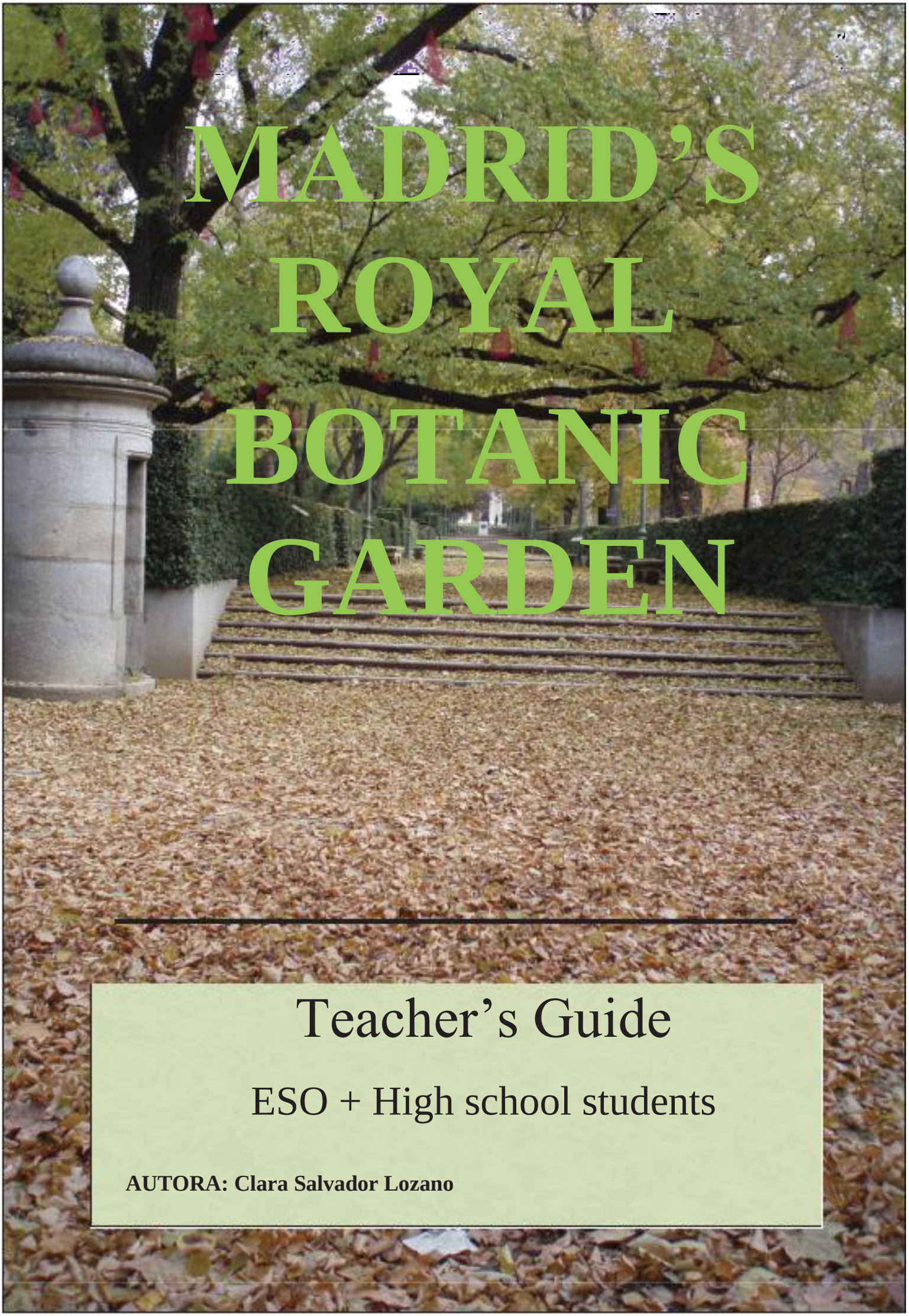


MADRID'S ROYAL BOTANIC GARDEN

Teacher's Guide

ESO + High school students

AUTORA: Clara Salvador Lozano

CONTENTS

1. PRESENTATION

The Royal Botanic Gardens (RBG) of Madrid stand as one of the best resources with which we have in this city in the field of botany didactics. The school students who visit it enjoy an open air master class that let them check with their own eyes all those elements appearing in the books.

The wide collection of plant species from many different parts of the globe helps to knowing on the spot plants adapted to the different climates. By studying them visitors learn the mechanisms they have developed in order to survive under conditions as diverse as those existing in deserts or tropics.

It is also interesting to know a little more about those species that we are used to seeing in the city. Poplars, London planes, elms and cypresses contain loads of curiosities that are waiting to be discovered. Knowing a little more our surroundings arouses both our interest in it and a desire for preservation.

This guide aims to be a tool for teachers so that students can get the most out of the garden visit.

As visits are conducted at different terms during the school year, it may happen that subjects to be dealt during the sessions may have not yet been studied in class. This is why this guide will be useful for students to be introduced to some basic notions before listening to the tutor explanations on the day of the visit.

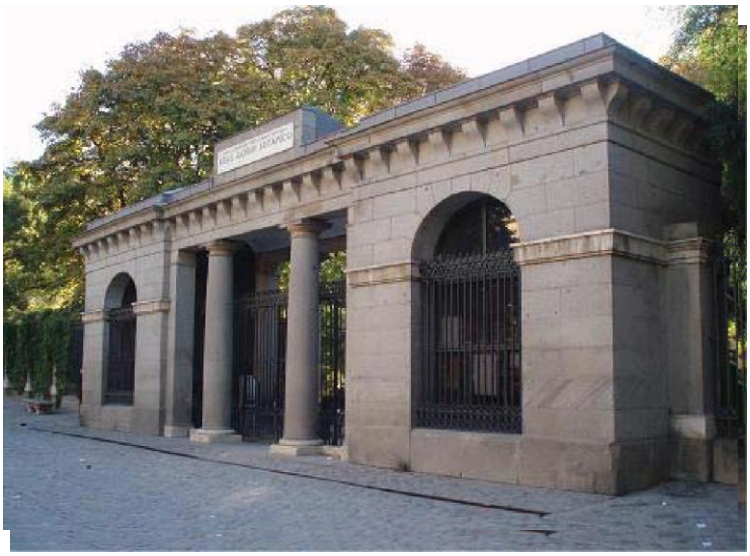
By receiving this guide in advance students will be able to prepare and carry out different activities prior to and after the visit. In order to captivate the highest possible attention on the side of the students these exercises have been designed to be develop within a classroom environment, therefore enriching the visit with assignments that reinforce what has been learned.

This guide is divided in two parts: a first one that includes different aspects of the Botanical Gardens (history, species preserved, stopovers during the visit, etc.), and a second part posing questions for the students.

It is essential that the teacher reminds the class of the rules to follow, so as to avoid interrupting other groups or disturb the rest of the visitors.

2. LOCATION

Madrid's Royal Botanic Gardens is located at Paseo del Prado - more specifically at Plaza de Murillo, nº 2 - in front of the Prado Museum, where the main entrance to the public is situated.



Transport – Cercanías (Madrid railways): Renfe Atocha station (C3, C4, C5, C8 y C10). Underground: Atocha Renfe metro station (lines 1 and 2). Bus lines: 10, 14, 27, 34, 37, 45, 6, 19, 26, 32, 59, 85, 86, C1, C2, 1, 2, 202, 3, 5, 9, 15, 20, 51, 52, 53, 74, 146 and 150.

3. RULES FOR VISITORS

The tour will be guided along the allotted dirt paths, as it is prohibited to step on the yard borders and in the gardens, so as the compacting action of our stepping will not allow seeds to germinate.

No screaming or running. So as to enjoy each and every corner without disturbing anyone around, we will talk and walk on a natural basis – which is really important in closed and covered sites as greenhouses.

Don't bother fauna. Birds (especially pigeons), squirrels, carps and cats share with us the whole space, the garden is their home and we shall not trouble them.

Better mineral water. Water fountains DO NOT deliver potable water.

"Souvenirs". Plants are living beings. So leaves, fruits or flowers may not be pulled out or picked. Neither is it recommended to touch any elements specially those on the floor, for they have been externally fumigated with chemicals.

Watch your hands! Many species are toxic, stinging or thorny. Avoid contact with plants and hands will not be hurt.

4. HISTORICAL CONTEXT

4.1. THE ENLIGHTMENT PERIOD. CHARLES III.

It was during the 18th century, under the reigns of Ferdinand VI and Charles III. Their ministers pushed for promoting cultural and economic level in Spain, which therefore brought about a century of progress in the field of rational knowledge and science development.

The Enlightenment in Spain took place within the parameters of the same movement in Europe. To us reached the influences of France and Italy. The pillars that supported this stream were four: security in science, critical spirit, faith in reason and didactic eagerness.

The bourgeoisie, nobles and clergymen formed the class of the "enlightened", intending to awaken the world from the lethargy in which they had fallen because of superstition, irrationality and traditions. The interest in the sciences was reflected in the creation of the Botanical Gardens and the Natural History Cabinet, along with major Academies such as the Royal Academy of Language, History, the Fine Arts, and Medicine. Man - with his reason, is capable of dominating the world.

The experimental sciences were strongly promoted, and researchers as Mutis and Cavanilles shone in biology.

During this period, the work of King Charles III stood out for being the founder of RBG in its current condition. Next, we will focus on his life and work.

Charles III (1716-1788), great impeller of the sciences. During his reign he came up with the idea to embellish the old Atocha meadows area, to which he ordered building a sort of a "City of Sciences". In this area of the outskirts of Madrid architect **Juan de Villanueva** projected three buildings of clear scientific nature: the Royal Cabinet of Natural History (which today holds the Prado Museum), the Royal Botanical Gardens, and the Royal Astronomical Observatory. Being the latter of great interest for the scientific expeditions of the time, whose journeys by boat required a detailed knowledge of the stars.

The Royal Botanic Gardens as seen from Paseo del Prado. Luis Paret y Alcázar (1790).

This outstanding reform – known as the Prado Hall, turned the place in a wooded area full of gardens, statues and fountains such as Cibeles, Neptune and Apolo, all designed by the great artist Ventura Rodríguez. It was also during this period that brought about the construction of Alcalá Gates and the San Carlos Hospital (which nowadays is the home of the Reina Sofía Museum).

This King, together with the help of his minister, the Marquis de Esquilache, sought to reform Madrid. When he came to the throne he found a city with serious problems of public hygiene. There was no water for all its inhabitants and the streets were full of mud and excrements: it was customary that the home dirt was thrown through the windows accompanied by the phrase "¡agua va!" (Water! Off below!!!). Consequently the smell was nauseating. In addition pigs and cattle were allowed to walk the streets normally. And to top it all, no lampposts lit the streets at night, so a population of thugs grew all over to take advantage of the situation and assaulting their victims.

Thanks to this king, a set of rules was approved:

- Cleaning and cobble stoning streets.
- Garbage recovery and transfer outside the town.
- Prohibition of pigs on public roads.
- Obligation of placing a lantern to illuminate each house.
- Obligation to build sinks or wells to eliminate dirty waters.
- Approval of a sewage system.
- Creation of an urban police that maintained order.

Madrid inhabitants reluctantly accepted these measures, which led King Charles III to allegedly say: (...) "My vassals are like children: they cry when they are washed ".

For all the reforms he made, he is remembered as the best Mayor that Madrid has ever had

Charles III as a child. Jean Ranc (1724).

4.2. ROYAL BOTANIC EXPEDITIONS

During the 18th and 19th centuries, the Spanish Crown financed a series of scientific expeditions to other countries, in order to increase the knowledge of these places and to discover new products for trading. Some of them also sought the scientific development of destination areas. Once they arrived in these colonies, material was collected in different formats (seeds, live plants, herborized plants) and were sent to Spain. The live plants were sent to the Canary Islands and Cadiz, while the seeds went to the Botanical Gardens of Madrid and Aranjuez. The seeds were planted here to "acclimatize" them, thus verifying if they were able to adapt to Madrid's weather. If they succeeded, their medicinal and commercial uses were studied.

An example of this commercial purpose is the **cinnamon weevil**, or *Drimys winteri*, whose possible use as a substitute for Ceylon's cinnamon - monopolized by the Dutch, went up in smoke, as its flavour turned out to be too hot spicy. All the commercial benefits expected from trading the plant ended in nothing.

The RBG retains many of the herbaria, sheets and drawings made during those expeditions.

Several of the most outstanding journeys were the following:

- Expedition to the Orinoco by Pehr Löfling (1754-1756).
- Botanic Expedition to the Virreinato of Peru (1777-1788), that counted on the Spanish botanists Hipólito Ruiz and Jose Pavón.
- Royal Botanic Expedition of the New Kingdom of Granada (1760-1808): led by José Celestino Mutis.
- Royal Botanic Expedition to the Viceroyalty of New Spain (1787-1803).
- Creation of the Royal Company of the Philippines, that counted on Juan de Cuéllar (1785-1795).
- Malaspina Expedition (1789-1794).

Former 2000 pesetas bill, showing the portrait image of Celestino Mutis.

5. BOTANICAL GARDEN

5.1. CONCEPT AND OBJECTIVES

A botanical garden is a place that contains a collection of living plants with a certain biological value, classified and ordered according to a series of scientific criteria, and which seeks to achieve three main **objectives**:

a) Education: The RBG tries to arouse the curiosity of the visitors towards the plants. Therefore, guided tours are organized where an educator transmits to the visitors the passion for the plant kingdom. In addition, the Garden serves as a platform for dissemination of scientific knowledge, whether it is allowing other scientists the use of its facilities and consultation of its materials, or through exchanging research with other botanical gardens. This makes it easier for botanists around the world to have all the knowledge that has been collected throughout history.

b) Research: Both in the past and at present many researchers have been part of the scientific staff of the Garden. A great number of projects, studies and publications attest the work done, which is one of the most important in Spain. The laboratory, the fantastic library and the large documentary fund help to describe and classify new species and to carry out phylogenetic and kinship studies.

c) Preservation: In order to carry out an *ex-situ* preservation work, the Garden harbours seeds and live plants of endangered species in the wild. It seeks to increase the number of specimens through recovery programmes, thus reducing their chances of disappearing, and thus helping to maintain the highest possible degree of plant biodiversity.

We could add a last objective that made more sense in the past: living plants adaptation to climate - specimens brought from other parts of the world were moved to the Garden to find out if they could adapt to Madrid's climate. Once achieved, it was time to look for potential pharmacological and commercial uses.

5.2 MATERIAL

a) Collection of live plants: Madrid's RBG holds a collection of 5,500 live plant species, amongst which 1,500 are trees. Some 100 of them are bonsai.

Within the garden 17 trees are preserved special, because they some of their features make them stand out from the others, either because of its large wingspan, its height, its trunk diameter or its age. Seven of them have been catalogued as Singular Trees by Madrid's Regional Administration.

b) Herbarium: It is the most important herbarium in Spain, with more than 1 million samples of dried plants (called sheets), mostly arrived with the scientific expeditions of the Spanish Crown to other countries.

It is consulted by botanists from all over the world.

c) Germplasm bank: it has a collection of seeds stored in a cold room where low temperatures, low humidity levels, and tightness of the flasks that contain the seeds maintain their germinative capacity for a long time. Numerous exchanges with other countries' botanical gardens are made through this Germplasm bank.

d) Drawings: the RBG houses a vast amount of materials elaborated during botanic expeditions, shaping a 16,000 stamps and drawings collections.

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Sheet drawn during the Royal Botanic Expedition to the New Kingdom of Granada

5.3. DISTRIBUTION IN TERRACES AND REMARKABLE SPOTS

The inclination of the land on which the Garden sits forced the architects to make a design in terraces, which facilitated the cultivation of species while avoiding the loss of soil by drag after water irrigation. The terrain can thus be subdivided into four major areas which are explained below:

Terraza de los Cuadros or Framed Terrace: its name is due to the square shape that gardens have while situated beside water fountains that in former times use to irrigate the grounds. Here the plants are arranged according to their use: ornamental (ancient roses), aromatic, medicinal and endemic (the orchard and fruit trees). The background is covered by rockery, where plants specially adapted to these conditions grow beautifully.

Terrace of the Botanical Schools: here plants are arranged according to their kinship and phylogeny, grouped by families, from the most primitive to the most evolved. In this way, visitors may enjoy historically from Bryophytes and Pteridophytes to Spermatophytes (Gymnosperms and Angiosperms).

Terrace or Flower Plane: in this terrace the plants are not ordered according to any criteria. They are only arranged to imitating an 18th century romantic garden, where beautiful views and a labyrinthine hedge await the visitors. A central gazebo was built within, showing a bust of Carl von Linnaeus, and beside the site known as Villanueva Pavilion.

Terraza Alta or Laurel Terrace: It was inaugurated in 2002 and contains an important collection of bonsai donated by former Prime Minister Felipe González.

Within these terraces some remarkable sites can be found and should be worth to visit:

Greenhouses: Formerly called "stoves" since they were heated by means of these artefacts located in the centre of the facility. The stoves were meant to heat the pipes with the water that later circulated throughout the room.

- Hot stove or Greenhouse "Santiago Castroviejo Bolívar": Named after one of the directors the Garden had, it holds three rooms in which the desert, subtropical and tropical climates are represented. The heat in the rooms is controlled by a computer system that regulates temperature and humidity by means of sensors, and which also controls the sprinklers when a high degree of humidity must be maintained. Furthermore, solar panels heat the water that runs through the greenhouse, which is extracted from an underground stream that is visible through gratings in the ground.

- Las Palmas Cold Stove (also known as Graells Cold Stove): It was built in the XIX century and contains a collection of tropical plants, aquatic ferns, ferns and mosses, surrounding a pond swum by carps. Here there is no computer system that controls temperature. There is a slightly higher temperature inside due to the glazed structure of the walls and the floor that is built below the ground level. The floor of the stove has a series of gratings that used to warm the room in a natural way: by bringing in manure, heat was evicted as it decomposed.

Officers had to stop the practice so as bringing manure was such a hard burden to carry out, and of course, because the smell did not make it very pleasant to stay in the place.

Images of the greenhouse and one of the grids placed on the floor.

Villanueva Pavilion: Originally a greenhouse, the architect who designed it - Juan de Villanueva, had no notions of botany and did a poor job orienting the light. To avoid plants from dying, every day they had to be taken out in trolleys to be exposed in the sun and then back in. Since it was such a tedious task, the greenhouse stopped being used as such, to later housing classrooms for Botany classes. At present, it is used as Exhibition Hall.

Research Building: It is located next to Cuesta de Moyano Gate. Its herbarium counts on more than 1 million plants (herborized plants), coming for the most part from the expeditions to South America in the 18th and 19th centuries. It holds also a Germplasm bank (of seeds) stored under adequate conditions to maintain its germination capacity over time. A library and a storage archive complete the set. All the materials generated by the Garden, as well as those brought by scientists from expeditions to the New World (books, drawings...) are under custody here. Special mention deserves 7 thousand plates which were donated by José Celestino Mutis, physician and naturalist from Cadiz and head of the Royal Botanic Expedition to the New Kingdom of Granada.

Puerta de Murillo (or Murillo Gate) is the entrance to the Garden and the location for the ticket offices. It is situated beside the Prado Museum.

Charles III Line ends up at King's Gate. It is divided into three parts: the central one (larger) was reserved for the King, while the other two was to be used by his entourage and the visitors of the Garden. Once a month those doors were opened to facilitate medicinal plants for free to Madrilenians who requested them. The trail also is embellished with a statue of founding King Charles III.

The Royal Botanic Garden's Gate. Francisco Sabatini (1780).

The Statues Walkway: At the bottom of the Terrace of the Schools four statues of illustrious Spanish botanists stand still: Joseph Quer and Martínez (1695-1764), Antonio Jose Cavanilles y Palop (1745-1804), Mariano Lagasca (1776-1839) and Simón Rojas Clemente y Rubio (1777-1827).

5.4. HISTORY OF THE GARDEN

The most important events surrounding the history of the Gardens are listed below:

October 17th 1755. King Ferdinand VI orders the creation of a Royal Botanic Garden near the area known today as Puerta de Hierro. The grove of Migas Calientes came to house a collection of more than 2000 plants brought together by botanist and surgeon José Quer from all over the Iberian Peninsula and areas of Europe.

1774. Charles III decides to move the Garden to the old Atocha meadows area as part of the plan to embellish the Paseo del Prado. He meant to create the City of Sciences - projecting three buildings of clear scientific nature: the Royal Cabinet of Natural History (which today holds the Prado Museum), the Royal Botanical Gardens, and the Royal Astronomical Observatory

1776. The Project is allotted to Royal Architect Francisco Sabatini who divides the grounds in three terrace areas to solve the problems derived from the loss of soil and water - due to the inclination of the ground. The King's Gate is built by the time too.

1779. First specimens are moved from Migas Calientes.

1780. The architect Juan de Villanueva assumes responsibility for the works and simplifies the design giving greater clarity and encompassing the ideas of Casimiro Gómez Ortega (the first university professor who advised the Garden). The idea was to come up with a design closer to the scientific and pedagogical character to be given to the Garden.

1781. The Royal Botanic Garden is inaugurated at its final location.

1801. Cavanilles is appointed director of the Gardens.

1808. War of Independence. A great deal of the work done by botanists is destroyed, although some of the important things like herbaria, drawings and library documents were preserved.

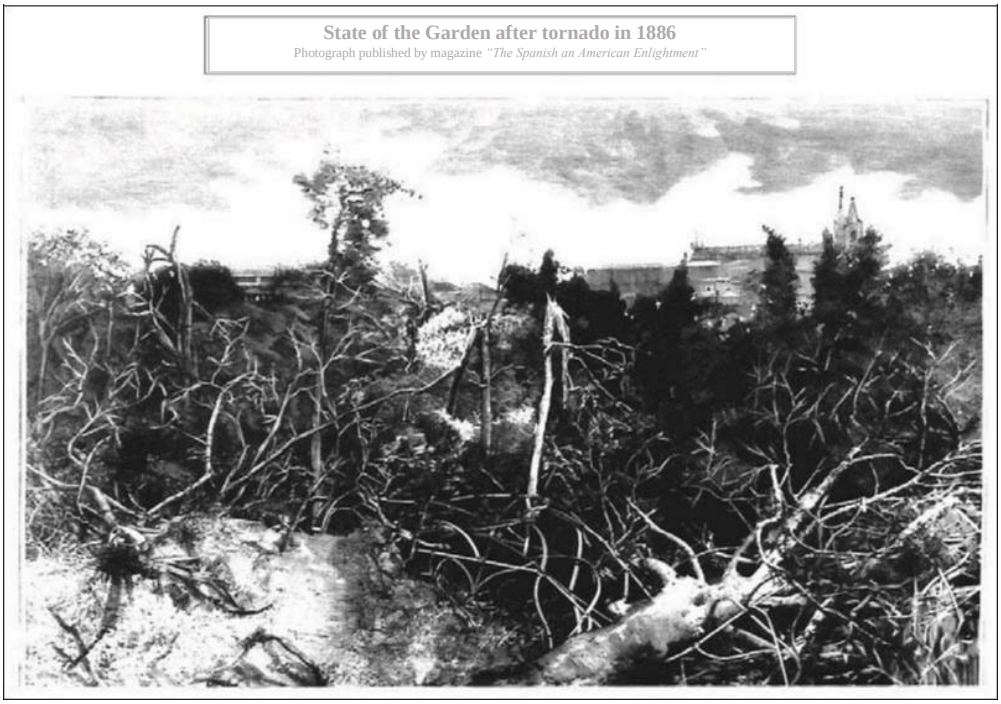
1814-1823. Mariano Lagasca takes the direction of the Gardens for a short time, for he is exiled to England and does not come back until 1835. During the period, the Gardens suffer great deterioration, which turn some facilities into ruins.

1851. Mariano de la Paz Graells is appointed director, holding office at the management of the Prado Museum too. He is responsible for building the Las Palmas Stove (also known as the Graells Stove). He also decides to install a zoo at the lower terrace. But the zoo was removed early as the animals did make serious damages to the plants and

trees. The animals were moved to the zoo facilities (the House of Beasts) at the Retiro Park.

1882. One fifth of the Gardens terrains are granted to the government to build the building that hosts today the Ministry of Agriculture.

1886. A tornado strikes the Botanic Garden and the Retiro Park, with a result of 560 trees pulled out by the roots.



State of the Garden after tornado in 1886
Photograph published by magazine *"The Spanish an American Enlightment"*

1893. 270 trees and part of the rockery is lost to open the so called Cuesta de Moyano – the old book market street.

1939. After the Civil War, the Central Scientific Research Institute takes responsibility for managing the Garden.

1942. The site is declared Artistic Historical Garden, which allocates state money for preservation.

1974-1981. Decadence takes over again and the Gardens are closed for visitors for reconditioning.

1981. The Gardens are re-inaugurated by the Spanish monarchs on the bicentennial of Migas Calientes Garden dismantlement.

1993. Exhibition greenhouses are opened for visitors.

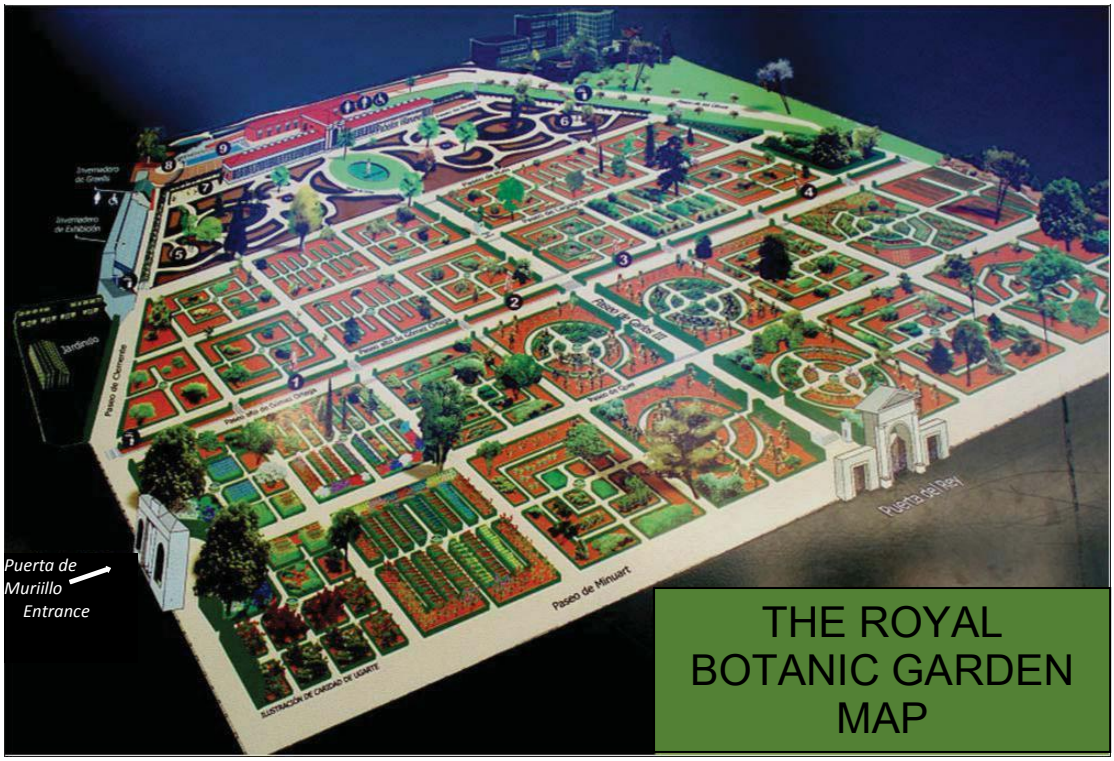
1996. Former Prime Minister Felipe González donates part of his bonsai collection. The specimens donated are installed at the Laurel Terrace, which was ready for exhibition in 2002.

6. VISITING THE GARDENS

6.1. LEARNING OBJECTIVES

- To reinforce and fix concepts studied in class through an open-air master class. Comprehensive understanding is easier if concepts are studied au naturel.
- Also it is important to learn how to behave in public, practicing good manners and keeping silence.
- To enhance interest on plants through a process of learning curiosities about them. To learn an issue means learning to respect it.
- Foster problem solving through deductive training.

6.2. SITE MAP



6.3. STOPS AND CONTENTS

(N.B.: the number and order of the stops, as well as the content to study, may vary depending on the weather and on the number of visitors).

STOP 1: Entrance through the Murillo Gate: Presentation. The trainer welcomes the students group, introduces him/herself and makes a brief count of the rules to be observed during the visit. Everyone participates on deducting what is a botanic garden and what is its purpose. Comparisons are made with the Retiro Park: Which are the differences? The entrance panel explains the organization of the terraced garden and how the plants are organized in each one of them. The buildings within the garden are identified thoroughly. Finally, visitors are briefly explained which areas will be visited.

CONTENTS: BOTANY. TYPES OF PLANTS

Botany is the scientific study of plants and botanists are researchers of this type of living beings.

A plant is a photosynthetic autotrophic organism, capable of producing its own nutrients through transforming inorganic matter (water, CO^2 and mineral salts) into organic matter (sugars) with the invaluable aid of sunlight. This process is known as photosynthesis, and produces on the leaves of the plant the matter known as elaborated sap, the nutrient that will circulate the rest of the tree (in the case of cactus, sap is elaborated in the stem). For this process to happen, it is essential to count on an element called chlorophyll, a pigment present in all green plants and in cyanobacteria, which is also responsible for the green colour of their leaves. Simultaneously, plants take water and mineral salts from the soil to produce raw sap.

Types of plants according to evolution (the most primitive first and the most evolved last).

- Green algae
- Bryophytes (Mosses).
- Pteridophytes (Ferns).
- Spermatophytes (seed plants):
    - Gymnosperms (gimnos-, naked, -sperma, seed): with no true flowers to produce true fruits to protect the seed, e.g. all the conifers like pine trees, cedars, etc.
    - Angiosperms (angio-, enclosure, -sperma, seed), grow true flowers that produce fruits to protect the seed, e.g. fruit trees like apple trees or orange trees.

STOP 2: Uses of plants. Terraza de los Cuadros, where plants are classified according to the uses given to them: ornamental, medicinal, cosmetic, edible, etc.

CONTENTS: USES OF PLANTS

Sharing environment with plants has led to human beings evolve and live a life linked to plants. Humans have used them since ancient times to make their lives easier, especially for the following processes:

-**Edible plants:** humans consume plants on a daily basis, as well as many of the animals that provide us with food. Amongst them: vegetables (lettuces, tomatoes, legumes), fruits (peaches, watermelons, hazelnuts), cereals (corn, millet, wheat), etc.

-**Aromatic plants:** plants whose essences serve to flavour our foods (rosemary, thyme, sage, oregano, peppermint), or to make natural flavourings (lemon lime, lemon verbena).

-**Plants for making beverages:** coffee (*Coffea arabica*), tea (tilo), infusions (Mint), mate (*Ilex paraguaiensis*), tequila (*Agave tequilana*), etc.

-**Plants for cosmetic use**, such as rose water, aloe vera cream, almond oil, lavender cologne, etc.

-**Ornamental plants:** plants whose colourful flowers embellish our homes or are present on special occasions: roses, dahlias, daffodils, tulips.

-**Medicinal plants**: a real help as antitumor treatment (yolk taxol), analgesics (willow salicin), purgatives (castor oil), anti-pain for muscles (rosemary spirit), and anti-sore throats (pomegranate, grenadine).

-**Plants for obtaining raw materials:** energy sources (firewood, coal, jojoba oil as biodiesel), production of vegetable fibres (pita, flax, wicker, esparto), construction scaffolds (bamboo), tire production (latex, rubber), glue (resin), dyes (walnut, pomegranate).

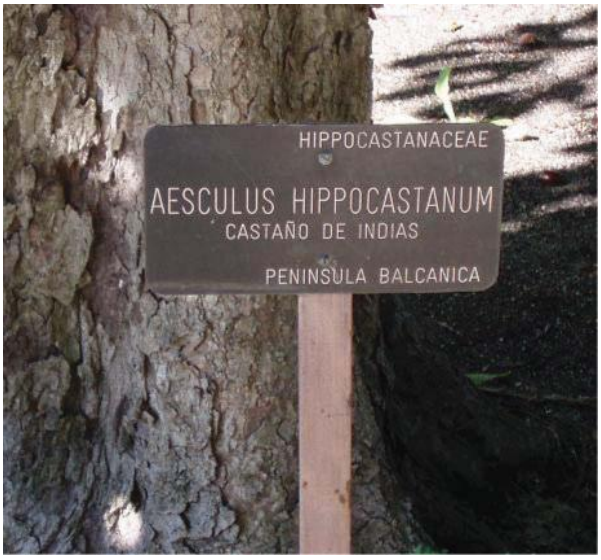
STOP 3: Plant taxonomy. Visitors gathered around the horse chestnut, to learn that the identifying sign located in front of them is useful to remember the difference between common names and scientific names. Explanations are given on who was Carl Linneo and why his binomial classification was so important for the scientific world.

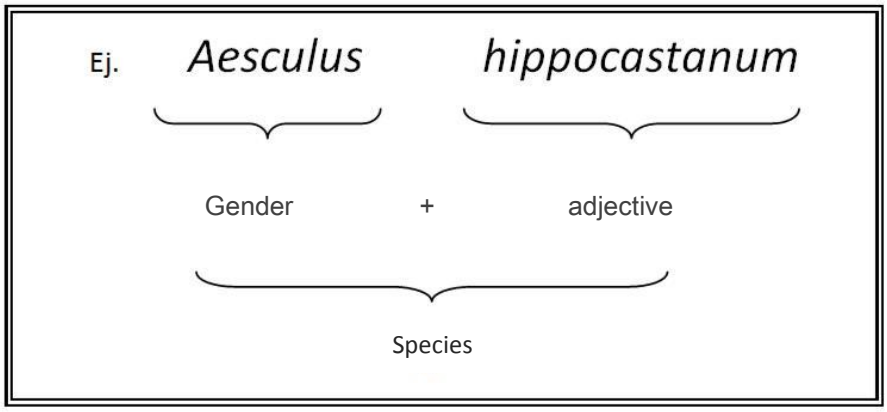
CONTENTS: BINOMIAL NOMENCLATURE

Taxonomy is the science of naming, describing and classifying organisms. It is indispensable in areas such as Botany and Zoology, where the absolutely huge amount of species request a system to put some kind of order to handle them. It has been established that modern Taxonomy starts with Linnaeus and his works *Species plantarum*, where he classified all known species at that time. He is known as "the father of taxonomy".

Carl Linnaeus or **Carl von Linné** was a Swedish botanist and physician living during the 18th century. In 1731 formalized the modern binomial system of naming and classifying organisms.

This binomial system consists on supplementing each living organism with two names ("binomials") written in Latin: the **generic name** in the first place, followed by a specific epithet, combination which could serve as a label to refer to the **species**. They must be always written in italics or, in case the names are underlined, then italics is not needed. Usually, the adjective refers to one or some of the plant properties, characteristics or use (e.g. "*pseudoplatanus*" refers to a leave whose shape is similar to a Platanus tree, but is not one of them; "*aquifolium*" denotes the high water content in the leaves, etc.). Besides, the signs show the **family** to which each plant belongs to in the upper part (written also in Latin and using the ending *–eae*). The lower part of each sign shows the plant's natural origin and distribution (the region where it grows and used to grow without before human intervention). The use of scientific names solved the problem of using common or vulgar names, which varied from one region or country to another, thus generating great confusion. The oak tree is one of these examples; in Spain it is given many different names: *alzina, chaparro, chaparra, carrasca, charrasco, marrasca, sardón,* etc. The scientific name given by the binomial nomenclature is the same to all the world, and therefore problems and confusions are avoided this way





In the past, classifications were based on scaling according to plants sexual structures, but at present genetic criteria are widely prevailing.

The taxonomic ranks most frequently used are the following:

- **Family:** major group of plants that hold some similarities amongst them.
- **Genus:** A division of the previous category. It is a subset of organisms that although they share similar features with the rest of the family members, they present differences that are their own.
- **Species:** A group of organisms having common characteristics and capable of mating with one another to produce fertile offspring.

STOP 4: Type of leaves (evergreen, deciduous and marcescent leaves) Red oak. Few times we take into account that besides the leaves that fall in autumn and those that remain green in the trees all year long, there are others that even dry remain attached to the branches. They are called marcescent. The gills that normally grow in this type of specimens have had an important use during ages thanks to their tannins compounds.

CONTENTS: TYPE OF LEAVES ACCORDING TO THEIR DECIDIOUS CONDITION

- **Deciduous leave**: those that live in cold winters areas. When summer is gone, chlorophyll is taken away from the leave and is kept safe in the stem of the tree, in this way giving the red, brown or yellow colours that feature in autumn. At the same time, the tree enters an energy reduction period, remaining like asleep until spring comes again. Examples of these kind of trees are: chestnut, platanus tree, elm, poplar.

- **Evergreen**: All gymnosperms and all specimens living under warm weather and Mediterranean climates hold this type of leaves. Leaf renewal occur very slowly, so that there is always stock on the tree top. Examples: pine, cedar, oak, cypress.

- **Marcescent leaves:** a type of leaf that dries up in autumn but, instead of falling, remains at the top of the tree until spring, when the new sprouts appear, i.e. oak trees.

STOP 5: Uses of river forests: birch trees. The birch tree is a fundamental component of woods crossed by rivers, due to adaptation to humid climate. These woods hold an utmost importance for wild fauna and domestic animals. It also performs a great job regulating the floods, filtrating the water, preventing soil erosion around the riversides, etc. During this stop visitors will discover the interesting use given to the *ritidoma* produced in the birch trees' bark.

STOP 6: The pomegranate: kinds of seed dispersal. Visitors will deal with the different dispersing agents that contribute to transport the seed away from the parent plant (water, animals, wind, o the plant itself). An example of each agent will be shown.

CONTENTS: PLANT REPRODUCTION

Plant reproduction may occur in three different ways, that can combine amongst themselves and whose procedures are:

- **Asexual reproduction**: by releasing spores.
- **Sexual reproduction**: produces offspring by the fusion of two sexual cells called gametes, resulting in a zygote that will produce a new individual.
- **Vegetative reproduction**: involves a vegetative piece of the original plant which is fractioned or broken from the main individual, like in the case of garlics, potatoes, and strawberry plants.

As for dispersion of genetic material, two types may be reported:

- Spore dispersal: spores are structure that carry genetic material, as a result of a cycle of asexual process. Spores form part of the life cycles of algae, mosses and ferns.
- Seed dispersal: a seed is an embryo covered by vital substances, e.g. it has a protective structure resulting from a sexual reproductive activity. It only occurs to spermatophytes (gymnosperms and angiosperms). For a flower to produce offspring seed, a fertilization process (the fusion of a female gamete – ovum, and a male gamete – pollen grain) shall take place.

Types of dispersal depending on the agent:

- **Anemochory:** it involves the wind to transport the seed. These types of seed count on some kind of feather type structure to float on the breeze and travel quite a long distance away from the main plant. The dandelion hair is an example of this process.
- **Hydrochory:** Seed dispersal through water, e.g. coconuts.
- **Zoochory**: Animals can disperse plant seeds in several ways from one area to another:
    - Endozoochory, a process in which the plant produces an edible fruit for the animal, who feeds on it introducing the seed into its digestive track. The seed has an external hard cover which only degrades in contact with stomach acids.
    - Exozoochory, the seed travels on the animal, whether segregating sticky substances to adhering to its skin, or developing anchoring structures like hooks or stings (i.e. "spiny cocklebur").

-**Autochory**: Autochorous plants disperse their seed without any help from an external vector, (i.e. castor-oil-plant).

STOP 7: Plants defence: The trifoliate orange. Its branches are populated with thorns, which explains how plants develop defensive mechanisms against animals.

CONTETS: PLANTS DEFENCE MECHANISMS (I)

-**Thorns:** on branches and stem (acacia), on branches (trifoliate orange), on leaves (Christmas holly), on the stem (cactus), on the fruits skin (chestnut burrs).

-**Toxins:** poisonous leaves and other parts prevent animals to feed from the plant. For instance, taxine (English yew), oleandrin y neandrin (oleander), ricin (castor beans oil), helleborine (hellebore), solanine (nightshade: tomatoes, potatoes), tannins (on oak gallas), hyoscine (*Datura arborea*).

STOP 8: Plant diseases: fungi. Placed under a honeyberry tree, with its stem mostly hollow, visitors are invited to think over why a tree has suffered such an attack. Finally the truth comes to light: Xylophagous fungi. Fungi will be analysed briefly, including its reproductive habits.

STOP 9: Protected species in Madrid's region: Christmas holly. Madrid hosts trees protected by law, due to the low number of individuals existing. Visitors are reminded that disturbing nature, neither fauna nor flora, is negative for everyone, because a day could come when nature might disappear. A curiosity in this species gives rise to deal with how plants communicate amongst them (ethylene in acacia, chemical substances in Christmas holly). At the sight of a female Christmas holly

visitors discover that there is a difference between monoicous plants and dioicous plants. Their thorny leaves put herbivore fauna on the run to prevent possible damages to their palates.

CONTENTS: MONOICOUS AND DIOICOUS ESPECIES

- **Monoicous species:** those plants producing male and female flowers (i.e. tulips). Some species within this type produce mechanisms to prevent self-fertilizing.
- **Diocous species:** Different plants of the same species hold different sexes (there are male plants and female plants) as in the case of Christmas hollies.

STOP 10: Nature is wise: energy saving by male Christmas hollies. Visitors learn that plants are very wise and try not to spoil their resources. Male Christmas holly does not show thorns on leaves growing at a given height…. Interesting, isn't it?

STOP 11: Vegetation adapted to Mediterranean climate: holm oaks and gum rockroses. At the sight of one of them visitors acquire the keys to survive during the usual summer draughts. Leaves have a lot to do with the process; they are hard, coriaceous, leaning sideways towards the the sun, closing stomata in the heat of the day… Advanced engineering!!

CONTENTS: ADAPTING TO MEDITERRANEAN CLIMATE

The Mediterranean climate is usually characterized by dry hot summers, and mild winters, with rainy springs and autumns.

Plants living in the areas affected by these conditions are commonly adapted to summer draughts and to recurrent woods fires. Therefore, they have developed heavy equipment to fight against these adverse situations:

- Some of them coat themselves with inflammable substances that captivate fire. Resin or laudanum burn very easily. Plants are so well adapted to fire that they need this kind of substances to produce new offspring. Pinecones need a strong heat strike to open up, and nutritious ashes after the fire make up the perfect fertilizer for rockroses to germinate.
- Some move their leaves sideways against the sun, which contributes to avoid overexposure to sunlight, and therefore, to prevent overheating and an excess of evapotranspiration. Thus, plants water loss is reduced during summer.
- Leaves with a hairy back side retain water against evaporation, thus reducing transpiration.
- Oils and waxes coat leaves building a waterproof layer to prevent evapotranspiration and water losses.
- Smaller leaves that provide a reduced exposition surface, a smaller number of stoma and thus less evapotranspiration and water loss.
- Evergreen leaves to travel summer and winter, avoiding energy waste to producing new leaves.
- Allelopathic chemicals to avoid competition with other species around in the fight to gather resources.

STOP 12: Medicinal use of plants: willows and aspirin. Aspirin is one of the most popular medicines used in the world, and this is largely due to willows. The bark of this species has been used since ancient times as analgesic. Visitors will hear about how humans evolved from salicin to acetylsalicylic acid.

STOP 13: Plant species in Madrid region: arbutus. Madrid's coat of arms shows a bear (male or female?) supported on a berry tree (arbutus) fruited. Visitors are reminded how dangerous it is to eat tree fruits in the cities, polluted with chemicals after fumigation. Also everyone is warned that nothing in the Botanic Garden must be collected for consumption. Gum rockrose, pine tree, holm oak, amongst other species well adapted to Mediterranean climate, draught and fires can be visited there.

STOP 14: ¿Cure or poison? All depends on the doses. The taxus. One on the most toxic species – which can provoke a heart attack, can at the same time be the most beneficial on humans due to their active ingredients. Many of our health problems find a cure on plants ¿shouldn't it be silly to deforest Amazonia without studying the existing plants there?

STOP 15: Sideway and statue of Charles III and Puerta del Rey. When arriving upon this area, visitors will be reminded of who was responsible for the creation of the Garden and when. ¿What was the relation between the RBG and the Natural History Cabinet and the Astronomical Observatory? Once introduced into the context, the Enlightment in Spain will be reviewed. Remarks will be done on the Villanueva Pavilion and what it has been used for during history.

STOP 16: La Rosaleda (the rose garden): wild roses and cultivated roses. The collection was created by donation of Mrs Blanca Urquijo of some old shrubs, which were used to obtain the modern cultivars. The tour guides will comment on curiosities like which is the fruit of the rose bushes, and the number of petals of the flowers (always a multiple of 5 for hybrid roses).

STOP 17: Aromatic herbs area: draught tolerance. The touch and smell senses will guide to visitors to appreciate the essences contained in aromatic herbs: rosemary, lavender, lemon verbena, sage, mint, etc. Visitors will share the memories brought about by the essences, the main uses of this type of plants, and what are the benefits for the Mediterranean climate plants to count on the essential oils that cover their leaves.

Comments will be done about pollination, about the importance of bees and their decline nowadays because of the general use of pesticides.

CONTENTS: POLLINATION

Bees are frequently found in aromatic plants areas. They visit each and every flower searching for nectar and pollen, thus carrying out - without a sense of what they do, the pollination process.

Pollination occurs in both gymnosperms and angiosperms. In the first case, they lack true flowers, stamens, stigmas and ovaries (but they do have pollen and eggs); and they are not very attractive because they have no nectar, petals or odours. So it is the air which turns to be the pollinating agent. In the second case, it is usually animals (insects, birds) who pollinate their flashy colourful flowers full of odours. In some cases the plant has become so specialized on the animal that visits them that only he will be allowed to pollinate them. What would happen if the insect or bird disappeared?

Nectar guides will be presented - visual patrons that certain flowers deploy to guide insects towards themselves and their nectar. UV light is needed to visualize many of them (patterns).

Some plants are capable of self-pollination to ensure the production of seed, but most of the specimens try to avoid this process in search of genetic exchanges that might enrich biodiversity, which is the key to be strong to face environmental changes.

Dahlia visited by a bumblebee

STOP 18: Dendrology. This time visitors will have the opportunity to visualise the growth rings of an oak tree cut down vertically, which show what age is the tree. Every tree produces two rings a year: a darker and narrower one in winter, and a lighter and wider one in summer. Wide rings also tell us when the tree grew more due to good environmental conditions, and on the opposite side, which stages where hard years to produce narrower rings.

STOP 19: Vegetable gardens: the origin of the vegetables we eat. A walk around the vegetable garden allows the visitor to appreciate how the fruits to be found at supermarkets grow. How does a pea look like in its sheath? How does the plant that produces the cotton that heals our wounds look like? How many varieties of squash are there? Is the nut a dried fruit? All these are issues that will be solved there. The tour guides will also cover the topic of why there is loss of local varieties due to the current interest of the markets to produce only a few of them. Is it positive or not to find only red apples?

STOP 20: Palm trees, an example of herbaceous plants. Types of palm trees: date and coconut palm trees. Visitors will learn to make a difference between trees, bushes and herbaceous plants. ¿Still thinking that palm trees are tress?

CONTENTS: DIFFERENCES BETWEEN TREES, BUSHES AND HERBS

Plants can be classified into three categories according to the type of growth their stems develop:

- Herbs: stems undergo just a primary growth - in other words, they grow in length. The stem gradually becomes longer, while keeping the same thickness. Stems are usually flexible, green and short sized. But there are exceptions: palm trees and bamboo.
- Bushes: Stems display both primary and secondary growth as regards thickness. The main differences with trees is that bushes feature various branch-like stems that grow from the base of the plant. The size of bushes is usually short, but this feature is not determining, for there are old-age bushes that are much taller than many trees.
- Trees: their growth is primary and secondary. In other words, the stem is gradually longer and thicker. In these cases, stems are called trunks. The thicker the trunk, the taller the plant can be, for accumulation on lignin in the xylem allows the trunk to support a higher weight on the tree top.

STOP 21: Plants evolution: the origins. The tour arrives at the second terrace. Here plants are organized by evolution age, from the most primitive to the most modern. A small pond brings the visitors to the first stages of evolution of plants. Tour guides will explain how plants came out form an aquatic environment to settle onto a soil environment.

CONTENT: THE EVOLUTION OF PLANTS

Before covering this section, it is necessary to get to know the main features of the major plant groups:

- **Bryophytes:** Mainly mosses and liverworts, they are little evolved and their tissue is not yet differentiated: bryophytes have fake roots and leaves, and lack of developed conductive tissues. They require humid environments to allow their sexual male cells to encountering female cells through swimming. Their reproduction pattern alternates between sexual and asexual (by means of spores).
- **Pteridophytes:** include ferns, horsetails, and the lycophytes. They are the first vascular plants, which feature sap conducting vessels in a very primitive stage. Anyhow the three main parts of a plant are perfectly displayed: roots, stem (underground located) and leaves ("fronds"). They still depend on humid environments, and reproduce alternating sexual and asexual (through spores) periods.

- **Spermatophytes:** comprise those plants that produce seeds. They represent a great step in evolution, because the embryo remains protected within a coat that protects it and keeps nutrient reserves, so that it can remain latent until the adequate conditions to germinate occur. That is why they do not depend on water as much as the previous two types. They feature also tissue and conducting vessels, very well developed, and they are capable of synthetizing lignin, a component which provides hardness to the plant and facilitates growth to considerable highs. Spermatophytes form different groups:

    - **Gymnosperms** (*gimnos-*, naked, *-sperma*, seed): They do not grow complete flowers, which means that real seed protective fruit cannot be produced. They show inflorescences named cones or strobili, which acquire the look of bracts that coat the gametangia (like the pines of pine trees). Examples are all the conifers: pine trees, cedars…

    - **Angiosperms** (*angio-*, coat, *-sperma*, seed): They do have complete flowers that transform into real fruits. Gametangia are located within the flower's ovary and should be fertilised to produce fruits. Examples are all the fruit trees: apple trees, pear trees…

STOP 22: Pine species and their use. The conifers area contain specimens of several types of pine tree: Himalayan blue pine, stone pines and others. Visitors will review the main benefits obtained from these plants: paper paste, resin for making glue, pine nuts, turpentine, rosin, pine honey, pine bark, etc. The story of the *Wollemia nobilis* will be revised, for it was believed extinct until 1994.

STOP 23: The tallest trees in the world: Sequoias. Visitors will stop by three specimens of sequoia to learn that they may grow 100 metres tall and live 2000 years. The tallest tree in the world in no a sequoia…

STOP 24: Three singular trees in the Garden. The tour will stop by three specimens that will be compared with similar ones in other countries that are scoring records.

- **"Pants":** The tree with the widest trunk diameter in the whole Garden. This bicentennial elm can be compared to the famous tree Tule in Mexico, which is more than 2000 years old. Graphioses disease will be commented to the visitors.

- **"The Lady":** a Caucasian elm which is more than 40 metres tall. It is not the tallest tree in the Wall, but it is the tallest in the Garden. Why is it called "elephant foot"?

- **"<u>Grandpa</u>":** The 250 year-old cypresses is the oldest specimen in the garden. Cypresses are trees deeply linked to cemeteries, which has a lot to do with their copes that look at the sky and their longevity.

"Pants", "Grandpa" and "the Lady".

STOP 25: Botanic expeditions to the new world: the winter bark. To revise the importance of plants trade in the past, visitors will stop by a specimen of *Drimys winteri*. A lot of expectations were placed onto this substitute of Ceylon's cinnamon, monopolized by the Dutch. But its spicy flavour didn't foster a desire to trade with it.

CONTENTS: THE ROYAL BOTANIC EXPEDITIONS

During the 18th century, the Spanish Crown led several expeditions to other countries to find, among other reasons, new plant species to trade with them. Visitors will learn what the role of Botanic Gardens was at that time, and will hear interesting stories like how quinine was discovered.

STOP 26: Hot stove: visit to the three rooms. This place reunites the desert, subtropical and tropical climates, and the different degrees of temperature and humidity in each one of them let the plants living inside to be very different from each other. Again the adaptation of plants to the different climates will be revised, and some interesting cases will be explained: aloe vera, mimosa pudica, drago, carnivorous plants…

CONTENS: PLANTS ADAPTATION TO CLIMATE

Living beings adapt to the environments in which they live, with the aim to survival or to increase the possibilities to survive. Examples of adaptation would be the changes undergone by one specimen's organism during generations, responding to biotic and abiotic factors, with a view to survive.

The way plants adapt to the different types of climate is detailed below:

a) **Desert climate:** Desert's extreme conditions lead plants to adapt heavily both to the existing abrupt changes in temperature (100º C at the Gobi desert: 50º C in the morning and -50ºC at night), and to the scarcity of rainfall (a whole year may pass without a drop water).

   Plants in the desert feature the following elements:

   - In contrast to non-succulent plants - that make photosynthesis during the day and open their stomata for gas exchange, succulent plants only open stomata at night, in order to avoid water losses through them.
   - Waxy stem and leaves on the outer surface, to avoid evapotranspiration.
   - Reduction in the leaf size (cacti leaf reduction is maximum as they have become thorns) to avoid water loss and evapotranspiration through stomata. With the same purpose, stomata are closed during day heat when insolation is at his highest point.
   - Very long roots that can reach 20 metres long, to find the deepest underground aquifers.
   - Hairy stems that bring about the water from dew by means of condensation during the night (and so they can benefit from this water), and which also coat the plant to withstand cold at night. Hairs are usually white, so that they can reflect the sunlight during the day.
   - Rib-shaped stems, which stretch as accordions during the rain, so as to increase their water storage volume inside.
   - Tissues thickened or fleshy usually to store water after the rain to use it when it is scarce. Water can be stored in leaves (crassulaceae) or in stems (cacti).
   - Thorny structures as defence mechanisms against animals looking for the water they hold stored inside.

Cactus sp. and *Lithops sp.* Also called stone plants

The fact of keeping endangered plants, i.e. the golden barrel cactus – also called "mother-in-law's cushion", empower us to talk about the preservation duties botanic gardens have, and how they must learn all the possible strategies to increase their populations.

Types of preservation actions:

- "*In situ*": "on the place". All those programmes that are implemented to preserve a plant in the very same place it lives at.
- "*Ex situ*": "out of the place". All those actions carried out outside the area where that plant species live. This kind of research is taken in the RBG, where plantation and collection of seed soon afterwards, helps to gather all possible genetically useful information to avoid endangering situations.

Echinocactus grusonii, also known as mother-in-law's cushion, *a species endangered*

b) **Subtropical climate:** it is a transitional stage between the desert and the tropical climates. Environmental conditions are more benign than in deserts so plants have larger leaves. In this room visitors will have the possibility to knowing plants that produce subtropical fruits like mango, avocados, pineapple, lychees, etc. In addition there is a corner with vegetable species from the Canary Islands among which stands out the Drago, symbol plant of the Island of Tenerife. The star however, is Mimosa pudica, a plant capable of moving its leaves to pretend it is dry. This temporary "dance" known as nastic movements occurs when the plant introduces or draws water from the leaves. After about 10 minutes it returns to its original state and turns out to be an effective mechanism against leaf-eating insects.

Mimosa pudica or sensitive.

c) **Tropical climate**: it holds a temperature of 24ºC all year round, with no cold seasons, and humidity around 80%. For this reason the tropics are the best areas for plant growth, which is why they concentrate the greatest biodiversity on the planet. Plants grow enormous and the biggest problems are how difficult it is to reach some sunlight when it is hidden by a huge amount of tree tops, the lack of space and the competition for nutrients. Types of plants that have adapted:

- Epiphytic plants that grow on other trees reaching better light (e.g. orchids).

Elk horn fern.

- Leaf gigantism: huge leaves to capture the greater amount of sunlight possible.

- Climbing plants such as vines or banyan figs that use the trunks of other trees to climb fast on them and arrive earlier to the area where the light is.
- Fast growth to reach the top of the forest as soon as possible.
- Aerial roots adapted to periodical flooding.
- High concentration of carotenes and xanthophylls: pigments that allow to absorb the dim light that reaches the lower part.
- Flexible and hydrophobic leaves on which rainwater can easily slide without breaking them (e.g. traveller's palms).

Traveller's palm.

- Carnivorous plants develop photosynthesis like all other plants, but need an extra supply of nitrogen which is obtained from insects they capture and digest. They lack nitrogen because of their inefficiency at capturing nutrients from the soil and because nitrogen runs away by means of the washing effect that rains heavy rains

provoke. Visitors will also hear about the different species of carnivorous plants in the Garden, some of them passive, and some of them active or semi active.

Carnivorous plants: two *Sarracenias*.

Nepenthes and Venus flytrap.

In a small pond visitors will be able to meet different aquatic plants: water lettuces, papyrus, water lilies, etc. Many of them equip bladders full of air thanks to which they float on the water surface without drowning.

A view of the aquatic plants area

At the end of the visit to this room, visitors will be reminded of the largest flowers in the world: *Raflessia arnoldii*, and *Amorphophallus titanum* (aka "Corpse flower"). These are examples of plants whose beauty make a contrast to their stinky odour.

d) **Defence against herbivores (II):** many plants feature mechanisms to avoid animal attacks. It means they have adapted to biotic conditions. Examples:

- Camouflage: Looking like something completely inedible is, without a doubt, a good camouflage trick. This is why stone plants in the Namibia make it right to confound herbivores looking like stones in disguise.
- Nastic movements: Mimosa pudica folds its leaves when exposed to any external stimulus. I n this way an insect wishing to take it away will get the idea that they are too dry to be edible.
- Another mechanism would be to pretend leaves have been already nibbled (as in *Caryota*).

Caryota.

An orchid image

STOP 27: Cold stove o Las Palmas Stove. This greenhouse was built during the 19th century, and houses a great variety of tree ferns and *Cycas*. Visitors will hear about how interesting these type of plants are, for they grew abundantly millions of years ago. Hybrid planes with huge leaves remind us of how present platanus have been "created". There are grids on the floor: interesting way they had to heat up the place in former times.

Tree ferns.

CONTENTS: MEDICINAL PLANTS

The pond located at the end of this greenhouse is flanked by two specimens of *Datura aerborea*, one of the many plant trees from which alkaloids may be obtained. Visitors will hear about scopolamine aka "Devil's breath", unfortunately famous nowadays for the different use some make of it (from a medical point of view and at low doses, scopolamine can be used to reduce dizziness provoked by travelling on transport, or to dilate the pupils to examine the back of the eye).

STOP 28: Bonsai. This stop will show visitors how an ordinary plant can be turned into a great short sized specimen. Some of the species visitors saw during the tour are here, on the shape of a bonsai. Nevertheless, its size should not mistake us, for their age could be even larger than the ones growing in the lower terraces. Visitors will hear about this art, which was already known 3000 years ago in China.

7. PROPOSED ACTIVITIES

Prior to the visit to the Royal Botanic Gardens

- In class revise those concepts that will be used afterwards during the visit to the Garden: Which are their previous ideas? Ask them to define, in their own words and understanding, what is the meaning of:

  - Biodiversity and lack of biodiversity.
  - Evolution-Adaptation.
  - Photosynthesis.
  - Endanger to extinction o plant reproduction.
  - Evapotranspiration.

- At the sight of a world map, review the most important features of the Mediterranean, desert, subtropical and tropical climates. Try to imagine the problems a plant may have when trying to survive in each one of them.

After the visit to the Botanical Garden:

- Discovering a new species. Bearing in mind all the knowledge acquired on the plant types, their adaptation to the environment, and how they are classified, propose students an exercise using their imagination.

  In a remote place, ever student has travelled to a remote place, and everyone have found out a new species. ¿How is it? ¿How does it produce offspring? ¿How have they adapted to the environment they live in? Choose a common name and a scientific name for the plant, and explain the whys of that name.

Crosstab that relates the three major plant groups features. Fill in the spaces according to what you have learned during the visit.

	PTERIDOPHYTES	GIMNOSPERMS	ANGIOSPERMS
Roots, stem and leaves can be identified			
Dispersal structure: spore or seed?			
Are they spermatophytes?			
Its leaves are named fronds			
Have sores			
Flowers are not fake			
Have cones			
Produce fruits			
Types, herbaceous, woody or both			

7.1. SOLUTIONS

Crosstab that relates the three major plant groups features. Fill in the spaces according to what you have learned during the visit.

	PTERIDÓPHYTES	GIMNOSPERMS	ANGIOSPERMS
Roots, stem and leaves can be identified	YES	YES	YES
Dispersal structure: spore or seed?	Spore	Seed	Seed
Are they spermatophytes?	NO	YES	YES
Its leaves are named fronds	YES	YES	YES
Have sores	YES	NO	NO
Flowers are not fake	NO	NO	YES
Have cones	NO	YES	NO
Produce fruits	NO	NO	YES
Types, herbaceous, woody or both	HERBACEOUS	ONLY WOODY	BOTH

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