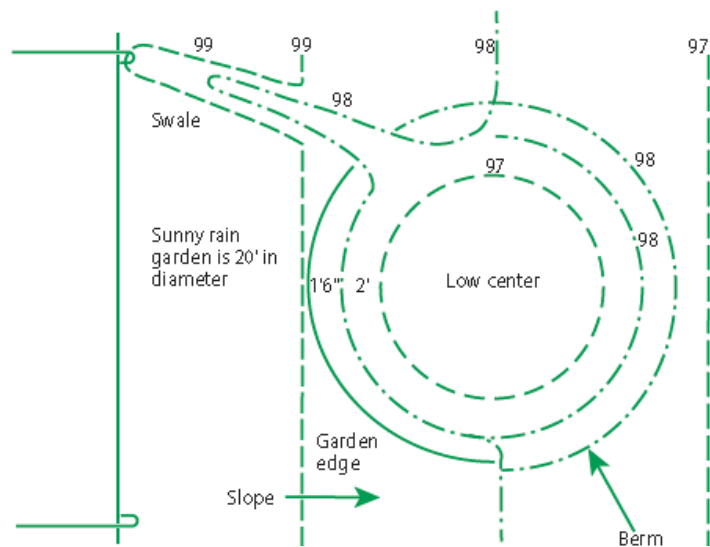


Table 1. Plants for coastal California rain gardens, by location in the garden

Plants for the bottom		Plants for mid-slope		Plants for the berm	
Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
creeping wildrye	<i>Elymus triticoides</i>	clustered field sedge S	<i>Carex praegracilis</i>	pitcher sage	<i>Salvia spathecea</i>
wild ginger S	<i>Asarum caudatum</i>	salt grass	<i>Distichlis spicata</i>	California polypody fern S	<i>Polypodium californicum</i>
torrent sedge	<i>Carex nudata</i>	common or spreading rush	<i>Juncus patens</i>	common yarrow	<i>Achillea millefolium</i>
scouring rush	<i>Equisetum hyemale</i>	Mexican rush	<i>Juncus mexicanus</i>	California fuschia	<i>Epilobium canum</i>
douglas Iris	<i>Iris douglasiana</i>	yerba buena S	<i>Clinopodium douglasii</i>	Ceanothus	<i>Ceanothus</i> spp.
yerba mansa	<i>Anemopsis californica</i>	wood rose	<i>Rosa gymnocarpa</i>	Siskiyou lewisia, cliff maids	<i>Lewisia cotyledon</i> 'Sunset Strain' and other succulents
New Zealand bush sedge S	<i>Carex solandri</i>	southwestern spiny rush	<i>Juncus acutus</i>	Cleveland sage, blue sage	<i>Salvia clevelandii</i>
basket rush	<i>Juncus textilis</i>				

Note: **S** = can be used in the shade.

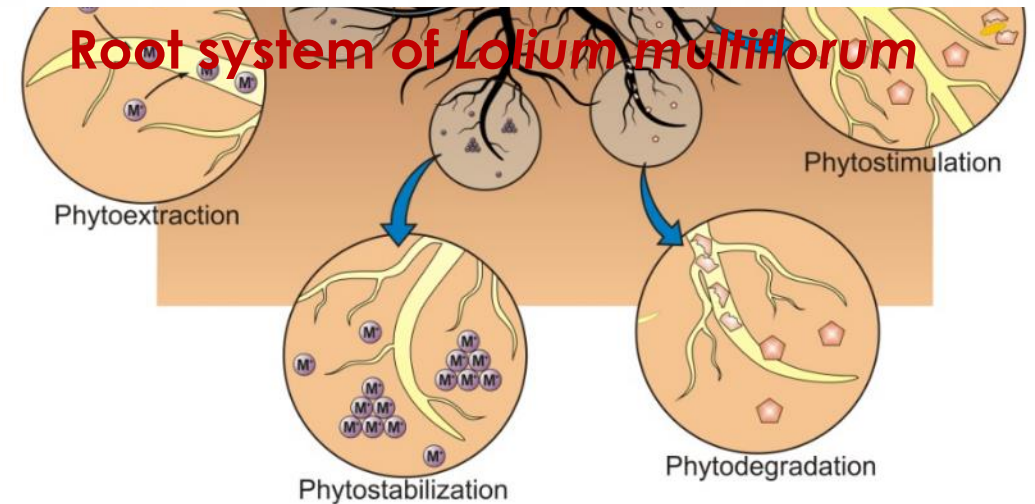
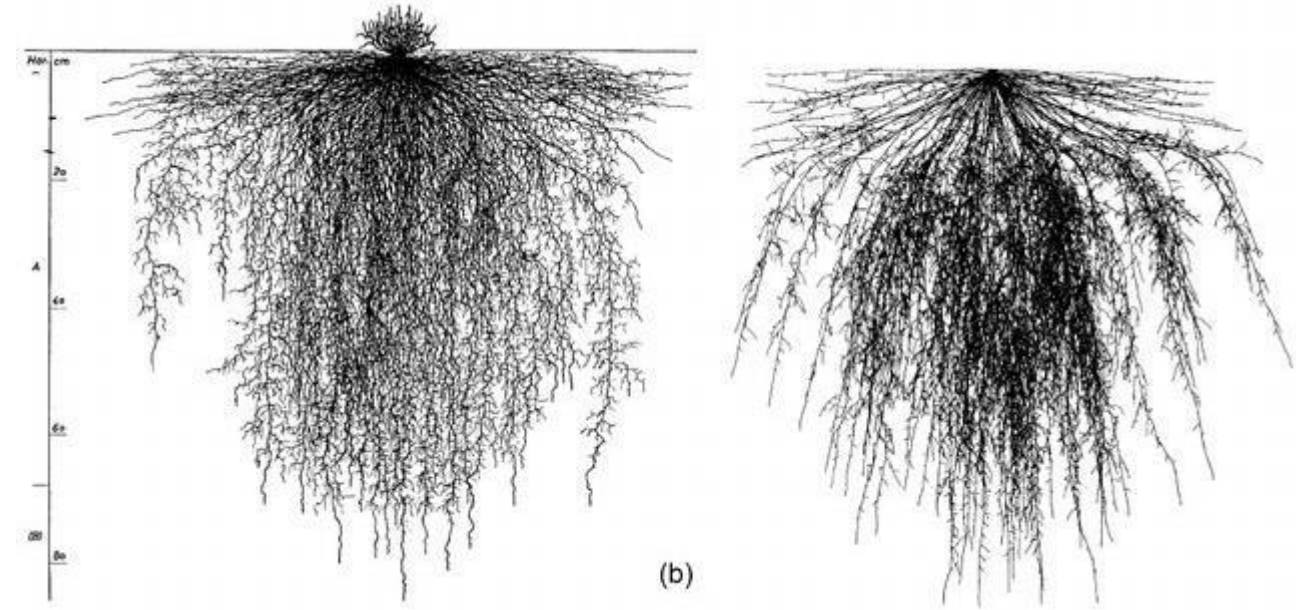
Plant selection

- ❖ Plants are an essential component - they filter and clean storm water, and stabilize the soil
- ❖ Use Native or adapted plants
- ❖ Use drought-tolerant plants
- ❖ Plants with fibrous root systems are very beneficial
- ❖ Plant roots will maintain and increase soil porosity
- ❖ Avoid plants that require well-drained soils
- ❖ Diversity of plant types:
 - Type: small trees, shrubs, perennials, bunch grasses, groundcover
 - Leaf retention: evergreen, semi-evergreen, deciduous

Source: Intechopen.com



Phytovolatilization



Plants suitable for rain gardens ...

- ✓ Tolerate periods of saturated soil, yet also thrive under drier conditions
- ✓ Persistent, long lived
- ✓ Low maintenance
- ✓ Do not require fertilization or irrigation

Plants not suitable for rain gardens ...

- ✓ Do not like «wet feet»
- ✓ Are susceptible to root rot
- ✓ Invasive plants (*Miscanthus* etc.)



Romano D. The choice of plant species for green roofs and rain gardens in the Mediterranean area

<https://www.greenvillesc.gov/DocumentCenter/View/1249/Rain-Garden-Guide-PDF?bidId=>

https://repository.library.noaa.gov/view/noaa/39801/noaa_39801_DS1.pdf

<https://www.austintexas.gov/sites/default/files/files/Watershed/growgreen/2016LPT/Rainscape-Plant-Selection-Nuffer-Kenzle-1-29-16.pdf>

<https://www.austintexas.gov/department/grow-green/plant-guide>

Planting Design:

for Clayey Zone 1: tolerate inundation,
poor drainage:

- Switchgrass
- Indian grass
- Inland sea oats
- Eastern gamagrass
- Meadow sedge
- Fall obedient plant
- Blue Mistflower
- Frog fruit
- Turk's Cap
- Dwarf palmetto
- Wax myrtle

Fall Obedient Plant



Inland Sea Oats



Blue Mistflower



Planting Design:

Plants for Sandy Zone 1 or Zone 2:
Upland or tolerate inundation with
better drainage:

- Autumn sage
- Big Muhly
- Gulf Muhly
- Maximillian sunflower
- Meadow sedge
- Pigeonberry
- Sideoats Grama
- Yucca sp.
- Turk's Cap



Pigeonberry



Gulf Muhly

Photos: www.wildflower.org, gulfcoastprairielcc.org



Big Muhly



Sideoats Grama

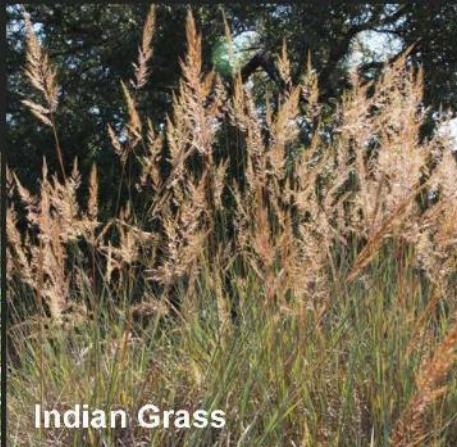


Autumn Sage

Photos: www.wildflower.org



Dwarf palmetto



Indian Grass



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RESEARCH ARTICLE

Check for updates

The influence of vegetation on rain garden hydrological performance

Jia Yuan^a, Nigel Dunnett^b and Virginia Stovin^c

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Three different vegetation treatments were used:

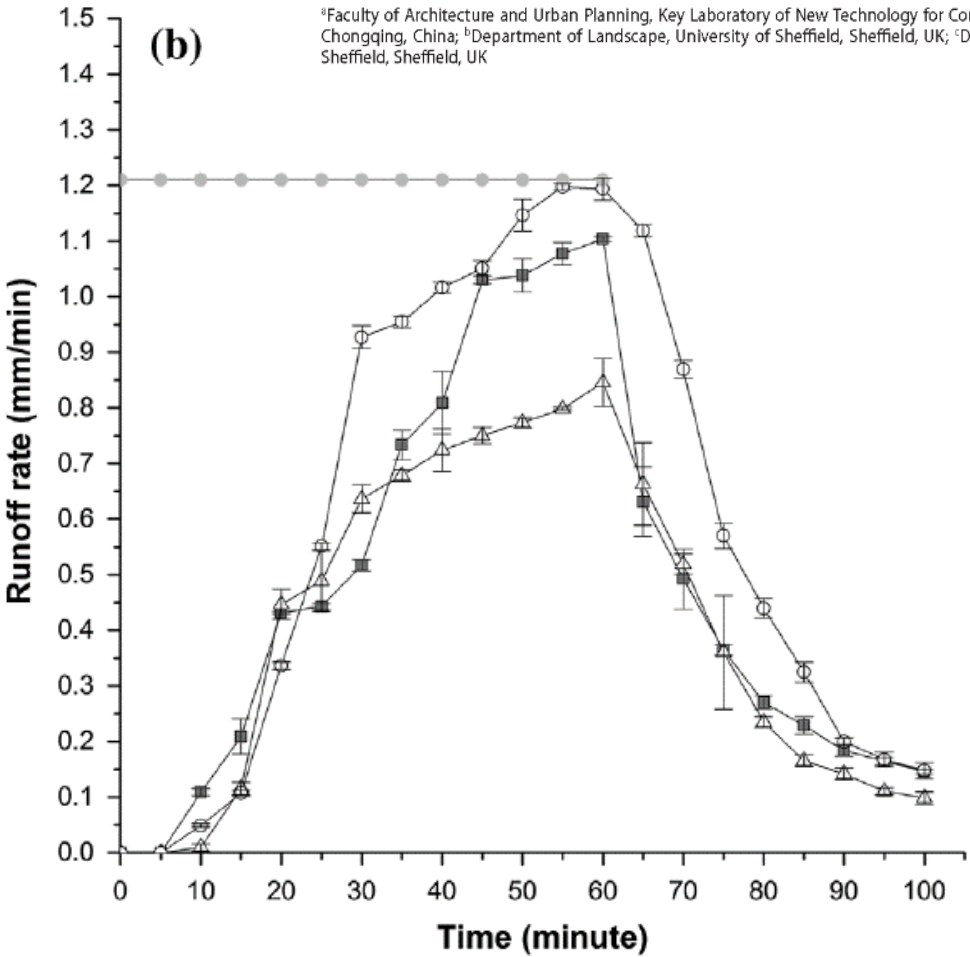
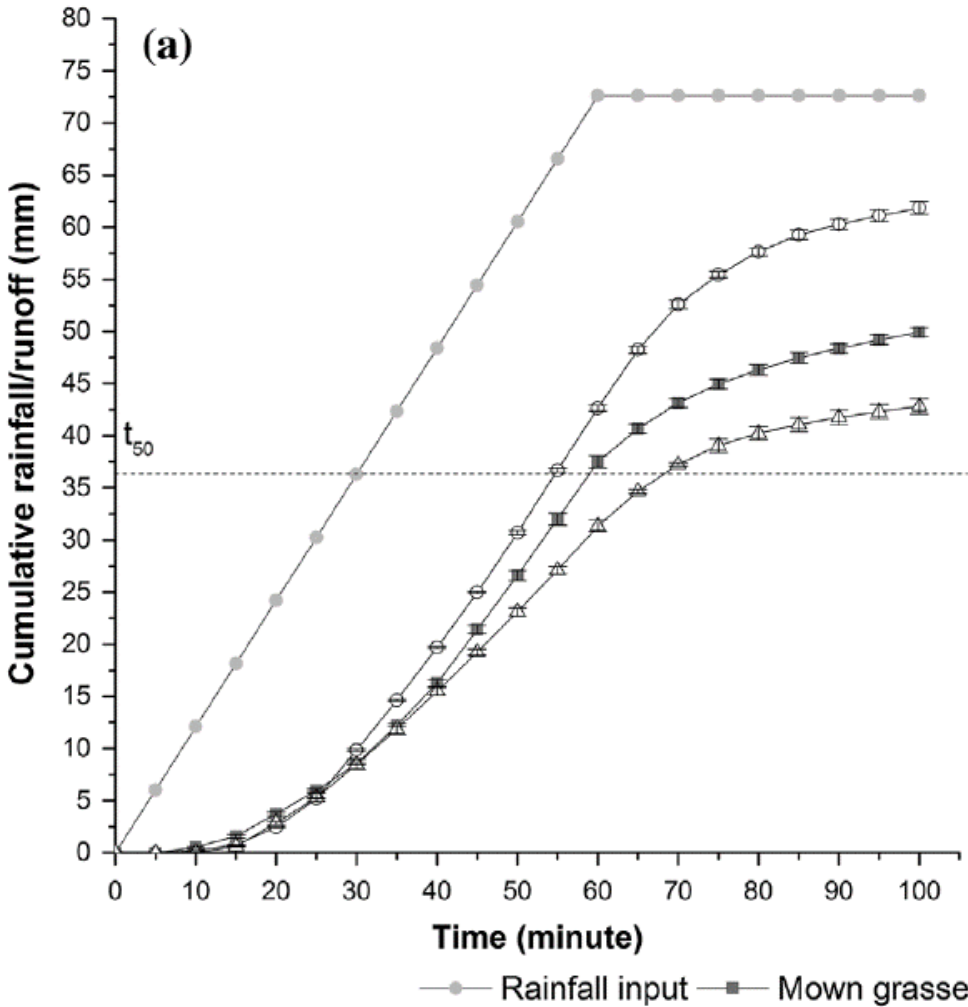
1. mown grasses (**A series**) = commercial mixture of six typical lowland grass species that between them should tolerate the range of soil moisture regimes in a typical rain garden profile: *Agrostis capillaris*, *Alopecurus pratensis*, *Anthoxanthum odoratum*, *Cynosurus cristatus*, *Deschampsia cespitosa* and *Festuca rubra*
2. mixed forb-rich perennials (**B series**): consisted of eight forbs and two grasses: *Amsonia tabernaemontana* var. *salicifolia*, *Astilbe* 'Purple Lance', *Calamagrostis brachytricha*, *Filipendula purpurea*, *Hemerocallis* 'Golden Chimes', *Iris sibirica*, *Molinia caerulea*, *Rudbeckia fulgida* var. *deamii*, *Sanguisorba tenuifolia* 'Purpurea', *Veronicastrum virginicum*
3. non-vegetated control group (**C series**)



The influence of vegetation on rain garden hydrological performance

Jia Yuan^a, Nigel Dunnett^b and Virginia Stovin^c

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Native wetland plants

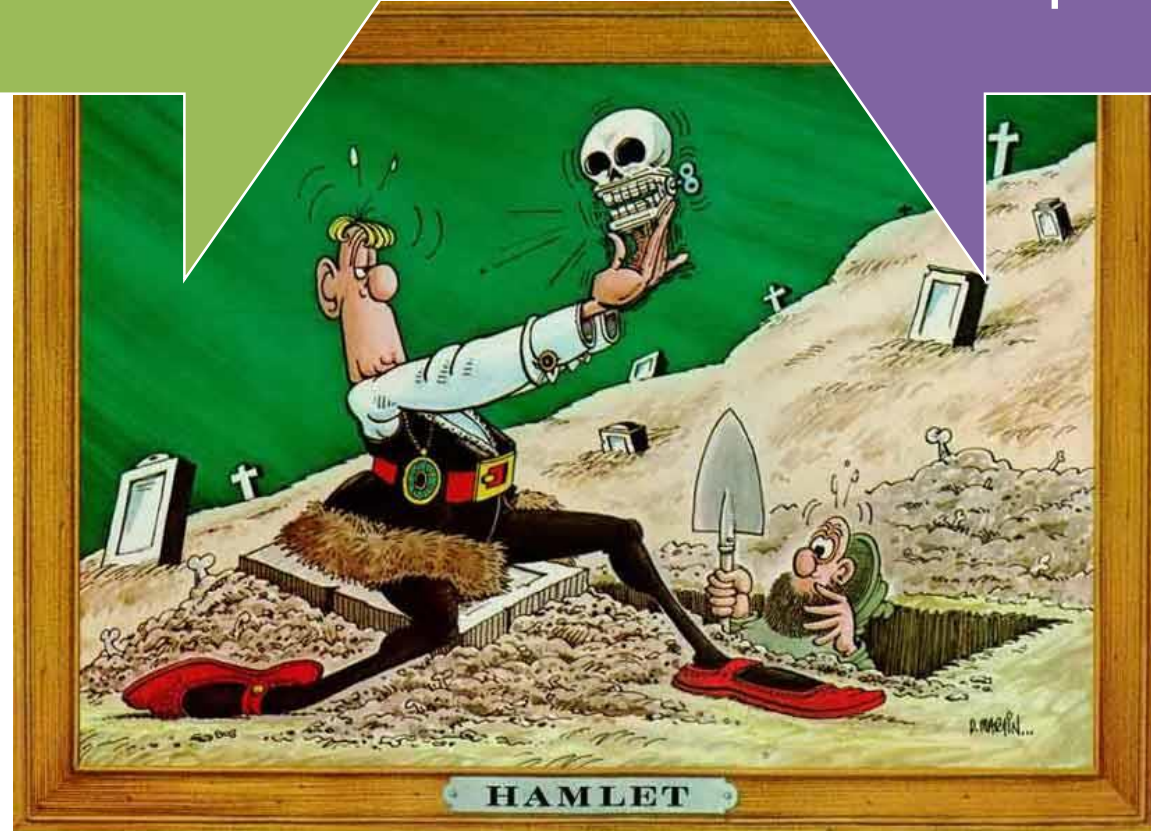
- ✓ Tolerate wet conditions – many also tolerate intermittent drought
- ✓ Accustomed to our climate and soil
- ✓ Typically low maintenance
- ✓ Beautiful selection
- ✓ Caution: some spread vigorously, e.g. *Arundo donax* L.



Native
plant

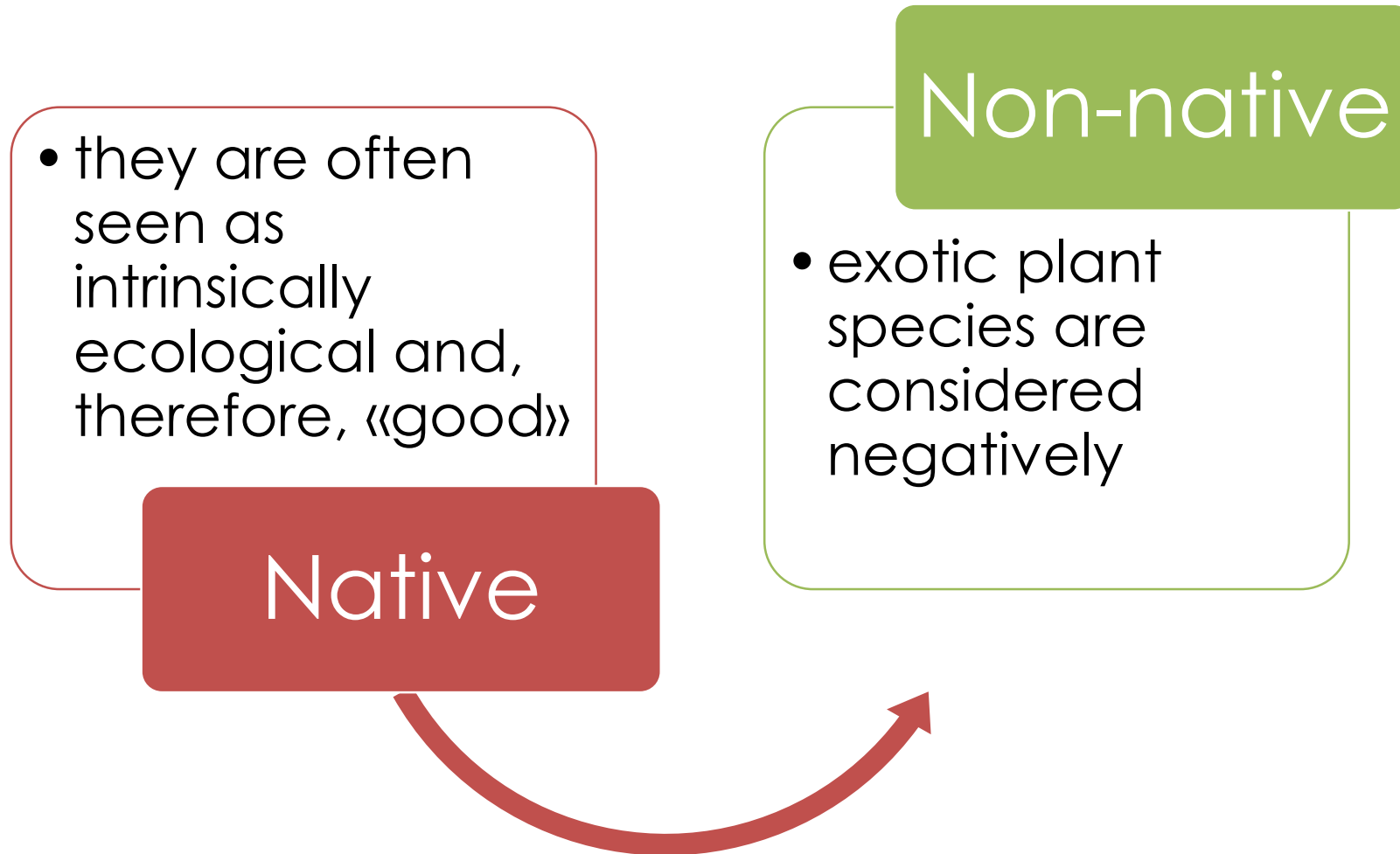
Non-native
plant

The question is
valid for both
green roofs and
rain gardens



HAMLET

There is a frequent statement, generally shared, according to which native plant species are somehow better in a context of biodiversity than exotic ones.

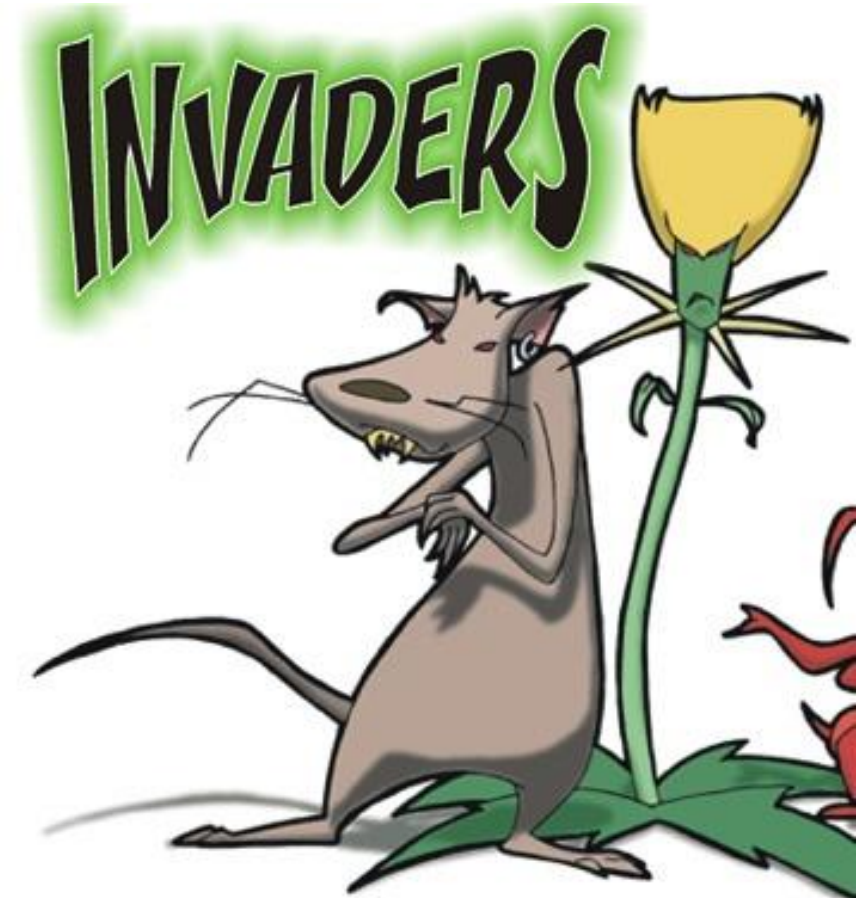


Non-native species are often considered **less adapted to the local climate** and environmental conditions and therefore more in need of care, attention and protection to ensure their survival.

At the same time, **alien species** are often considered highly **invasive, dangerous and too competitive**

The fact that some plants are **invasive** has little to do with their geographical origin, but is, instead, in relation to some of their biological traits, such as:

- ✓ abundant seed production;
- ✓ efficient seed dissemination;
- ✓ low liking of herbivores towards them.





Invasive

Not invasive



Native
plant
species



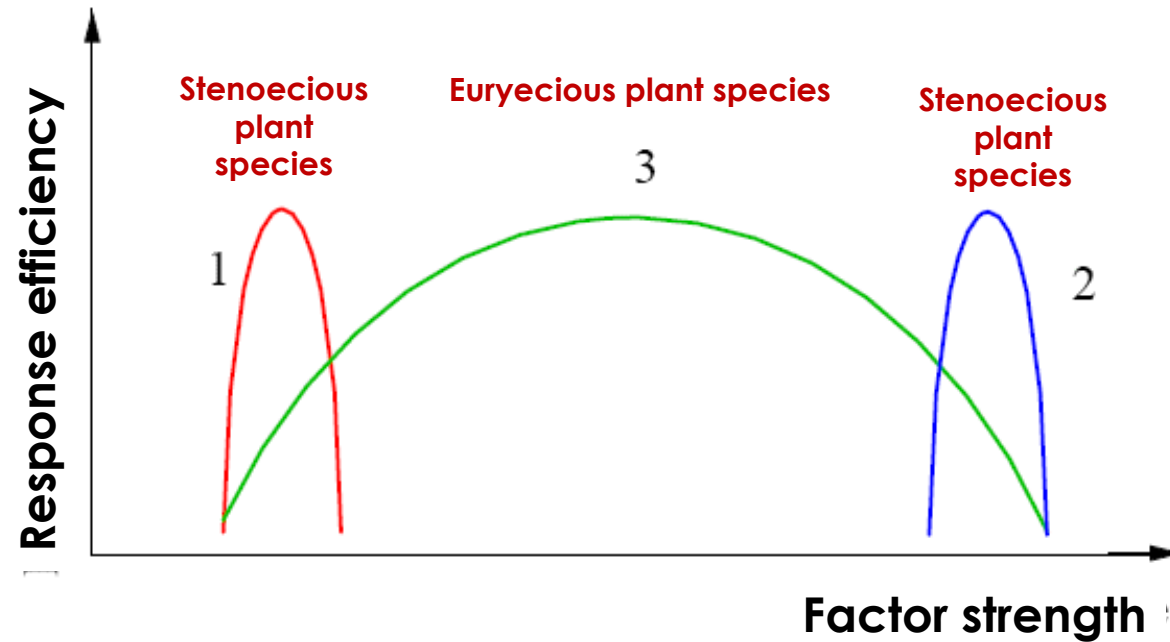
What is the
most functional
choice?



Non-
native
plant
species



Is it good to use stenoecious or euryecious plant species?



Stenoecious: Applied to an organism that can live only in a restricted range of habitats

Euryecious: Applied to an organism that is able to live under variable conditions

Cerastium aetnensis



THANK YOU



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