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Water resources management and ecological response in the Albufera lagoon of Valencia

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Abstract

The Albufera of Valencia is a freshwater lagoon and estuary on the Valencian coast in eastern Spain, declared Natural Park in 1986 and included as a Ramsar site in the list of Wetlands of International Importance for birds in 1990. Rice fields surrounding the Albufera lagoon form a system of wetlands which provide habitat for the survival of aquatic vegetation and macroinvertebrates, which constitute the main food source for fish and birds. Despite the relevant level of anthropization, it still represents one of the most important wetlands of the Iberian Peninsula, constituting an ecosystem of great biodiversity value with a wide variety of fauna and flora; a correct water management is important to ensuring a good water quality and quantity and preserve the ecosystem.

This research, conducted with the help of a research group of the Polytechnic University of Valencia leaded by Prof. Guillermo Palau Salvador, has explored the relationship between wetland communities and anthropogenic disturbances with the purpose to demonstrate that a correct water management can help to make possible a sustainable development of the area.

The Albufera lagoon and the surrounding wetlands receive water for irrigation from various sources, including as major contributors two rivers, Jucar and Turia, and, during summer, the waste water treatment plant of Pinedo. Due to the complexity of the system and the different water sources, an assessment of the ecological response is currently needed. Benthic macroinvertebrate communities have been used as biological indicators and biotic indices have been applied to characterize them; in parallel some physical-chemical, chemical and microbiological parameters have been measured. To evaluate possible differences in terms of diversity of macroinvertebrates, four different sampling areas have been selected in this study according to the origins of water. One in the north that receive water from the WWTP of Pinedo, one in the south supplied

by the river Jucar and two other irrigation areas directly supplied by the lagoon, namely North Tancats and South Tancats.

For the purpose of this study, two sampling periods in 2018 have been selected according to the flooding cycles: the winter period during which wetlands are flooded for bird breeding and nesting and the summer period, during which agricultural areas are flooded for rice cultivation. In general, flooded area is much bigger in summer than in winter, with average values respectively of 170 km^2 and 90 km^2.

As we expected from such an anthropic territory, the average of biotic indices shows a moderate pollution level and a low water quality in all the areas. Furthermore, the Shannon diversity index (SDI) has been employed to compare the four selected areas and to extrapolate local results to the entire Albufera system. Differences between sampling areas and periods have been observed: northern areas, namely the one supplied by the wastewater of Pinedo and North Tancats, show a SDI average value of 1,2 in winter and 1,8 in summer whereas southern areas, namely the one supplied by Jucar river and South Tancats, show a SDI average value of 1,5 in winter and 2 in summer. In general, indices values are higher in summer than in winter.

Through SDI can be concluded that waste water treatment plant in the north is causing major ecological problems, whereas the water coming from Jucar river seems to be of higher quality. Further studies and more extended samplings are needed to better describe spatial and temporal variation of the ecological response in the entire Albufera system.

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Introduction and Objectives

Wetlands are one of the most productive ecosystems on the planet. They are critical for the maintenance of biodiversity and play an important role in the biosphere.

As defined by the Convention on Wetlands of International Importance (RAMSAR): "Wetlands are areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."[1]. The Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

Wetlands benefits are summarized as follows:

- purification, pollutants dilution and carbon sequestration;
- flood control;
- maintenance of water quality;
- maintenance of surface and underground water supply;
- support for fishing and agriculture;
- outdoor recreation and education for human society;
- provision of habitat for wildlife, especially waterfowl;
- contribution to climatic stability.

The importance of these ecosystem services is enormous as they are essential benefits that nature brings to society. For this reason, it is necessary to ensure the functions of ecosystems and to protect biodiversity.

The cumulative effects of human actions on wetlands ecosystems make the environment undergo major pressures that can affect biological communities present.

[1] RAMSAR. 2013. Contracting Parties in order of their accession. www.ramsar.org

One of the most important problems of the Mediterranean wetlands is their contamination by discharges of different origin. The study has been developed in the rice fields of the Albufera of Valencia, a coastal lagoon in Eastern Spain, declared Natural Park in 1986 and included as a Ramsar site in the list of Wetlands of International Importance for birds in 1990. This lagoon is an anthropic system due to the fact that his natural regime has been affected by the consequences of the urban and industrial development. Despite this, it still represents one of the most important wetlands of the Iberian Peninsula, constituting an ecosystem of great biodiversity value with a wide variety of fauna and flora.

Rice crops form a system of wetlands which provide habitat especially for birds. In fact, the Albufera was declared Site of Community Importance (SCI) under the Habitats Directive and a Special Protected Area (SPA) under the Birds Directive.

Figures 1.1 : Exemplars of Flamingos and Red-Crested Pochards [2]

This research has been conducted with a research group of the Polytechnic University of Valencia, leaded by Prof. Guillermo Palau Salvador, with the aim to better understand the relationship between biodiversity of wetland communities and water

[2] www.lifealbufera.org

management. Previous studies in rice fields were developed in 2011[3] and 2018 and this activity is presented as a continuation.[4]

To establish the water quality in these areas, the benthic macroinvertebrate community has been used as biological indicators, according to the EU Water Framework Directive 2000/60/EC. Benthic macroinvertebrates are one of the most widely used biological groups as indicators of water quality. This is because they integrate many qualities expected from an indicator: relatively large size, long development cycles, high taxonomic diversity and low costs of samples. The following biotic indices were applied to characterize them: Shannon and Simpson diversity indices, QAELS (Índex de Qualitat de l'Aigua d'Ecosistemes Lenítics Soms) and IMN (Índice del Modo de Nutrición). In addition to the macroinvertebrate sampling, a water quality analysis has been carried out, collecting at first some physical-chemical parameters in situ and secondly chemical and microbiological parameters have been measured in laboratory. The amount of data collected in the study required a statistical analysis with the aim of describing better the Albufera environment, comparing different areas and periods.

[3] Calera María, (2011). "Estudio de macroinvertebrados bentónicos en los arrozales del Parque Natural de l ' Albufera . Influencia de la procedencia del agua.". Trabajo fin de carrera. Escuela Técnica Superior de Ingeniería Agronómica y del Medio Natural. Universidad Politécnica de Valencia.

[4] Ibarra S. (2018). "Influencia de la inundaciòn invernal en la biodiversidad y calidad del agua de los arrozales del Parque Natural de la Albufera". Trabajo final de grado. Escuela tècnica superior de ingenierìa agronòmica y del medio natural. Universitat Politecnica de Valencia.

Study case

2.1 The Natural Park of the Albufera

The Albufera is a coastal lagoon situated 12 km south of Valencia, in eastern Spain. It is separated from the Mediterranean Sea by a large sandbank and surrounded by marshlands mainly devoted to agriculture. The entire system, formed by the lagoon, the marshland and sandy dunes, was declared Natural Park in 1986 with a surface of 21.120 hectares.

It extends, along the coastline, between the mouth of Turia river to the North and the Jucar river to the South; occupying part of the municipalities of: Albal, Albalat de la Ribera, Alfafar, Algemesí, Beniparrell, Catarroja, Massanassa, Cullera, Sedavi, Silla, Sollana, Sueca, Valencia. The exact delimitation is included in the 71/1993 decree, of May 31, of the "Consell de la Generalitat Valenciana" of the Natural Park legal system.

Figure 2.1: Geographic location of the Albufera lagoon. On the left red colour indicates the Valencian Community, while on the right green colour indicates the delimitation of the Natural Park.

The Albufera can be divided into three ecosystems:

- The lagoon, which gave the park its name. Situated in the centre of the Natural Park, its shape is almost circular, about 6-8 kilometres of diameter and an average surface of 2,433 hectares.
- "La Restinga": the sandbank, which separates the lagoon from the sea. It includes more sub-ecosystems such as coastal beaches, internal or external dunes and "malladas" (salt marshes).
- The marshland, namely wetlands devoted to agriculture, where the present study has been developed.

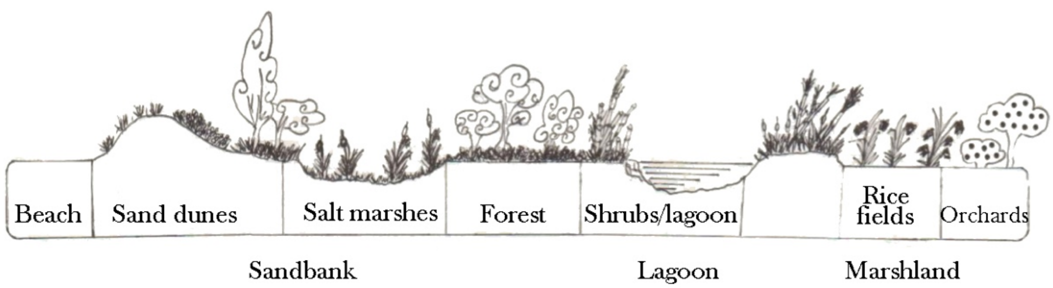

Figure 2.2: environmental units of the Natural Park of the Albufera[5]

The lagoon communicates with the sea through a system of three channels or "golas", named "El Perellonet", "El Pujol", "El Perellò". These channels, to control water level, have a system of floodgates, which can be opened to facilitate the drainage of rice paddies and closed to flood paddies and to prevent entries of salt water. Floodgates are managed by the "Junta de Desague", an entity constituted by only farmers.

[5] MORENO RAMÓN, H. (2013). Evaluación espacio-temporal de las aguas y suelos de la zona colindante al lago de la Albufera de Valencia: Intento de recuperación. Riunet.

2.1.1 Historical background

Until a few thousand years ago, the Albufera of Valencia was a sea gulf that over time was enclosed by the advance of a sand bar to become the actual coastal lagoon connected to the sea. This sand bar was growing and slowly extending from north favoured by marine currents and sediments of the Turia and Jucar rivers. However, this enclosure wasn't total and for centuries the Albufera was connected to the sea by a natural "gola". At this time, the environmental characteristics of this coastal wetland must have been very different from the current ones, with a fauna and a flora typical of brackish environments, especially in the areas most directly influenced by the sea.

Decisive environmental changes took place from the eighteenth century when the development of rice agriculture led to manage the water regime up to limit substantially inputs of salt water; for this reason, the interchange of water and fishes between the sea and the lagoon became more complex. So began conflicts between fishermen and farmers, still in force today: they fought for the control of communications between the sea and the Albufera. The first were motivated by interests of ensuring the entry of fishes and the latter wanted to control water levels according to the needs of rice crops.

Due to the irrigation development through a complex networks of channels, surface water inputs increased and the lagoon became progressively less saline. Main irrigation channels derived to the lagoon a high amount of fresh water which before flew into the sea.

Moreover, new "golas" were built, in order to simplify the drainage of the crops, up to the three which exist nowadays, namely, Perellonet, Perellò and Pujol Nou. The management of the floodgates allowed the drainage of the fields and prevented the entry of saltwater: it is clear at this stage the anthropogenic interference.

Figure 2.3. "Golas" positions

Despite this environmental change, namely landscape dominated by rice paddies and its consequent impact on flora and fauna, throughout the nineteenth century and up to 1960, the Albufera lagoon was still a great source of natural resources and biodiversity, maintaining its functions as a wetland. There are many descriptions from this period which show the Albufera as a true oasis for birds with a good conservation of aquatic ecosystems: waters were transparent and immersed vegetation covered the lagoon.

In the middle of the nineteenth century, the situation worsened due to a rapid urban and industrial development promoted in the early sixties. Moreover, intensive agriculture replaced traditional agriculture, with the introduction of chemicals. Wastewaters and sewages discharged into the lagoon without any control. At the same time, tourism increased involving the construction of new apartment blocks and the planning of major urban projects on the coast.

The ecological balance got broken: water became dirty, the excess of nutrients inputs from untreated agriculture resulted in a hypertrophic system. The concentration of nutrients in the water caused an uncontrolled explosion of phytoplankton and an increase of blue-green algae, or cyanobacteria: the sunlight did not reach the bottom, causing severe lack of oxygen. The underwater plants, which grew everywhere in the lagoon and in the channels too, being unable to photosynthesis due to lack of oxygen and sunlight, started to disappear: consequently, also many animal species, vertebrate and aquatic invertebrate communities, decreased.

This process, known as eutrophication, is fundamental in order to fully understand the environmental deterioration of the Albufera lagoon. In few years, the Albufera became one of the most polluted lakes in Europe.

2.1.2 Protective figures

The environmental deterioration culminated in the 1970's. At this time, citizens started to claim the recovery and the conservation of the wetland. As a result, a number of initiatives and projects were launched and these protection figures have followed over years:

- Natural Park, 1986
- Wetlands of International Importance, Ramsar Convention, 1990
- Natura 2000 network: Special Protection Area for birds, 2002
- Catalogo Valenciano de Zonas Humedas, 2002
- Natura 200 network: Site of Community Importance, 2006

Among the projects submitted, the Master Plan of Sanitation was drawn up, which included several wastewater treatment plants.

All these measures were fundamental for preventing the destruction of the ecosystem. However, despite all these international and local protection figures and all the projects carried out during the past forty years, the Albufera lagoon has not been recovered yet, still being a hypertrophic system, with waters rich of nutrients.

The key factor for the survival and recovery of the Albufera is the water quality. There are many factors that put at risk the future of the wetland: productive activities, namely agriculture, hunting and tourism; proximity to the urban centres, including Valencia, and resulting anthropic pressures. At this point, a correct water management is important to ensuring a good water quality and quantity and preserve the ecosystem.

2.2 Rice fields

There are no doubts about the importance of rice agriculture in the Albufera and its role in the local economy. Rice fields occupy approximately 14.000 hectares, representing the greater environment of the Natural Park. This ecosystem is strongly anthropic, subject to an intensive exploitation. However, it constitutes an essential habitat for the survival of aquatic vegetation and macroinvertebrates, which constitute the main food source for fish and birds.

Figure 2.4: Picture of rice fields taken on June 2018

2.2.1 Environmental effects

Water needs for the rice crop, both for the development of the plant and for the associated cultural practices, guarantee the flooding of a large area during a long period and the consequent maintenance of the characteristics of this space as a wetland. In the Albufera, there are two flooding periods: the summer period, between May and September, which coincides with the production of cereal and the winter period between October and February.

Allowing long flooding of rice fields is a key factor in promoting the development of rich biological community, both of aquatic invertebrates and of aquatic vegetation, which constitute the refuge and food base of the aquatic birds present in the Natural Park, as well as of other vertebrates. In this way, there is a clear dependence between the agricultural ecosystem and the associated flora and fauna: any intervention (i.e. pest control, harvesting, maintenance of irrigation network) directly affects these communities.

Irrigation water in the Natural Park has an extensive and complex network. This hydraulic regulation system is the result of long agricultural tradition and allows the uniform distribution of water in all rice fields, as well as the evacuation and drainage of surplus water. The maintenance of these infrastructures depends on the different Irrigation Communities of the Albufera, which ensure the adequate distribution for agricultural needs.

It should not be forgotten the role of rice paddies played in the prevention of periodic floods in the regulatory system of the Jucar river basin: thanks to the storage capacity of a large water volume, rice paddies are a temporary reservoir of surface floods that prevents and minimises the disastrous effects of floods.

It should be also mentioned the beneficial effect that rice fields have on the local maintenance of a particular microclimate of this territorial area.

The environmental effects of rice cultivation in the Albufera can be summarized in several aspects, including the environmental importance of the maintenance of flooded areas, its role in the conservation of waterfowl and its weight in maintaining an agricultural landscape of great tradition value.

2.2.2 Crop cycle

Rice cultivation completely regulates the water regime in the Albufera lagoon. Floodgates are opened in the middle of February to permit the drainage of fields and then begins the soil preparation with mug. Between the end of February and the middle of March, the ground is crushed and by the use of milling machines and then levelled. In April, the background fertilizer is applicate by providing phosphorus in the form of superphosphate lime and nitrogen in the form of urea. [6]

In the middle of May, rice is planted: seeds are deposited in soil and floodgates are closed to cover the fields. Crops remain flooded until the harvested in September. However, in the summer period, fields are usually dried for short periods of time: this practice is called “Eixugò” and it is needed to invigorate the stem and to applicate other doses of fertilizers.

Once harvested, fields are flooded again in the middle of October or November, for the entire winter period, until the crop cycle begins again.

[6] Ucha, A.; Fernández, E. 2001. Dinámica del Nitrógeno en los arrozales de Valencia. Generalitat Valenciana. Valencia. España. pp. 155

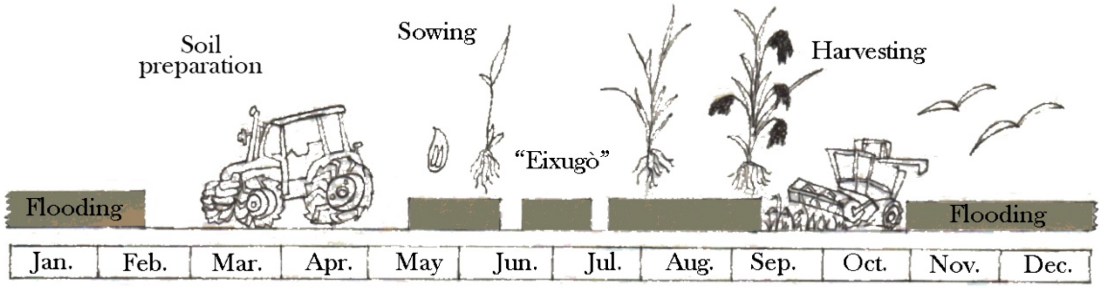

Figure 2.5: Crop cycle

2.2.3 Waterfowl community

Winter flooding is fundamental to preserve habitats: wetlands are flooded for bird breeding and nesting.

The avifauna of the Albufera is the main natural richness of this ecosystem, reason that has earned it to be considered a protected natural space and to enjoy different protective figures. More than 350 species of birds have been mentioned in this area, of which about 250 are observed regularly each year.

Although continuous interventions of farmers limit its importance as a breeding area, this system houses the majority of nesting population of the Black-winged Stilt (*Himantopus himantopus*) in addition to a certain number of Little Ringed Plover (*Charadrius dubius*) and other aquatic birds, such as Mallard ducks and Moorhens. In addition, it should not be forgotten the network of irrigation channels, in which nest a good number of species like the Little Bitterns or the Little Grebe.[7]

[7] Martinez C. (2013). Arroz en el Parque Natural de l'Albufera: un futuro sostenible. ECORICE. p 354-364.

Figure 2.6: Exemplars of Black-winged Stilt (Life Albufera)

At the same time, rice fields offer a place used as a feeding area by almost all the nesting and migrating waterfowl in the Albufera. The capacity of the environment of the Natural Park to produce food is limited as a consequence of its reduced surface and the poor water quality: therefore, the prolonged flooding of fields favours the growth of an important invertebrates' community, food base for these birds.

There are various reasons for this high biodiversity in the Natural Park; the geographical location of the Albufera in the European context shows a key area for the migration of birds, with mild temperatures and increased food availability.

Moreover, the role of rice fields in unquestionable: it has been observed that the highest figures of waterfowl in the Albufera coincide with the maximum area of flooded paddies.

2.2.4 Tancats area

Part of rice fields is supplied directly by the Albufera lagoon. This fields are called "Tancats", that means "closed" in Valencian language: in fact, they are units hydraulically closed. These section were isolated from the lagoon by land elevations, called “motas”, in order to expand the agricultural area and, consequently, reducing the lagoon.

Tancats are differed into two types:

- Lower Tancats, if the level is lower than the lagoon flood level. Pumping is needed to drainage the field. They are situated immediately around the lagoon.
- Upper Tancats, if the level is highest than the lagoon. In this case, pumping is needed to irrigate the fields. These are located around the other Tancats and so they are further away from the lagoon.

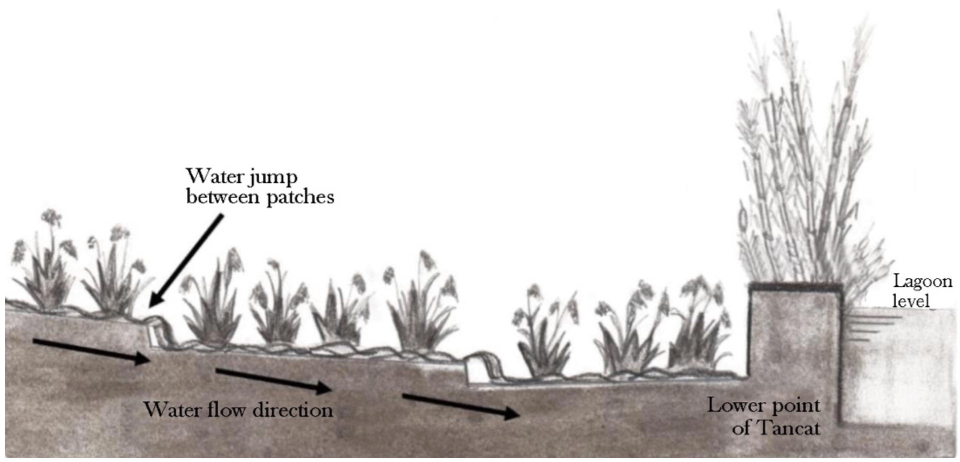

Figure 2.7: principle of operation of a Lower Tancat [8]

In Appendix A, all the Albufera Tancats are defined, with corresponding surface in hectares and belonging municipality.

[8] MORENO RAMÓN, H. (2013). Evaluación espacio-temporal de las aguas y suelos de la zona colindante al lago de la Albufera de Valencia: Intento de recuperación. Riunet.

2.2.4.1 *Life Albufera project*

"Life Albufera" project is led by the Polytechnic University of Valencia and other actors like SEO/Birdlife, financed by the "Confederación Hidrográfica de Júcar" [9]. The objective of this project is recovery clean waters of the Albufera lagoon by increasing the efficiency of artificial wetlands; three artificial Tancats were built: "Tancat de la Pipa", "Tancat de MilIa", "Tancat de l'Illa".

Artificial wetlands are purification systems, specifically built to control water pollution, consisting of lagoon or shallow channels usually planted with macrophyte plants; decontamination process take place through water, solid substrate, microorganisms, vegetation and even fauna.

Artificial wetlands in the Albufera, popularly known as "Filtros verdes", are designed to recirculate the water coming from the lake, reducing its load of organic pollution and in some cases they can function as a subsequent treatment to WWTP.

Figure 2.8: Tancat de la Pipa

[9] www.lifealbufera.org

2.3 Water regime

The Natural Park of the Albufera receives water from various sources, in example sewage, irrigation surplus water, groundwater discharge, natural run off. The total annual volume of water discharged to the Natural Park is 484 hm^3/yr. An average 280 hm^3/yr. reaches the lake itself [10].

Water supplies come from several brooks and ravines. The northern part of wetlands was previously supplied by the Turia flow, derived by the irrigation channels ("acequias") of the community of Valencia in the right bank of this river and the "Acequia del Oro". At present, due to the transfer of water from the Jucar to the Turia river, the canalization of wastewaters of the WWTP in Pinedo and sewages from various populations of the basin (i.e Quart, Xirivella, Aldaia, Alaquas), in the northern area the inputs correspond to waters of different compositions and origins. On the other hand, western and southern areas are supplied by waters from Jucar river, from discharges of some populations (i.e Almussafes, Benifaiò, Alginet, Sollana, Sueca) and from numerous groundwater springs, better known as "ullals" (Soria et al. 2002).

[10] Soria, J. y Vicente, E., (2002). Estudio de los aportes hídricos al Parque Natural de la Albufera. Departamento de Microbiología y Ecología. Facultad de Ciencias Biológicas. Universidad de Valencia. Limnética 21 (1-2). pp 105-115.

Figure 2.9: Baldovì "ullal", situated in the municipality of Sueca

These characteristics differentiate the Albufera from other natural coastal aquatic ecosystems not subjected to massive human pressure, where cycles are adjusted to seasons and climatic factors without the interferences which afflict the Albufera[11].

2.3.1 Water inputs in the lagoon

The main channels that currently supply the Albufera lagoon are:

- In the north, "El saler" channel which includes water coming from Oro irrigation channel, wastewater from Pinedo, sewages from some communities such as Aldaia, Alaquas, Manises, Quart de Poblet, Mislata, Alfafar, Sedavì (situated in the south of Valencia).
- In the north-west, the Torrent ravine which includes rainwater, urban and industrial wastewater coming from a wide basin in the municipalities of Chiva, Torrent, Massanassa.

[11] VICENTE, E. & M. R. MIRACLE. 1992. The coas- tal lagoon Albufera de Valencia: An ecosystem under stress. Limnetica, 8: 87-100.

— In the west, some irrigation ditches such as “Nova de Silla”, “Senyoret” with urban and industrial wastewater coming from the municipalities of Silla and irrigation surplus water.

— In the south west, “Overa” and “Campets” irrigation ditches with irrigation surplus water coming from the “Acequia Real de Jùcar” and urban wastewater of the municipalities of Sollana, Benifaiò.

— In the south, “Dreta” irrigation ditch with water coming from the Jucar river, some “ullals” and irrigation surplus of orchards and rice crops of Sueca community.

Figure 2.10: Oro irrigation channel and particular of input coming from the WWTP in Pinedo into the Oro channel

Material and Methods

3.1 Sampling periods

According to the flooding cycle, two sampling periods have been selected: the winter period, from December 2017 until February 2018, and the summer period, from June 2018 until September 2018.

These periods differ from one to another for several reasons. First of all, their functionalities: in summer agriculture areas are devoted to rice cultivation instead in winter areas are flooded to preserve important habitat characteristics. As a result, flooded area in these two situations is not the same.

The Albufera undergoes a transformation from a lagoon environment in winter to an agriculture medium in summer. Both ecosystems are interconnected and mutually conditioned. However, there are many factors which differ from an ecosystem to another, indicators of the unequal environments in the Natural Park: climatic conditions, water chemical and biological properties and water management.

3.1.1 Remote sensing

Remote sensing has allowed the detection of flooded areas. Landsat images have been elaborated by a research group of the University of Salerno, leaded by Maria Nicolina Papa. Following results were elaborated by Stefano Polito, in his master thesis. [12]

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object. This discipline, applied for diagnostic-investigative purposes, allows to obtain qualitative or quantitative information on the environment; objects, placed at a distance from the sensor, are detected by

[12] Polito Stefano, (2018). "Utilizzo di tecniche di remote sensing per il monitoraggio delle risorse idriche superficiali". Tesi di laurea magistrale in River and Coastal Management. Dipartimento di ingegneria civile, Università degli Studi di Salerno.

electromagnetic radiation measurements (emitted, reflected or transmitted) interacting with the physical surfaces of interest. Sensors used for the acquisition of remote sensing data can be mounted on different platforms such as aircraft, satellites or space probes: the sole purpose of which is to capture and receive the electromagnetic waves that the surface of interest emits, transmits or reflects.

Remote sensing may be split into "active" remote sensing (such as when a signal is emitted by a satellite and its reflection by the object is detected by the sensor) and "passive" remote sensing (such as when the reflection of sunlight is detected by the sensor). Typical examples of passive sensors are optical or infrared sensors, such as Landsat.

Landsat program is an information system that collects, stores and distributes moderate-resolution data on the entire Earth's surface. The innumerable information collected and processed has been and continues to be used for various purposes such as monitoring and studying the environment, resources, natural and man-made changes on the Earth's surface, obtaining information on land cover, ecosystem health and water availability. The monitoring of the superficial waters is generally conducted extracting the characteristics from different satellite images before effecting comparisons to notice the trend over time.

Landsat images are free available on the website of the USGS (United States Geological Survey), which is a scientific agency of the United States government, responsible for monitoring landscapes and natural resources. On the website it is possible to access to data of any area. [13]

Satellites images have been processed through the software QGIS (previously known as Quantum GIS), which is a free and open-source desktop geographic information system (GIS).

[13] www.usgs.gov

Optical data can be used by using the spectral signature of the natural elements to be studied. Spectral signature is basically a graph that shows the reflection capabilities of a given surface as a function of the wavelength of the incident radiation. By using the spectral signature, it is possible to calculate spectral indices which can delineate landscape features, such as snow, clouds, vegetation and water, in Landsat images.

Flooded area has been calculated extracting, from Landsat images, the Normalized Difference Water Index (NDWI), which permits water body mapping. Water bodies have low radiation and a strong absorption capacity in the visible wavelength range. The NDWI makes use of reflected near-infrared radiation (NIR) and visible green light (GREEN) to enhance the presence of such features while eliminating the presence of soil and terrestrial vegetation features [14]

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$$

Specifically, the aim of the index is to maximize the reflectance of the water using wavelengths in the green band and to minimize the low reflectance of the same in the band of near infrared.

[14] McFeeters, 1995.

Figure 3.1: NDWI index referring to the 05/12/17, namely without rice presence

Furthermore, for the images related to the summer period, it has been necessary also the application of the Normalized Difference Vegetation Index (NDVI), due to the conspicuous presence of rice. In fact, rice presence masks water presence, which is generally below the vegetation since passive sensors mounted on satellites can only read the spectral signature of vegetation. NDVI gives information about rice presence and so, indirectly, about water body.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where RED and NIR are the spectral reflectance measurements acquired in the red (visible) and near-infrared regions, respectively.

Figure 3.2: NDVI index of the 17/07/18

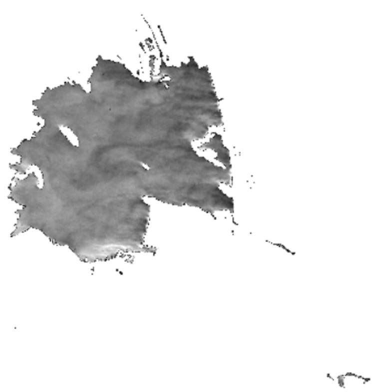

Figure 3.3: Corresponding NDWI index referring to the same date 17/07/18. The remaining water is hidden by vegetation

3.1.1.1 Monitoring of flooded area in time

After extracting the NDWI and the NDVI, it is possible to evaluate the entire flooded area in a specific day to which Landsat image is referred.

As shown in Table 3-1, flooded area in winter and summer period are quite different due to their distinct functionalities and water regimes. Flooded area in summer is almost twice then in winter; reasons are better explained below.

Table 3.1: Flooded area values over the year

Day	*Flooded area [km²]*
11/10/17	25,94
27/10/17	55,78
12/11/17	79,03
05/12/17	96,16
22/01/18	78,05
31/01/18	69,55
27/03/18	24,54
05/04/18	24,06
07/05/18	24,06
17/07/18	169,68
14/08/18	168,49
28/09/18	147,39

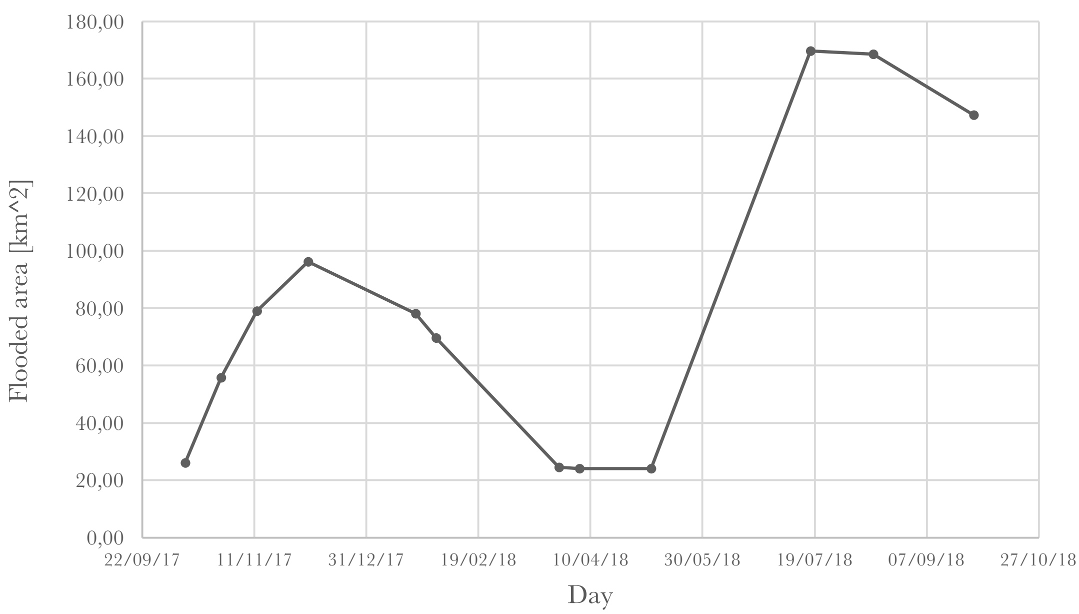

Figure 3.4: Monitoring of flooded area in time. The lower value (24 km2) almost corresponds to the lagoon surface.

3.1.2 Winter period

As already mentioned, winter flooding in rice fields is of great importance for the entire ecosystem of the Albufera, since it hosts lot of birds of environmental interest. This period is called "Perellonà" in Valencian.

Winter flooding only affects the Tancats area; slice gates are closed (always referring to the "golas"), around the first days of October, to allow that the lagoon level rise up. Lower Tancats are consequently flooded, while pumping is needed for the Upper Tancats (figure 3-5, (a-b)). In this period there are no agricultural activities and fields are kept flooded from one to four months depending on their level. Around the firsts of February, "golas" are opened: natural drainage of fields begins and, consequently, lagoon level decreases (figure 3-5, (c)).

Until 2016, it was also used the surplus water irrigation and the wastewater of the treatment plant in Pinedo but nowadays flooding water only comes from the lagoon. It follows that the flooded area has suffered a significant decrease; it has been estimated that the value in previous years was 120 km^2 while currently it is around 80 km^2.

In this study, samplings have been carried out on three dates, once a month: on 19 December 2017, 16 January 2018 and 13 February 2018.

Figures 3.5: Landsat images describing the "Perellonà". From left to right: (a) 27/10/17, slice gates are closed and fields begin to be flooded; (b) 15/01/18, all Tancats are flooded; (c) 27/03/18, flooding is over and starts the preparation of fields for rice cultivation

3.1.3 Summer period

From April to September, the Albufera is devoted to rice cultivation, which completely regulates water regime of the lagoon. Unlike winter flooding, this period involves all fields devoted to rice agriculture of the Natural Park, so the resulting flooded area is almost twice.

Slice gates are closed at the end of April or at the first days of May. Sowing is carried out in early May: in this stage, the level must be very low (two or five centimetres) to favour the initial development and the formation of productive stems. As plants develop, water level increases: in the month of June all fields are flooded, as can be seen in figure 3-6, (a). However, level do not remain constant all the summer: in the months of June and July slice gates are temporally opened, more than once, to permit the "Eixugò": fields are dried for short periods of time to invigorate the stem and to applicate fertilizers (figure 3-6, (b)). The last image (3-6, (c)) shows the spectacular vegetation growth, reaching its maximum at the end of July: the intense green shown in the colour combination represents the high percentage of vegetation cover, indicating that the crop is in the highest state of development. In the month of August, as the crop matures, fields begin to be drained for harvest in September.

In this study, samplings have been carried out on three dates, trying to cover different stages of rice cultivation: on 19 June 2018, 26 July 2018 and 19 September 2018.

Figures 3.6: Landsat images describing rice farming. From left to right: (a) 15/06/18, slice gates are closed, all fields are flooded; (b) 24/06/18 "Eixugò" time; (c) 14/08/18, vegetation has grown and its presence covers the water presence

3.2 Sampling areas and points

The Natural Park of the Albufera receives water from various sources, in example sewage, irrigation surplus water, groundwater discharge, natural run off: in this study, different agricultural areas have been selected according to the origins of water, considering only superficial waters. Four sampling areas have been identified: one in the north that receives water from the WWTP of Pinedo, one in the south supplied by the river Jucar and two areas of Tancats, namely North Tancats and South Tancats.

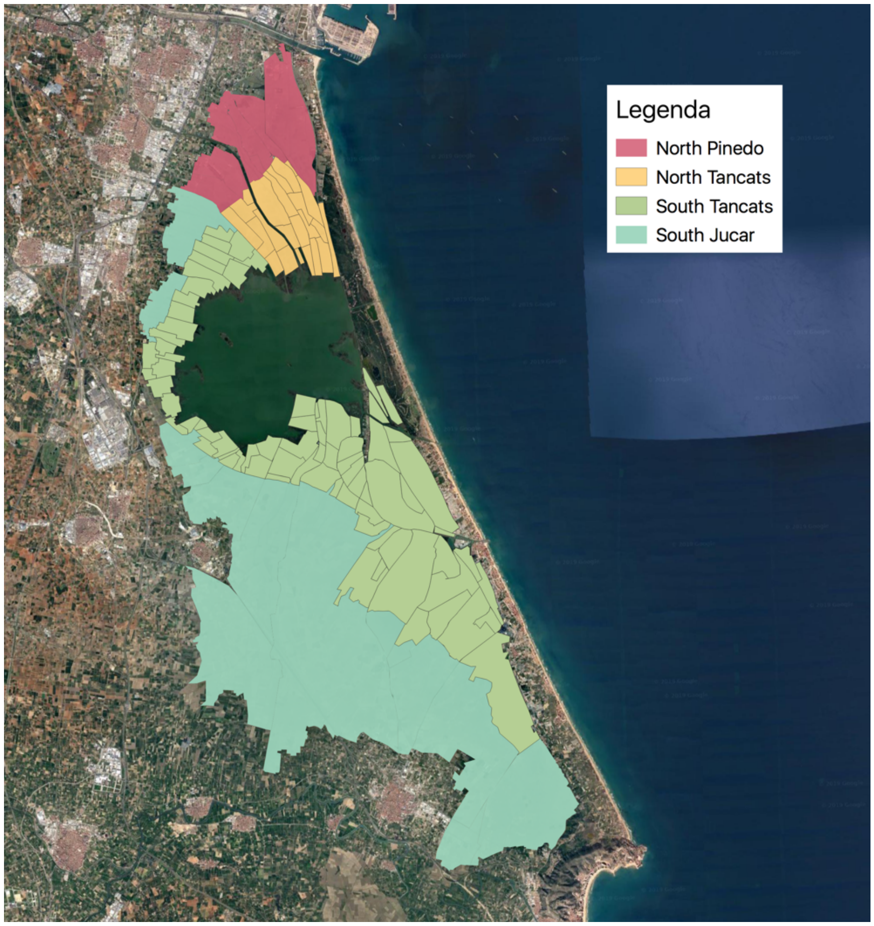

Figure 3.7: Delimitation of sampling areas

North Pinedo: includes rice fields flooded by the "Acequia de Oro" with waste water of Pinedo. It also includes a small area flooded by the "Acequia de Favara", with water that comes from Turia river. However, this area has been incorporated into the Pinedo area both because of negligible surface and because samplings were not carried out in that area. All Pinedo area have a surface of 1130 hectares. Sampling points (figure 3.8) belonging to this area are: N4, N5, N6.

South Jucar: last area defined in this study includes rice fields flooded by water mainly coming from the Júcar river and the "Acequia Real de Júcar". It incorporates irrigation sectors of Sueca, Silla, Sollana and Cullera. This area is much bigger than the northern area and receives great flows from the Júcar river; it can be considered as part of the river basin (Soria et al. 2002). This area is characterized by the presence of the so called "ullals" (groundwater springs). All Júcar area have a surface of 7400 hectares. It should be mentioned that some factors have been neglected to include all west part in this area, especially the influence of urban and industrial wastewater of some municipalities such as Torrent, Massanassa and Silla. Sampling points (figure 3.9) belonging to this area are: S4, S5, S6.

North and South Tancats: as already mentioned, Tancats are all the fields which are supplied directly by the lagoon. However, the distinction between North and South has been maintained to evaluate possible influences by the respective "upper" areas, namely North Pinedo and South Júcar. Sampling points (figure 3.8 and 3.9) belonging to these areas are respectively: N1, N2, N2 and S1, S2, S3. Delineations of all Tancats are defined in Appendix A. As result, North Tancats have a total surface of 906 hectares, while South Tancats of 4780 hectares.

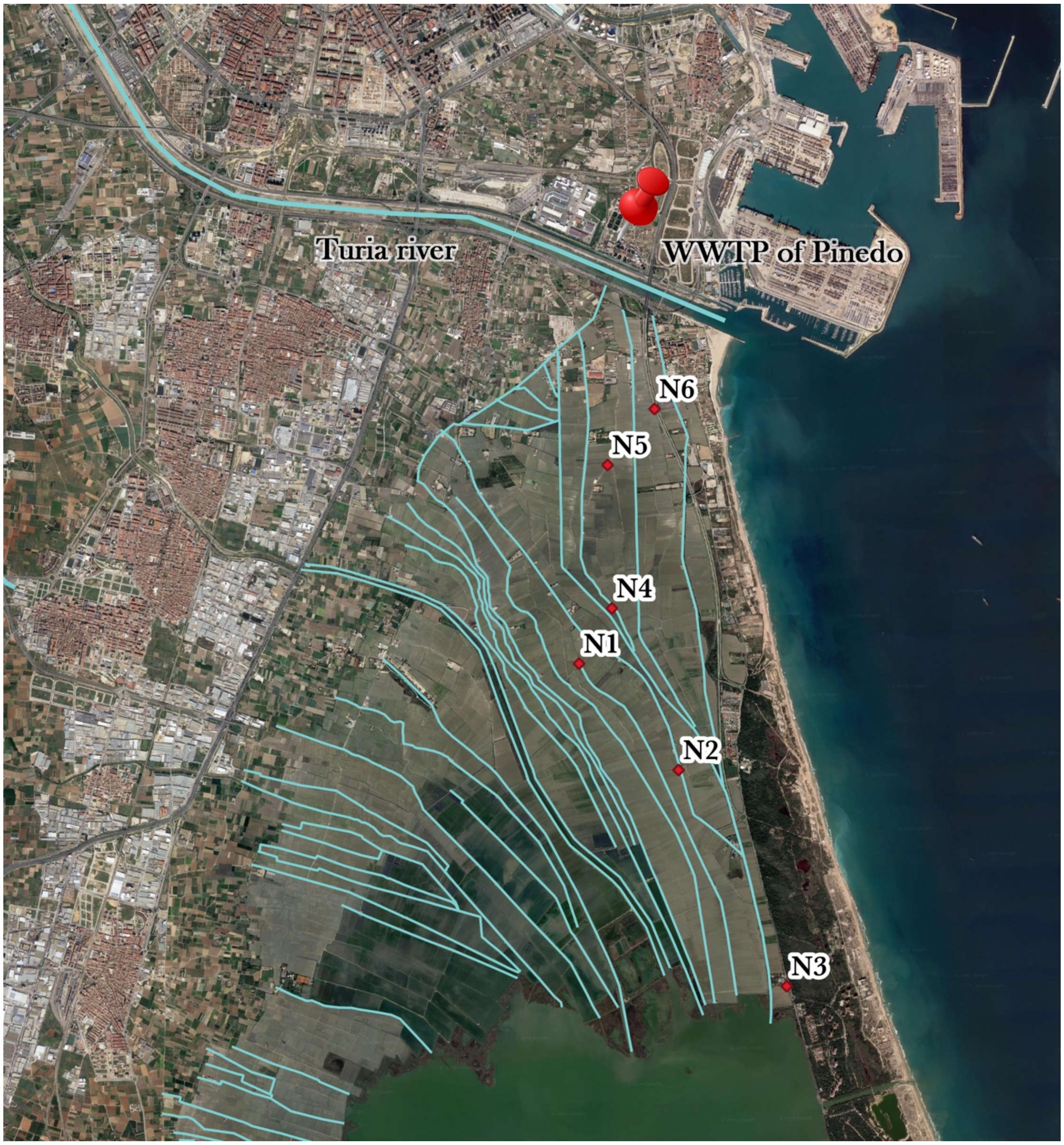

Figure 3.8: sampling points in northern areas.

Figure 3.9: Sampling points in southern areas

3.3 Benthic macroinvertebrates as water quality indicators

Macroinvertebrates are invertebrates large enough to be visible to human eye. A concrete definition: "those invertebrate organisms inhabitants of aquatic habitats, at some point in their life cycle, and which are retained by meshes of light between 200 and 500 μm" [15]. Their size is relatively large, usually greater than 3 mm. They mainly include arthropods (namely insects, arachnids and crustaceans), especially in their larval forms; also they include oligochaetes and molluscs [16] . Macroinvertebrates are a dominant group in rivers but there are also found in lakes and wetlands.

Benthic macroinvertebrates are one of the most widely used biological groups as indicators of water quality. This is because they integrate many qualities expected from an indicator: mainly the high diversity and different taxa that they can represent, with different ecological requirements related to the hydro morphological characteristics (water speed, substrate), physicochemical and biological aspects of the aquatic environment. They indicate alterations both in medium and long term, as their species have life cycles between less than a month and more than a year: its indicator value covers an intermediate time range compared with other biological elements with shorter response time, such as phytobentos, or longer, such as fish [12].

In summary, main benefits of using macroinvertebrates as water quality indicators are:

- The relatively large size: they can be seen with the naked eye
- They have relatively long development cycles that allow for analysis temporary

[15] Rosenberg, D. M. y Resh, V. H., (1993). Introduction to freshwater biomonitoring and benthic macroinvertebrates. Freshwater biomonitoring and benthic macroinvertebrates. Nueva York, pp. 1-9.
[16] Alba-Tercedor, J., Pardo, I., Prat, N., y Pujante, A., (2005). Metodología para el establecimiento del Estado Ecológico según la Directiva Marco del Agua (Protocolos de muestreo y análisis para invertebrados bentónicos). Confederación Hidrográfica del Ebro. pp 1: 1-14, 6: 19-22, 9:27-30 y 10: 30-32.

- They are relatively sedentary and therefore representative of the area where they are collected
- Samplings can be done with material low cost
- They have high taxonomic diversity and high diversity also in the types of food and in the life cycles

As mentioned above, this community presents a great variety of tolerance ranges to disturbances: there are species that, when disturbed, can disappear or reduce their abundance while the most tolerant species may even increase their densities when others have already disappeared. This property has allowed the development of biotic indices, based on the tolerance of the different taxa of of macroinvertebrates to pollution or human disturbances [17]. For instance, among the less tolerant groups are the larvae belonging to the orders Ephemeroptera, Trichoptera and Plecoptera and larvae or adults of some families of Coleoptera: that means they can show a high sensitivity to pollution and degradation of aquatic ecosystems.

One of the issues that have been founded in this study was the low presence of the most sensitive families mentioned above. In wetlands and in particular in rice paddies, due to their high eutrophication, EPT (Ephemeroptera, Plecoptera and Trichoptera) almost do not appeared; instead the dominant groups encountered were families most tolerant to pollution and human disturbances.

Biological indices in wetlands, associated with macroinvertebrates, are not yet widely diffused. In this study the following biotic indices have been applied: Shannon and Simpson diversity indices, QAELS (Índex de Qualitat de l'Aigua d'Ecosistemes Lenítics Soms) and IMN (Índice del Modo de Nutrición).

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[17] Alonso, A. y Camargo, J., (2005). Evaluating the effectiveness of five mineral artificial substrates for the sampling of benthic macroinvertebrates. Journal of Freshwater Ecology 20: 311-320.

3.3.1 Shannon-Wiener Index

Diversity indices use the community structure in term of its diversity to estimate the water quality: it is a valid alternative to the study of "indicator species" presence, especially in this study, conducted in such a eutrophic ecosystem. Generally, good water quality is synonym with a diversified community. The diversity indices which are widely used are the Shannon-Weaver Index and the Simpson Index; they incorporate, in a single value, richness and abundance of the species.

The Shannon-Wiener Index *H'* (1949) [18], or Shannon Diversity Index (SDI), describes the diversity as a measure of uncertainty to predict which species would belong to an individual chosen at random from a sample of S species and N individuals. Therefor, H'=0 when the sample contains only one species and H' will be massive when all the species S are represented by the same number of individuals n_i (where "i" is the species considered), that means that the community has a perfectly equitable abundance distribution.

$$H' = -\sum_{i=1}^{s}(p_i \times log_2 p_i)$$

where p_i is the proportional abundance of the *i*-th species, representing the probability that an individual of the species *i* is present in the sample (being then the sum of p_i equal to 1).

$$p_i = \frac{n_i}{N}$$

This index has been widely used since it was developed and its results are considered as good indicators of biodiversity.

[18] Developed by Claude Shannon in 1949.

Table 3.2: Relations between Shannon Diversity Index and Pollution level

SDI	Diversity Level	Pollution Level
3.0-4.5	High	Slight
2.0-3.0	Moderate	Light
1.0-2.0	Less	Moderate
0.0-1.0	Very less	Heavy pollution

3.3.2 Simpson index

The Simpson Index S_{Di} [19] indicates the probability of finding two individuals of different species in two successive random "extractions without replenishment"; it gives a higher weight to abundant species underestimating rare species, taking values between 0 (low diversity) up to a maximum of [1-1/S].

$$D_{Si} = \sum_{i=1}^{S} {p_i}^2$$

Simpson index is expressed as a measure of dominance and it is related to relative abundance and species richness. However, the dominance and the diversity are proprieties opposed to each other. An appropriate transformation to obtain an index positively correlated with diversity is needed, since diversity the most common form in ecology:

$$S_{Di} = 1 - D_{Si} = 1 - \sum p_i^2$$

[19] Developed by Edward H. Simpson in 1949

3.3.3 QAELS

Biological quality indicator based on benthic macroinvertebrates are less developed in lakes and wetlands.

The QAELS index (Índex de Qualitat de l'Aigua d'Ecosistemes Lenítics Soms) has been elaborated to determining the ecologic state of shallow lagoon systems in Cataluña [20]. It combines aspects of taxonomic richness and abundance. It responds to the following formula:

$$QAELS = (ACCO + 1) \times Log(RIC + 1)$$

where ACCO is an index based on the abundance of cladocereans, copepods and ostracods while RIC is an index based on the insects and crustaceous richness.

In detail,

$$ACCO = \sum_{i=1}^{j} k_i \times n_i$$

i : indicator taxon

j : number of indicator taxa

n_i : relative abundance of i^{th} taxon, $n_i = \frac{N_i}{N_{tot}}$

N_{tot} : sum of abundance of all indicators taxa

k_i : quality value of i^{th} taxon

k_i values are shown in figure 7.2 (Appendix B). For this study, the option "temporary freshwater wetland" has been chosen, because fields do not remain flooded all the time.

Moreover, the RIC index is based on the insect and crustacean richness:

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[20] Agència Catalana de l'Aigua. (2004). Caracterització, regionalització i elaboració d'eines d'establiment de l'estat ecològic de les zones humides de Catalunya.

RIC = N° of crustacean genera + N° of Heteroptera and Coleoptera adult genera + N° of larval and insect families

Considering microcrustaceans can be very useful for the determination of the ecological status of lagoons and wetlands: in addition to be good indicators they leave identifiable remains in sediments.

The obtained value corresponds to a certain quality class (Table 3.5).

Table 3.3: classification of water quality according to QAELS value (ACA,2004)

QAELS	Water Quality
>8.0	Very Good
6.0-8.0	Good
4.0-6.0	Moderate
2.0-4.0	Poor
>2.0	Very Poor

3.3.4 IMN

The IMN (Índice del Modo de Nutrición) is based on the feeding mode of aquatic macroinvertebrates and their relationship to the trophic structure of the community. The heterogeneity of organisms is directly related to the diversity of the sampling point: therefore, a heterogeneous environment would correspond to an environment of high diversity, in such a way that, if the environment is altered, a decrease in the diversity in the types of feeding of macroinvertebrates would be obtained. The best condition of the ecosystem is caused by the presence of all trophic groups in proportions ranging from 5 % to 15 %.

This index is applicable to all aquatic systems from rivers to lagoons and wetlands ; [21] for this reason it has been used in this study, although it is not yet widespread.

To applicate the IMN, an identification at family level is needed, following the classification in nutritional groupings proposed by Tachet et al. [22] (Figure 7.3, Appendix B), which are created in function of the mandibular apparatus or in the form of macroinvertebrates' food catching .

Once the trophic affinity has been assigned to each macroinvertebrate and the relative percentage of each nutritional groups, this index considers positive the presence of a high number of nutritional groups (and considers that these nutritional groups oscillate between 0 and 40), increasing the positive score as the percentage of them increases. At the same time, the absence of certain groups or a proportion of them greater than 40 would imply negative scores, which increase as the percentage and the number of groups not existing increase. This process results in a positive and a negative score. By subtracting the negative from the positive, the final IMN value is obtained.

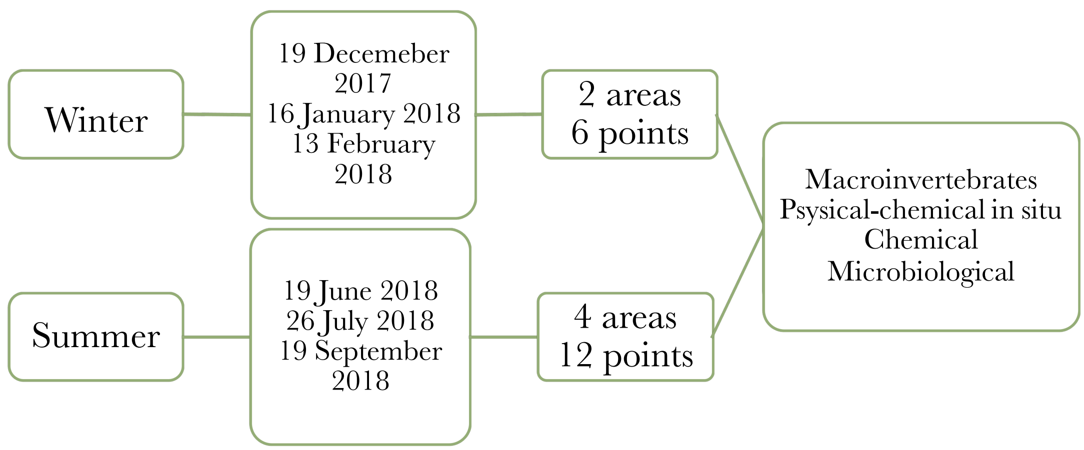
As for the other indices mentioned above, the value obtained corresponds to a certain quality class:

Table 3.4: Ranges of food web and trophic quality accorded to de IMN value

IMN	***Class***	***Food Web Diversity Level***	***Interpretation***
>70	I	Very High	Unpolluted
55-69	II	High	Clean but slightly impacted
40-54	III	Moderate	Moderately impacted
20-39	IV	Less	Impacted
0-19	V	Very Less	Heavily impacted

[21] Rueda, J., López, C. y Hernández, R., (2005). Evaluación de la calidad de los ecosistemas acuáticos a partir del modo de nutrición (IMN) de sus macroinvertebrados. Didáctica de las ciencias experimentales y sociales.
[22] Tachet, H., Bournaud, M. y Richoux. 1987. Introduction à l'‘étude des invertébrés des eaux douces, systématique élémentaire et aperçu écologique. Université de Lyon. Association Française de Limnologie. 155 pp.

3.4 Sampling methodology



3.4.1 Macroinvertebrates sampling

Macroinvertebrate samplings were carried out in accordance with European Standard EN 27828:1994, following *"Guía para el Muestreo Manual con Red de Macroinvertebrados Bénticos"* published in 1995, where sampling procedures for ponds and estuaries are specified.

For the macroinvertebrate capture, a driftnet of 250 µm of light and an opening of 200 mm of diameter was used. The "Dipping" method [23] was performed: it consists in drugging down the driftnet, transiting for one metre near to the bottom and finally going up to the surface. It was made in three representative point for each patch.

[23] Alba-Tercedor, J., Pardo, I., Prat, N., y Pujante, A., (2005). Metodología para el establecimiento del Estado Ecológico según la Directiva Marco del Agua (Protocolos de muestreo y análisis para invertebrados bentónicos). Confederación Hidrográfica del Ebro. p-155

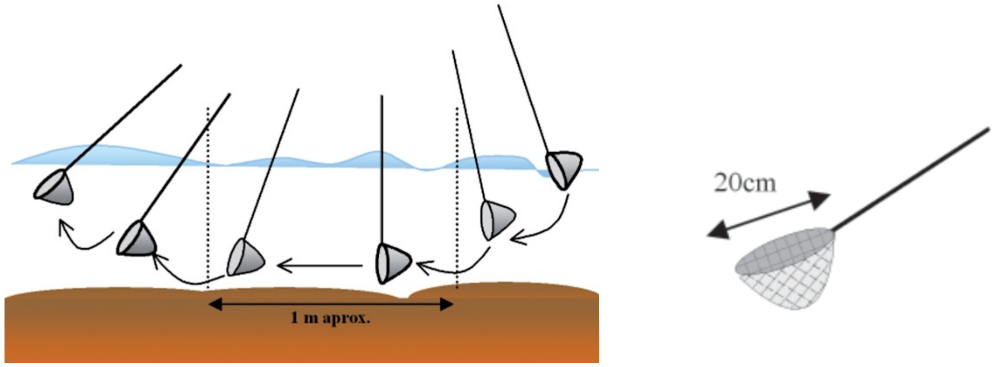


Figure 3.10: Dipping method represented graphically [21]

The contents of the driftnet were poured into a sealed container. Once the samples were collected, a first cleaning was carried out in situ with the aim of extracting macrophyte or microalgae; this material was examined in order to detach organism that could be attached to extracted materials. All the containers were labelled with sampling site and date.

Figure 3.11: Picture of macroinvertebrate samplings taken in different sampling periods, respectively in winter and summer (with rice presence)

3.4.1.1 *Samples treatment in laboratory*

The macroinvertebrate identification has been carried out in the Laboratory of Ecology (Agroforestry Department) of the Polytechnic University of Valencia.

Once the samples were collected, they were transported to the laboratory for examination. If they were not examined on the day of collection, they were kept in refrigerators at a temperature of 4°C to avoid deterioration and the to be able to carry out the work in the laboratory correctly; moreover, preventing macroinvertebrate death made identification and counting easier. They were cleaned by placing the samples on white trays (Figure 3.14), adding some water to individuate and separate macroinvertebrate from silt and small macrophyte using tweezers and teaspoons. Once separated, they were put into Petri dishes and placed under the binocular for the identification.

Figures 3.12: Samples in labelled containers.

In particular, at first larger individuals were separated and often were clearly recognizable without the binocular. Secondly, organisms which required a major attention were isolated in Petri dishes and often frozen at a temperature of -19°C, in order to have all the time necessary to identify them. Before freezing them, Petri dishes were labelled with the collected information indicating sampling site and date.

The keys used during the identification stage in the laboratory were:

— Invertébrés d'eau douce systématique écologique. Henri Tachet. CNRS. Editions 2003.

— Atlas fotográfico de los invertebrados acuáticos de la cuenca del río Júcar en la provincia de Albacete. Juan Rueda, Ramón Hernández. Instituto de estudios Albacetenses "Don Juan Manuel". Diputación de Albacete. 2009.

Figures 3.13: Macroinvertebrates identification in the Laboratory of Ecology

3.4.2 Physical-chemical parameters

In addition to the macroinvertebrate sampling, a water quality analysis was carried out, collecting at first some physical-chemical parameters in situ. These parameters are representative for the state of water quality.

Table 3.5: Parameters collected in situ and corresponding instruments

Parameters	***Units of measurement***	***Instruments***
pH	–	pH/mV & lon/Ph Meter series. Eutech instruments.
Electrical Conductivity (20°C)	µS/cm	Hand-held conductivity/TDS Meter. Con 6/TDS 6 Eutech Instruments.
Dissolved oxygen	mg 0_2/l	DO 6 Economy Hand-held Dissolved Oxygen. Eutech instruments.
Oxygen Saturation	%	DO 6 Economy Hand-held Dissolved Oxygen. Eutech instruments.
Temperature	°C	All instruments above can measure temperature

The metabolism of aquatic environments is strongly conditioned by the availability of dissolved oxygen. Mainly, in lagoons, dissolved oxygen can be produced for diurnal photosynthetic activity, inside the mass of water. This photosynthetic activity is also conditioned by the transparency of waters. The dissolved oxygen is constantly consumed through the respiration of organism: it can be seen as the resultant of this consumption and the reoxygenation due to the photosynthetic production (and even exchanges with the atmosphere). Dissolved oxygen is an important parameter to be measured because it is associated with pollution level: waste water inputs, with the consequent contribution of organic matter, subtracts oxygen to the mass of water. Concentrations of dissolved oxygen < 5 mg/l start to be limiting for the maintenance of forms of life.

Electrical conductivity provides a measure of dissolved salts in water. It is measured in μS/cm, however, in this study, it is indicated for convenience in mS/cm due to the high values. Conductivity depends on the temperature, so it is necessary to bring the values to the temperature of reference (20 °C). High values of electrical conductivity correspond to a high pollution level.

Figure 3.14: Measurement of water parameters in situ

3.4.2.1 *Chemical parameters measured in laboratory*

Chemical and microbiological laboratory analysis have been carried out in the Valencia Catholic University (Department of Biotechnology), by a research group leaded by Ana de Luis Margarit.

Two water samples were taken in each sample point: one for analysis in situ and one for laboratory analysis. Each samples were a set of three subsamples taken in three different points of the patch. Water samples for laboratory analysis were collected in two litre bottles and transported as soon as possible to the laboratory, where they were stored at 4°C until chemical and microbiological analysis, which were carried out over 24 hours.

Chemical analysis consisted in measuring the amount of nitrates ($N0_3$), nitrites (NO_2) and phosphates (PO_4) in water.

Figure 3.15: Equipment needed in laboratory for chemical measurements

3.4.3 Microbiological parameters

Microbiological analysis consisted in measuring the amount of Total Coliforms, Faecal Coliforms and Enterococci in water.

Total Coliforms are considered indicative organisms of pollution, thus they assumed an important role as microbiological parameters to define the quality of water environments.

Faecal Coliforms are a subgroup of Total Coliforms and represent a more specific index of faecal contamination of waters.

In most waters the most common Faecal Coliform is *Escherichia Coli*. E. coli is distinguished from other coliforms by its smaller survival in water respect other kinds of the group, therefore one presence of E. Coli is index of a more recent pollution.

Enterococci include species of the genus Streptococcus and are a subgroup of the wider faecal streptococcus group. There are high concentrations of intestinal enterococci in wastewater and in aquatic environments contaminated by wastewater or human or animal waste (WHO, 2006).

3.5 Statistical analysis

The amount of data collected in the study required a statistical analysis with the aim of describing better the Albufera environment.

Shapiro-Wilk test was used to check numerically the normality of the variable, at a 95 % significance level. General descriptive statistical variables were used: mean, median, maximum, minimum, variance and standard deviations. An Analysis of Variance (ANOVA) was conducted to compare areas and sampling periods.

Also Mann-Whitney and Kruskal-Wallis tests allowed to define the significant differences between areas, according to median values. These tests are non-parametric methods for testing if samples originate from the same family (or distribution); more specifically, Mann-Whitney test allows comparisons between two groups whereas Kruskal-Wallis is an extension of the latter to compare more groups of variables.

Moreover, a Random Forests[24] regression analysis was implemented in R (RStudio version 1.1.4) [25], to try to understand the relationship between environmental variables considered and biodiversity, and to extrapolate local results to the entire Albufera system.

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[24] Cutler, D. R., Edwards, T. C., Beard, K. H., Cutler, A., Hess, K. T., Gibson, J., & Lawler, J. J. (2007). Random forests for classification in ecology. *Ecology*, *88* (11), 2783–2792.
[25] R package "randomForest"

Results and Discussion

4.1 Data collected and evaluation criteria

Winter sampling period started on December and ended on February obtaining a total of 18 samples (6 points each time for 3 sampling dates).

A major number of samples has been collected in summer, from June to September, namely 33; they should have been 36 (12 points each time for 3 sampling dates), but in September three ponds were already dry.

Each sample has been associated to all variables collected: biotic indices, physical-chemical and microbiological parameters.

Spatial and temporal assumptions have allowed to compare areas and seasons, simplifying the available database:

- All dates from the same period have been unified, considering only differences between winter and summer. Median values of all the variables have been chosen.
- The same thing has been done for sampling sites: median values have been taken unifying sample parches belonging to the same areas, due to the fact that these patches are supplied by waters from the same origins.

These simplifications can be justified by the objective of this study, which is to understand how a water management could affect biodiversity, distinguishing temporally winter and summer for their different water regime and spatially areas according to the water origins.

4.2 Benthic macroinvertebrate families

During the winter sampling period a total of 25746 macroinvertebrates were recorded, belonging to 17 families, within 15 orders, 9 classes and 4 phylum (Table). Most abundant families were: *Daphniidae* (52,6 %), *Cyclopidae* (37,2 %), *Candonidae* (7,2%);

other families with lower but substantial abundance were *Physidae* (1,06 %), and *Chironomidae* (0,86%). There were other families from which very few individuals were obtained, with values between 0,003 and 0,1%.

During the summer sampling period a total of 10344 macroinvertebrates were recorded, belonging to 18 families, within 14 orders, 7 classes and 3 phylum (Table). Most abundant families were: *Daphniidae* (35,4 %), *Cyclopidae* (31,9 %), *Candonidae* (16,7%) and *Physidae (8,4 %)*; other families with lower but substantial abundance were *Chironomidae* (2,5%), *Dytiscidae* (1,6%), *Ephydridae* (0,76%), *Corixidae* (0,68%) and *Planorbidae* (0,63%).

It can be observed that dominant families in both periods are the same, as they are very tolerant of pollution. However, a significant change in the composition of the macroinvertebrate community is observed from one period to another, even if the number of families is almost the same. In summer period the total number of individuals recorded is much smaller than in winter, but this difference is due to the major presence of species more resistant to pollution (namely *Daphniidae* and *Cyclopidae*). These species are essential to calculate the QAELS index, which is specific for lentic environments. In summer there is a lower presence of these species and a more balanced percentage of Heteroptera and Coleoptera; for these reasons a greater biodiversity level has been observed in summer than in winter, as will be shown below.

Table 4.1: List of benthic macroinvertebrate families identified in the two sampling periods

Phylum	***Class***	***Order***	***Family***	***Winter***	***Summer***
Annelida	Oligochaeta	Haplotaxida		X	
Annelida	Oligochaeta	Clitellata			X
Arthropoda	Malacostraca	Isopoda		X	X
Arthropoda	Branchiopoda	Cladocera	Daphniidae	X	X
Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	X	X
Arthropoda	Ostracoda	Podocopida	Candonidae	X	X
Arthropoda	Malacostraca	Decapoda	Cambaridae	X	X
Arthropoda	Insecta	Diptera	Chironomidae	X	X
Arthropoda	Insecta	Ephemeroptera	Baetidae	X	X
Arthropoda	Insecta	Odonata, Zygoptera		X	X
Arthropoda	Insecta	Diptera	Tabanidae	X	
Arthropoda	Insecta	Coleoptera	Dytiscidae	X	X
Arthropoda	Insecta	Odonata	Libelluidae	X	
Arthropoda	Insecta	Heteroptera	Notonectidae	X	
Arthropoda	Insecta	Coleoptera	Hydrophilidae		X
Arthropoda	Insecta	Diptera	Limoniidae		X
Arthropoda	Insecta	Diptera	Ephydridae		X
Arthropoda	Insecta	Heteroptera	Corixidae		X
Arthropoda	Insecta	Arachnida	Hidracarina		X
Arthropoda	Insecta	Coleoptera	Hydraenidae		X
Chordata	Actinopterygii	Cyprinodontiformes	Poeciliidae	X	
Mollusca	Gastropoda	Basommatophora	Physidae	X	X
Mollusca	Bivalvia	Arcoida		X	
Mollusca	Gastropoda	Hygrophila	Planorbidae	X	X

Main families are described form an ecological perspective. All pictures shown below have been taken with a help of a binocular in the Laboratory of Ecology and they are all referred to the summer sampling.

Daphniidae: cladocera suborder. They are capable of colonizing all continental aquatic environments in permanent water as well as in temporary waters, stagnant or current. Cladocereans accept high salinity conditions and fresh water too; they also accept a varied diet, feeding from bacteria, algae and organic matter. For all these reasons, it can be seen the resistance of cladocereans at high level of pollution and the versatility to different types of environments. The value of Cladocereans as biological indicators is currently being studied (Juan Rueda et al. 2009).

Cyclopidae: copepoda class. They occupy different lentic environments. Their feeding is based on organic detritus and phytoplankton algae (Juan Rueda et al. 2009).

Candonidae: ostracoda class. Although they could be confused for molluscs, due to their aspect, a more detailed observation will allow to be sure that they are crustaceans. They are capable to live in any kind of waters. Also important is their ability to survive long periods of drought thanks to the system of closure of their shells (Juan Rueda et al. 2009).

Chironomidae: diptera order. Chironomids are one of diptera families most widely diffused in inland water systems, being the range of conditions where they could be found larger than any other group of aquatic insects [26]; they are characterized by being rapid colonizers, adapting to fluctuating conditions. Some species, such as Chironomus sp., are able to capture oxygen due to the presence of hemoglobin in lymph (which give the characteristic red colour), which gives them a great resistance to almost total anoxia conditions. In Mediterranean lagoons, the increase in abundance of this family has

[26] Cranston, P., (1995). The Chironomidae. The biology and ecology of non-biting midges, London, Chapman & Hall

been related to the increase of the eutrophication of waters, as in the case of the Albufera lagoon. [27]

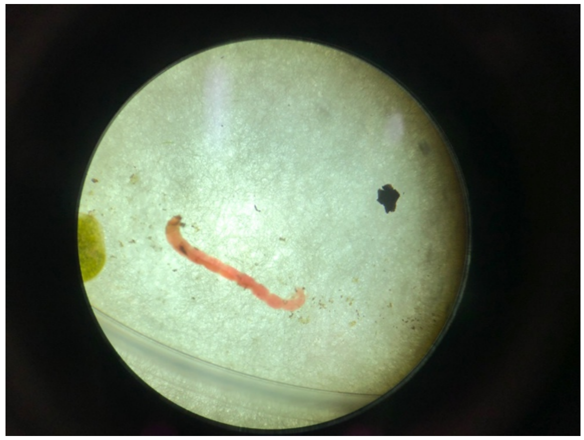

Figure 4.1: Exemplar of Chironomus sp.

Physidae: Basommatophora order. This family, like all molluscs, is a good indicator of contamination by its sedentary habits, longevity and resistance to variations and easy availability. Within the molluscs, this is the family that most tolerates pollution, followed by *Planorbidae* family.[28] In Mediterranean rivers the families with the highest tolerance to pollution is *Physidae* along with *Chironomidae* [29]. The characteristic species of the Albufera is the *Phisella acuta*: its great resistance to pollution allows it to occupy both the canals and ditches, with cleaner waters, as the lake, more affected by eutrophication [30].

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[27] Sahuquillo, M., Miracle, M.R., Rieradevall, M. y Kornijów, R., (2008). Macroinvertebrate assemblages on reed beds, with special attention to Chironomidae (Diptera), in Mediterranean shallow lakes. Asociación Ibérica de Limnología. Limnetica, 27.

[28] Naranjo, E. (2003). Moluscos continentales de México: Dulceacuícolas. *Revista de Biologia Tropical*, *51* (SUPPL. 3), 495–505.

[29] Vivas, S., Casas, J., Pardo, I., Robles, S., Bonada, N., Mellado, A., … Moyá, G. (2002). Aproximación multivariante en la exploración de la tolerancia ambiental de las familias de macroinvertebrados de los ríos mediterráneos del proyecto GUADALMED. *Limnetica*, *21*(3–4), 149–173.

[30] www.albufera.com

It is a biological indicator of waters rich in nutrients, which favours the growth of algae in the aquatic environment (Juan Rueda et al. 2009).

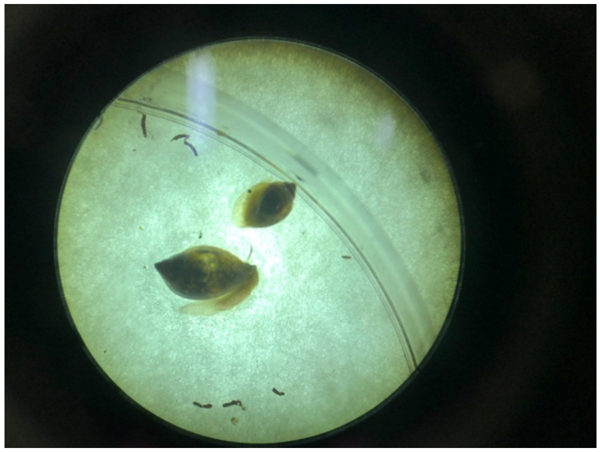


Figure 4.2: Exemplar of Physidae

Dytiscidae: Coleoptera order. This family may be found in a variety of ecosystems and water bodies. They usually live in waters up to one-metre-deep, as they need to introduce fresh air. They are recognized within the group of bioregulating species, with greater prospects for control in aquatic ecosystems, due to their morphological characteristic that make them have the best adaptive conditions for existence in varied environments [31].

[31] Schäfer, M., Lundkvist, E., Landin, J., Persson, T. y Lundström L., (2006). Influence of landscape structure on mosquitoes (Diptera: Culicidae) and dytiscids (Coleoptera: Dytiscidae) at five spatial scales in Swedish wetlands. Wetlands 26(1):57- 68.

Figure 4.3: Exemplar of Dytiscidae

Corixidae: Hemiptera order. They live in ponds and currents, swimming near the bottom. Some species are predatory, but most are phtyophagous, feeding on aquatic plants and algae. This taxon is indicated as very tolerant to pollution. Both larvae and adults of *Corixidae* and *Dytiscidae* were collected in summer.

Figure 4.4: Exemplar of Corixidae

Cambaridae: Decapoda order. All the individuals of this family that have been found are of the species *Procambarus Clarki* [32] (or American River Crab). This species, introduced in the early seventies, has experienced a progressive increase in the Albufera, to the point of being currently a pest for rice cultivation [33]. Its strategy consists of a short life cycle and a high fertility rate. These characteristics allow him to adapt to new environments and to be considered the species with greater ecological plasticity of all the decapods. It also tolerates low oxygen levels and prolonged periods of drought, that is essential to survive in the Albufera system, along with a great resistance to high temperature and high salinity values.

Figure 4.5: Exemplar of Procambarus Clarki, easily deducted without the binocular

4.2.1 Composition of macroinvertebrate differentiated by area

The compositions of macroinvertebrates can be differentiated from one area to another, always keeping separated sampling periods, in the same way as biotic indices have been calculated. Percentage ratios of families are graphically shown below.

[32] Girard, 1852
[33] www.albufera.com

Winter period

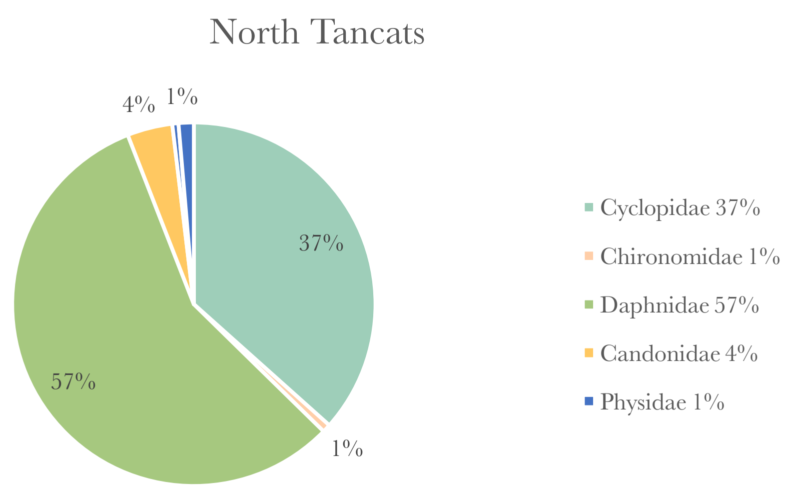


Figure 4.6: Composition of macroinvertebrate families in North Tancats, in winter.

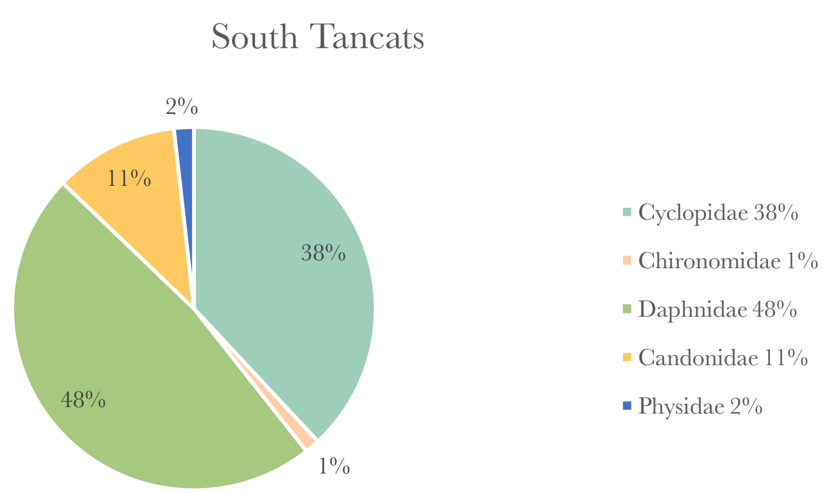


Figure 4.7: Composition of macroinvertebrate families in South Tancats, in winter

Summer period

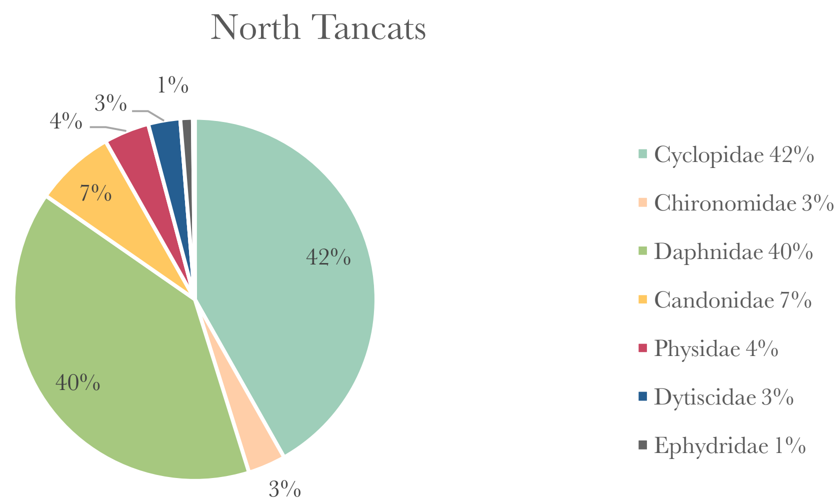


Figure 4.8: Composition of macroinvertebrate families in North Tancats, in summer.

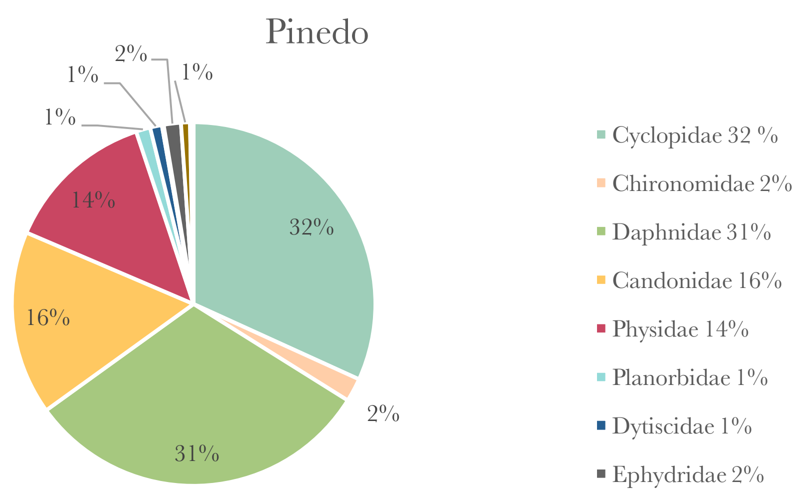


Figure 4.9: Composition of macroinvertebrate families in Pinedo area, in summer.

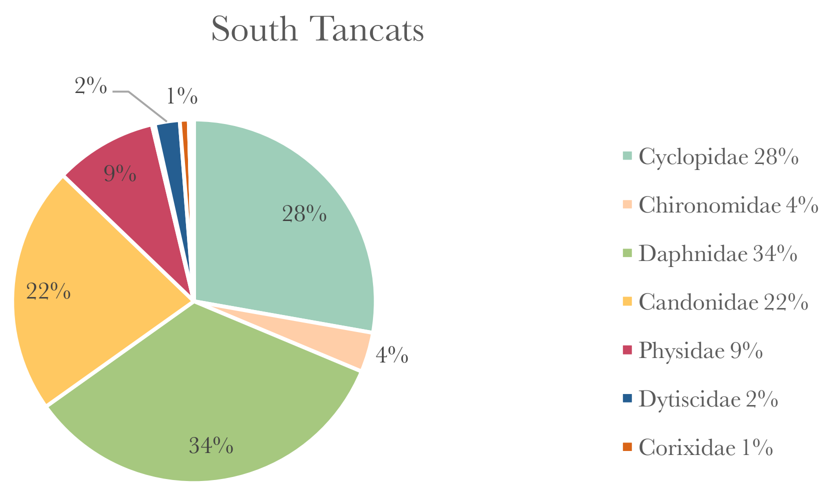


Figure 4.10: Composition of macroinvertebrate families in South Tancats, in summer

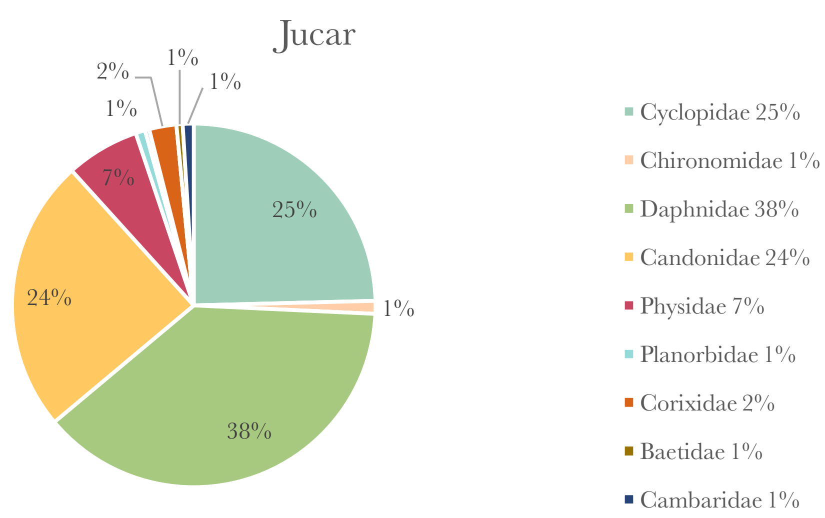


Figure 4.11: Composition of macroinvertebrate families in Jucar area, in summer

4.3 Biotic indices

Biotic indices have been applied to evaluate water quality and biodiversity. Through a statistic analysis all results have been compared to find significant differences between areas and sampling periods.

At first, Shapiro-Wilk test was used to check numerically the normality of the variable, at a 95 % significance level. Given that all distributions of biotic indices values followed the normally distribution, an Analysis of Variance (ANOVA) was conducted.

4.3.1 Shannon and Simpson diversity indices

In this study biodiversity has been evaluated through two diversity indices: Shannon-Weaver (or Shannon Diversity Index) and Simpson Index; they integrate richness and abundance of macroinvertebrate community into a single value and they have been widely used in ecology.

In the table below, median values are shown, relating to data distributions as explained in the evaluation criteria.

Table 4.2: Median values of diversity indices

	Area	***Shannon***	***Simpson***
Winter	North Tancats	1,19	0.50
	South Tancats	1,51	0,59
Summer	Pinedo	1,8	0,66
	North Tancats	1,74	0,64
	South Tancats	1,93	0,69
	Júcar	2,08	0,69

All Shannon index values indicate a moderate pollution level, with the exception of the Júcar area, classified as light polluted.

4.3.1.1 Comparison between areas

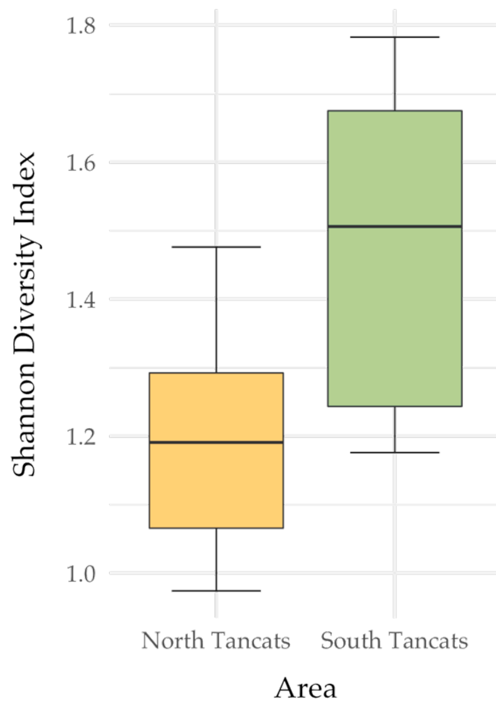


Figure 4.12: Variation of SDI depending on winter areas

Significant differences of SDI have been observed in winter between North and South Tancats *(ANOVA: F=10, d.f.=1,16, p-value=0,0506)*, obtaining a major value of biodiversity in the South area. The same can be concluded for Simpson index, which follows the same trend of SDI with similar results *(ANOVA: F=8,127, d.f.=1,16, p-value=0,0116)*.

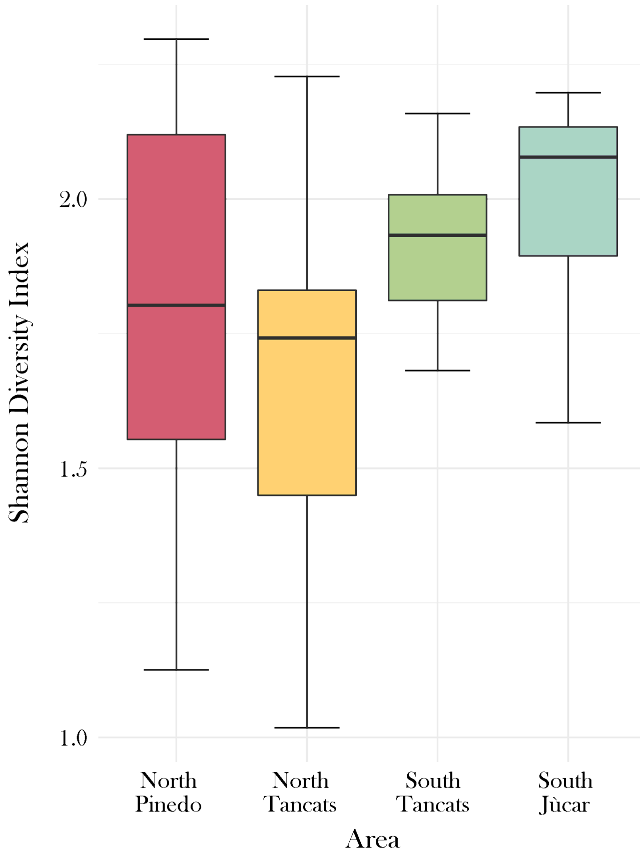


Figure 4.13: Variation of SDI depending on summer areas, from North to South

In summer, higher values of SDI and Simpson Index have been observed in southern areas. North Tancats seems to be the area which receives water of lower quality.

However, unlike originally expected, differences are not so significant between areas (SDI, *ANOVA: F=1,725, d.f.=3,29, p-value=0,184)*. Results change when southern areas and northern areas are considered together, making a distinction only between North and South (SDI, *ANOVA: F=4,136, d.f.=1,31, p-value=0,05)*.

4.3.1.2 Comparison between sampling periods

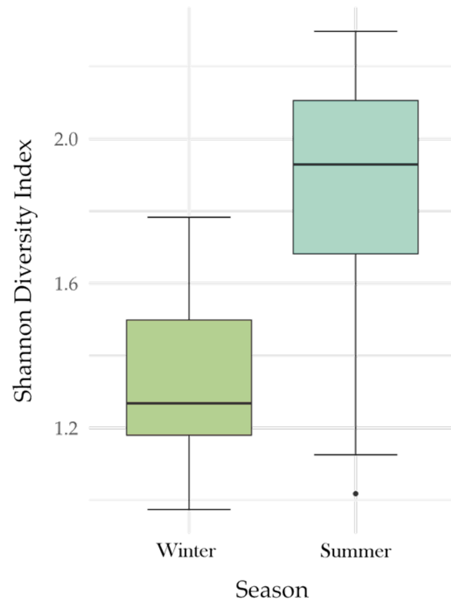


Figure 4.14: Variation of SDI depending on sampling periods

According to both diversity indices, a major level of biodiversity has been observed in summer than in winter. As can be seen in figure 4.8, winter samples show a SDI overall value of 1,27, compared to a SDI overall value in summer of 1,93. *(ANOVA: F=34,72, d.f.=1,49, p-value<0,001).*

The same can be deducted with the Simpson Index, which follows a similar trend *(ANOVA: F=21,88, d.f.=1,49, p-value<0,001).*

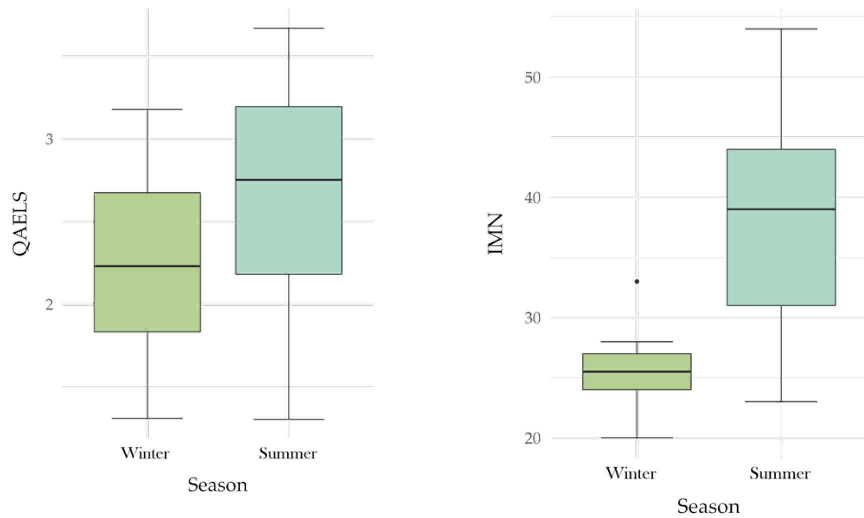
4.3.2 QAELS, IMN

Water quality has been evaluated through the QAELS (Índex de Qualitat de l'Aigua d'Ecosistemes Lenítics Soms) index and the IMN (Índice del Modo de Nutrición); all these indices are based on the presence or absence of certain species indicative of water quality, weighting them according to their tolerance to pollution (namely pollution tolerant taxa).

Table 4.3:Median values of biotic indices

	Area	QAELS	IMN
Winter	North Tancats	2,62	24
	South Tancats	2,15	27
Summer	Pinedo	3,16	41
	North Tancats	2,75	36
	South Tancats	2,33	41
	Júcar	2,79	36

For none of water quality indices have been observed significant differences over the sampling areas. QAELS index indicates a poor water quality for all areas and periods, even if summer period shows higher values *(Kruskal-Wallis, chi-squared=3,8859, d.f.=1, p-value=0,048)*. The same can be concluded for the IMN index, the result of which indicates an impacted environment with a "low food web diversity level" and significant differences only comparing seasons *(Kruskal-Wallis, chi-squared=19,982, d.f.=1, p-value<0,001)*.



Figures 4.15: QAELS and IMN depending on sampling periods

4.4 Physical-chemical parameters

In the same way as described for biotic indices, a statistical analysis was conducted to compare all data collected. For this group of data, the Shapiro-Wilk test showed that not all the distributions followed the normally distribution. For this reason, it was considered more appropriate to recourse to non parametric tests, namely Mann-Whitney and Kruskal-Wallis tests.

4.4.1 Dissolved oxygen, Electrical conductivity, pH

As mentioned above, these parameters have been measured in situ, directly from small bottles of water taken in few points over the patch. In the table below, median values of these variables are shown, relating to data distributions as explained in the evaluation criteria.

Table 4.4: Median values of in-situ physical-chemical parameters

	Area	***pH***	***EC [µS/cm]***	***Dissolved Oxygen***	***Oxygen Saturation***
Winter	North Tancats	7,87	3,72	7,62	64
	South Tancats	8,24	2,19	12,72	110,27
Summer	Pinedo	7,5	2,1	4,31	52
	North Tancats	7,52	2,49	5,76	50,35
	South Tancats	8	1,57	8,54	107,5
	Júcar	7,97	1,16	7,56	92

For all physical-chemical parameters have been observed significant differences between areas and sampling periods. The results of the statistical analysis and the boxplots are in Appendix B.

The most affected area seems to be North Tancats area, with higher values of electrical conductivity and lower values of dissolved oxygen. As regards sampling periods, all parameters are higher in winter then in summer.

4.4.2 Nitrites, Nitrates, Phosphates

Chemical parameters were measured in the Laboratory of the Valencia Catholic University: water samples were collected in two litre bottles and transported as soon as possible to the laboratory, where they were stored at 4°C until chemical and microbiological analysis, which were carried out over 24 hours.

Table 4.5: : Median values of laboratory chemical parameters

	Area	NO_2 [mgN/l]	NO_3[mgN/l]	PO_4[mgP/l]
Winter	North Tancats	0,01	0,9	0,87
	South Tancats	0,01	0,9	0,7
Summer	Pinedo	0,06	1,67	0,9
	North Tancats	0,06	1,66	0,68
	South Tancats	0,07	1,3	0,7
	Júcar	0,02	1	0,47

In winter, both nitrites and nitrates remained constant in both areas, with concentrations about 0,01 mgN/l for nitrites and 0,9 mgN/l for nitrates; these values are the detection limits, which means that lower concentrations cannot be measured in laboratory. In summer, values oscillate but no significant differences have been observed between areas (NO_2, *Kruskal-Wallis chi-squared=1,088, d.f.=3, p-value=0,78;* NO_3, *Kruskal-Wallis, chi-squared=3,735, d.f.=3, p-value=0,292*). Significant differences for nitrites and nitrates have been only observed from one period to another with higher concentrations in summer than in winter, supposedly due to agriculture activities and resulting fertilizers. (NO_2, *Kruskal-Wallis chi-squared=13,34, d.f.=1, p-value<0,001;* NO_3, *Kruskal-Wallis, chi-squared=11,935, d.f.=1, p-value<0,001*).

On the contrary, phosphates concentrations have shown significant differences between summer areas and not between periods (Areas, *Kruskal-Wallis chi-squared=9,713 d.f.=3, p-value=0,022;* Periods, *Kruskal-Wallis, chi-squared=0,01 d.f.=1, p-value=0,92*).

4.5 Microbiological parameters

As for chemical variables, microbiological analyses were carried out in laboratory, dealing with the measurement of Total coliforms, Faecal coliforms and Enterococci concentrations in water.

Table 4.6: : Median values of microbiological parameters

	Area	**Total Coliforms [UFC/100 ml]**	**Enterococci [UFC/100 ml]**	**Faecal Coliforms [UFC/100 ml]**
Winter	North Tancats	>300	26	6
	South Tancats	>300	86	3
Summer	Pinedo	>300	>300	17
	North Tancats	>300	>300	137
	South Tancats	>300	>300	9
	Júcar	>300	>300	43

Total coliforms resulted as "uncountable" both in winter and summer, due to high concentrations, which exceeded the detention limit (300 UFC/100 ml).

Also Enterococci concentrations were higher than 300 UFC/100 ml for the entire summer; instead in winter varied values were obtained, with a median value of 26 UFC/100 ml in North Tancats and of 86 UFC/100 ml in South Tancats. However, this difference between north and south resulted as no significant (*Kruskal-Wallis, chi-squared=2,0065, d.f.=1, p-value=0,1566).*

Faecal Coliforms concentrations varied greatly between areas in both periods, with a range of 0-47 UFC/100 ml in winter and of 0-124 UFC/100 ml in summer; however, also in this case, not significantly (Winter by areas, *Kruskal-Wallis, chi-squared=0,032 d.f.=1, p-value=0,857;* Summer by areas, *Kruskal-Wallis, chi-squared=3,248, d.f.=3, p-value=0,355)*. The only significant difference was observed by seasons (*Kruskal-Wallis, chi-squared=3,74, d.f.=1, p-value=0,05).*

4.6 Biodiversity and flooded area over time

Shannon diversity index (SDI) was also employed to outline a biodiversity trend over time for the Albufera. Local results were extrapolated to the entire system, according to the related area: South and North Tancats, Pinedo and Júcar. These areas were summarized with their median values (Table 4.2).

Biodiversity at a given point in time was established on the basis of the related flooded area: the resulted SDI was obtained by weighing each SDI median value, representative of a given area and period, according to the corresponding percentage of flooded area at that time.

Percentage ratios of each area in a given date was estimated by calculating polygon areas in QGIS, comparing with the corresponding Landsat image and NDWI extracted (see section 3.1.1).

In the table below, final SDI values are shown and graphic in Figure along with flooded area values. It should be clarified that SDI equal to 0 means that in that time fields are no flooded and biodiversity in this study has not been evaluated in the lagoon. Dates are referred to Landsat image acquisition day.

Table 4.7: SDI and flooded area values over the year

Date	***Shannon Diversity Index (SDI)***	***Flooded area [km^2]***
11/10/17	0	25,94
27/10/17	1,620	55,78
12/11/17	1,607	79,03
05/12/17	1,627	96,16
22/01/18	1,607	78,05
31/01/18	1,611	69,55
27/03/18	0	24,54
05/04/18	0	24,06
07/05/18	0	24,06
17/07/18	1,851	169,68
14/08/18	1,851	168,49
28/09/18	1,863	147,39

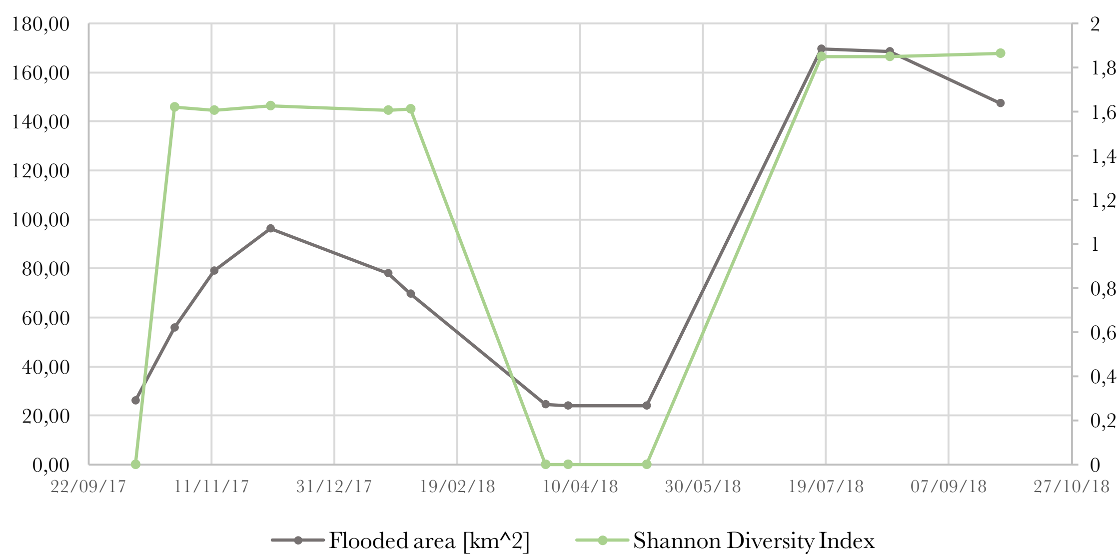


Figure 4.16: SDI and flooded areas trends over a year

At the same way as explained for one year, biodiversity trend, in terms of Shannon Diversity Index can be extrapolated in function of all values of flooded areas. The figure below shows a hypothetical trend of the SDI for the last five years (available Landsat data).

Figure 4.17: SDI and flooded areas trends over the last five years

CONCLUSIONS

7.1 Conclusions

This research was conducted with a research group of the Polytechnic University of Valencia. The objective was to explored the relationship between wetland communities, in terms of biodiversity, and water management.

Benthic macroinvertebrates were used as indicator to evaluate the ecological response in the Albufera. 51 samples were carried out in rice fields in two periods, winter (December-February) and summer (June-September). According to water regime, four different sampling areas were identified.

Macroinvertebrates belonging to 24 families, 17 orders, 9 classes and 4 phyla were classified over the year. Most abundant families in both periods were *Daphniidae*, *Cyclopidae* and *Candonidae*, followed by *Physidae, Chironomidae*, *Dytiscidae, Corixidae*. All families identified are very tolerant to pollution.

All biotic indices applied (Shannon, QAELS, IMN, Simpson) generally indicated a stressed environment system, with a moderate pollution level and a low water quality, with the exception of Júcar area, which resulted as light polluted.

The application of biotic indices, in particular the Shannon Diversity index (SDI), allowed comparison between areas and seasons. Significant differences, in terms of diversity of macroinvertebrate community, were observed especially between North and South. Northern areas, which suffer most the influence of wastewater treatment plant, resulted as the one with least quality, leading to the conclusion that waste water treatment plant is causing major ecological problems, whereas the water coming from Jucar river seems to be of higher quality.

Differently than expected, the delimitation of the four areas in summer period was not so effective in relation to biodiversity: comparing the four areas, no significant differences were observed between Júcar and South Tancats and between Pinedo and North Tancats. This can be explained partly by the fact that Tancats, even if supplied by the lagoon, are affected by the irrigation activity: irrigation surplus waters in fact are spilled in the lagoon. For the same reasons, significant differences were observed in winter between North and South Tancats, which are also flooded with the surplus irrigation waters of summer period, and so they are affected respectively by the WWTP in Pinedo and the Jucar river.

Moreover, a higher diversity level was observed in summer than in winter, according to all biotic indices evaluated.

In addition to the macroinvertebrate sampling, a water quality analysis was carried out, collecting physical-chemical and microbiological parameters. For all physical-chemical parameters were observed significant differences both between areas and sampling periods. The most affected area seems to be North Tancats area, with higher values of electrical conductivity and lower values of dissolved oxygen. Moreover, it could be observed a remarkable increase of electrical conductivity, almost three times greater than values obtained in the previous study in 2011.

Shannon diversity index (SDI) was also employed to outline a biodiversity trend over the year for the Albufera, along with related flooded area, identified using satellite images with remote sensing.

7.2 Future developments

The study provided a methodology to evaluate the ecological response of the Albufera lagoon. However, a more extended sampling is needed to better describe spatial and temporal variation of biodiversity in this wetland system.

As the peak of biodiversity was observed for both periods on the second day (at times when the flooded area was greatest), only one representative sampling day of the entire period could be sufficient. Resources could be better used for sampling more points, including western areas (municipality term of Silla and Sollana) and areas supplied by Turia river (municipality term of Favara).

Moreover, as regards macroinvertebrate classification in laboratory, a distinction should be made between species more abundant and resistant to pollution (*Daphniidae*, *Cyclopidae* and *Candonidae*) and other species present in smaller quantities. The wide gap between abundances could have greatly affected the results of biotic indices.

Appendix A

Map and delimitations of Albufera Tancats

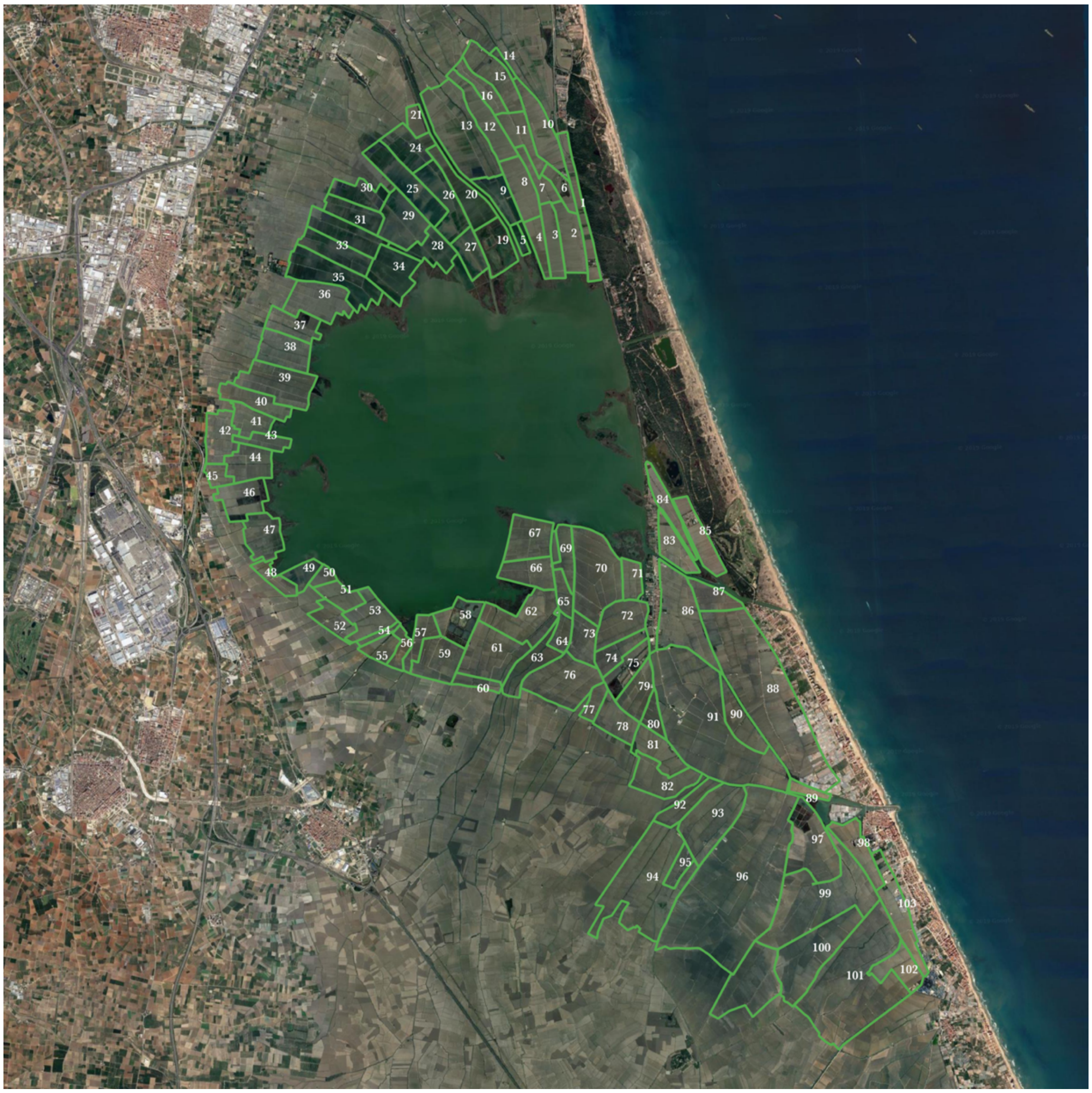


Figure 8.1 : Albufera Tancats

Table 8.1: Favara/Pinedo (North Tancats)

ID	Tancat Name	Area [ha]
1	Tancat del Pujol o del Pomero	36,6
2	Tancat del Cabiles	40,8
3	Tancat de l'Escorredor Fondo	30,3
4	Tancat de Gambell	20,7
5	Tancat del Noi	7,4
6	Tancat de Foro	18,4
7	Tancat de Buenos Aires	21,4
8	Tancat de la Modernista	40,0
9	Tancat de Burriel	29,8
10	Tancat de la Rambla	48,8
11	Tancat de Villalba	32,4
12	Tancat de Rabisanxo	47,3
13	Marjal de Massanassa	110,7
14	Tancat de les Monges	5,2
15	Sequía Nova	46,4
16	Tancat de Benjamin	24,3
19	Tancat de la Pipa o Tancadeta	40,7
20	Tancat de la Sardina	42,7
21	Tancat de l'Alfafarenc	13,5
23	Tancat de la Font de la Rambleta	117,4
24	Tancat de Naia	40,3
25	Tancat del Sarier	59,8
26	Tancat del Sarier	49,7
27	Tancat dels Peixcadors	27,8

Table 8.2: Silla (South Tancats)

ID	Tancat Name	Area [ha]
35	Tancat del Sequiaset	69,2
39	Tancat del Rorro	63,5
36	Tancat del Desaigue	54,1
29	Tancat del Comù	53,9
34	Tancat del Dulero	50,6
32	Tancat del Figuero	46,5
38	Tancat de la Vega	44,6
46	Tancat de la Ratlla	42,8
47	Tancat de la Foia	40,6

33	Tancat del Mill-Hueso	40,5
44	Tancat del Passiego	38,6
42	Tancat de Lluent	38,2
28	Tancat dels Germanells	33,9
37	Tancat de la Torreta Ampla	33,6
40	Tancat dels Calvo o de Mustieles	32,8
31	Tancat de Carota	32,6
30	Font Nova	30,9
41	Tancat dels Uisos	26,9
43	Tancat del Palaco de Plus-ultra	17,5
48	Tancat de l'Amarguet	17,3
45	Tancat Rioler	13,5

Table 8.3: Sollana (South Tancats)

ID	***Tancat Name***	***Area [ha]***
49	Tancat de Grau	18,4
50	Tancat del Xicorro	9,6
51	Tancat de Farfall	22,6
52	Tancat de Rafalet	26,2
53	Tancat de Foro	40,0
54	Tancat de Tapia	7,4
55	Tancat del Mellat	19,7
56	Tancat del Ferm	14,3
57	Tancat de Peret	23,8
58	Tancat del Moreno	41,1
59	Tancat de la Coronela	47,0
60	Tancat de Micò	13,8
61	Tancat de Zacares de Dalt	71,9
62	Tancat de Zacares de Baix	69,7
63	Tancat de la Quadra	37,7
64	Tancat de Curro Zapatos	16,4
65	Tancat de Foro	16,7
69	Tancat de l'Abadejo	24,3
68	Tancat de la Taut	6,0
67	Tancat del Senyoret	47,6
66	Tancat del Passiego	37,0

Table 8.4: Sueca (South Tancats)

ID	Tancat Name	Area [ha]
70	Tancat de Baldovì	99,5
71	Tancat de la Mata de les Rates	20,0
73	Tancat de la Barraca	31,0
76	Tancat del Xato	74,0
77	Tancat de Miragall	14,5
78	Tancat de la Sardina	33,4
72	Tancat del Fangar	48,1
74	Tancat del Rei	27,7
75	Tancat de Malta	32,1
79	Tancat del Rei	34,7
80	Tancat d'Ompedra	15,9
81	Tancat de Noira	38,0
82	Tancat de Flores	45,6
86	Tancat de l'Establiment	91,9
87	Tancat de les Piules	37,6
85	Tancat de l'Alcatì	36,9
84	Tancat del Racò de l'Olla	26,7
83	Tancat de l'Illa	30,8
88	Tancat del Recatì	260,2
89	Tancat de l'Ortells	10,4
90	Tancat de Porta	40,0
91	Tancat de l'Estell	263,7
97	Tancat Anxumara	80,0
99	Tancat Arce i Sebater	151,8
96	El Malvinar	373,8
92	Tancat de Genovès	26,9
93	Tancat de Camot	68,4
95	Finca de Raga	15,7
94	Tancat de Caro	166,2
100	Tancat Corretjola	98,9
102	Tancat Rosari	33,8
101	Tancat Tamarital	215,9
98	Tancat del Barò	36,7
103	Tancat de la Loteria	51,4

Appendix B

Figure 9.1: Scores assigned to the different aquatic macroinvertebrate families for the IBMWP calculation

TALASSOHALINES	k_i	N_i	n_i	k_i*n_i
CLADÒCERS				
Chydorus	5			
Daphnia	1			
Pleuroxus	3			
Simocephalus	4			
COPÈPODES				
Acanthocyclops	4			
Calanipeda	6			
Canuella	4			
Cletocamptus	4			
Cyclops	7			
Diacyclops	7			
Eucyclops	3			
Eurytemora	7			
Halicyclops	5			
Harpacticus	7			
Mesochra	10			
Nitokra	7			
Pseudonychocamptus	5			
Tisbe	3			
Tropocyclops	9			
OSTRACODES				
Cyprideis	5			
Cypridopsis	7			
Eucypris	6			
Heterocypris	4			
Loxoconcha	5			
Sarscypridopsis	1			
Xestoleberis	6			

DOLCES-OLIGOHAL. PERMANENTS	k_i	N_i	n_i	k_i*n_i
CLADÒCERS				
Alona	8			
Bosmina	5			
Ceriodaphnia	4			
Chydorus	3			
Daphnia	2			
Moina	1			
Oxyurella	8			
Pleuroxus	5			
Scapholeberis	8			
Simocephalus	7			
COPÈPODES				
Acanthocyclops	4			
Calanipeda	6			
Cyclops	8			
Ectocyclops	7			
Eucyclops	4			
Macrocyclops	8			
Megacyclops	10			
Tropocyclops	6			
OSTRACODES				
Cypria	3			
Cypridopsis	8			
Eucypris	8			
Herpetocypris	4			
Heterocypris	1			
Paracyclops	1			

DOLCES-OLIGOHAL. TEMPORÀNIES	k_i	N_i	n_i	k_i*n_i
CLADÒCERS				
Alona rectangula	3			
Ceriodaphnia quadrangula	5			
Ceriodaphnia reticulata	3			
Chydorus sphaericus	6			
Daphnia curvirostris	10			
Daphnia magna	3			
Daphnia obtusa	1			
Daphnia pulicaria	7			
Moina braquiata	5			
Simocephalus expinosus	6			
Simocephalus vetulus	7			
COPÈPODES				
Acanthocyclops gr. *robustus*	5			
Canthocamptus staphylinus	9			
Cyclops sp.	5			
Diacyclops bicuspidatus	8			
Diacyclops bisetosus	4			
Diaptomus cyaneus	10			
Megacyclops viridis	5			
Metacyclops minutus	7			
Mixodiaptomus incrassatus	7			
Mixodiaptomus kupelwieseri	6			
Neolovenula alluaudi	4			
OSTRACODES				
Cyclocypris ovum	4			
Cypridopsis vidua	8			
Eucypris virens	5			
Herpetocypris chevreuxi	7			
Heterocypris barbara	4			
Heterocypris incongruens	5			
Plesiocypridopsis newtoni	4			

Figure 9.2: k_i values for the ACCO Index (ACA, 2004). For this study, the third column has been chosen, that it means "temporary freshwater wetland", because fields do not remain flooded all the time.

Tabla 1. Recopilación de los macroinvertebrados con sus afinidades tróficas (Tachet et al, 1987). MN = Modo de nutrición; Ad = Adultos; La = Larvas; H = Herbívoros; O = Omnívoros; D = Detritívoros; P = Predadores; Rm = Ramoneadores; Rs = Raspadores; F = Filtradores; L = Limnívoros; ChH = Chupadores herbívoros; ChP = Chupadores predadores.	
Taxón	**MN**
PORIFERA, BRYOZOA	F
CNIDARIA, NEMERTINA: **Tetrastemmatidae, Hirudidae;** *Haemopis* sp. **Erpobdellidae**	P
PLATHYHELMINTHA, NEMATHELMINTHA: Nematodo, Gordiacea	ChP
Aelosomatidae, Naididae	O
Branchiobdellidae, Glossiphoniidae, Piscicolidae, Hirudidae; *Hirudo* sp.	ChP
Otros anélidos	L
Acroloxidae, Ancylidae, Bythinellidae, Ferrissiidae, Melanopsidae, Neritidae, Valvatidae	Rs
Bithyniidae, Hydrobiidae, Lymnaeidae, Planorbidae, Physidae, Viviparidae	Rm
Bivalvia	F
Acari La.	ChP
Acari Ad.	P
Ostracoda, **Triopsidae, Gammaridae,** Decapoda	O
Chirocephalidae, Limnadiidae	F
Argulidae	ChP
Asellidae	D
Caenidae, Ephemerellidae: *Ephemerella* sp., **Ephemeridae, Leptophlebiidae, Oligoneuriidae, Polymitarcidae, Potamanthidae, Siphlonuridae, Capniidae, Leuctridae, Nemouridae**	D
Prosopistomatidae, Heptageniidae, Taeniopterygidae: *Brachyptera* sp., *Rhabdiopteryx* sp.	Rs
Baetidae (excepto *Raptobaetopus*)	Rm
Raptobaetopus sp.	P
Ephemerellidae: *Torleya* sp.	H
Taeniopterygidae: *Taeniopteryx* sp.	D
Chloroperlidae, Perlidae, Perlodidae, Odonata	P
Heteroptera (excepto Corixidae)	ChP
Corixidae	Rs
Agriotypidae, Sisyridae	ChP
Osmylidae, Sialidae	P
Pyralidae	H
Dytiscidae: Ad., **Hygrobiidae, Hydrophilidae:** Larvas, **Gyrinidae**	P
Dytiscidae: La.	ChP
Elmidae,Eubriidae, Haliplidae, Helodidae, Hydraenidae, Hydrophilidae: Ad.; **Limnebiidae**	Rm
Chrysomelidae, Helophoridae: Ad., **Hydrochidae**	H
Helophoridae: La.	O
Dryopidae	D
Ecnomidae, Molannidae, Polycentropodidae, Rhyacophilidae	P
Brachycentridae, Glossosomatidae, Goeridae, Helichopsychidae, Leptoceridae, Drusinae, Stenophilacini, Cheatopterygini, **Odontoceridae, Thremmatidae,**	Rs
Hydroptilidae	ChH
Hydropsychidae, Philopotamidae, Psychomyiidae	F
Phryganeidae	O
Beraeidae, Limnephilidae: Apataniinae,	H
Dicosmoecinae, Limnephilini, **Lepidostomatidae, Sericostomatidae, Calamoceratidae,**	D
Blephariceridae, Orthocladiinae, Diamesinae, Corynoneurinae; **Dixidae, Psychodidae**	Rs
Tipulidae, Ephydridae	D
Limoniidae, Chaoboridae, Chironomidae: Tanypodinae	P
Cylindrotomidae	H
Ptychopteridae, Chironomidae: Chironominae	L
Culicidae, Simuliidae, Stratiomyidae, Syrphidae	F
Ceratopogonidae	O
Anthomyidae, Athericidae, Dolichopodidae, Empididae, Muscidae, Rhagionidae, Scatophagidae, Sciomyzidae, Tabanidae,	**ChP**

Figure 9.3 : Classification in nutritional groupings proposed by Tachet et al. (1987)

Appendix C

Physical-chemical parameters trends and statistical results

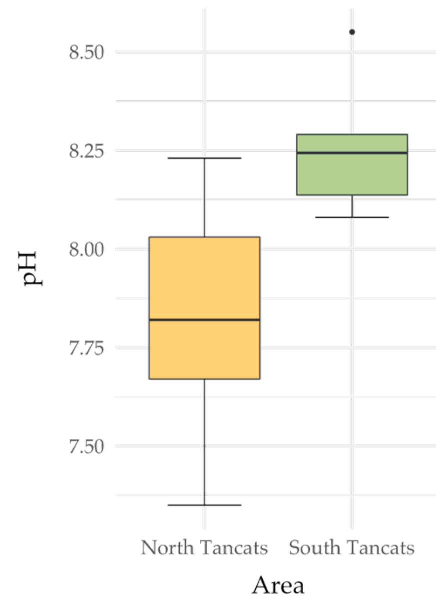


Figure 10.1: pH depending on winter areas (Kruskal-Wallis, chi-squared=10,453, d.f.=1, p-value=0,0012)

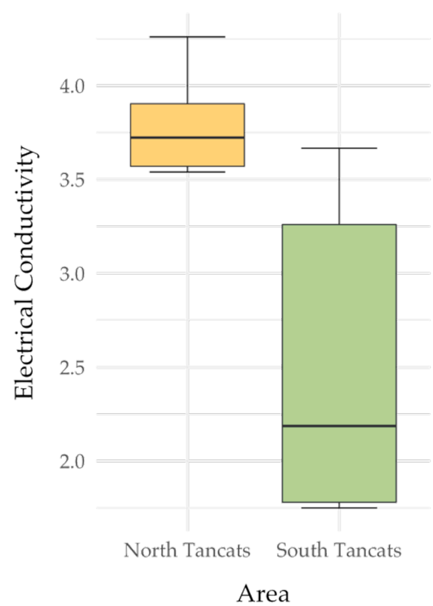


Figure 10.2: Electrical Conductivity depending on winter areas (Kruskal-Wallis, chi-squared=10,453, d.f.=1, p-value=0,0012)

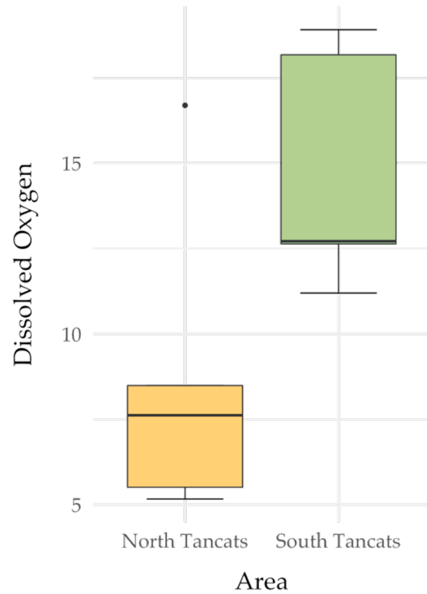


Figure 10.3: Dissolved Oxygen depending on winter areas (Kruskal-Wallis, chi-squared=9,3385, d.f.=1, p-value=0,0023)

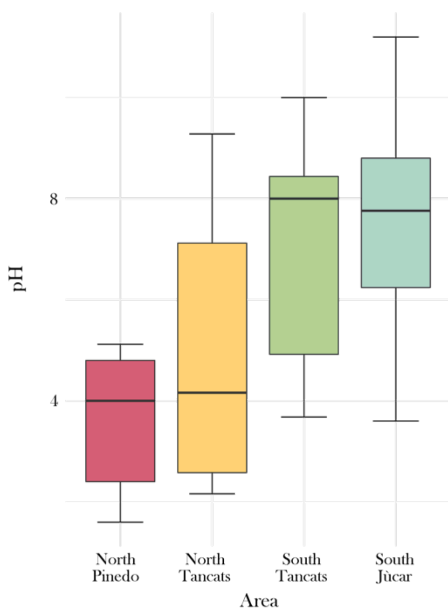


Figure 10.4: pH depending on summer areas, in order from North to South. (Kruskal-Wallis, chi-squared=10,713, d.f.=3, p-value=0,0134)

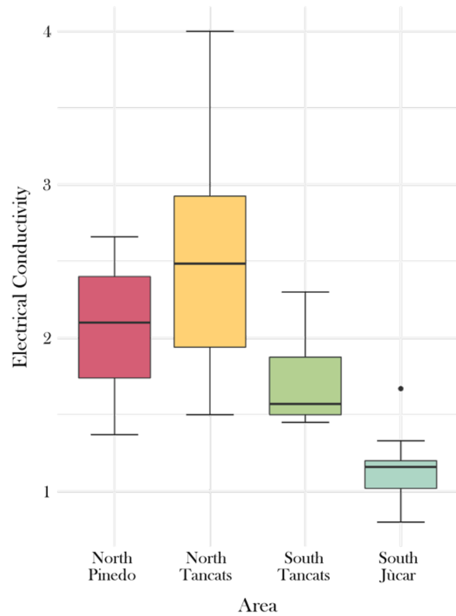


Figure 10.5: Electrical Conductivity depending on summer areas (Kruskal-Wallis, chi-squared=10,713, d.f.=3, p-value=0,0134)

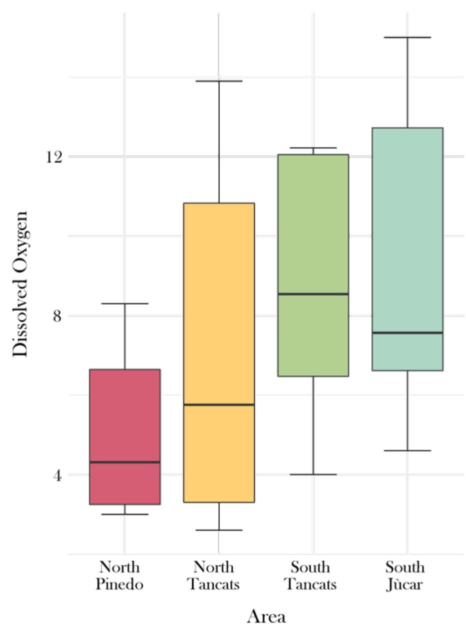


Figure 10.6: Dissolved Oxygen depending on summer areas (Kruskal-Wallis, chi-squared=6,3187, d.f.=3, p-value=0,0970)

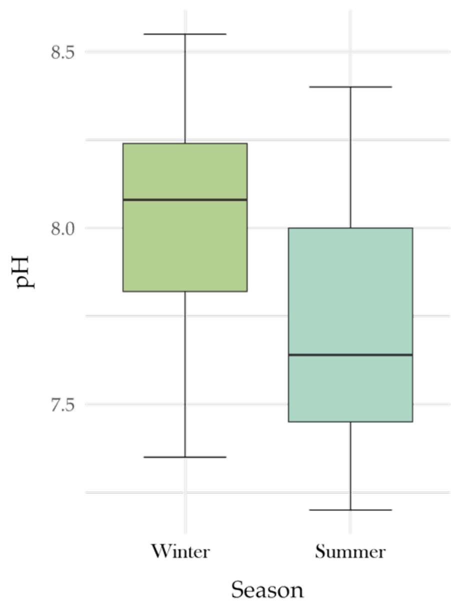


Figure 10.7: pH depending on sampling periods(Kruskal-Wallis, chi-squared=9,8301 d.f.=1, p-value=0,0017)

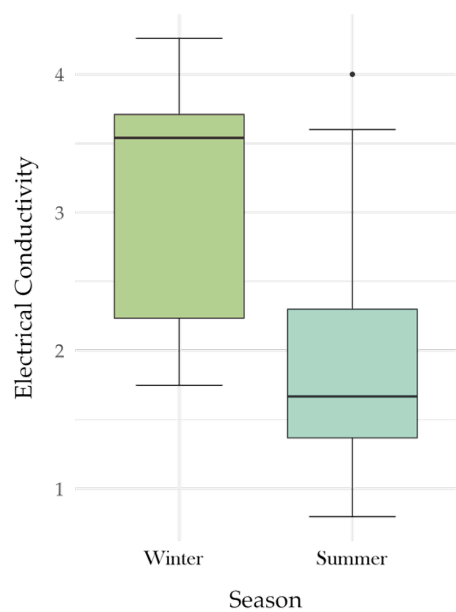


Figure 10.8: Electrical Conductivity depending on sampling periods (Kruskal-Wallis, chi-squared=16,177, d.f.=1, p-value<0,001)

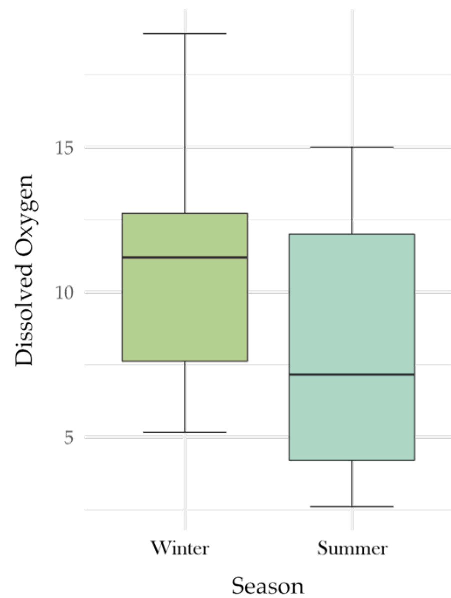


Figure 10.9: Dissolved Oxygen depending on sampling periods (Kruskal-Wallis, chi-squared=6,7856, d.f.=1, p-value=0,0092)

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