



Fishes in Lagoons and Estuaries in the Mediterranean 1

Diversity, Bioecology and Exploitation

**Mohamed Hichem Kara
Jean-Pierre Quignard**

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Foreword

Lagoons, deltas and estuaries are by definition transition zones and represent a distinctive element of the Mediterranean shoreline. In days of old, people used to come here to catch an abundance of fish, and this coastal fishing – practiced behind the shoreline in the channels of the salt marshes and in the estuary mouths – was at that time more highly prized than fishing in the open sea. Nowadays, although lagoon fishing represents only a small fraction of annual fish catches in the Mediterranean, estuarine and lagoon habitats continue to play a major role, be it as nurseries or in supporting an often-intensive mariculture, such as in Egypt, Italy and Greece.

This academic publication, patiently compiled by two eminent ichthyologists who are familiar with both shores, covers in three volumes the ichthyofauna of 303 lagoons and estuaries in the Mediterranean region, from the coastline of the Alboran Sea to Anatolia. Volume 1 outlines the vast geographical, geomorphological, hydrological, physicochemical and also historic diversity of Mediterranean lagoons, a diversity that has led to marked differences in the biology, reproduction, genetics, feeding and behavior of lagoon fishes.

Further, the reader will find illustrated descriptions of 47 lagoon and estuarine species that have been studied, with a detailed discussion of systematics and of issues relating to biogeography, reproductive and feeding strategies, genetics and biodiversity. Throughout this work, distinction is drawn between sedentary and migratory species – those that come and go each year between the lagoons where they find refuge, and the sea where they reproduce. However, the dividing line between these two worlds can sometimes be tenuous, and the authors introduce many central issues that remain unresolved, relating

to, for instance, the genetic differentiation and adaptation (or preadaptation) between migratory and sedentary stocks, or the respective contributions made to the local fisheries by the lagoon nurseries and the marine shore area. The ichthyofauna of the studied sites is remarkably discrete: of the 249 species inventoried in 45 representative estuaries and lagoons, it will be noted that only 15 are found in 50% or more of the studied sites.

In the face of increasing anthropic pressures on the Mediterranean coast, already weakened by concrete urban development and its pathogenic wastes, by erosion, climate change, industrial and agricultural discharges into the sea, irresponsible mass tourism and the arrival of invasive Indo-Pacific species, the conservation and sustainable management of these areas and of lagoon fishing take on a certain urgency. The authors consider these topics at some length; their views are invaluable, drawn from their long experience in the field; I hope that many practitioners will find inspiration in them.

Because of the variety and expert knowledge of the themes covered, to its extensive bibliography and illustrations, this work is sure to become indispensable to the technicians and managers involved in fisheries and Mediterranean aquaculture. On a wider level, it will interest the many students and researchers working in ichthyology.

Frédéric BRIAND
Director General
CIESM Mediterranean Science Commission

Preface

The conservation of the natural and economic heritage represented by Mediterranean lagoons and estuaries and the associated adjacent areas (wetlands, reed beds, *sansouires* and salt marshes) calls for an in-depth scientific knowledge of the past and present state and of the functioning of these environments, and particularly of their plant and animal components. It is on this basis that appropriate management policies can be formulated.

Classed as transition zones between land and sea, these special ecosystems are matters of concern for both scientists and managers. The former group has accumulated significant knowledge of their abiotic characteristics and their functioning. They are now investigating the individuality of the resident populations, their interactions with the adjoining ecosystems and their future in the context of climate change. The latter group is seeking scientific and technical tools that will enable them to use these environments to their full potential, taking into account the increasing anthropic pressures.

In this book, divided into three stand-alone, complementary volumes, we have brought together scientific knowledge amassed over nearly two centuries on the fishes of the Mediterranean lagoons and estuaries. This summary has been compiled from documents published in local and international reviews and in general or specialized bioecological works on pure and applied ichthyology. We are, however, conscious that an entire fringe of works concerning lagoon and estuarine fishes has been omitted, this being the “gray literature” consisting of expert reports, academic projects and theses, etc.

The first volume, entitled *Diversity, Bioecology and Exploitation*, is a non-exhaustive approach to the characteristics of lagoons and estuaries, from a “geo-geographical”, hydrological and general bioecological viewpoint, and also looking at the ecophysiology and behavior of the fishes that live there. The general features of the exploitation and management of fish resources are also considered.

The second volume, *Sedentary Fish*, is devoted to the fishes that are so named because, being very euryvalent, they live out their entire lifecycle inside lagoons and estuaries. These fishes are not all specific to these environments; some have their counterparts in the sea or in fresh water.

The third volume, *Migratory Fish*, is concerned with fishes that, after spending time in lagoons, are obliged to return to their native marine or river environment to complete their lifecycle (genesic migrations), the physicochemical conditions in lagoons and estuaries (temperature, salinity, turbidity, etc.) being incompatible with the water properties required for their reproduction. Strictly hydroclimatic events can also be at the origin of migratory journeys.

The data provided in volumes two and three of this book are at three taxonomic levels: family, genus and species. Those concerning family and genus are relatively brief and general, while those relating to species are exhaustive and very detailed, for every aspect dealt with: systematics, genetics, phylogenesis, ecology, biology, behavior, etc.

This summary has been designed to permit rapid and comprehensive access to the body of scientific knowledge on lagoon and estuarine fishes and their sources. These data are indispensable in order to develop projects of research, infrastructure, management and conservation concerning these environments and their populations.

Mohamed Hichem KARA
Jean-Pierre QUIGNARD
September 2018

Introduction

“Knowledge of fish is as ancient as fishing”. These words were written in 1958 by two ichthyological experts, Léon Bertin and Camille Arambourg. In our Mediterranean world, we must give credit to Aristotle the Greek (350 B.C.) for having written “A History of Animals”, in which fish are taken into consideration. In this book, our scholar gives succinct information on lagoon-dwelling fishes, saying:

“A quantity of fishes can be found in the lakes formed by the sea: the Mediterranean bream, the gilthead sea bream, the red mullet and most other coastal fishes” – Book VIII, chapter 15 (Aristotle, 1883).

“Mulletts, sea bream and sea bass spawn best where rivers flow into the sea [...] the sea bass and the mullet spawn in winter [...] there are some mullets that are not the result of copulation: they are born from the silt and sand [...] just like eels which are born from larvae, mud and worms” – Book V, chapter 10 (Aristotle, 1883).

The interest in lagoon-dwelling fish faded with the disappearance of this “master”. However, the Hispano-Islamic historian and geographer, Abou Obeïd El Bekri, in his *Book of Roads and Kingdoms* (1068), reports, on the basis of merchants’ and fishermen’s accounts, that “fish are very abundant” in the Lake of Tunis, and he cites the Mediterranean bream, the gilthead sea bream, the “menkou” (which may be the striped sea bream), the “baconis” (which we take to be the mullet), etc. (Miquel, 2003).

Subsequently, the official geographer of King Roger II of Sicily, Al-Idrîsî, in his great work, *The Book of Roger* or *A Companion Book for He Who Wishes to Travel the World* (circa 1154-1157), remains silent on virtually all the Mediterranean lagoons, but in Tunisia, the salt lake, Bizerte, and the freshwater lake, Tinja (Lake Ichkeul), which are connected to each other, caught his attention. The author tells us:

“Lake Bizerte is one of the wonders of the world: 12 species of fish can be found there [which he names] and, during each month of the year, one single species is dominant, not mixing with any other [...] Its corresponding species disappears and is replaced by a new one” (Bresc and Nef, 1999).

After a long hiatus, Mediterranean interest in ichthyology reawakened in the 16th Century with two famous scholars, the Italian, Ippolito Salviani, and the Frenchman, Guillaume Rondelet. In 1554, the latter published *De piscibus marinis*, translated from the Latin in 1558 under the title of *L’histoire entière des poissons* (A complete history of fishes) (Figure I.1). Primarily inspired by Languedoc, this book is, nevertheless, of more general interest because the author presents 241 fish species from the Mediterranean, the Red Sea, etc. Remarkably, Rondelet devotes a chapter to lagoon-dwelling fishes: “Des poissons des estangs marins. Des estangs é des poissons d’iceux” [*On the fishes of marine lakes. On lakes and the fishes therein*]. After that, it was not until the 19th Century that pertinent data relating to ichthyofauna and lagoon fishing on the French coasts were made available with the works of Marion, published between 1886 and 1890, and those of Gourret, between 1896 and 1907.

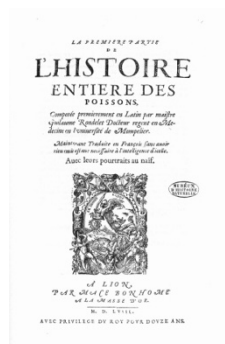


Figure I.1. G. Rondelet, *L’histoire entière des poissons*, 1558
(French edition of *De piscibus marinis*, published in 1554)

In our times, the bibliographical database *Web of Science* (Thomson Reuters), discontinued on March 5, 2015, enables us to appreciate the scientific research efforts devoted to the Mediterranean lagoons during the period 1975–2014. More than 2,000 references were inventoried, with a steady growth between 1977 and 2014. Over this time span, three periods can be distinguished (Figure I.2):

- 1977–1990: a 14-year period with an average of two publications per year;
- 1991–2004: a 14-year period with an average of 42 publications per year;
- 2005–2014: a 10-year period with an average of 146 publications per year.

At the source of these works, the Italian and French teams published the most, with 601 and 548 scientific papers, respectively (Figure I.2). They are followed by the Spanish (329), Greek (163) and Tunisian (144) teams. Studies on biodiversity, biology and ecosystems are the most numerous (1,449). Next are the studies relating to aquaculture and fishing (962), geology and sedimentology (869) and pollution (744) (Figure I.3). Studies focusing on economics (487) and climate (433) show a sharp increase in recent years.

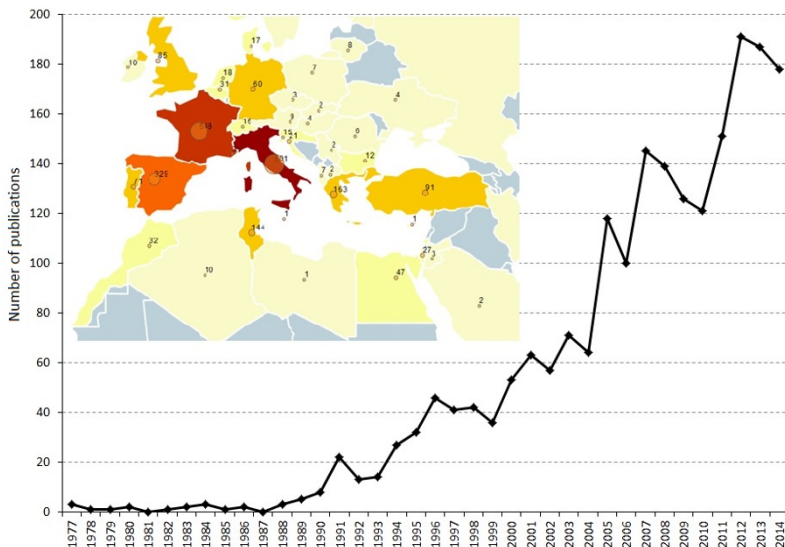


Figure I.2. Numerical evolution of publications about Mediterranean lagoons between 1977 and 2014 and their distribution according to country of author.
For a color version of this figure, see www.iste.co.uk/kara/fishes1.zip

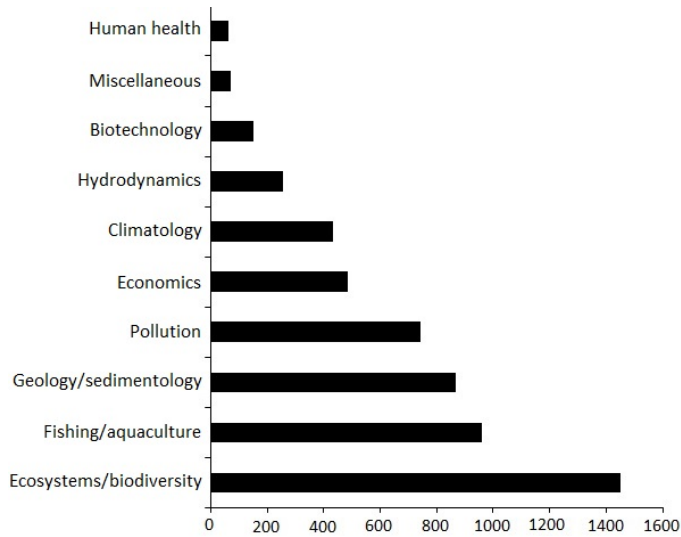


Figure I.3. Numerical distribution of publications about Mediterranean lagoons between 1977 and 2014 by research topic

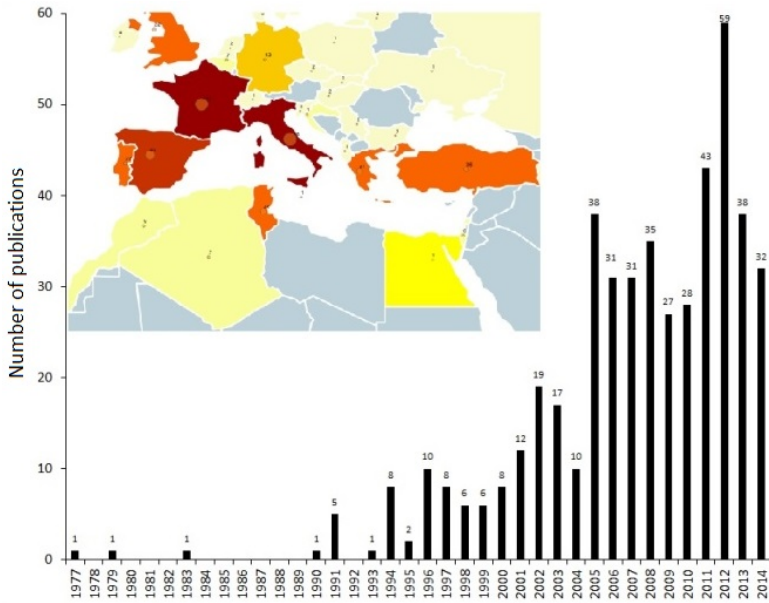


Figure I.4. Temporal evolution (1977–2014) of number of publications on fishes in the Mediterranean lagoons. For a color version of this figure, see www.iste.co.uk/kara/fishes1.zip

The number of publications devoted to fishes (491) represents 23% of the total number of works devoted to Mediterranean lagoons, and these have been especially numerous over the last decade (Figure I.4). The fishes with which these publications are chiefly concerned are the mullet, eel, gilthead sea bream, gobies, silverside and sea bass (Figure I.5).

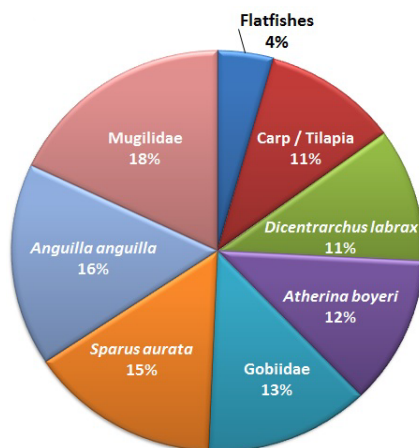


Figure I.5. Numerical distribution of publications on fishes of the Mediterranean lagoons between 1977 and 2014 according to species or species groups.
For a color version of this figure, see www.iste.co.uk/kara/fishes1.zip

Studies focusing on ecology predominate with 174 publications (Figure I.6). Next are those dealing with biodiversity, fishing, genetics, biology, aquaculture and pollution, with between 89 and 76 publications. Finally, pathology and toxicology have 41 and 34 publications, respectively. The countries whose lagoons are most studied for their fishes are Italy (87 publications), France (69), Tunisia (41), Spain (38), Greece (24), Turkey (23), Egypt (13), Israel (7) and Croatia (7).

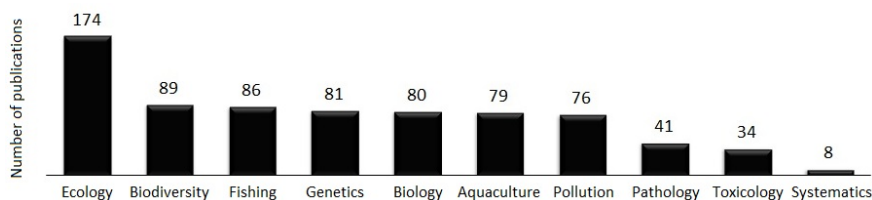


Figure I.6. Main topics associated with fishes of the Mediterranean lagoons, according to works published between 1977 and 2014

Despite the wide surface area covered by lagoons, their ecological role and their socioeconomic interest, as well as the existence of an abundance of specialized scientific literature, there have been few syntheses devoted to Mediterranean lagoons and their ichthyofauna. We should mention Kiener (1978) who looks at the ecology, physiology and economics of brackish waters, Kapetsky and Lasserre (1984b) who studied the ecology and exploitation of Mediterranean lagoons, and Cataudella *et al.* (2015) who compiled information on the interactions between aquaculture, fishing and the environment. Syntheses of a more local nature are available to researchers and managers, such as those devoted to the lagoons in the Gulf of Lion and Corsica (Gourret, 1897; Quignard and Zaouali, 1980 and 1981; Cuenca and Gauthier, 1987; Graille *et al.*, 2000–2001).

The lagoons that are considered here are usually defined as transitional aquatic areas between the continental and marine worlds, connected either permanently or temporarily to the sea. According to the local climate and the relative magnitude of the connection with the catchment basin and the sea, the salinity of lagoon waters varies greatly in space and time. For this reason, these environments host freshwater and marine fauna and flora, lagoon endemism being exceptional (*Aphanius iberus*, *Symphodus cinereus staitii*, etc.).

In fact, virtually all the species that live in lagoons and estuaries have representatives in the adjacent fresh and marine waters. Their euryvalence enables them to support the very variable or even extreme conditions in lagoons. Fishes that are able to live and reproduce there permanently are termed “sedentaries” (*Pomatochistus microps*, *Atherina lagunae*, etc.); those that live temporarily in lagoons are termed “migrators” (*Sparus aurata*, *Solea solea*, *Cyprinus carpio*, etc.). Of the latter, some undertake regular journeys between lagoon and sea where the adults find favorable spawning conditions (sea-spawning species: *Dicentrarchus labrax*, *Diplodus annularis*, etc.); the rest migrate between the lagoon and fresh water where the spawning adults reproduce (river-spawning species: *Carassius gibelio*, *Tinca tinca*, etc.).

Finally, certain species make the journey across estuaries (in both directions) in order to reach their spawning grounds in rivers (amphidromous river-spawning species: *Alosa fallax*, *Alosa algeriensis*, etc.) or in the sea (amphidromous sea-spawning species: *Anguilla anguilla*).

Other species, which are relatively numerous, pay random visits to lagoons (*Sardinella aurita*, *Belone belone*, etc.). These species are the source of the great biodiversity of 249 inventoried taxa. Thus, fish life in lagoons is, over a limited area, rich and varied and, moreover, in a state of perpetually renewal due to the magnitude of the migration and visitor phenomena.

In this work, we have attempted to inventorize and characterize Mediterranean lagoons from the geographical, morphological and hydroclimatic point of view and then to provide information on the diversity of the fish that live there and also on the main features of their bioecology and exploitation.

Mediterranean Lagoons and Estuaries

Coastal areas provide the majority of the biosphere's current economic wealth. They account for 38% of the value of all services rendered by its ecosystems, representing over 12,600 billion dollars per year out of a total value of services rendered by natural ecosystems of 33,300 billion dollars per year (Costanza *et al.*, 1997). Among the coastal ecosystems, the paralic domain only covers just over 6% of the globe's surface, but produces 26% of the biosphere's total food resources, representing around 366 billion dollars a year (Figure 1.1).

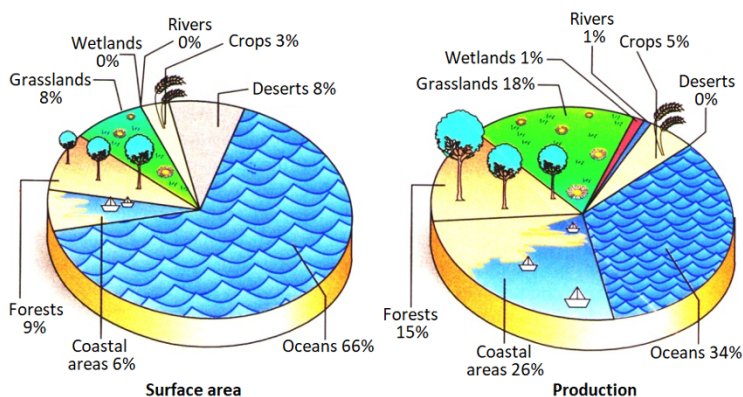


Figure 1.1. Surface area and production of the Earth's various ecosystems (Guelorget *et al.*, 1998). For a color version of this figure, see www.iste.co.uk/kara/fishes1.zip

Guelorget and Perthuisot (1983, 1984, 1992) define the paralic domain as “permanent or temporary bodies of water that are closely or less closely

(and/or intermittently) connected to the sea”. In the Mediterranean, these water bodies, known as “transitional”, are classified from a hydrogeological point of view into three physiographic types: river mouths (estuaries and deltas), lagoons and salt marshes. They are defined by Kjerfve (1986) as follows: “shallow aquatic environments, located in the transitional zone between terrestrial and marine ecosystems (marginal shoreline aquatic systems), which span from freshwater to hypersaline”.

1.1. What is a lagoon and what is an estuary?

Lagoons and estuaries account for around 13% of the world’s shoreline (Lasserre, 1979). These two features occur at all latitudes (Kiener, 1978); more abundantly in some coastal regions than others (Table 1.1). On the land–sea border, they are characterized by steep physicochemical gradients, very variable ionic relationships (Kiener, 1978) and environmental fluctuations that necessitate physiological and ecological adaptations on the part of the species that live there. These environmental gradients are fundamental in the processes of shaping species composition (Sanders, 1992). Their common characteristics mean that they share, within a given biogeographic sector, the same basic species, and that we can talk about “lagoon/estuarine guilds”.

Continent	Length (in km) of lagoon shoreline	Lagoon shoreline (%)	Global lagoon coast (%)
North America	10,765	17.6	33.6
Asia	7,126	13.8	22.2
Africa	5,984	17.9	18.7
South America	3,302	12.2	10.3
Europe	2,693	5.3	8.4
Australia	2,168	11.4	6.8
Total	32,038	–	–

Table 1.1. World distribution of the coastal lagoon barrier (Cromwell, 1971)

The Mediterranean estuaries and certain lagoons correspond to the definition of transitional water bodies given in the DCE¹, but a number of

1 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water, Official Journal L327 of December 22, 2000.

lagoons do not correspond exactly with the given description, since they have no freshwater inflow. In fact, according to this definition, “transitional waters are bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows”.

According to Pritchard (McLusky, 1999), “an estuary is a semienclosed coastal body of water, which has a free connection with the open sea, and within which sea water is measurably diluted with fresh water derived from land drainage”. According to Fairbridge (McLusky, 1999), an estuary is the part of a fluvial valley that is subject to tidal influences (estuary, from the Latin *aestus*, tide). These definitions are not without controversy. The mouths of Mediterranean rivers are commonly called estuaries, even if the tidal influence is very slight and sometimes non-existent. Traditionally, coastal lagoons have been considered as transitional systems between the continental and marine domains (Bianchi, 1988). Barnes’ definition (1980), according to which “coastal lagoons are areas of salt or brackish water separated from the adjacent sea by a low-lying sand or shingle barrier” do not allow for them to be clearly differentiated from estuaries that can in some cases be briefly cut off from the sea. Tagliapietra *et al.* (2009) seek to clarify the scientific, historical and geographic context of the terms used to define estuaries and lagoons, but conclude that currently no commonly accepted term or common definition exists for the whole of the semienclosed coastal environment and, more importantly, the crucial question – whether they can be considered as one functional ecological group – remains unclarified.

Pérez-Ruzafa *et al.* (2011) produced a summary (Figure 1.2) of different types of water bodies and aquatic assemblages in lagoons based on three main factors: ionic composition (from limnogenic to thalassogenic), saline concentration and confinement. The ionic composition of the water can be a determining and destabilizing factor in cellular osmotic balances, the regulation of which calls for physiological adaptations, requiring significant energy expenditure. Limnogenic waters contain mostly HCO_3^- , Ca^{2+} and SO_4^{2-} ions, but with substantial differences in the relative proportion (rapic or rhopic factor) and composition of the ions depending on the origin, then the salt composition of the soils in the catchment area. In contrast, thalassogenic waters have a homogeneous ionic composition and stable ionic relationships, unconnected to saline concentration, and are dominated by Cl^- and Na^+ ions. In coastal lagoons, salinity varies from below 0.5‰ to above 140‰ in

β -hypersaline waters and above 300‰ in δ -hypersaline lagoons, according to Por (1980). Although estuaries have a generally fairly stable saline gradient going from fresh water to brackish water and then saline, lagoons are exposed to a far wider range of situations, inter- and intralagoon, depending on the “fresh water versus seawater” influence and the “precipitation versus evaporation” balance, and also on other factors such as the localization of fresh water and sea water inflows, hydrodynamics, vertical zoning and input of nutritional salts. Thus, in lagoons there is not necessarily a clear unidirectional salinity gradient.

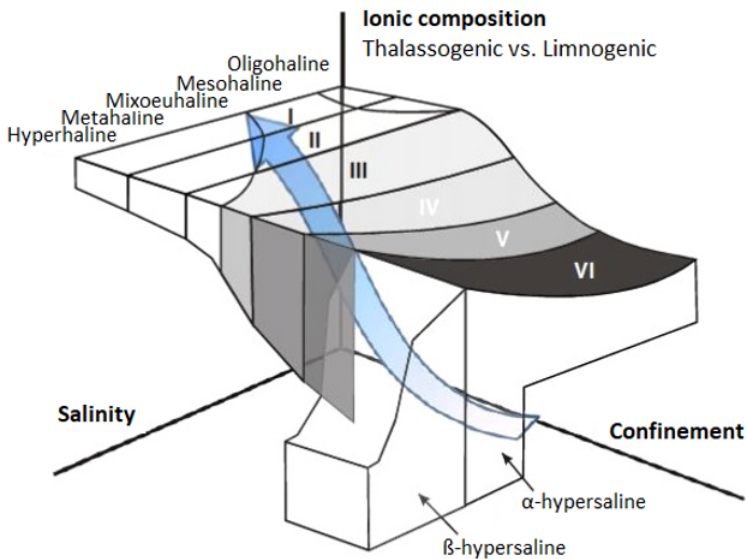


Figure 1.2. Conceptual model of the different types of water bodies and aquatic assemblages in lagoons (in black) and estuaries (blue arrow) according to three main structural factors (ionic composition, salinity and confinement) (Pérez-Ruzafa et al., 2011). For a color version of this figure, see www.iste.co.uk/kara/fishes1.zip

“Confinement”, defined as being the inverse of the rate of colonization by marine organisms, leaving aside the factors mentioned earlier, and the renewal time for elements of marine origin at a given point in the lagoon, leads to a “sea–continent” horizontal zoning model (Guelorget and Perthuisot, 1983; Frisoni *et al.*, 1983) (Figure 1.3).

It should be noted that Guelorget and Perthuisot’s model has been reinterpreted in line with other concepts such as that of “saprobity” (the state

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