Brackish coastal lakes

Italian habitats
Italian Ministry of the Environment and Territory Protection / Ministero dell'Ambiente e della Tutela del Territorio
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Scientific coordinators
Alessandro Minelli · Sandro Ruffo · Fabio Stoch

Editorial committee
Aldo Cosentino · Alessandro La Posta · Carlo Morandini · Giuseppe Muscio

"Brackish coastal lakes - A delicate balance between fresh and salt waters"
edited by Fabio Stoch

Texts
Giovanni Caniglia · Luca Lapini · Giuseppe Muscio · Sergio Paradisi · Fabio Perco · Enrico Ratti · Lorenzo Serra · Margherita Solari · Fabio Stoch

In collaboration with
Uberto Ferrarese

English translation
Elena Calandruccio · Alison Garside · Gabriel Walton

Illustrations
Roberto Zanella
except 77, 78, 81, 84, 85, 86 (Andrea Toselli)

Graphic design
Furio Colman

Photographs
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ITALIAN HABITATS

Brackish coastal lakes

A delicate balance between fresh and salt waters

MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO
MUSEO FRIULANO DI STORIA NATURALE · COMUNE DI UDINE

Italian habitats

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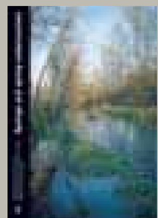

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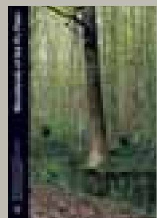

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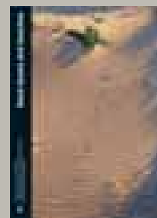

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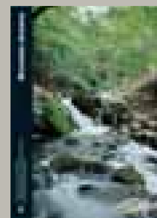

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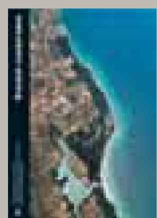

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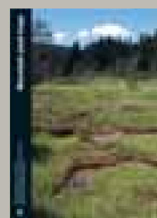

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Introduction

FABIO STOCH

Green sandpiper (*Tringa ochropus*)

Italian coastlines stretch for 8000 km, sometimes rocky and steep, even plunging into the sea, at other times low and sandy near river mouths, all with different environments. This brief description already identifies areas containing coastal lakes and brackish ponds.

Deltas are environments in which, on the one hand, the power of the sea hinders river transport of particle-sized material and, on the other, favours the accumulation of a large quantity of debris. Over the years, these processes give rise to long strips of sand and silt parallel to the coastline. The resulting bars lead to the formation of lagoons, coastal lakes and ponds.

Later, complex interactions between sediments, water salinity, basin morphology and plant associations further diversify these environments, in which two geomorphological processes, one due to the power of rivers, the other to the sea, seek a balance.

It is through this eternal process that bars form and disappear, thus creating, maintaining and destroying coastal wetlands - true environments between land and sea.

Endowed with a complex nature, as they contain neither salty nor freshwater, but "brackish" water, these habitats are unique and particularly evocative from the natural viewpoint.

Their complex morphological characteristics, high salinity and temperature variations profoundly affect the life cycles of the animals and plants that inhabit them. Coastal wetlands are not easy to live in, as they are harsh, highly selective, even extreme habitats. Only species with peculiar physiological adaptations can live there all their lives. Their great complexity and sometimes curious strategies for survival are illustrated in this volume.

A coastal pond at Villasimius (Sardinia)

Severe environmental conditions limit the biodiversity of aquatic and riparial fauna. However, species adapted to these living conditions often proliferate in large numbers and constitute an exceptionally important source of food for other, opportunist organisms that visit coastal wetlands.
Among them are many species which, although not exclusive to these environments, nevertheless give rise to a large, fascinating group: birds. The variety of their colours and shapes is undoubtedly the most captivating, well-known and appreciated feature of these areas.
The abundance of food and availability of land do not attract only marsh birds. Man has not been a mere onlooker, and has soon understood how important these elements are for his survival. In these areas, fishing and hunting have existed since the appearance of man. The exploitation of resources has continued until today, by means of methods which have not only become more and more modern, but also produce deeper impacts, such as intensive fish-farming and mechanised fishing.
However, this is only one of the aspects of this “love-hate” relationship that has always associated man with coastal wetlands. Although until a century ago lagoons, retrodunal ponds and brackish lakes were a common sight along

The coastal pond at Porto Taverna, near Olbia (Sardinia)

Italian shores, reclamation of land marked a radical change in the relationship between man and marshland.
Undoubtedly, reclamation – aimed both at defeating malaria and at seizing barren land from water for farming purposes - was a struggle between man and coastal wetlands, which ended successfully for the former, bringing economic and social development. But at the same time, this practice upset the coastal landscape and altered the centuries-old balance between man and his natural environment.
Unfortunately, the most recent implications of the unnatural relationship between man and wetlands are now before everybody’s eyes. Although extensive reclamation of land ended in the past century, coastal wetlands have been inconsiderately abused and violated. Expansion of industrial areas to the detriment of marshland, extensive urbanization of coastlines, recent exploitation for tourist purposes, which has become increasingly profitable but which has severe consequences, have all slowly and inexorably destroyed what was left of these environments. Stretches of brackish water have been replaced by industrial and tourist complexes, and flamingos have diverted their flights elsewhere.
Today, Italian coastal lakes and brackish ponds are relict environments, forlorn traces of those 8000 km which in the past seemed endless and which are now constrained.
Destruction of the environment is often caused by ignorance, improper and selfish exploitation of its resources, and disregard of its importance. These topics are all treated in this volume which, like the other Habitat volumes published so far, aims at informing the public of those Italian environments on the verge of extinction. The following chapters deal with the natural aspects of brackish ponds and coastal lakes, their genesis and evolution, flora and vegetation, their aquatic and shore fauna, their ecology, and the surviving strategies of the species which inhabit them.
The world we disclose is complex, a mosaic of environments which contrast with the apparent uniformity of coastal wetlands. But above all, we discuss management and conservation issues, sustainable exploitation of resources, i.e., what today is called “natural conservation”.
We also discuss the two most important topics, perhaps because they are full of hope for the future. On one hand, we examine the results of restoration of this environment, an attempt at giving nature back what man took away. On the other, we provide suggestions for teaching, so that new generations may approach these habitats with awe and respect, hoping that in the future man will no longer simply take, but also give.

Geology

GIUSEPPE MUSCIO

■ Introduction

Bodies of water in wide, deep cavities in the ground are called lakes; those contained in small cavities are called ponds. This classic definition of lakes already emphasises that the environments treated here - coastal lakes - are often barely included in the above-mentioned category. Among the characteristics of coastal lakes is their limited depth. This is only one of their peculiarities.

Limnology, the science that studies lakes and particularly their geological, physical, chemical and biological characteristics, divides them according to their origin. However, one of the most important distinctions is between freshwater lakes (open, or communicating with the sea through outflows) and salty, closed lakes.

The former include the great Alpine lakes with large tributaries and outflows and constant chemical characteristics of water. The latter, salty lakes, vary in salinity (between a few grams/litre and the high percentages in the Dead Sea).

This introductory note already shows how a comprehensive description of lakes is very difficult (many lakes are huge, as extensive as seas, others are extremely small), and even more so if we consider lakes as rapidly evolving and comparatively short-lived geomorphological units.

Their existence is endangered by sediments which eventually fill them, they may be effaced if their dams are destroyed, if their generating water supply is suspended, or if they empty due to the gradual rise of their beds - all situations which may occur very easily, in the Italian context.

The characteristics of coastal lakes - shallow water and the dynamism of shore environments - enhance this instability, to the extent that recent study of Italian coasts threatened by floods (according to data forecasting a 25-30-cm rise in sea level) includes the lakes of Lesina and Varano (on the Gargano promontory, the “spur” of the Italian boot, Apulia), the lagoon of Orbetello (Tuscany, Tyrrhenian) and the ponds of Cagliari (Sardinia) among the 33 most threatened areas.

Aerial view of lake of Sabaudia (Circeo, Latium)

The origin of coastal lakes

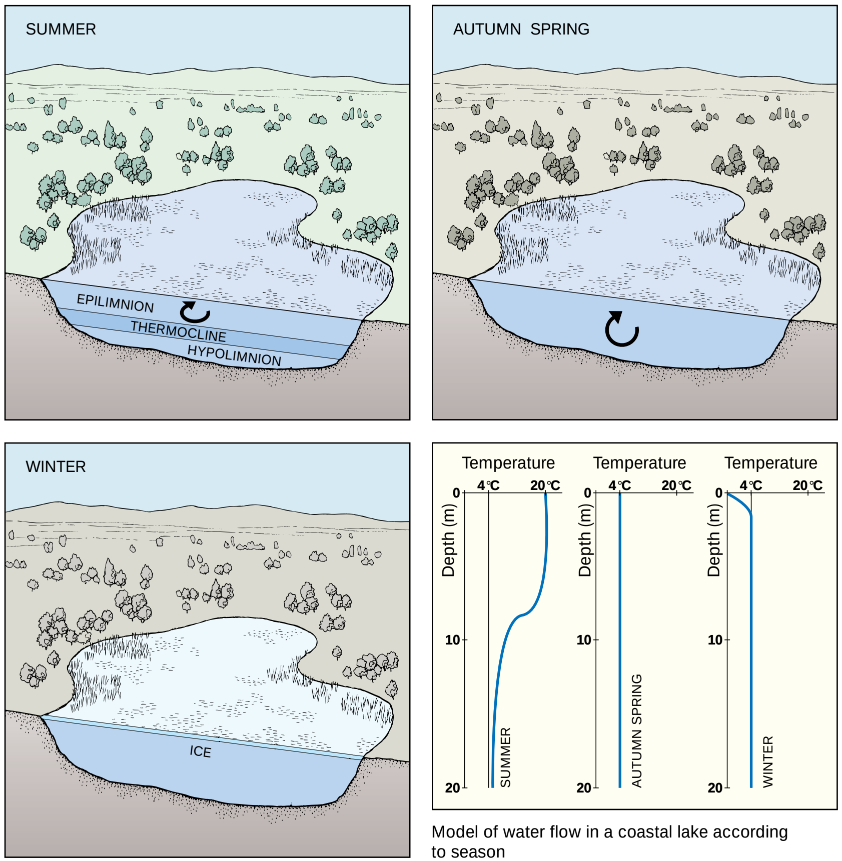
Coastal lakes are generated when water “invades” abandoned beaches. They may be enclosed by dunes (and are therefore called retrodunal ponds), or derive from the formation of shore deposits called beach bars. These look like elongated islands or peninsulas (when linked with the beach at one end they are called barrier spits), or have both ends linked with the beach. When bars enclose large inlets, they form closed, seawater basins.
Beach bars are formed when sediments accumulate, often facilitated by underwater rises, favourable currents and large amounts of particle-sized sediments carried by the sea. Those enclosing wide, deep basins give rise to coastal lakes; whereas small areas and shallow depths generally produce dynamic ponds. Many large outflows between the sea and internal basins give rise to lagoons.
Coastal lakes usually have elongated shapes that develop parallel to the coastline, as their formation is due to the closing of beach bars.
Particular beach bars are called pendent terraces, i.e., long, sandy stretches containing dunes stabilizing them. Sometimes, pendent terraces may also enclose lakes, as in the lagoon of Orbetello.
Although there is no clear distinction between coastal lakes and ponds, lagoons are easily identified by large outflows connecting them with the sea. However, the levels of ponds are variable and depend on rainfall, which often gives rise to small retrodunal ponds. To complicate matters even further, deltas may contain closed basins formed by coastal dams which give rise to freshwater lakes, the morphology of which is the same as that of coastal lakes. Another peculiar case regards lakes of karstic origin along the shores.
This taxonomical confusion is worsened by differing terminology: the basins of Varano and Lesina are generally called lakes, but some scientists call them lagoons, and the lagoon of Orbetello was given this name even if it has none of the above-mentioned lagoon characteristics. But these names are now very familiar and are maintained here to prevent further confusion.
Coastal lakes are therefore marine inlets closed off by beach bars and may have uneven contours which enable occasional or periodical connections with the open sea.
Parameters are further complicated by another factor, i.e., the extensive human intervention on Italian coastlines. Various reasons (fish-farming, agriculture, reclamation of marshes, exploitation for tourist purposes, industry) have contributed to profound morphological changes in Italian coastal lakes, and modified not only their physiognomy and extent, but also their water supply.

Simplified model of the origin of the lakes of Lesina and Varano.
At the beginning of the Holocene, as the sea level rose, the Adriatic occupied two large inlets along the Gargano coast. Erosion of the coast favoured the accumulation of sand, and local currents, which carried and deposited sediments westwards, formed beach bars, which later closed off.
In the case of the lake of Lesina, enclosure of the basin was also favoured by accumulation of sediments at the mouth of the river Fortore.

Physical factors

Although Italian coastal lakes have variable areas, their depth is always restricted to a few metres: the huge lake of Lesina covers 50 km^2, but is nowhere deeper than 2 metres! Bathymetry plays an important role in identifying the characteristics of lakes, the possibility of water turnover and temperature distribution along isobaths. Obviously, lakes that are only a few metres deep do not feature this temperature stratification.

Limnology describes the thermal proprieties of lakes as related to water circulation; in summer, there is a superficial warm level (*epilimnion*), followed by a middle (*thermocline*) and a lower, cold level (*hypolimnion*), whereas in winter, temperate lakes a dozen metres deep are considered to have a



Model of water flow in a coastal lake according to season

constant temperature of 4°C at all levels. Variations in water circulation also favour water oxygenation, but this process cannot fully develop in such shallow lakes. For instance, in summer, the water temperature of the lake of Lesina reaches its maximum of about 28°C between August and September, and its minimum of 5-8°C between February and March. The lake of Sabaudia is quite different: although it is much smaller (only about 4 km^2), its average depth is 4.5 metres and water temperature differs according to isobaths. Between July and August, it reaches its maximum temperature of 30°C and, between January and February, its minimum of 6-8°C. Between March and October, it has summer temperatures, and winter ones in the remaining months, with homothermal conditions (constant temperature at different depths) in the short transition periods.

The lake of Lesina is separated from the Adriatic by a thin sandy beach bar - in a few places less than 1 km wide – which favours the subterranean entrance of seawater in the basin

The highest thermocline (a word indicating good temperature variations in relation with depth) occurs at high temperatures (July-August), which fall to 4°C at -4m.

In these lakes, shallow water is also associated with lack of significant currents, except for superficial ones due to winds, which only produce movements of a few centimetres/second. As lakes are generally shallow, significant movements are associated with long-term seiches. A seiche indicates variations in the surface level associated with periodical currents. Generally, seiches are mainly due to variations in atmospheric pressure, and secondly to winds. Their importance is often underestimated, but they actually play an essential role in causing high tides in Venice.

The lagoon of Orbetello has often been studied, because its hydrodynamics are complicated by two distinct circulation regimes: one is natural, with mouths connecting the lake to the sea, and subjected to tidal variations; the other consists of two closed mouths, and flow is regulated by water-scooping machines; the fourth mouth is free. Measurements show relatively fast currents near the mouths (0.30 m/s) and slower in the middle (between 0 and 0.004 m/s), closely associated with winds. Study indicates that only areas near mouths undergo great variations, whereas those even a few hundred metres away are only subjected to varying local atmospheric conditions.

Lake of Fogliano near Sabaudia (Latium)

■ Water characteristics

Among the most significant elements describing coastal lakes are the chemical characteristics of water, and above all, their salinity. Of course, the hydrodynamics of closed basins deeply influence oxygenation of water (although this is not the only factor). It may also seem obvious that these lakes contain salty water, but this is not always true.

Some Italian coastal lakes are, at least partially, either of karstic origin or supplied by water of this same origin, such as the Alimini lakes near Otranto (Apulia).

Connection with the sea is essential for the movement of river water; these connections are often modified by man’s intervention (Alimini Grande lake, Salento)

Actually, these are two connected lakes: the northern one, Alimini Grande, is a typical coastal lake with brackish water, the southern, smaller lake, Fontanelle, is supplied by karstic water. Salinity in this basin is clearly lower, also because the narrow canal linking the two lakes hinders the rapid mixing of waters and this situation influences the local biotic communities.

Water supply is therefore very important for coastal lakes, which generally do not have classic tributaries (i.e., rivers), but owe their water turnover to natural or artificial outlets to the sea. If outlets are invisible, turnover may sometimes occur only by means of small subterranean streams (rills), whereby seawater is filtered under extremely thin beach bars.

Another important water supply is rainfall, which causes great variations in salinity, especially in small lakes. This may have significant effects on local animals, particularly on very sensitive species. We must also bear in mind that when salinity is lower than 6-9 g/l, these areas are colonised by freshwater species.

The morphological characteristics of the lake of Sabaudia are so complex and significant, that they deserve detailed analysis. Following reclamation of land and lowering of the watertable, salinity rose to 25-35 g/l.

In summer, evaporation raises these values, which then plummet between January and March, when it rains heavily. In October, salinity is generally constant at varying depths (the thermal characteristics of the lake are described above).

As regards oxygen content, until the 1980s, high pollution gave rise to high eutrophycation of the lake, i.e., very low oxygen content. Later, improved environmental conditions raised the level of dissolved oxygen, which is now 6-12 mg/l at the surface. However, in summer, and at -4 m, anoxia persists.

■ Italian coastal lakes

A journey along the Italian coastline provides a description of these lakes although, as mentioned before, the boundaries between lake, lagoon and pond are very variable.

Let us begin from the northern Adriatic coast, which features several coastal ponds associated with the large lagoons of Grado-Marano (Friuli) and Venice-Chioggia (Veneto), and the extensive wetlands of the Po Delta: near Ravenna (Emilia Romagna), there are interesting marshes and brackish ponds.

Large basins which have been modified by man for fishing purposes are, like coastal lakes, very extensive and share similar characteristics: in addition to the well-known Valli di Comacchio (extending for about 100 km^2, with an average depth of 0.6 m and a maximum of 2 m, separated from the sea by a

Lake of Monaci near Sabaudia (Latium)

1. Po Delta - Ravenna (Valle Bertuzzi, Valli di Comacchio, Pialasse, etc.)
2. Lakes of Lesina and Varano
3. Alimini lakes
4. Vendicari marsh
5. Pachino marsh
6. Lake Biviere
7. Phlegraean Fields
8. Lakes of Sabaudia
9. Lagoon of Orbetello, Lake of Burano
10. Lake of Massaciuccoli
11. Pond of Cabras
12. Ponds of Cagliari

Location of main coastal lakes and brackish water ponds in Italy beach bar a few kilometres long, along which the Romea state road and the river Reno run parallel to each other), is Valle Bertuzzi, near the Lido of Volano (three connected brackish ponds, covering a total area of 20 km^2).

Only after travelling all along the Adriatic and reaching Apulia do we find the first - and most important - coastal lakes. In northern Gargano, between Lesina, Rodi Garganico and Peschici, are the lakes of Varano and Lesina.

The lake of Lesina, which many call a lagoon, has an elongated, elliptical shape and two artificial outlets to the sea: the Acquarotta canal to the west, which flows along the old bed of the river Fortore, and the Schiapparo canal to the east. The lake of Lesina has an area of over 50 km^2, but its maximum depth never exceeds 2 m.

East of the Lesina is the lake of Varano, which is square and has an area of over 60 km^2, now becoming smaller because its eastern section is turning into marshland. It is connected to the sea by means of two canals: the easternmost is used as a dockyard. It is also supplied by subterranean water.

Near Otranto are located two connecting bodies of water, the Alimini lakes. The northern one is larger and surrounded on three sides by rocky surfaces deriving from the consolidation of ancient coastlines, and by a large area of marshland. Its seaward limit is constituted by dunes, some of which are over 10 m high. The beach bar is interrupted by a canal containing a fish-farm, which enables water turnover between the lake and the sea, although there is also a

Apulia contains some of the most important Italian coastal lakes (Alimini lakes, Otranto)

freshwater supply. A canal called Lu Strittu, closed by a dam, links the same lake with a smaller, southern basin (called Alimini Piccolo, or Fontanelle), which has different characteristics, as it is supplied by karstic springs and mainly contains freshwater. The lake is surrounded by marshland.

Along the Apulian coast is lake Salinella, near the mouth of the river Bradano, and even the Mare Piccolo of Taranto used to be a coastal lake of karstic origin.

In the past, and before extensive reclamation of land occurred, the most important series of coastal lakes and retrodunal ponds was along the Tyrrhenian coast, from Campania to Tuscany.

Today, these basins are highly fragmented, although some of them are still of particular significance. In Latium, a series of fossil dunes parallel to the present one is called “ancient dune” or “red dune”, and hosts a watertable that also supplies coastal lakes.

The area called Campi Flegrei (the Phlegraean Fields) north of Naples, contains a few small, residual basins, such as the lakes Fusaro and Patria.

Lake Astroni, near Agnano, is worthy of mention. Until a century ago, this volcanic area contained a large marsh, which was probably supplied by subterranean water, not by the sea: the area was reclaimed, and all that remains is this small lake.

Near Sabaudia, in the Circeo National Park, there are still four coastal lakes called Sabaudia (or Paola), Caprolace, Monaci and Fogliano. They are rather

LAKE	PROVINCE	AREA	MAX DEPTH	LENGTH
LESINA	Foggia	51.4 km^2	2.0 m	22.2 km
VARANO	Foggia	60.5 km^2	5.5 m	10.9 km
ALIMINI GRANDE	Lecce	1.3 km^2	4.0 m	2.6 km
ALIMINI PICCOLO	Lecce	1.0 km^2	1.2 m	2.0 km
SABAUDIA or PAOLA	Latina	3.9 km^2	10.0 m	6.7 km
CAPROLACE	Latina	2.3 km^2	3.0 m	4.6 km
MONACI	Latina	0.9 km^2	1.2 m	1.5 km
FOGLIANO	Latina	4.0 km^2	2.0 m	5.0 km
ORBETELLO	Grosseto	27.7 km^2	2.3 m	8.0 km
BURANO	Grosseto	1.4 km^2	1.5 m	3.2 km
MASSACIUCCOLI	Lucca	6.9 km^2	4.4 m	3.6 km
BIVIERE	Caltanisetta	1.2 km^2	1.5 m	2.4 km

Morphometric characteristics of main coastal lakes

small (about 10 km^2 in total) but important from the natural viewpoint; they are part of the National Park and have been thoroughly studied.
The best-known is Lake Sabaudia, which is elongated and has irregular banks. It covers an area of 3.9 km^2, with a maximum depth of 10 m and an average of 4 m. Its irregular banks represent traces of ancient riverbeds. Today, in addition to water supplied by the small spring Lucullo, at the southern end of the lake, water turnover occurs through two canals, one of Roman origin, and the other built during reclamation of the Pontine marshes.
The largest coastal lake in Circeo is Lake Fogliano, which is very shallow (maximum 2 m), but with an area of 4 km^2. In the past, it used to have variable levels and shape, but was later re-organised and regulated. It is supplied by the Fosso della Cicerchia and in summer, also by the Astura. Lake Caprolace is linked with Lake Sabaudia by the Fosso Augusta. Lake Monaci is extremely small.
Proceeding northwards along the coastline is the peculiar morphology of the lagoon of Orbetello, near Grosseto. Actually, this is a coastal lake, enclosed by the pendent terraces Giannella to the north and Feniglia to the south, whereas the pendent terrace on which Orbetello lies is partly artificial and divides the lake into its eastern and western parts. They have a typical mixed water supply, deriving from the sea and from reclaimed canals and small streams.

Vendicari marsh (Sicily)

The lake of Burano near Capalbio (Grosseto) is a typical example of retrodunal pond, although it is quite large (1.4 km^2, average depth 1 m). Today, it is supplied by rainfall and three reclaimed canals.
The plains west of Pisa (Tuscany) contain the large Lake Massaciuccoli; originally a retrodunal brackish lake, its water is now scantily supplied by the sea and mainly by reclaimed canals, one of which (Burlamacca) connects it with the sea. Variation in its water supply has led to maximum lake levels during autumn rains, with an annual range exceeding 1 m and reduced salinity - 1 g/l.
In Sicily, most coastal lakes are found in the southeast. Near Gela is the largest, Lake Biviere: its area has shrunk (it is now 1.2 km^2) after the river Dirillo was diverted to create a reservoir. Many lakes of the Pachino area (called *pantani*) are very interesting from the natural viewpoint, but those preserving almost natural conditions are the small lakes in the natural park of Vendicari, south of Noto.
The tiny Specchio di Venere (Venus's Mirror) on the island of Pantelleria (between Sicily and Tunisia), which cannot be considered a true coastal lake, is the result of a particular phenomenon worthy of mention. This small lake occupies the bottom of a caldera and is supplied both by thermal springs and rainfall.
In Sardinia, coastal brackish areas are extensive and interesting, but their basins are large ponds, rather than coastal lakes, and are completely dry in summer.

Specchio di Venere (“Venus's Mirror”) on the island of Pantelleria (south of Sicily)

Valli di Comacchio (Emilia Romagna)

■ Coastal wetlands

Although coastal lakes are well-defined basins, other wetlands - generally called coastal ponds and marshes - are highly variable, changing interfaces between land and sea, both for their position and size. The Ramsar Agreement devised some kind of taxonomy of wetlands which, with regard to coastal belts, distinguishes between slightly and highly brackish coastal lagoons and marshes.

The complex interactions between sediments, chemical contents (especially salinity) of water, depth, temperature and local plant associations are the key values determining the variability of these environments, in which two geomorphological processes seek a balance. On one hand is accumulated sediment carried by rivers flowing into the sea, on the other is sea action, which may erode but also accumulate. This is how barriers favouring the maintenance or disappearance of wetlands are continually formed and destroyed.

One particular word in Italian is *valle* which, in this context, does not mean “valley”, but is the local name given to wetlands of the southern Po Delta, (the Valli di Comacchio) and nearby areas, now used extensively for fish-farming.

The Pialasse are two extensive brackish lakes north of Ravenna (Emilia Romagna), and provide an excellent example of how these areas evolve rapidly. In the Middle Ages, between the mouth of the river Primaro and the delta of Punta Marina, a small marine inlet formed and rapidly became a lagoon, on which even Leonardo da Vinci worked. In the 19th century, the formation of beach bars closed off the area.

Further examples of this and other similar, complex environmental situations may be found along Sardinian shores and in the Po Delta.

Along the Sardinian coastline are several ponds and lagoons, none of which can be called coastal lakes, although some are extremely large (pond of Cabras and ponds of Cagliari, both over 20 sq.km.). They are all near Oristano, Cagliari and south of Carbonia, and are of great importance: they are often mentioned for the presence of significant nesting birds and for all the fauna and flora they host. A worthy example is the Stagno di Sale ’e Porcus, which covers 3.5 sq.km.: in summer, it looks like a large, dry plain covered with salt.

Many brackish lakes, most of which are artificial, owe their existence to the collecting of salt. Their formation is due to the “reclamation” of the many salt-pans which, in the past, were scattered along Italian coastlines, particularly near Ravenna, in Santa Maria di Savoia (Apulia), Sicily and Sardinia.

Flora and vegetation

GIOVANNI CANIGLIA

■ Adaptations

Reeds (*Phragmites australis*) are one of the most typical elements of the transitional belt between lake and dry land

The clay-loam soils found in areas close to the sea or brackish lagoons are rich in chlorides. Although water is abundant, it cannot be exploited directly by plants, so the soils are physically arid. No-one would even dream of watering their garden with seawater, because the plants would very soon suffer and then die.

All plants require water. As well as supplying basic physiological cellular needs, water translocates through the xylem system to the green organs, usually the leaves: some of it enters the complex photosynthetic system and some is dispersed to the exterior, thus contributing, through transpiration, to the water flux.

Most plants need water with a low salt content to perform these functions. Only a few species, the halophytes, specialise in tolerating salty water. They have developed adaptive strategies which allow them to expel or impede the entry of ions, or to accumulate water in their tissues (water parenchyma) and thus acquire the swollen appearance of fleshy plants or, more correctly, succulents.

Some halophytic plants have roots which are not very permeable to salt. Due to the presence of osmotically active substances, they still manage to absorb water but do not accumulate it in their cells. Others constantly eliminate the salt and so appear to be covered by fine salt incrustations, which gleam in bright sunbright.

Vegetation at the edge of the Alimini Lakes in Salento (Apulia) - contact between climatic climax vegetation and kermes oak woods (*Quercus coccifera*)

Halophytes

Halophytes, despite being an extremely small minority among plants, have quite a wide geographical distribution, mainly influenced by the chemical characteristics of the environment in which they grow, instead of by other ecological factors. The halophytic flora of lagoons bordering the Atlantic thus differs little from those near the Mediterranean.

Halophytes include some herbaceous plants which live totally submerged, forming underwater fields, but the majority are terrestrial and sink their root apparatus into salt-impregnated soils.

Littoral wet areas are generally shallow, reaching a few metres in depth at the most, as in the case of the coastal lakes of Lesina, Varano and Alimini (southern Adriatic). It is this shallowness which allows meadows of submerged phanerogams to develop, the extent of which depends mainly on the type of substrate, which may be sandy or definitely clayey. These underwater meadows contribute greatly towards diversifying the lagoon environment,

Open halophile grassland, a typical nesting site for many birds

making it particularly favourable for the development of the fauna, which can feed and reproduce in a protected habitat.

The underwater meadows are usually formed of populations of just one or a few species. They may be truly marine, like *Posidonia oceanica*, a plant not often found in lagoons which usually grows, even at some depth, along the coasts of the mid- and lower Adriatic, Ionian Sea and Tyrrhenian Sea. *Zostera marina*, *Nanozostera noltii* and *Cymodocea nodosa*, also genuinely marine species, may be more common, but rarely penetrate ponds with low salinity.

Stranded algae at Lake Lesina (Apulia): the “spheres” are formed by colonies of *Valonia aegagrophila*, a chlorophyte (green) alga

In shallow brackish ponds, with little water exchange and often with high seasonal variations in salinity between dry summers and rainy winters, it is not rare to find populations of *Ruppia*. These plants have long branched stalks and leaves with a characteristic, somewhat swollen sheath. *Ruppia* which live in salt-marshes belong to two separate species of tasselweed: *Ruppia maritima* and *R. cirrhosa*, which are very similar to one another and difficult to identify with certainty.

Ruppia populations, while tending to be monospecific, frequently host macroalgae belonging mainly to the genera *Enteromorpha* and *Chaetomorpha*, thus forming an association named *Chaetomorpho-Ruppietum*. This vegetation is not very widely distributed because most of the ponds in which it grows (or rather, used to grow) have been drained: it can therefore be found only in suitable micro-environments in more diversified littoral areas.

Macroalgae are other, at times rather invasive, plants growing in brackish ponds, and their proliferation, which coincides with an abundance of nutrients and an increase in temperature, can lead to serious anoxia and damage to the fauna.

However, the most interesting aspects of the flora and vegetation are to be found on the land surrounding brackish ponds which is still affected by the presence of salt.

Salicornia veneta

Suaeda maritima

As mentioned above, these soils are often soaked in salty water or, when they are dry, develop surface cracks in characteristic many-sided patterns, encrusted with crystallised salt. In both cases, they represent a myriad of micro-environments which only a few particularly specialised species manage to colonise, thus forming homogeneous communities.
The more selective an environment is, the fewer species can colonise it – thus, the communities formed of pioneer species are invariably monospecific. Instead, a less selective environment is able to host a larger number of species which, aggregating in a homogeneous way, forms more complex vegetation.
If the sides of ponds slope gradually towards the central area, communities of glassworts may develop, which are more characteristic of *haline* environments. It is worth giving some general information on these plant communities, which are particularly favourable habitats for wading birds.
Glassworts are annual herbaceous succulent plants, i.e., they complete their biological cycle in the course of one year - from seed germination to flowering and fruiting - and then die.
The various species of glassworts are not always easily distinguishable from one another. Some, like *Salicornia veneta*, endemic to the northern Adriatic, and the more widespread *S. europaea*, are generally erect and colonise mud

Salsola soda

Limonium narbonense

barely submerged by the water, while along the damp many-sided cracks commonly found in clay soils a little further away from the water body, are other more prostrate glassworts, such as *S. patula,* which generally become reddish in autumn.
At times, glassworts are associated with other halo-nitrophilous species like *Suaeda maritima*, hairy seablite (*Bassia hirsuta*) and opposite-leaf Russian thistle (*Salsola soda*), forming an association called *Suaedo-Salicornietum patulae* which, especially in Mediterranean regions, colonises arid clay exopercolative soils.
If the pond border has any kind of sharp projection or spur towards the water, it is possible to spot *Limonio-Spartinetum maritimi*. This is a perennial herbaceous vegetation, practically exclusive to north-eastern Italian lagoons, in which small cord-grass (*Spartina stricta = Spartina maritima*) forms narrow belts rimming the banks of canals and islets.
Spartina juncea belongs to the same genus. This species, introduced into Italy at the end of the 19th century, has not yet assumed a clearly defined role in Italian flora. It grows both in brackish marshes, mixing with the strictly halophytic vegetation, and on damp littoral sands, where it competes with the psammophilous flora.

Glassworts

Glassworts are perhaps the most representative of the halophytes growing on the edges of brackish marshes. Their fleshy appearance immediately reminds us that these plants are parsimonious in their use of water: in order not to waste it, they store it in their tissues.
Photosynthesis is entrusted to the fleshy stems, and the leaves are so small as to be almost imperceptible. The flowers, which are also small, are inconspicuous and embedded in the branches.
When talking of "glassworts", reference is commonly made to all those halophilous plants with the above characteristics, which make them similar to the succulents growing in arid sub-desert environments. There is a certain analogy between desert and haline environments: water is the factor which limits plant survival in both. In deserts, water is almost entirely absent; in haline environments, there may sometimes be plentiful water, but it is not readily available because of the high salt concentration. A convergent survival strategy is therefore adopted, and the plants which grow in these environments store water in their tissues and minimise water loss by reducing their leaf apparatus and transferring the photosynthetic capacity of the leaves to young green stems. In papers dealing with Italian flora until about 1950, the genus *Salicornia* covered many species with this appearance, but in more recent years *Salicornia* has been attributed only to those species with an annual biological cycle. The others, perennials, which lignify and form low dense shrubs, have been identified as belonging to the genus *Arthrocnemum*.
In the light of a further revision of the Salicorniaceae by A.J. Scott in 1997, other characteristics have emerged which subdivide Italian glassworts into three separate genera: *Salicornia*, *Sarcocornia* and *Arthrocnemum*.

Sarcocornia fruticosa

Arthrocnemum macrostachium (= *A. glaucum*)

The genus *Salicornia*, as mentioned, includes only annuals. They are easily recognised because, germinating in spring and ending the biological cycle in autumn, they always retain a herbaceous consistency. The species in the Italian flora are not always easy to identify because they mainly differ in the number of chromosomes - a character that is difficult to recognise without microscopic analysis, although the tetraploid forms are usually larger than the diploid ones.
Glassworts (*Salicornia europaea* s.l.) may be creeping plants and grow on haline clay soils, especially along the damper many-sided cracks which gradually appear as the soils dry out. Otherwise, they grow on soils impregnated with brackish water, where they form a dense monospecific population with an erect bearing, like the endemic *Salicornia veneta*, a tetraploid species of the northern Adriatic.

With perennial species, it is the position of the tiny flowers, practically hidden by the bracts, which differentiates the genus *Arthrocnemum* from *Sarcocornia*: *Arthrocnemum macrostachyum* (= *A. glaucum*) has deep-seated flowers, but they are not easily seen. The ecology of the species, which prefers hard substrates, the colour of the plant (greyish-green) and the inflorescences, which leave a deep undivided cavity on ripening, are the characteristics which aid identification.
Sarcocornia fruticosa (= *Arthrocnemum fruticosum* = *Salicornia fruticosa*), which often grows in association with its affine *Sarcocornia perenne*, for which it may be mistaken, can also be found with other halophytes, forming extended shrubby carpets about half a metre tall. *S. fruticosa* is almost always the dominant species on exopercolative soils on the edges of brackish marshes, which are generally dry, but with a high salt content.

Salicornia patula

■ Lakesides

Gradually moving away from the edges of lakes, the saline characteristics of the soil are attenuated and phyto-climatic and environmental features become of increasing importance. However, the soils are still affected by moderate salinity for quite a distance, so the plants which grow there are still purely halophilous, but with an increasing number of species forming the community.

This is how *Arthrocnemum* communities are formed. These are perennial halophilous communities formed of both shrub and herbaceous species which form a type of garrigue, at times very dense, at others rather patchy with wide bare spaces.

Arthrocnemum communities include a maximum of about twenty species, including *Sarcocornia fruticosa* (=*Arthrocnemum fruticosum*), *S. perennis* (= *A. perenne*) and *Arthrocnemum macrostachyum* (=*A. glaucum*). These are really species preferring arid soils with a high salt content. They differ from glassworts in the strict sense, with which they were grouped in the past, by the

Glasswort colony on a coastal marsh (Apulia)

fact that they are perennial shrubs, and they have recently been further subdivided into the genera *Sarcocornia* and *Arthrocnemum*.

Other frequent species in *Arthrocnemum* communities are *Puccinella palustris*, sea rush (*Juncus maritimus*), *Halimone portulacoides*, *Suaeda fruticosa*, sea aster (*Aster tripolium*), *Limonium narbonense* (= *L. serotinum*) and *Limonium* sp. pl.

As soil salinity diminishes, the environment becomes less selective and the number of species forming the population progressively higher, some beginning to dominate others. In this way, numerous facies, variants and sub-associations become differentiated within the same plant association (*Puccinellio festuciformis-Arthrocnemetum fruticosum*).

The cause of these variations on a theme is usually due to micro-environments which lead to diversification of the substrate. Sub-associations with a significant proportion of sea rush or *Juncus subulatus* reveal depressions in the ground which are periodically inundated by brackish water or influenced by the water table, while slight rises in the land may display a slightly nitrophilous variant in the vegetation, with *Artemisia coerulescens*.

Sea aster (*Aster tripolium*)

Climatic factors and geographical distribution of plant associations

Although the main factor determining the development of flora and vegetation in halophilous environments is the salty substrate, the climatic factor is also important. In north-eastern Italy, the Atlantic element negatively affects both floral and vegetational diversification, certain types being better represented in areas with Mediterranean influence.

For example, some *Arthrocnemum* associations like *Puccinellio convolutae-Arthrocnemetum glauci*, *Arthrocnemo glauci-Halocnemetum strobilacei* and *Halimiono-Suaedetum verae* are almost exclusive to brackish areas in southern Italy and on the islands where, in addition to the climatic factor, a substrate with rocky outcrops also often contributes.

Towards the northern sector of the Adriatic, halophytic vegetation with *Limonium narbonense* and *L. virgatum* becomes more frequent, especially in areas where *Sarcocornia fruticosa* populations are less dense.

Populations belonging to the class *Juncetea maritimi* are less steno-Mediterranean, and are probably associated more with a regularly flooded substrate or with stagnant water.

Puccinella palustris and sea rush are the most common species and are typical of these environments, but these populations also have many variants in their floral composition, the different types always reflecting ecological and edaphic characteristics.

Vegetation at the edge of the Valli di Comacchio (Emilia Romagna)

Bolboschoenus maritimus

Juncus acutus

The differentiating species which allow the main associations of these classes to be identified include long-bracted sedge (*Carex extensa*), golden samphire (*Inula crithmoides*), *Plantago crassifolia*, black bog-rush (*Schoenus nigricans*), *Juncus litoralis* and *J. acutus*.

Moving farther away from the edaphic-influenced area, the vegetation begins to assume a physiognomy more similar to the potential flora of the site. Climatic and phytogeographical factors become more marked, and the floristic elements of the surrounding vegetation enrich and better characterise the environment. In lagoons with quite low salinity due to the freshwater which flows into them, or with spring water sources, it is common to find a hygrophilous flora which persists in the areas where salinity remains limited.

The reed (*Phragmites australis*) is one of the hygrophilous elements most commonly found in ecotones but, depending upon the different situations which are created in the marginal areas, many sedges also grow, such as sea club-rush (*Bolboschoenus maritimus*), roundhead bulrush (*Holoschoenus romanus*), *H. australis*, *Scirpus* sp. pl., black bog-rush, *Cyperus* sp. pl., and others.

Halophile vegetation with *Suaeda* near Chioggia (Veneto)

Elsewhere, especially along low rocky coastlines, in which small ponds alternate, species of the class *Crithmo-Staticetea* also grow, a patchy vegetation which almost always includes sea fennel (*Crithmum maritimum*) and golden samphire in association with a species of *Limonium*, often endemic and characteristic to a particular site. Examples of this vegetation can quite often be found in Apulia, on the Salento coastline, and along the Sardinian and Sicilian coasts.

Inula crithmoides

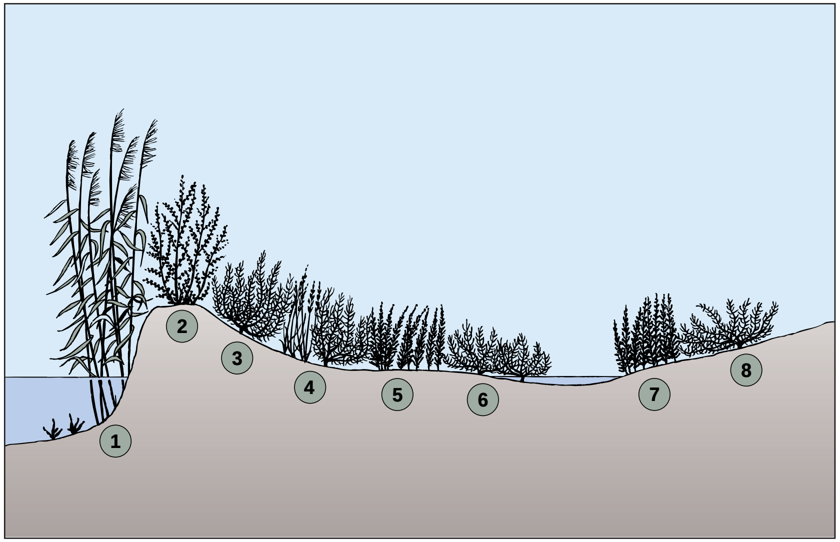
The most interesting and original aspects of salt-marshes occur in areas where there is contact with the "climatic climax" vegetation. A brief survey of these sites follows.

Leaving aside the northern Adriatic lagoons and travelling southwards down the Adriatic coast, let us stop between Termoli and Rodi Garganico, where floods of the river Fortore have formed the coastal lakes of Lesina stretching along the coastline, and Varano, hollowed out of the rocky bulk of the Gargano promontory. Here, the sand dunes are extremely interesting with their Mediterranean maquis of juniper (*Juniperus oxycedrus*) which, despite heavy human pressure, still conserves a wild aspect.

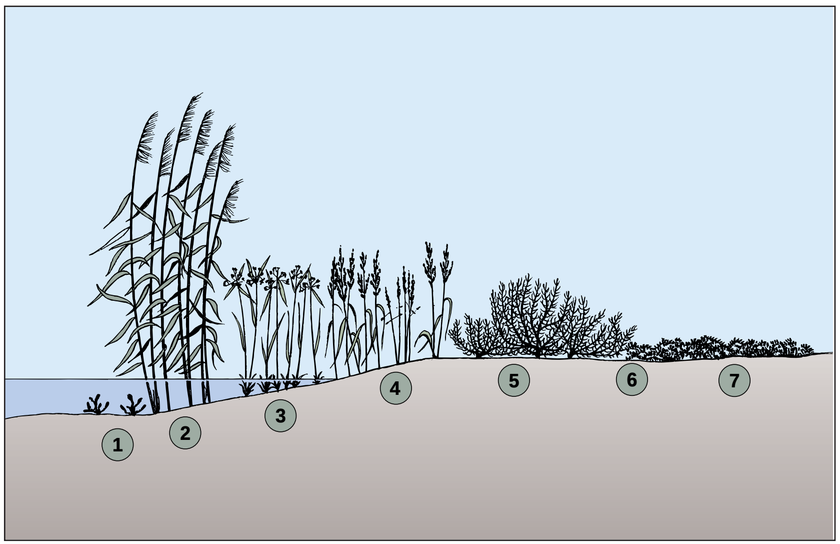
Further south, just beyond the Gargano promontory, we find a series of lakes, some drained or transformed, forming the complex of the Saline di Margherita di Savoia (salt-pans). Here, the most obvious aspect is the contact with "synanthropic" vegetation, but corners exist where some degree of naturalness still survives, perhaps linked to the selective action of the haline environment.

Moving further southwards we travel across the Salentino peninsula where surface hydrography is almost absent and therefore the primary conditions for the formation of coastal basins do not exist. Despite this, there are some wet coastal areas, thanks to sources of spring water.

On the Adriatic side lie the Alimini lakes, where contact with the climatic climax vegetation is with woods of kermes oak (*Quercus coccifera*). On the Ionian coast, the many marshes between Gallipoli and Taranto, now mostly drained,



Vegetation succession at Lake Salinella (Taranto, Apulia)
1 > Halophile reed-beds, 2 > Group with *Atripex humilis*, 3 > *Puccinellio-Arthrocnemetum glauci*, 4 > *Puccinellio-Arthrocnemetum fruticosi* , 5 > *Suaedo-Salicornietum patulae*, 6 > *Arthrocnemo-Salicornietum emerici*, 7 > *Suaedo-Salicornietum patulae*, 8 > *Puccinellio-Arthrocnemetum fruticosi*



Vegetation succession in ponds near Cagliari (Sardinia)
1 > *Chaetomorpho-Ruppietum*, 2 > Halophile reed-beds, 3 > *Scirpetum compacto-litoralis*, 4 > *Puccinellio-Arthrocnemetum fruticosi juncetosum subulati*, 5 > *Puccinellio-Arthrocnemetum glauci*, 6 > *Puccinellio-Arthrocnemetum fruticosi*, 7 > Group with *Frankenietea*

are still interesting. One peculiarity is the presence of coastal formations, locally known as "*spunnulate*", where the siphoning action of the sea, following karstic phenomena on the carbonate layers of the Murge, has formed characteristic deep ponds. Halophilous vegetation grows on the rocky edges and in pockets of red soil which, moving inland, becomes a dry garrigue of Spanish oreganum (*Thymus capitatus*) with burnet thorny poterium (*Sarcopoterium spinosum*), a relict species at the western limit of its distribution area.

Diverse vegetation surrounding the Sabaudia lakes (Latium)

Crossing over to the Tyrrhenian coast, brief mention may be made of the marshy coastal area of the Phlegraean Fields (near Naples), the lake of Fondi and the Sabaudia lakes (near Rome), all in close contact with a typical Mediterranean maquis.

Further north there is the lagoon of Burano (Tuscany), the ponds and marshlands of Uccellina, at Bolgheri and lastly, at the mouths of the rivers Serchio and Arno (Tuscany), various marshy areas and Lake Massaciuccoli (which, however, does not have haline characteristics).

Brackish lakes on the islands are fairly well distributed along the Sardinian and Sicilian coasts. Some, very extensive - like the Stagnone di Marsala (Sicily) or those of Cagliari (Sardinia) - have been transformed into salt-pans, so that their more interesting natural aspects are mainly in the marginal areas. Others have maintained a lagoon structure and are used for fishing, like the Pond of Cabras near Oristano (western Sardinia). Yet others are interesting environments because of the presence of varied birdlife, for example, the Pond of Santa Gilla (southern Sardinia), but are gravely endangered by industrial pollution. Others, such as the coastal ponds near Capo Tindari in Sicily, are small and more like deep holes in the beach, fed directly by the sea and populated by a basically algal vegetation.

The flora and vegetation of Sardinian and Sicilian coastal wetlands are far better studied than those on the mainland. This is probably because islands, apart from their obvious fascination, by their very insularity have many endemic or rare species which confer a particularly rich composition on the halophilous vegetation.

Terrestrial and riparial invertebrates

ENRICO RATTI

The ecotone strip between water and land encircling brackish ponds and lakes hosts a rich shore fauna of halophile and euryhaline species

The huge drainage projects which aimed at eradicating malaria and reclaiming new farmland are things of the past, but drainage and reclamation of coastal wetlands goes on, in a less conspicuous way, where their vicinity to the sea makes them worth exploiting for tourism. Although the larger coastal lakes have been the subject of recent acts of environmental protection, the situation is still critical for brackish ponds behind dunes. Knowledge of terrestrial invertebrate fauna, with few exceptions, is still quite scanty.

The fauna of the riparian belt of brackish ponds and coastal lakes has profoundly different characteristics, depending on the presence or absence of riparian vegetation, the type of soil (sand, clay, silt), its salinity and moisture content. The main limiting factor for terrestrial species in these environments is without doubt salinity. In reality, very few terrestrial invertebrates can be defined as halophilous, i.e., demonstrating a preference for salty soils. In the majority of cases, they are euryhaline or salt-tolerant, despite the fact that many species are apparently inextricably associated with brackish areas.

In brackish lakes and ponds on sand or prevalently sandy soils of the upper beach, the influence of the sea is still strong, with supplies of seawater arriving regularly because of its vicinity, or now and again when there are exceptionally high tides or heavy seas. The salinity of brackish areas is therefore similar to that of the sea (sometimes even higher) and riparian vegetation is usually absent. Because of high soil permeability, the wet strip is fairly narrow and confined by extremely arid sandy soils. The invertebrate fauna is poor in terms of species, although there may at times be large numbers of individuals. The origin of psammophilous populations is basically Mediterranean, although

Tiger beetle *Cylindera trisignata*

Emerging sandy areas, consolidated by vegetation, form small islands on the lake

there are also some species of Atlantic origin. According to their relationships with the environment, these populations may be subdivided into stable, migrant, and/or occasional.

Stable populations are similar to, though poorer than, those of the higher part of the beach, including some truly marine species. The presence of terrestrial invertebrates is determined by the availability of macroalgae and marine phanerogams (sea grasses), which are sources of refuge or food for amphipod crustaceans.

Migrant populations are composed of insects, especially dipterans (but also carabid beetles, staphylinid beetles, etc.). These spend the night buried in the sand of dunes (*Fucellia intermedia*, *Lispe caesia*, *Hecamede albicans*, *Homalometopus* spp.) or at the foot of pioneer plants, migrating during the warmer part of the day (micro-migration) on to the wet sand by the water's edge. Occasional populations are composed of insects which arrive from neighbouring environments during the day in search of food, or which are simply attracted by the damp sand.

Typical invertebrates of these wet beach environments are, quite naturally, psammophilous and halophilous, and there are many both diurnal and nocturnal predators. Phytophages are associated with decomposing plant remains (phyto-saprophages), often made up of macro-algae or sea grasses, and some fossorial species appear to feed on micro-algae.

Moving away from the beach, there are generally lakes, pools and astatic ponds, of varying depths and sizes behind the dunes, on soils ranging from prevalently sandy (but still with a reasonable amount of silt and clay) to prevalently silty-clay. Salinity is generally very low, although it may vary widely depending on temporary events. Rainwater, with low percentages of salt due to supplies of brackish water through capillarity, may occasionally mix with sea water during exceptional weather events.

Riparian fauna is usually richer and more varied than in the brackish lakes and ponds on the seaward side of dunes, because the moderately halophilous species are joined by hygropsammophilous species, associated with sandy, not just marine, soils, which are often transported by rivers in flood and become acclimatised to this littoral environment, encouraged by the low soil salinity.

This colonisation of wet coastal environments behind the dunes by fluvial riparian invertebrates is particularly evident along the northern Adriatic coast, because of the influence of the large Alpine rivers (Po, Adige, Piave, Tagliamento). Examples include many beetles, especially carabids (*Broscus cephalotes*, *Acardystus flavescens*, *Dyschirius* spp.) but also a hygropsammophilous orthopteran (*Xya variegata*).

With increasing percentages of silt and clay and the contemporary reduction of sand, riparian invertebrate fauna becomes progressively more rich and complex. Soil permeability falls and the damp riparian belt widens. Clay maintains the soil moisture content at a certain depth, even when the surface is dry, offering refuge to fossorial hygrophilous species or ones which profit from surface cracks to introduce themselves into the ground to find the moisture they need for life. Soil salinity probably contributes towards preserving moisture, and this may be the real reason why so many terrestrial species considered halophilous (and, not merely by chance, all hygrophilous) are attracted, notwithstanding the physiological problems created by the high percentage of salt. Because terrestrial invertebrates usually lack physiological mechanisms for osmotic regulation and the elimination of excess salt, it is not the presence of sodium chloride which attracts many halophilous species, but rather the presence of salts in general. An example is that of the coastal pond on the island of Pantelleria (between Italy and the North African coast), which is isolated from the sea and fed exclusively by thermal springs. Its waters are extremely alkaline (pH 9.0-9.2) and are very rich in phosphates but not in sodium chloride: despite this, the riparian belt is populated by several species considered halophilous in the strict sense.

Coastal lakes may be surrounded by very diverse environments: in this case, on one side the coastal dune which separates this basin from the sea, and inland, a line of hills

The characteristic fauna of riparian silty-clay soils (or at least those with low sand content) are lutohalophilous species. The populations are generally of composite origin, with two major components, one Mediterranean, the other European-Central Asian or European-Turanian. Depending on soil texture and salinity, the vegetation is composed of *Schoenus*, glassworts, sedges, rushes and reed-beds, which attract many phytophages and phyto-saprophages, with their respective predators. The number of invertebrate species frequenting brackish lakes and ponds is therefore high, even when limited to halophilous species: the following sections will give a brief overview, with particular reference to the more well-known and better-studied groups.

Accumulations of macroalgae, marine phanerogams, fragments of crustaceans and molluscs, are a source of refuge or food for invertebrates (Lake Lesina, Apulia)

■ Spiders

Spiders living near brackish water bodies are generally abundant, although only a few species are actually associated with salty or brackish environments. Lycosids (wolf spiders) of the genera *Arctosa* and *Pardosa* predominate, some of which tolerate high salinity (*P. luctinosa*, *P. cribrata*). Soils covered by vegetation (such as reeds and rushes) are populated by hygrophilous and not halophilous species, such as lycosids of the genus *Pirata*, clubionids of the genus *Clubonia*, linyphiids of the genus *Gnathonarium*, and jumping spiders like *Marpissa radiata* and *Mendoza canestrinii*. On short vegetation near the water are philodromids such as *Tibellus maritimus*, and linyphiids of the genus *Microlinyphia*, tetragnathids *Tetragnata* also weave their webs here. In the reed-beds, webs of araneids or true orb weavers, such as *Larinoides folium*, can often be seen.

■ Centipedes

Although there are generally very few centipedes in these environments, some species belonging to the genera *Clinopodes*, *Pachymerium* and *Geophilus* may be found among plant debris at the edge of salty waters.

Sympetrum fonscolombei

■ Insects

Insects are by far the dominant terrestrial invertebrates at the edge of or near brackish lakes and ponds.

Collembola (Springtails). Among the truly terrestrial or riparian species, brackish lakes and ponds host diverse species of Collembola, which increase in number with increasing vegetation cover.

Odonata (Dragonflies). There are few species of dragonfly capable of growing in very salty water; those which do include *Lestes macrostigma* and *Ischnura fountainei* (the latter also capable of living in highly alkaline water).
The almost constant presence of some species of dragonfly in standing coastal waters usually depends on factors other than salinity: e.g., the high temperature of the water (which is generally quite shallow, and therefore easily warmed by the sun) and rapid larval cycle (adults emerging from their pupae prior to any possible drying up of the waters). These include the dragonflies *Sympetrum fonscolombei*, *Selysiothemis nigra*, *Anax parthenope*, various species of *Lestes*, and *Lindenia tetraphylla*, which is rare and vulnerable in Italy and included in Annex II of the Habitat Directive.

Lestes viridis

Orthoptera. In slightly brackish riparian environments with little vegetation cover, orthopterans are represented by the genus *Gryllotalpa*, easily identified by the traces left by the digging of their shallow tunnels.
A psammophilous tridactylid generally associated with river sands, *Xya variegata*, lives in tiny tunnels excavated in damp sand, is an excellent swimmer,

Acridid *Epacromius coerulipes*

Acridid of the genus *Aiolopus*

and may sometimes colonise brackish silty-sandy ponds close to the foreshore.

Most orthopterans of wet brackish environments prefer areas with rich vegetation: the small tetrigid *Tetrix ceperoi* and the acridid *Chorthippus bicolor* live among the sedges and rushes behind the dunes, and acridids of the genus *Aiolopus* in brackish-water sedges and rushes; acridids of the genus *Epacromius* usually prefer saltier environments.

Dermaptera. Among the earwigs only *Labidura riparia*, active during the night, is often found close to standing brackish waters, with sandy or at least loose-textured soils, although it is not exclusive to these environments.

Heteroptera. Among the true bugs, many species of saldids are characteristic of damp brackish soils, such as *Halosalda lateralis*, *Saldula pilosella*, *S. pallipes*, *S. sardoa* (endemic to Sardinia, described from the Stagno di Chia) and the euryecious *S. palustris*. Saldids are fast runners on the ground and occasionally make short flights.

Homoptera. The homopterans associated with halophilous vegetation include the flatid *Cyphopterum difforme*, which lives on glassworts (*Arthrocnemum* spp.) near brackish ponds, and the aphid *Staticobium limonii*.

Coleoptera. Many riparian or terrestrial beetles are associated with brackish waters. Among the carabids, which are nearly always predators, there are many cicindelines or tiger beetles, such as *Cephalota circumdata*, which live on the edges of salty ponds and lagoons behind dunes with *Salsola* vegetation, which often dry up in summer leaving the surface encrusted with salt.

Other examples are *Cephalota litorea goudoti* (widespread in Sicily and Sardinia, sympatric with the former but with different phenology); *Cylindera trisignata* (in sandy soils) and *Myriochile melancholica* (in more silty-clay soils); *Lophyridia littoralis* and *Lophyra flexuosa*, which do not disdain river banks sometimes several kilometres inland. Halophilous carabid beetles with fossorial habits are *Parallelomorphus terricola*, macropterous and sub-halophilous; *Distichus planus*, typically associated with coastal brackish lakes; various species of *Dyschirius* (*D. apicalis*, *D. salinus*, *D. luticola*, *D. longipennis*, associated with sandy brackish soils), which are mostly predators of rove beetles of the genus *Bledius*; and some *Clivina*. There are also many bembidiine carabids, such as *Notaphemphanes ephippium*, some species of *Emphanes*; *Talanes aspericollis* and *T. subfasciatus* (associated with halophilous reeds); *Tachys scutellaris* (also living in very salty soils, with glassworts) and *T. dimidiatus*. Among the most typical riparian beetles of brackish waters are

Parallelomorphus laevigatus

Parallelomorphus terricola

Pogonus riparius

the pogonines, such as *Pogonus chalceus*, *P. gilvipes*, *P. riparius*, *P. littoralis*, *Syrdenus filiformis* (Sardinian ponds) and *Pogonistes*. Some of these species, as well as *Dicheirotrichus obsoletus* (very widespread) and *D. punicus* (in Italy only in the Saline di Cagliari, in Sardinia), display considerable tolerance for sometimes very high levels of salinity (20 ‰ and above), and so can even colonise environments as harsh as salt-pans.

Staphylinid beetles (rove beetles) are mainly represented by numerous species of *Carpelimus* and *Bledius* (the latter, which have fossorial habits, probably feed on micro-algae), such as *B. unicornis*, *B. furcatus* and *B. graellsi*, associated with soils at least part sand and not very salty. The predator *Orthidus cribratus* is also frequent. Other beetle families are represented by a few truly halophilous species: some small pselaphids of the genus *Brachygluta*, heterocerids (with fossorial habits) like *Heterocerus flexuosus*; tiny limnichids like *Bothriophorus atomus* (associated especially with halophilous rushes); anthicids, such as some species of *Cyclodinus*, and endomychids like *Dapsa trimaculata*. Some phytophagous beetles are associated with the halophilous vegetation surrounding brackish ponds and coastal lakes. Among the chrysomelids are *Chrysolina schatzmayri*, of the northern Adriatic coasts, with nocturnal habits, associated with *Inula*; the alticines *Longitarsus absinthii*, common on *Artemesia coerulescens*, *Chaetocnema tibialis* on chenopods and *Crepidodera impressa* on sea lavender; and the cassidines *Cassida nebulosa*, *C. nobilis* and *C. vittata* (living on

Dicheirotrichus obsoletus

chenopods). The long-horned beetles include *Agapanthia villosoviridescens*, which can develop in the stems of the halophyte *Aster tripolium*, and various species of weevils, associated with halophilous chenopods (cleonines, lixines).

Diptera. The dipterans are represented by many species whose larvae develop in salty or brackish waters, whereas adults live on vegetation close to the edges. Nematoceran dipterans include culicids (mosquitoes) of the genera *Culex* and *Aedes*, and various chironomid midges. Brachyceran dipterans include stratiomyiids such as *Stratiomys cenisia*, *S. longicornus*, *S. singularior*, *Odontomya limbata*, *Oplodontha viridula*, *Nemothelus crenatus* and *N. notatus*; and ephydrids like *Psilopa nitidula* and *P. polita*. Notable for their daily micro-migrations are the anthomyid *Fucellia intermedia*, the muscid *Lispe caesia*, and many other ephydrids and tethinids.

Lepidoptera. The moths which frequent the vegetation of brackish water bodies include the lymantriid *Laelia coenosa*, associated mainly with reeds and sedges. The caterpillars over-winter on reeds and debris emerging from the water, and their uncertain survival depends on winter variations in water level: if it rises too high, the caterpillars drown.

The caterpillars of some moths feed on halophilous plants, such as *Discestra sodae* (which browse on *Salsola* and *Chenopodium*), *D. dianthi* (on *Aster tripolium*), *D. stigmosa* and *Diataraxia blenna* (on *Chenopodium* and *Salsola*).

Laelia coenosa

Aquatic invertebrates

FABIO STOCH

Brackish lake – despite its monotonous and uniform appearance, it is a mosaic of complex environmental situations

The brackish coastal lakes found along Mediterranean coasts are of enormous hydrobiological interest. This has mainly emerged from research conducted in France in the Camargue, at the mouth of the Rhône, which revealed a series of incredibly rich ecosystems in terms of numbers of species and high production. Similar studies have been carried out in Spain and northern Europe.

Unfortunately, there have been extremely few thorough investigations into similar ecosystems in Italy, which, with rare exceptions, were restricted only to a section of the fauna or, more frequently, the plankton in lagoons or large coastal lakes. This brief chapter on aquatic invertebrates first of all examines the types of brackish waters present in the Italian peninsula and their classification; readers will discover that these are not monotonous and uniform environments, as might appear at first glance, but a mosaic of micro-habitats with extremely complex physico-chemical characteristics. The ecology and adaptation of invertebrates to life in brackish waters is then described briefly and the major representatives of the fauna in these habitats discussed.

■ Ecological classification of brackish ponds

The many classification systems proposed for brackish waters demonstrate how difficult and subtle it is to establish intermediate limits between fresh and salt water. Most of these systems are, obviously, based on water salinity (usually expressed in grams per litre and indicated as S ‰). In reality, however, coastal lakes or brackish ponds are not stable and have a well-defined range of salinity, quite variable in space and time, and something of a "riddle" for ecologists.

There are many coastal lakes in Apulia

The most widely adopted classification in Italy is the "Venice System", so called because it was proposed at a symposium held in Venice in 1958. The adoption of the classification shown below was recommended:

CATEGORY	SALINITY (‰)	
Hyperhaline	> 40	
Euhaline	40 - 30	
Mesohaline		
Mesoeuhaline	> 30	but < salinity of adjacent sea
(Meso-) polyhaline	30 – 18	
(Meso-) mesohaline	18 – 5	
(Meso-) oligohaline	5 - 0.5	
Limnic	< 0.5	

Hyperhaline waters are over-salty. Ponds in which evaporation causes a higher concentration of dissolved salts than that of seawater belong to this ecological category. They are obviously extremely harsh environments as regards the survival of organisms; the salt concentration, higher than that of animal tissues, drastically selects only those species which can survive in such waters.
The force known as osmotic pressure makes water pass through cell membranes from areas with lower salinity (in this case, inside the cells) to those of higher salinity (external environment), so that any organism without specific adaptations, placed in a hyperhaline environment, rapidly becomes dehydrated and dies. Species which have adapted to these high levels of dissolved salts include an anostracan crustacean, *Artemia salina*, which, finding no competitors, may sometimes reach extremely high densities in hyperhaline waters.
Euhaline waters are marine. Mesohaline waters correspond to brackish waters, further divided into subcategories, the ecology of which will be discussed in this chapter. Lastly, limnic waters are fresh.
The Venice system, although of practical use for reference purposes, has many weak points - most importantly, the classification value is limited in time. A brackish pond may obviously fall into different categories during different seasons of the year, in relation to fluctuating salinity. These fluctuations may be extremely large in small ponds, and often abrupt, sometimes changing from one day to the next or even, depending on tides, at different hours of the day. For example, if salty water is diluted by a violent rainstorm or a river flooding, a euhaline environment may rapidly be transformed into a mesohaline or, exceptionally, a limnic one. In the opposite case, other factors may increase salinity: for example, a high tide, with consequent penetration of seawater into the pond; high evaporation during hot summer days; or the scarcity of rainwater during dry periods. This means that an environment cannot generally be ascribed to only one category, but to a range of categories, which may be wider in smaller basins. The extent of this range is related to the morphology of the pond, its position with respect to the coastline, and the climatic conditions of the area.

In an attempt to solve these problems, other classification systems have been proposed based on annual average salinity, but their application is usually unsuccessful because they are often too specific to the geographical area in which they were calibrated (mainly the Camargue and the Baltic). In general, according to annual average salinity, the following categories of water have been proposed:
- salty: annual average salinity above 40 g/l
- polybrackish: annual average salinity between 16 and 40 g/l
- brackish: average annual salinity between 5 and 16 g/l
- oligobrackish: annual average salinity between 0.5 and 5 g/l.

Coastal lakes and ponds display great variations in salinity during the year (Lake Burano, Tuscany)

Po Delta: a mosaic of micro-environments with varying salinity levels

In the Camargue, very complex water classification systems have been proposed, known as "poikilohaline", a term indicating all waters which are not fresh. These are theoretical distinctions of little practical use, because average salinity may alter from one year to the next, depending on weather patterns and the sometimes rapid transformations which take place in these environments. Furthermore, for aquatic fauna, it is the degree of variation in salinity in a given habitat which is more important, and not its average value: empirical classifications of this type are therefore of no real ecological interest, but do serve as points of reference within the ambits of a discussion or description. In the following pages, therefore, we refer to the "Venice System".

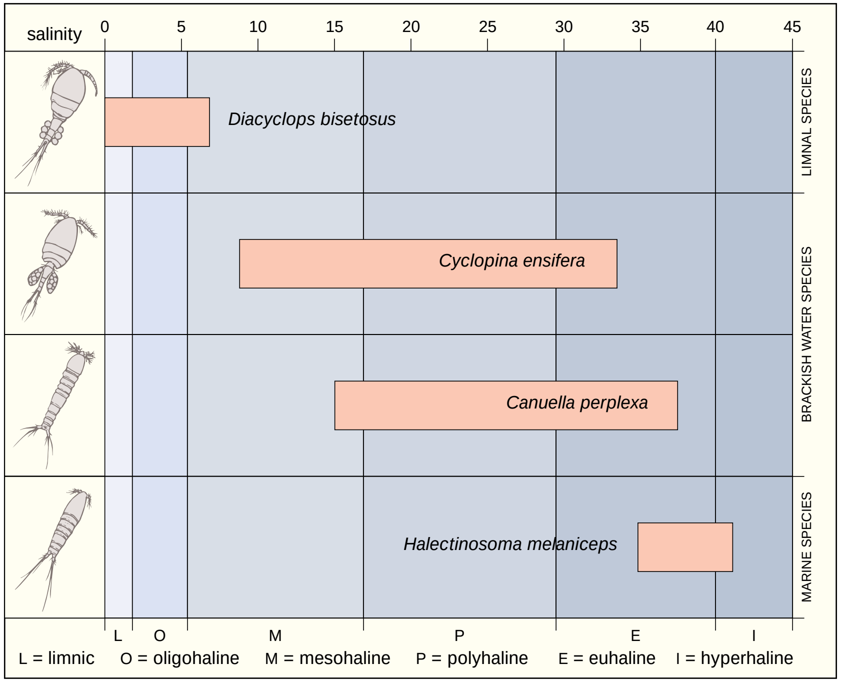
■ Limiting factors in brackish waters

As well as variations in salinity, which numerous studies demonstrate as obviously being the greatest limitation to life, other physico-chemical factors, such as temperature, pH, dissolved oxygen and water regime play a fundamental role in structuring aquatic communities. The most important of these seem to be fluctuations in temperature and dissolved oxygen (which is inversely correlated with temperature), closely associated with water regime. Temperature influences the biological cycles of organisms, regulating their metabolism and reproduction; the shallower the water in a pond, the greater the temperature fluctuations over time, often even at different times of the day. In summer, a Mediterranean pond may change its temperature by as much as 15 °C between day and night: in this case, temperature, or rather the extent of its variation, may become a limiting factor to the survival of many species.

Dissolved oxygen also displays daily and seasonal variations according to temperature, photosynthesis of algae and aquatic macrophytes, as well as the accumulation of decomposing organic matter, caused mainly by bacteria which notoriously consume oxygen.

In general, the bottoms of brackish lakes and ponds hold large amounts of detritus. On muddy beds, conditions of anoxia (i.e., absence of oxygen) are often reached even only one centimetre beneath the surface of the sediment. Most benthic organisms, i.e., those living on the bottom, are therefore usually on the surface of the sediment, with only burrowing organisms, which have obviously evolved specific breathing strategies (e.g., the siphons of bivalve molluscs) penetrating beneath.

Presumably however, the factor which more than any other influences life in



Different salt tolerance levels (mg/l NaCl) of some euryhaline species of copepods, based on data collected at mouth of river Isonzo (Friuli Venezia Giulia)

brackish ponds is the water regime, which is responsible for both fluctuations in temperature and salinity, and particularly the length of time the water remains where it is. Ponds with very wide variations in level, which sometimes completely dry up, are called *astatic*. The survival of aquatic fauna during periods of water stress requires specific adaptations and limits biodiversity. These survival strategies may be summarised as follows:

a) poorly mobile organisms withstand periods of drought by hiding in the mud on the bottom, where they find suitable moisture conditions (particularly molluscs);

b) more mobile organisms abandon the pond during dry periods (e.g., flying insects); insects often pupate or emerge as adult butterflies in time to avoid unfavourable conditions;

c) organisms which have developed quiescent stages (cysts, resting eggs) can survive extremely long periods of time without water; these are the only inhabitants of temporary waters, and include mainly protozoans, rotifers, tardigrades and crustaceans (anostracans, cladocerans, copepods).

■ Variations of biodiversity in time and space

A group of brackish ponds even in a very small geographical area can often range over all the different categories of water salinity (from entirely fresh water to salt). Even neighbouring environments often have various morphological characteristics (i.e., water volume, temperature, oxygen content, salinity), to the point of being inhabited by completely different aquatic populations.

Depending on water circulation, larger environments like coastal lakes may often also include areas of varying vegetation cover and salinity. The overall biodiversity of an area increases in relation to the number of micro-habitats forming the environmental mosaic. So, there are generally few species in a pond limited by the severity of its abiotic parameters, whereas a great many species may gather in an area with a well-preserved environmental mosaic.

Recent studies on the meiofauna (organisms generally of less than one millimetre) in various Italian brackish environments, from the Valli di Comacchio in the Po Delta to the large coastal lakes in Sardinia, have revealed the presence of several dozen species. Detailed research in systems of ponds at the mouth of the river Isonzo in Friuli Venezia Giulia also display very high biodiversity (of crustaceans and aquatic beetles) in comparison with previously studied adjacent areas. The number of species is therefore directly correlated with the variety of environments occurring in the area in question.

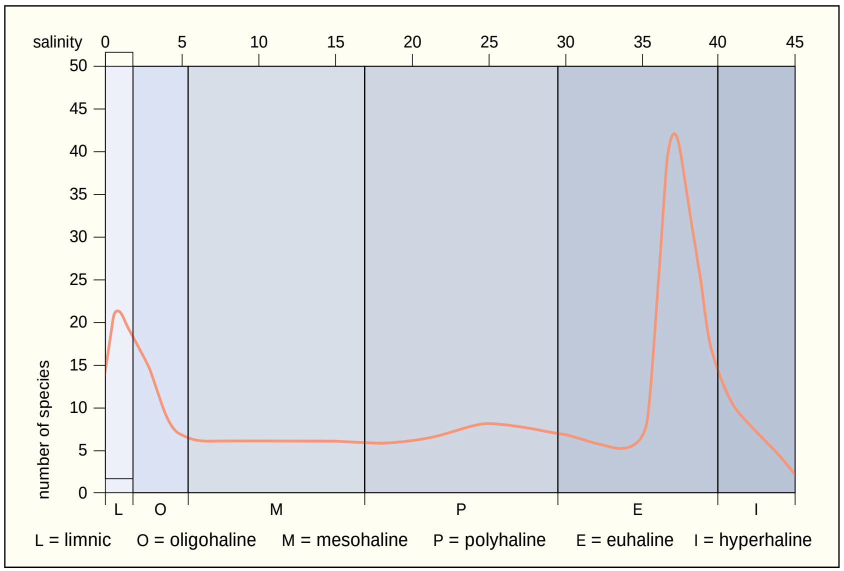
Coastal lake in natural conditions, with a well-preserved environmental mosaic (Alimini Lakes, Apulia)

An area where freshwater gradually merges with seawater is not a single environment, but rather a mosaic of environments, allowing the existence of many ecological niches and so the cohabitation of relatively rich and varied fauna, which contrasts with the apparent homogeneity and monotony of the ponds.

Naturally, not all environments are equally rich in species. Limnic and oligohaline waters are the richest, hosting many insects as well as crustaceans (mainly anostracans, cladocerans, copepods and ostracods). Brackish waters in the true sense are species-poor, with crustaceans prevailing because the highly variable environmental conditions only allow a few well-adapted species to survive. Instead, marine, coastal, euhaline waters are much richer.

This variation of biodiversity with salinity, studied for decades, is one of the keys to understanding species distribution and has obvious implications for the safeguarding, proper management and conservation of these environments.

Of equal importance to spatial variations in biodiversity are seasonal ones. If brackish ponds are visited at different times of the year, it can be observed that their populations do not remain constant, but fluctuate widely according to the environmental parameters regulating their life cycles.



Correlation between increase in salinity (mg/l NaCl) and number of species present (ponds at mouth of river Isonzo, Friuli Venezia Giulia)

Whilst this is very obvious in the case of migrating birds, those which over-winter in Italian brackish waters, or amphibians, which move to water in spring for breeding, the seasonal vicissitudes of small organisms are inconspicuous and more or less unknown to the public at large. This is partly due to the difficulty of collecting them.

The best season for observing aquatic invertebrates is without doubt springtime, during which various species reproduce, but a patient and attentive observer can make interesting observations throughout the year.

Seasonal successions have been well studied, particularly in plankton, i.e., that multitude of tiny organisms which live suspended in the water; those of benthic organisms are much less well known.

A series of studies by Cannicci were published as early as the 1930s and 1940s on the plankton of brackish coastal lakes (Lake Massaciuccoli, Sabaudia lakes, Sardinian coastal lakes, Lake Lesina). These have only recently been completed by research, mainly in the Valli di Comacchio (Po Delta), which has demonstrated that, during the year, there are a succession of different species with different ecological requirements. The smaller the body of water, the more marked these successions, reaching maximum variability in temporary waters.

Flooded areas near Valli di Comacchio (Emilia Romagna) show exceptionally high biodiversity of aquatic invertebrates

Main brackish-water invertebrates

Molluscs. Although molluscs are one of the most common animal groups in brackish waters, very few species are exclusive to or closely associated with these environments, because, in them, only decidedly euryhaline species can survive, either of continental or marine origin, having mostly arrived from neighbouring habitats. In particular, in oligohaline basins, where there are constant inflows of freshwater, it is easy to find limnal species which tolerate a certain amount of salt (gastropods of the genera *Physa*, *Bithynia*, *Viviparus* and, among the limnaeids, mostly *Radix auricularia*; bivalves such as *Pisidium amnicum* and *Sphaerium corneum*), whereas truly marine species frequent ponds close to the sea. In studies of the coastal lagoons of the northern Adriatic, the effect of heavy seas is demonstrated by the distribution of marine species, which can survive there only for short periods. More tolerant marine and brackish species which may be found throughout the year include the gastropods *Hydrobia ventrosa* and *H. acuta*, which reach very high densities in coastal ponds, sometimes together with *Truncatella subcylindrica*, the bivalves *Cerastoderma glaucum* and, to a lesser extent, *Abra tenuis*. Other marine species found in coastal lakes along the northern Adriatic because of the effect of heavy seas, such as the gastropod *Bittium reticulatum* and the bivalve *Lentidium mediterraneum*, do not survive long.

Crustaceans. Brackish-water crustaceans range from species only three-tenths of a millimetre long - for the minute copepods - to crabs, perhaps a dozen centimetres long (including pincers). They are among the major animals of the benthos and zooplankton, but a clear distinction between the two categories is not always possible in shallow ponds. As there are vast numbers of brackish-water crustaceans, only the most common and widespread taxa will be mentioned here.

Anostraca. These are typical crustaceans of temporary waters. They lay resting eggs which allow them to overcome periods of drought easily - cases have even been recorded of these eggs hatching after ten years. This characteristic means that the anostracans can easily be transported by migratory birds and this is how they may suddenly make their appearance in brackish ponds, where they reach extremely high densities. The species which are exclusive to these environments include *Branchinella spinosa*, in Sardinian and Apulian ponds, *Artemia salina* and *A. parthenogenetica*, which also frequent hyperhaline waters, like salt-pans, and are very well-known, being sold as food for aquarium fish. Anostracans are a major link in the food chain of these environments as they form an important part of the diet of some birds, especially flamingos.

Cladocera. Typical freshwater species like *Daphnia magna* or *D. curvirostris* can be found in oligohaline waters, sometimes at very high densities, but they are not exclusive to them. But *Moina salina*, recently recorded in Sardinian coastal lakes in the provinces of Cagliari and Oristano, is highly halophilous.

Copepoda. These are undoubtedly the taxonomic group with the highest number of species in brackish waters; apart from the parasitic forms, three orders of copepods are found here: calanoids, cyclopoids and harpacticoids. Calanoids are clearly adapted to planktonic life; their long antennae allow them to compensate for their jerky swimming as they move through the water. Their mouth apparatus is of typically filtering type and their diet consists mainly of phytoplankton and suspended detritus. They often penetrate into brackish ponds and, in coastal lakes, marine species of the genus *Acartia* can be found. Instead, *Calanipeda aquaedulcis*, a very widespread species around the Italian peninsula and the main islands, is exclusive to these environments.

Cyclopoids of brackish waters are mainly benthic and prefer muddy substrates; some are found among the vegetation. In oligohaline waters, predatory cyclopoids of the genera *Cyclops*, *Megacyclops* and *Diacyclops*

Physa fontinalis

Hydrobia ventrosa

Bittium reticulatum

Interstitial harpacticoid
Psammopsyllus maricae
(electron microscope image)

are common in winter and early spring. *Diacyclops bicuspidatus lubbocki* is a species of great ecological importance which is found in waters from limnic to mesohaline, where it is sometimes one of the dominant species. It prefers environments which dry out in summer: during these adverse periods, juveniles enclose themselves in a cyst. Instead, the species of the genus *Halicyclops*, such as *H. neglectus*, are decidedly halophilous and are very common in mesohaline ponds. Some species of the genus *Cyclopina* live in euhaline waters, and may be locally abundant. Lastly, the order of the harpacticoids includes species which live in the silt on the bottom and among the algae in brackish ponds, feeding on detritus. There are numerous species, belonging to a variety of genera (*Nitokra*, *Mesochra*, *Cletocamptus*, *Tsibe*, *Harpacticus*). *Cletocamptus confluens* and *Mesochra lilljeborgi* may form locally abundant populations. Where the substrate is sandy and at the mouths of rivers interstitial euhaline forms live in the sediment (*Psammospyllus*, *Apodopsyllus*).

Ostracoda. These are present everywhere in brackish waters. Their bodies are enclosed in a bivalved carapace similar to a shell, which gives them a characteristic "egg-like" or "bean-like" appearance. There are many species which live on the bottom feeding on detritus and decomposing animal remains. One of the most common and exclusive to brackish ponds is *Cyprideis torosa*.

Tanaidacea and Mysidacea. The Tanaidacea are small tube-dwelling crustaceans. The tubes in which they live are formed by the agglutination of solid particles around a spiral cylindrical structure secreted by special glands. They are all benthic and prevalently marine; in brackish waters, and especially in extreme environments, they may be abundant. *Heterotanais oertedi* is a species found in coastal lakes and estuaries of the Adriatic. Mysidacea are frequent in brackish ponds and canals with species of the genus *Diamysis*.

Isopoda. Various families of isopods live in Italian brackish waters. Among the most characteristic species are those belonging to the sphaeromatids, which can curl up to escape from predators, like armadillos. A very common species in brackish ponds and lakes is *Lekanesphaera hookeri*.

Amphipoda. Many families of amphipods frequent brackish waters. Representatives of the gammarids may be locally abundant, particularly the genera *Echinogammarus* and *Gammarus* - these omnivores are true scavengers. Of particular interest for their behaviour are the talitrids: these are jumping amphipods found along the shores of brackish lakes and along sand and shingle beaches beneath heaps of stranded vegetation - *Orchestia mediterranea* and *O. gammarella* are among the most common species, and *Platorchestia platensis* is often found roaming on the bottoms of small brackish ponds.

Decapoda. Marine decapod crustaceans belonging to numerous species are often found in brackish waters, but few can be considered exclusive to these environments. They are among the most conspicuous invertebrates in these areas and, being edible, are also of economic importance. The locally most abundant species is undoubtedly the shrimp *Palaemonetes antennarius*. It populates coastal lakes and ponds, lagoons and estuaries, and moves upriver to form colonies even in freshwater environments of the Po Valley. *Atyaephyra desmaresti* is a shrimp found in Italy in the coastal lakes of Sardinia, Sicily and the Tyrrhenian coast. The common crab *Carcinus aestuarii* is also very common in brackish ponds. It is an extremely mobile estuarine and lagoonal species, which often colonises coastal ponds, where it sometimes reaches very high densities.

Mysid *Diamysis* aff. *bahirensis*

Amphipod *Echinogammarus veneris*

Decapod *Carcinus aestuarii*

Insects. Most insects which frequent coastal ponds are only associated with water in certain stages of their life cycle, particularly for reproduction, and only pass the larval stage (mayflies, dragonflies, some beetles and dipterans) in water. However, many species are aquatic throughout their lives, such as the water bugs and many beetles; among the latter, there are several species which are aquatic only as adults, whereas their larvae are terrestrial or semi-terrestrial (e.g., hydraenids and hydrophilids).

Ephemeroptera. The ephemeropterans or mayflies, with aquatic nymphs, are poorly represented in brackish waters. *Caenis luctuosa* and *Cloeon dipterum* are the most common species along the shores of lakes, ponds and puddles. They are abundant in oligohaline waters, but disappear totally in euhaline environments.

Odonata. The presence of dragonfly larvae is also usually limited to oligohaline waters. These large predators are normally at the top of their food-chain, and prey on small fish or other aquatic invertebrates with a mouth apparatus modified into an incredible capturing organ, the mask. Odonate species are described in the chapter on terrestrial and riparian vertebrates, as the highly conspicuous adults are terrestrial and excellent flyers.

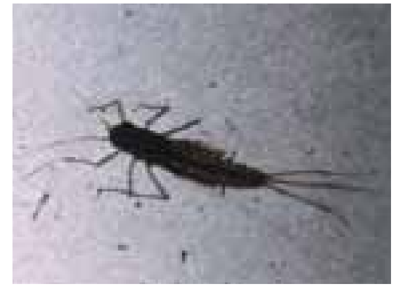
Heteroptera. Among the aquatic bugs, species of the genus *Velia* can be observed skating, and those of the genus *Gerris* walking and jumping, on the

Dragonfly larva of genus *Lestes*

surface of brackish waters. These insects exploit surface tension to move on the water, where they prey on other small arthropods. Swimming species include some corixids, such as *Cymatia rogenhoferi* and *Sigara selecta*. Corixids may reach extremely high densities in mesohaline ponds in some periods of the year, with hundreds of individuals per square metre. They are optimal colonisers, being among the first organisms to appear in temporary ponds immediately after the waters return.

Coleoptera. Aquatic species are usually less conspicuous than terrestrial ones, and are to be found among aquatic or riparian vegetation. Numerous families live in brackish waters.

Hydrophilid *Hydrochara caraboides*



Mayfly larva *Cloeon dipterum*

Predators include the ditiscids, aquatic both during the larval stage and as adults; a few species can be considered halophilous, such as *Potamonectes cerisyi*, or euhaline, like *Hydroporus limbatus* and *Guignotos signatellus*.

Beetles which prefer small meadow ponds include various species of the genus *Helophorus*, hydraenids of the genus *Ochthebius* (some strongly halophilous) and hydrophilids of the genera *Berosus*, *Enochrus* and *Paracymus*. *Paracymus aeneus*, with aquatic larvae and riparian adults hiding in tiny cells dug beneath detritus, are markedly halophilous. The largest of the hydrophilids is *Hydrochara caraboides* (= *Hydrophilus caraboides* in old texts), is an attractive, slow-moving, black beetle over 15 mm long. The spheridiid *Coelostoma hispanicum* also habitually frequents brackish waters. Yet other beetles prefer sandy areas, where they live buried among the roots of riparian plants - these are small members of the genus *Heterocerus*.

Diptera. Aquatic only during the larval stage, but terrestrial and fliers as adults, the dipterans of brackish ponds are described in the section on terrestrial invertebrates. Among the decidedly halophilous larvae, for their importance in the aquatic community, those of the families of the Culicidae and Chironomidae are worth special mention - see the notes on pages 70-71.

Halophilous chironomids

At times, particularly when the horizon is wide and open, huge swarms of insects can be observed just after sunset. This phenomenon is often especially evident near brackish ponds and wet coastal areas, where the view can sweep over vast horizons without obstruction. These insects are quite often enormous breeding swarms of male midges (chironomids), gathering above the plant canopy or other formations which stand out above the surrounding environment. The swarm is criss-crossed by females, which will then mate and shortly be ready to lay their eggs in the water. After a time, larvae hatch and are subsequently transformed into pupae, from which adult insects emerge for their subaerial life. The larvae of many species build "houses", cases or tubes, inside which they live, attached to stones or other hard substrates, or buried in sand and silt.

These larvae feed on detritus or bacterial flora or filter particles suspended in the water, thanks to the structure of their mouths, or other type of filtering apparatus. Species which feed on aquatic plants in environments with high primary production are also abundant. They scrape algal films from various substrates or eat the tissues of aquatic macrophytes. A small number of species live by preying on other aquatic invertebrates.

The specific diversity of the chironomid communities in brackish waters depends on several environmental factors, the most important of which is salinity. In brackish waters, as in other paralic environments, a fall in the number of species in a community has often been observed with increasing salinity. This variation in specific richness is accompanied by a change in the composition and structure of the community itself. In particular, the dominant species are replaced by euryhaline elements (i.e., species which tolerate a wide range of salt concentrations). Chironomids, usually with highly diversified populations in every type of environment colonised, are no exception to this rule. It is for this reason that, adapting this criterion to chironomid communities, systems of classification of internal brackish waters are based on their composition and structure. As Italian coastal ponds fall into this category, the most important chironomid species which may be found at various salinity levels will be described here, together with some salient aspects of their biology.

Ponds with very low salinity are inhabited by species which are also found in similar freshwater environments (marshland, rice-paddies, littoral and sub-littoral lake areas, rivers with slow-moving currents and macrophytes): here the dominant species are typically *Cricotopus sylvestris* and, less often, *C. bicinctus*. The former tolerates salinity up to 8‰. Their larvae are associated with vertical submerged vegetation and are also often found in the mud and on stones on the bottom. In all cases, their diet consists of aquatic plants, especially the leaves. The lower frequency of *C. bicinctus* is due to the fact that their larvae prefer flowing waters.

Other lentic orthocladiines, such as various species of the genus *Psectrocladius*, may be found in this type of pond. Many chironomids also found in freshwaters are well represented, especially *Chironomus* gr. *thummi* and *C*. gr. *plumosus*, *Camptochironomus pallidivittatus* and *Einfeldia* spp., which live in the sediment on the bottom. *Tanytarsus fimbriatus* has also been found in slightly salty rice-paddies. Among the chironomids with larvae associated with macrophytes, the genus *Glyptotendipes* is sometimes well represented by species which excavate plant tissues, and also *Dicrotendipes*.

Lastly, among the moderately salt-tolerant chironomids, although never present in significant numbers, *Microchironomus deribae* is worthy of mention. This species, found until now in Italy only in coastal lakes in Sardinia, is probably also present in other similar environments in Italy. In the chironomid community of coastal lakes with low salinity, there are plenty of predators, represented almost exclusively by tanypodines of the genus *Procladius*, especially *Procladius choreus*.

At higher salinity, the chironomid community becomes drastically simplified and remains represented by a few halophilous species such as *Chironomus salinarius*, or even halobionts like *Halocladius varians*, *H. mediterraneus* and *Baeotendipes noctivagus*. These are species whose larvae have various ranges of tolerance to the salinity level. *C. salinarius* may be defined as halophilous, as their larvae usually live in brackish water with medium-high salt concentrations (28-36‰), but they are also found in freshwaters or with low salinity. Species of the genus *Halocladius* live exclusively in waters with medium-high salinity, whereas *B. noctivagus* can be found only in water with high salinity, like those of salt-pans: the latter species are therefore defined as halobionts.

Specimens of *Chironomus salinarius* and (right) a swarm of adults over the Lagoon of Venice

Fish

SERGIO PARADISI

Canestrini's goby (*Pomatoschistus canestrinii*)

As in estuaries, the ecological factor which more than any other influences the fish population of internal bodies of water very close to the sea (littoral marshes, coastal ponds, lagoons) is – as may easily be guessed – salt concentration, or rather its variability. In these biotopes there is some degree of mixing between fresh and sea waters, by their inter-connection, or by groundwater ingression, both of which vary depending on contingent events, periodic or otherwise, such as freshwater distribution, tidal flows, solar radiation and consequent evaporation, and rainfall. Freshwaters, by definition, have a salt content of less than 0.6‰, while in seawater the value is around 35‰; in brackish waters, the salt concentration, usually widely fluctuating, falls between these values or is higher - sometimes by quite a lot - if evaporation is high.

The problems posed to aquatic organisms by the presence of salt are associated with the phenomenon of *osmosis*: when two solutions are divided by a semi-permeable membrane (i.e., permeable to the solvent but not the solute), the solvent tends to pass from the more dilute solution towards the more concentrated one. Similarly, the difference in saline concentration between the inside of an organism immersed in a solution (as are all aquatic organisms) and the external environment is neutralised by the passage of the solvent (i.e., water) in one or the other direction. Traditionally, we distinguish between sea fish and freshwater fish (a difference recognisable even just by tasting the different organoleptic qualities of their flesh), and all fish species can normally be attributed to one of the two groups. The basis for this clear-cut separation is the different osmotic pressure undergone by an organism immersed in freshwater or seawater. The body fluids of sea fish have a lower saline content than that of the environment (they are *hypotonic* compared with the water surrounding them). They therefore lose water by osmosis through

Area now used for fish-farming in Valli di Comacchio (Emilia Romagna) skin and gills, which behave like semi-permeable membranes. For this reason, they absorb a great deal of water through the walls of the intestine (it may seem paradoxical that a fish must drink a lot to avoid becoming dehydrated, but this is exactly what happens). In addition, there is re-absorption by the distal tubules of the kidneys to attenuate water loss, so that the urine of sea fish is concentrated. The salts swallowed with seawater (sodium chloride, potassium chloride) are partly eliminated with the urine, but mostly by special glandular formations (pharyngeal glands); other salts present in the ingested water (such as calcium sulphate and magnesium sulphate) are not absorbed by the walls of the intestine.

The body fluids of freshwater fish have a higher salt content than the water in which they live (i.e., they are *hypertonic* with respect to the environment). In this case, the water, by osmosis, penetrates into the body of the fish through the epithelia. The countermeasure is the release of a large quantity of urine. In this way, the fish also loses mineral salts, which are however recuperated in the proximal part of the contorted renal tubules. Freshwater fish also have many muciparous glands in their skin, the secretion from which – as well as being an efficient barrier against various pathogens – forms an obstacle to the absorption of water through the integument.

These are obviously adaptations that require complex and sophisticated physiological processes. For this reason, most fish are usually adapted to face extremely limited variations in salinity (i.e., they are *stenohaline*, from the Greek *stenos* = narrow, and *hals* = salt) and are thereby confined to a single environment (*holobiotic*, from *holos* = all, and *biotikos* = inherent to life): they are therefore either exclusively freshwater (*holobiotic potamobiont*, from *potamos* = river) or exclusively marine (*holobiotic thalassobiont*; from *thalassa* = sea).

However, some *amphibiotic* species (from *amphi* = double) do exist, which are equally at ease in both environments. Examples are all the “forced migrants”: those fish which migrate to breed (*gamodromous*; from *gamos* = nuptials), going to spawn in the sea (*thalassotokous*) or travelling upriver from the sea (*potamodromous*). Amphibiotic gamodromous potamodromous fish are more commonly defined *anadromous* (“ascenders”, from the Greek *ana* = back, and *dromos* = running), while the amphibiotic gamodromous thalassotokous are called *catadromous* (“descenders”, from *kata* = down). The group of *euryhaline* fish species (i.e., those tolerating widely fluctuating levels of dissolved salts, from *eury* = widely), which populate river mouths, where sudden changes in salinity are the norm, are also amphibiotic. Some may swim upriver for long stretches (they are commonly referred to as upstream migrating fish), but their migrations are for trophic reasons and not breeding (they are *agamodromous*).

Anadromous, catadromous and upstream migrating fish must adapt to the different osmotic conditions. In anadromous fish, for example, the passage from sea to fresh water is marked by enhanced filtering activity of the renal glomeruli and an increase in the amount of urine passed. This usually involves a period spent in brackish waters prior to starting the ascent upriver. The upstream migrating species have shorter adaptation times than anadromous and catadromous species.

The species found in coastal lakes, either with direct communication with the sea or separated from it by narrow littoral strips, are necessarily euryhaline. The only catadromous member of the Italian fish fauna always to be found in these environments is the eel (*Anguilla anguilla*), with that aura of mystery which still surrounds the migrants.

Eels may reach coastal lakes through practicable channels, or by exploiting their ability to leave the water and cover stretches overland with the aid of favourable atmospheric conditions (rainy or very damp nights). They are also frequently introduced for rearing: just metamorphosed eels (elvers) and slightly older ones (locally called “*ragani*”) are used for this purpose, being actively caught in various regions of Italy, especially in estuaries along the Tyrrhenian coast where they ascend in greater numbers: the fish farms of the northern Adriatic also benefit at least to some extent from this source of fry.

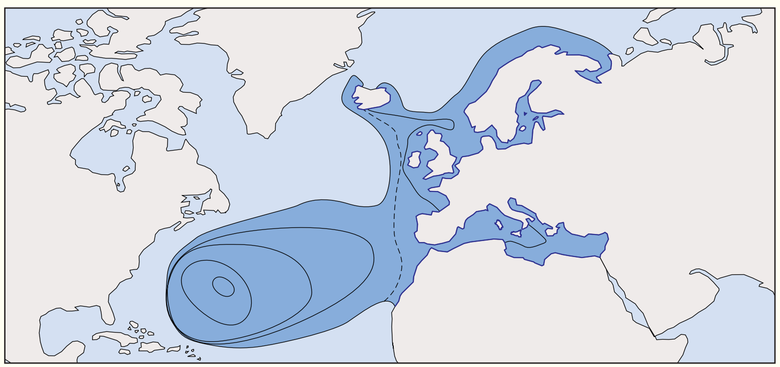
There are a few other species of fish which, after spawning in marine waters,

The Valli di Comacchio (Emilia Romagna)

Eels

Sergio Paradisi

It is now widely accepted that all European eels breed in the Sargasso Sea, where the mature adults arriving from the freshwaters of the Old World come to die, after fertilising and laying their eggs. A transparent, lanceolate-shaped larva, a few millimetres long, hatches from the egg, called *leptocephalus*. The leptocephalus is borne along by surface ocean currents and, after a voyage lasting 3-4 years, it reaches the coasts of Europe, North Africa and the Mediterranean. At this stage, it is around 6-7 cm long. Near the coast, metamorphosis occurs: the leptocephalus becomes an *elver*, assuming the form of a small transparent eel which begins ascending internal waters, where it reaches adulthood over the next 4 to 14 years. During this period, its diet is formed of benthic invertebrates, mainly amphipod crustaceans (*Corophium*, *Gammarus*), isopods (*Idotea*) and decapods (*Palaemon*, *Carcinus*), of progressively larger size as the elver grows. As the quantity of food increases, it starts to include small fish (in brackish-water ponds, frequently *Atherina boyeri* and *Aphanius fasciatus*). Growth is influenced by temperature as well as abundance of food, and is more rapid in the Mediterranean than in the waters of the European Atlantic coasts. During the trophic stage, eels are different shades of greenish-brown, with a yellowish belly ("yellow" eels). The animals which undertake the breeding migration have a very dark back and silvery belly, as well as larger eyes, thicker skin and more obvious scales ("silver" eels). The ratio between the sexes is also regulated by environmental factors. In step with the availability of food, it shifts progressively in favour of the males as population density increases. Until the middle of the 19th century, when the Trieste naturalist Simeone de Syrski found male gonads in some specimens, it had been believed that reproduction in eels was parthenogenetic, and only at the end of that century did Grassi and Calandruccio make the discovery that leptocephali are not a separate species, but the larval stage of eels. Many aspects of the biology of this fish still remain to be clarified: population structure and dynamics, route and orientation when migrating, and yet more.

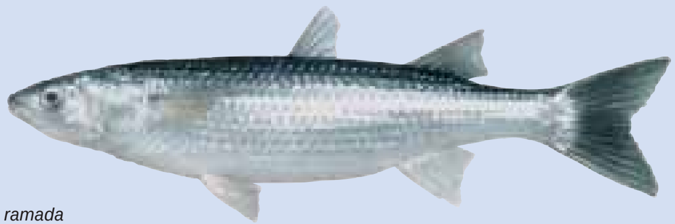


normally pass part of the year in brackish or even fresh waters. These are not obligatory migrants however: theirs is trophic migration, not linked to breeding. They are therefore agamodromous fish, which penetrate into lakes and coastal ponds by natural or artificial channels or by being introduced by man, usually in the form of fry, for restocking extensive fish farms. Mullet, plaice, bream and sea bass belong to this category.

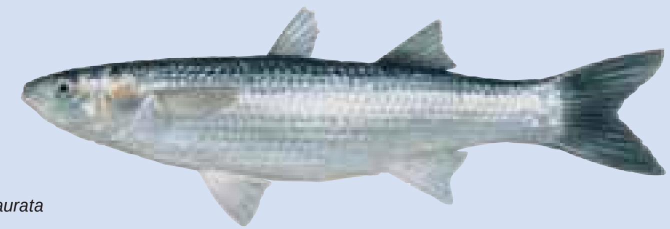
Mullet are gregarious, medium-sized fish, strongly euryhaline and eurythermal, which populate the soft bottoms of coastal sea waters, also tolerating marked conditions of pollution. Juveniles have a zooplankton diet, which is abandoned after they reach 30 mm in length. The omnivorous adults mainly feed on organic detritus, algae and small invertebrates by filtering the surface layer of the silt on the bottom: their pharyngeal-branchial apparatus is capable of selecting particles only a few tens of millimicrons across. They also feed at the water surface when it has a film of bacteria and/or algae. As mentioned, mullet breeds exclusively in the sea; when imprisoned in freshwaters, it may even demonstrate degenerative forms of the gonads. Sexual maturity is reached, with few exceptions, in the third year by females and the second by males. The eggs are pelagic, spherical, and contain a small oily globule. Juveniles usually go almost at once into brackish or fresh waters, where they pass a trophic stage of varying length. All Italian mullet are of some economic value: they are fished, and are among the most commonly farmed in lagoons and coastal lakes, both extensively and semi-intensively. As well as the flesh, the eggs are appreciated, which in some regions (e.g., Sardinia), are traditionally salted and dried and known as *bottarga*. The best-known species is flathead mullet (*Mugil cephalus*); it is also the largest (average length around 35 cm, maximum 70 cm) and undoubtedly the one most exploited in fish farming, because of its fast

Eel (*Anguilla anguilla*)

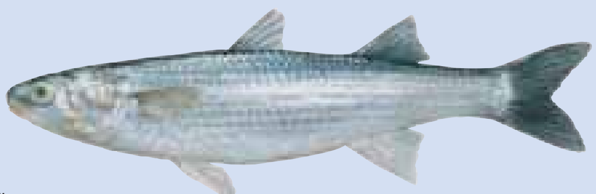
Mugil cephalus



Liza ramada



Liza aurata



Liza saliens

Chelon labrosus

growth rate and wide tolerance to rapid variations in salinity and temperature. Flathead mullet spawns in coastal waters at night, in late summer. The maximum upriver migration is in October-November, with a second peak in February-March in the mid- and upper Adriatic. It is during these periods that young fish used for restocking fish farms are harvested by professional fishermen known as "*novellanti*": this is a traditional type of fishing with very ancient origins.

Thinlip grey mullet (*Liza ramada*), golden grey mullet (*Liza aurata*), leaping grey mullet (*Liza saliens*) and thicklip grey mullet (*Chelon labrosus*) are related to flathead mullet, and are all common or very common along Italian coasts. The species which best tolerates low temperatures and salinity is *Liza ramada*, which may swim upriver for very long stretches (in the river Po for over two hundred kilometres, as far as the confluence with the river Taro); the least tolerant species is *Liza aurata*.

The spawning seasons of the different species follow one another during the year: from February to April for *Chelon labrosus*, from May to August for *Liza saliens*, in August-September for *Mugil cephalus*, from September to November for *Liza aurata*, and throughout autumn until December for *Liza ramada*. The subsequent periods when the fry enter internal waters is therefore also well distributed, but with ample overlaps. This cohabitation of highly gregarious species occupying the same ecological niche in the same habitats lies at the base of some strategies aimed at reducing competition for food: for example, *Liza saliens* feeds during daylight hours, whereas *Mugil cephalus* – which is present during the same period – extends its feeding activities to the hours of twilight. Species of the genus *Liza*, despite their numerically higher populations and – in some cases – the better taste of the flesh, do not keep pace with the others in fish farms, because of their markedly slower growth rate.

Bream and sea bass are also of great importance in brackish-water fish farming. Bream (*Sparus auratus*) is a coastal species frequent along the edges of reefs and meadows of *Posidonia*. It is a protandrous hermaphrodite, i.e., the gonads possess male and female regions which mature at different times: the same animal is thus a mature male at the end of the second year, whereas in the following breeding season the male region of the gonad regresses and that of the female matures. After the autumn spawning season, many fry migrate from February onwards to brackish environments, where they gain weight more rapidly than their peers remaining in the sea. Their diet evolves with their size: zooplankton for the fry and various benthic invertebrates (in particular polychaetes and amphipod crustaceans) in the juvenile stages, while the dietary range of adults widens to include small fish and especially both gastropod (*Hydrobia*) and bivalve (*Cerastoderma*, *Mytilus*) molluscs, on which they prey by breaking the shells with their strong teeth.

Bream are sensitive to low temperature: values below 5 °C are lethal and this often necessitates abandoning internal waters and returning to the sea in the winter months - cold is often the cause of massive die-off in fish farms. There is a very high market demand for this fish. The requirements of fish farms are not satisfied by natural migration, and often not even by the catches of the "*novellanti*" fishermen. The spread of artificial insemination, increasingly practiced in recent years with now well-established techniques, appears to be the only answer in the future to the progressive decline in natural populations.

The situation is similar for sea bass (*Dicentrarchus labrax*), a species much in demand for its excellent flesh, both adults and fry having a high market value. However, the rearing of sea bass, traditionally done in extensive form in bodies of brackish water, must take into account the strong predatory habits of this species (the "wolf" of Pliny and many Italian local dialects), which is at the top of the food chain in brackish waters. Their diet, based on zooplankton for the fry, becomes progressively augmented by macrobenthic crustaceans and fish, which come to represent the major part of stomach contents in adults, and cannibalism is habitual - already starting at the juvenile stages. This is the reason why fish farmers, wishing to protect the fry of this and other species of commercial value, usually confine adults in isolated fish-ponds, with suitable amounts of food (e.g., whitebait).

The future for sea bass also appears to be that of widespread artificial insemination and intensive forms of rearing. In the wild, spawning takes place in winter, always at sea. The fry begin to migrate in March and this reaches a maximum in April-May, particularly at twilight. Juveniles are typically gregarious, while adults are solitary predators. As well as being euryhaline, the species is markedly eurythermal and so, unlike bream, it does not require a period of over-wintering at sea.

Another upstream-migrating species is plaice, a characteristic, very flat fish, oval in shape, strictly benthic, which lies on the bottom on one whitish flank (almost always the left), exposing the other greyish-brown to olive-coloured flank upwards. Starting from normal bilateral symmetry in the fry, migrates one eye towards the other on the pigmented flank, and there are many other less obvious but profound modifications involving the skeleton, muscles and nervous system. Plaice frequent deep, sandy or muddy bottoms, and the coloration of the pigmented flank may become more or less intense, with excellent capacities for mimicry. Plaice spawn in winter, exclusively in coastal sea waters, with sexual maturity being reached at the end of the second or

Sea bass (*Dicentrarchus labrax*)

Bream (*Sparus auratus*)

Plaice (*Platichthys flesus*)