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Research Article

Overview on the state of marine remarkable habitats and their biodiversity in front of tourism activities and other disturbances in Tunisia

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Abstract: In general, biodiversity in the Mediterranean Sea is concentrated in the 0-50 m deep coastal strip. It is linked mainly to photic, climatic and hydrodynamic factors. Similarly, some ecosystems are characterized by high biodiversity/biological productivity and high presence of endemic, rare and threatened species.

In Tunisia, they are particularly lagunar/island ecosystems, submarine banks, *Posidonia* meadows, coralligenous biocenosis and *Cystoseira* beds. Among the human activities that threaten marine habitats in Tunisia, we can cite tourism. It is relatively old activity concentrated primarily on the coast, notably on the East coast, Djerba (SE) and Tabarka (NW). It contributes significantly to the national economy, but fluctuating from year to year, mainly since the revolution (2011).

According to international organizations, around 35% of marine species are threatened in the coast of Tunisia. In the Gulf of Gabès, the *Posidonia* meadows have strongly declined due to several factors, including siltation caused in particular by discharges of phosphogypsum, trawling, organic pollution, and maritime constructions.

Biological invasions also represent an additional disturbance factor which has been accentuated in recent decades with the increase in human activities. Some of them, as blue crabs *Portunus segnis* (Forskål, 1775) and *Callinectes sapidus* (Rathbun, 1896), fish species of the genre *Lagocephalus* introduced in Tunisian waters in recent years and the green algae *Caulerpa taxifolia* (M. Vahl) C. Agardh, 1817 introduced about thirty years ago, are invasive and considered as the second cause of biodiversity loss.

Keywords: Tunisian coasts, remarkable ecosystems, biodiversity, anthropogenic disturbances, tourism

1. Introduction

The Mediterranean Basin is recognized as a biodiversity hotspot. Its exceptional flora counts between 15,000 and 25,000 species, 60% of which are unique to the region. and almost a third of its fauna are endemic (CSE, 2008; Afli, 2021, 2023a). In the Mediterranean, specific/functional biodiversity is unevenly distributed. In general, it is concentrated in the 0-50 m deep coastal strip where macro-algae and phanerogams live (Ben Mustapha et al., 1999; Afli, 2023a, b).

This distribution is linked to several factors, mainly climatic and hydrodynamic, and is strongly correlated with the presence of animals, in particular through trophic chain (Boudouresque, 1997; Numa & Troya, 2011; CEPF, 2017; Afli, 2023b).

Although marine biodiversity is concentrated in the coastal strip, some habitats and ecosystems are distinguished by high biodiversity and certain specificities, such as the high presence of endemic, rare, and threatened species (Ben Mustapha et al., 2004; Ben Mustapha & Afli, 2007; Ghrabi-Gammar et al., 2009; UNEP/MAP-RAC/SPA, 2015). The Mediterranean Basin is recognized as a biodiversity hotspot, its exceptional flora count between 15,000 and 25,000 species, 60% of which are unique to the region, and almost a third of its fauna are endemic (CSE, 2008).

Tunisia is known for the great diversity of its marine environment (Boudouresque, 1997; Ministère de l'Environnement et du Développement Durable, 2014), with the presence of remarkable habitats and ecosystems rich in species. In general, the geomorphology of the Northern region, a mosaic of biotopes (e.g. rocks, cliffs, loose sediments, islands and submarine banks), offers diverse habitats and micro-habitats that are remarkable for the presence of benthic species. As for the Southern coasts, they are characterized by sandy and sandy-muddy bottoms, favorable to the development of sea plant meadows, mainly Posidonia meadows.

They have a very extensive continental shelf, with a very gentle slope, and are characterized by a large tide and relatively higher salinity. This gives them a particular biodiversity. The Eastern coasts are an alternation of rocky bottoms and soft bottoms, and provided with a relatively extensive continental shelf with Posidonia meadows and lawns with Caulerpa and Cymodocea which are quite frequent and in almost good condition (Afli, 2023a).

Although these marine ecosystems are characterized by rich and diverse flora and fauna, certain marine habitats (e.g. Posidonia meadows, coralligenous) and certain important taxonomic groups (e.g. bryozoans, ascidians, crustaceans, cnidarians) remain little or poorly studied (De Gaillande, 1970; Chebbi, 2010; Afli, 2024a, b). Knowledge of marine "biodiversity hotspot" habitats along the Tunisian coasts remains partial due, on the one hand, to the lack of complete and updated data and, on the other hand, to the spatial and temporal discontinuity in studies.

This makes it difficult to monitor the spatio-temporal evolution of a particular habitat or ecosystem (Afli, 2023a).

The aim of this work is to study, on a bibliographic basis, the ecological quality of the principal habitats in the Tunisian marine waters, focusing on remarkable ecosystems (biodiversity hotspots and presence of sensitive, rare, threatened, and endemic species), in a climate change context, and their relationship with tourism development and other anthropogenic activities.

The data are collected from scientific articles, PhD theses, and published reports on the subject, and were selected based on its relevance and quality.

2. Identification of habitats and biodiversity threats and their impacts on coastal ecosystems

2.1. Identification of Habitats

In addition to the euphotic coastal zone which concentrates most of the biodiversity, some remarkable ecosystems stand out for their high biodiversity/productivity (Ghrabi-Gammar et al., 2009; UNEP/MAP-RAC/SPA, 2015; Afli, 2023a). Among these habitats, we can cite:

2.1.1. Lagunar ecosystems

Coastal lagoons are generally the area of a high primary production, induced by the continental inputs of nutrients and the long photoperiod.

Tunisia has about ten major coastal lagoons (Bizerte, Ghar El Melh, Kalâat Andalous, Tunis "North and South", Korba, Monastir, Rass Dimass, Boughrara, El Bibane) spread along the coast and covering about 100,000 hectares (Figure 1). These lagoons host a specific fauna with several endemic, rare, threatened, and exotic species (Bradaï et al., 2004).

Among the most important in terms of geographical extent and biodiversity are the lagoons of Boughrara and El Bibane:

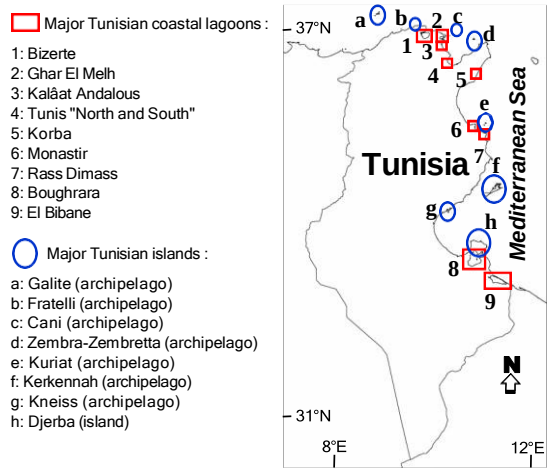

Figure 1: Major islands and coastal lagoons in Tunisia

- Lagoon of Boughrara:

The Boughrara lagoon is located in the South-East of Tunisia. It extends over approximately 500 km^2, thus representing the largest surface area of all Tunisian lagoons. It is surrounded to the North by the island of Djerba and to the other sides by the continent. The maximum depth in Boughrara Lagoon is around 16 m, but the majority of bottoms vary from 3 to 8 m depth (Khadhri, 2016).

In 2000, 37 species of macrophytes were reported including 2 Phanerogams (*Cymodocea nodosa* (Ascherson, 1870) and *Posidonia oceanica* (Linnaeus) Delile, 1813), 11 Rhodophyceae (red algae), 12 Phaeophyceae (brown algae) and 12 Chlorophyceae (green algae) (Khedhri, 2016; Afli, 2023a). Benthic Cyanophyceae, including *Lyngbia majuscula* (Harvey ex Gomont, 1892), are present and develop in clusters covering large areas. The phanerogam *Cymodocea nodosa* (Ascherson, 1870) represents 70% of the phytomass, and the green algae *Caulerpa prolifera* (Forsskål) J.V. Lamouroux, 1809) 20%. Green nitrophilic algae are only important in some areas near the South-East and South shores and around Jlij islet (10%) (Afli, 2021). As for the benthic macrofauna, it is distributed between the mediolittoral stage, of tidal swing, and the infralittoral stage. In the mediolittoral, the gastropod *Potamides conicus* (Blainville, 1829) dominates this zone, especially in the Southeastern region (Khedhri, 2016).

For the infralittoral stage, especially in the first three meters, the benthic community consists mainly of euryhaline and eurythermal species, like the bivalve *Cerastoderma glaucum* (Bruguière, 1789) (Derbali, 2011).

For the Northwestern sector, the bivalve *Venerupis decussatus* (Linnaeus, 1758) is very abundant, while the Guellela region is dominated by the species *Pinctada imbricata* (Röding, 1798). The Ajim-Jorf canal area is characterized by the bivalves

Donax venustus (Poli, 1795), *Venus verrucosa* (Linnaeus, 1758), *Mimachlamys varia* (Linnaeus, 1758) and *Flexopecten glaber* (Linnaeus, 1758). On the other hand, the Northwestern region is marked by the presence of *Pinna nobilis* (Linnaeus, 1758) and *Pinctada imbricata*. Nevertheless, the diseases have destroyed *Pinna nobilis* population in 2016-2018 (Vázquez-Luis et al., 2017; Catanese et al., 2018; Katsanevakis et al., 2022; Afli, 2024b), and mortality reached 100% in the Bizerte lagoon, except in the northeastern part where some specimens only were able to survive, and which allowed the population to recover gradually afterwards (Labidi et al., 2026).

The central zone of the lagoon, with a muddy bottom, is characterized by the species *Axinella polypoides* (Schmidt, 1862) and *Polycarpa pomaria* (Savigny, 1816), and the detrital coastal bottoms by *Cardites antiquatus* (Linnaeus, 1758) and *Mimachlamys varia*. While the Southern part of the lagoon is characterized by *Modiolus barbatus* (Linnaeus, 1758) and *Pinna nobilis*. Note also the abundance of sponges, characteristic of hot sciaphilic areas, mollusks with around 38% of the fauna, and echinoderms represented mainly by sea cucumbers (Cherbonnier, 1956; Rützler K, 1976).

- Lagoon of El Bibane:

It is located in the SE of Tunisia and is characterized by the presence of a *Neogoniolithon* (calcareous red algae) reef, over 30 Km long and unique in the Mediterranean. This hypersaline lagoon (41 to 49 PSU) is remarkably lined by the phanerogams *Ruppia maritima* Linnaeus, 1753, *Cymodocea nodosa*, as well as the pheophyceae *Cystoseira* spp. which occupy almost all the available substrate. While *Posidonia oceanica* is confined to the El-Marsa area, *Caulerpa* proliferates in the El-Oued and El-Marsa areas (Afli, 2021). The bottoms are characterized by the presence of dense populations of *Pinna nobilis* and *P. rudis* Linnaeus, 1758 (Bivalves) as well as certain Sponges (e.g. *Aplysina aerophoba* (Nardo, 1833), *Ircinia chevreuxi* (Topsent, 1894), *I. fasciculata* (Pallas, 1766), *Cacospongia mollior* Schmidt, 1862, *Tethya aurantium* (Pallas, 1766), *T. citrina* Sarà & Melone, 1965). These areas are also well frequented by avifauna (Afli, 2023a).

But the peculiarity of this ecosystem lies in the presence of a kind of sponge reef, built mainly by *Ircinia* sp. and *Fasciospongia cavernosa* (Schmidt, 1862) which can be 0.4—0.8 m wide and extend over 2 m² in area. This is the first time that such formations are described in the Mediterranean (Afli, 2021).

2.1.2. Island ecosystems

Tunisia has about 62 islands and islets (e.g. Galite, Zembra, Zembretta, Kneiss, Kuriat, Kerkennah). These ecosystems, both rich and fragile, are home to characteristic flora and fauna, many of which are rare, threatened or endemic and, therefore, require special attention (Hattour & Ben Mustapha, 2015; Afli, 2024a, b). Other species are introduced, and some are invasive (Mili et al., 2020). The islands of northern Tunisia, mainly the Galite and Zembra-Zembretta archipelagos, are characterized all around by a mosaic of seabeds with an alternation of soft/coarse/rocky sediments, thus offering a multitude of habitats and microhabitats for animal/plant species, including rare/threatened/endemic species (Afli, 2024a, b).

- Archipelago of Zembra-Zembretta:

This site is characterized by the exceptional beauty of the seabed and the emerged landscape as well as by the presence of a high number of benthic populations (characteristic of the Mediterranean), several of which are threatened, rare or endemic. For example, the islet of Entorche, which belongs to the

Zembra-Zembretta archipelago, constitutes the most beautiful underwater landscape in the whole Mediterranean (Ben Mustapha et al., 2004, 2007; Afli, 2023a).

On the biocenotic level, the vegetal/animal populations are very rich, and the not exhaustive inventories carried out on this site made it possible to identify more than 70 vegetal species, 130 mega-benthos species (e.g. sponges, cnidarians, bryozoans, echinoderms, ascidians), and nearly 60 species of fish (Ben Mustapha et al., 2004, 2007). However, the originality of this site lies in the presence of species requiring special attention such as the Phaeophyceae *Ralfsia verrucosa* (Areschoug) Areschoug, 1845 (Mediolittoral), *Cystoseira amentacea var. stricta* Montagne, 1846 (near the surface), and *C. spinosa* Sauvageau, 1912 and *C. zosteroides* C. Agardh, 1821 (in depth), the phanerogam *Posidonia oceanica*, gastropods *Patella ferruginea* Gmelin, 1791 (endemic to the Mediterranean) and *patella rustica* Linnaeus, 1758 (up to 6 m above sea level), anthozoan *Astroides calycularis* (Pallas, 1766) (down to -27 m), gorgonian and *Alcyonium* stands (in depth), Echinoderm *Paracentrotus lividus* (Lamarck, 1816). This site remains to this day natural, wild and showing no signs of deterioration of its ecosystem (Ben Mustapha et al., 2004; Afli, 2021).

- Archipelago of La Galite:

The archipelago of La Galite is located in the North of Tunisia, 81 km from Bizerte and 64 km from Tabarka. It is made up of 6 islands and islets (Galite, Galiton, Fauchelle, Gallo, Gallina and Pollastro). The archipelago of La Galite presents an exceptional biological and ecological wealth with several endemic, rare, threatened and protected species.

The shallow rocky bottoms covered with phanerogam/coralligenous beds are home to many species of purely ecological or fishing interests (Ben Mustapha et al., 2004, 2007; Afli, 2021, 2023). These habitats represent a natural nursery for many species. A multitude of species of biological interest for the Mediterranean spread over many underwater landscapes including the organogenic formations of Vermets (*Dendropoma petraeum* (Monterosato, 1884), *Goniolithon byssoides* (Lamarck) Foslie, 1898, *Astroides calycularis*, *Cladocora caespitosa* (Linnaeus, 1767), *Cystoseira* beds, *Laminaria rodriguezii* Bornet, 1888 beds, *Dictyopteris polypodioides* (A.P.De Candolle) J.V. Lamouroux, 1809 populations, and maerl beds (Antonioli et al., 1999).

2.1.3. Submarine banks

A marine bank is a submarine plateau or mountain that rises from the seabed towards its surface. In Tunisia, most of the submarine banks (e.g. Sorelles, Speiss, Mezzarilles, Esquerquises) are located in the North zone, beyond 100 m depth.

They are areas of high biological productivity and are home to diverse and specific deep-sea communities made up, notably, of sponges and corals (Ben Mustapha et al., 2004, 2007; Afli, 2021). Fish and other commercial species aggregate in these areas and are highly vulnerable to trawling.

The Tunisian submarine banks undoubtedly have a great role to play in maintaining marine biodiversity, especially regarding safeguarding the many endemic species frequenting these sectors. Among these important offshore ecosystems, we can cite:

The subarine bank of Hallouf: Located to the East of Monastir, this bank is characterized by the immersion at 45 m depth of a rocky bottom, 8 to 12 m high and surrounded by loose bottoms made up mainly of coarse sand, gravel, large shell debris and maerl (calcareous algae) (Ben Mustapha et al., 2007; Afli, 2023a).

Several species, mainly sciaphiles, and remarkable biocenotic associations have been reported at this site and most of them require protection, like marine turtles.

The bottom of the Hallouf bank is covered with several vegetations among which we can cite the Fucophyceae (e.g. *Sargassum hornschuchii* C. Agardh, 1820), the Rhodophyceae (e.g. *Ptilophora mediterranea* (H. Huvé) R.E. Norris, 1987, *Phyllophora nervosa* (A.P.de Candolle) Greville, 1830, *Vidalia volubilis* (Linnaeus) J.Agardh, 1863), and the Chlorophyceae (e.g. *Caulerpa racemosa* (Forsskål) J. Agardh, 1873, *Udotea petiola* (Turra) Børgesen, 1925, *Palmophyllum crassum* (Naccari) Rabenhorst, 1868). This area is also the preferred habitat of several animal populations such as sponges, sea urchins *Centrostephanus longispinus* (Philippi, 1845) and *Sphaerechinus granularis* (Lamarck, 1816), the gorgonian *Eunicella singularis* (Esper, 1791), and fishes such as *Epinephelus alexandrines* (Valenciennes, 1828), *E. marginatus* (Lowe, 1834), *Seriola dumerili* (Risso, 1810), *Serranus scriba* (Linnaeus, 1758), *S. cabrilla* (Linnaeus, 1758), *Boops boops* (Linnaeus, 1758), *B. salpa* (Linnaeus, 1758), *Spicara maena* (Linnaeus, 1758), *Sciaena umbra* Linnaeus, 1758 (Ben Mustapha et al., 2004, 2007).

2.1.4. Posidonia meadows

The phanerogam *Posidonia oceanica* is a Mediterranean endemic species. It develops in the coastal fringe, from the shore to the lower limit of the infralittoral (Ben Maïz et al., 1987). The *Posidonia* meadow represents a major hotspot of marine biodiversity since it hosts more than 25% of Mediterranean species (Hattour & Ben Mustapha, 2013). In Tunisia, *Posidonia* meadows are unevenly distributed along the coasts. The most important are those of the Gulf of Gabès (SE) where the presence of the densest *Posidonia* meadow has been reported across the Mediterranean (Ramos-Esplá et al., 2011; Hattour & Ben Mustapha, 2013). The current state of this ecosystem in Tunisia is fragile, especially in the SE of the country, for various reasons (Aloui-Béjaoui & Afli, 2012). On the one hand, trawling activities cause the uprooting and damage of these meadows, destabilize the nature of the substrate, and increase the turbidity of the water, which decreases the penetration of the light necessary for the development of the vegetations (Zaouali, 1993; Ingénierie de l'Hydraulique, de l'Equipement et de l'Environnement, 2016). On the other hand, the *Caulerpa* and *Zostera* meadows, which facilitate the establishment of *Posidonia* by enriching the substrate with mucus (organic matter), have also clearly declined (Langar et al., 2002).

2.1.5. Coralligenous biocenosis

The coralligenous biocenosis is formed by a concretion of coralline and sciaphilic calcareous algae. It is generally colonized by many animal species with hard and coarse substrates (e.g. sponges, ascidians, bryozoans, cnidarians).

It constitutes the main hotspot of marine biodiversity in the Mediterranean since between 1,400 and 1,600 benthic species have been reported there. It is the most beautiful underwater landscape in the Mediterranean (Ben Mustapha et al., 2004, 2007).

In Tunisia, the coralligenous biocenosis occupies large areas, located mainly in the North region. It can be found either on the littoral rock (e.g. island cliffs of Zembra, Cap Bon, entrances to caves and tunnels in the Cani Islands and Tabarka), or in hard bioconcretion forming the plateau coralligenous (true coralligenous deposit surrounded by soft bottoms), or on offshore rock (generally benches).

The coralligenous biocenosis can also be found on a loose substrate (maerl bottom) formed by a coarse detrital and concreted by corallinaceae algae of the

Neogoniolithon genre and where the sponges of the Clionidae family present predominant facies between 35 and 65 m depth. But this coralligenous is subject to the devastating action of trawls given the accessibility of soft bottoms by these fishing gear (Ben Mustapha et al., 2007; Afli, 2003b).

According to Ben Mustapha et al. (2004), the coralligenous ecosystem plays an important role in the conservation of marine biodiversity in the Mediterranean:

- Morphological role: It protects the shore from the actions of waves and swells, and conditions the movement of water masses.
- Biological role: It ensures the bio-mineralization of carbonates, shelters the vagile organisms (e.g. crustaceans, echinoderms, fish) and sessile (e.g. annelids, anthozoa, algae), and releases organic matter in particulate or dissolved forms which will in turn be used later by pelagic species.
- Sedimentary role: Biodestructive organisms work the sediment and suspend large quantities of sedimentary materials which disperse over large areas.

2.1.6. Cystoseira beds

The *Cystoseira* beds (*Cystoseira* spp.) are still badly known in Tunisia (Ben Maïz et al., 1987). Scientific studies have shown the presence of 16 species whose distribution is not limited to particular areas. These *Cystoseira* spp. are generally in a good status and form beds that can be grouped into:

- *Cystoseira* beds in beaten mode: They are frequent in hard substrates (1 m depth) subjected to strong agitation. The characteristic species are *Cystoseira stricta*, *C. mediterranea* (*Ericaria mediterranea* (Sauvageau) Molinari & Guiry, 2020).
- *Cystoseira* beds in calm mode: They consist of species of *Cystoseira* living in the first meters of the infralittoral stage such as *C. sauvageauana* (*Gongolaria* sauvageauana (Hamel) Molinari & Guiry, 2020), *C. crinita* Duby, 1830 and *C. coespitesa* (*Ericaria brachycarpa* (J. Agardh) Molinari & Guiry, 2020.
- Deep *Cystoseira* beds: The characteristic species are *Cystoseira spinosa* (infralittoral) and *C. zosteroides* (circalittoral). These beds are home to a wide variety of populations of cnidarians, sponges, bryozoans, and epiphytes such as Ectocarpaceae, Elachistaceae and Ceramiaceae.

In polluted areas, *Cystoseira* are gradually giving way to more resistant species such as the Fucophyceae *Padina pavonica* (Linnaeus) Thivy, 1960 and *Stypocaulon scoparium* (*Halopteris scoparia* (Linnaeus) Sauvageau, 1904).

2.1.7. Lithophyllum lichenoides sidewalks, vermet sidewalks and Neogoniolithon reefs

Lithophyllum lichenoides (*Lithophyllum byssoides* (Lamarck) Foslie, 1900) entanglement is better known as sidewalk. It is a bioconcretion built by the calcareous rhodophyte *Lithophyllum* which lives at the base of the mediolittoral stage, a little above mean sea level, especially in very beaten mode and when the lighting is reduced (e.g. case of leaves, corridors) (Laborel, 1987; Boudouresque, 1997). These bioconcretions are threatened in the Mediterranean, especially by surface pollution (hydrocarbons in particular) (Afli, 2023b).

Vermets' sidewalks generally develop in the same tier as *Lithophyllum* entanglement (mediolittoral). These bioconcretions are built mainly by the gastropod *Dendropoma cristatum* (Biondi, 1859) (also called *Dendropoma petraeum* and unfairly *Vermetus cristatus*)), with the participation of other organisms, in particular a calcareous rhodophyte *Neogoniolithon brassica-florida* (Harvey)

Setchell & L.R. Mason, 1943 and a foraminifera *Miniacina miniacea* (Pallas, 1766). According to Boudouresque (1997), vermets' sidewalks cover the erosion platform (a few centimeters thick) and delimit basins; on the edge (wide side) of this platform, the vermets (*Dendropoma*) build a bulge that can reach several tens of centimeters in thickness. These external bulges are often hollowed out with cavities that host a rich sciaphile flora and fauna. The width of the vermets' sidewalks is between a few meters and a hundred meters. Vermets can also build on the subvertical rock wall of the bulges. Several kinds of micro-atolls built by vermets have been described (Laborel, 1987; Boudouresque, 1990;1997).

Lithophyllum sidewalks and vermets' sidewalks are characteristic of warm temperate waters of the Atlantic and the Mediterranean. In the Mediterranean, they can be observed on the Southern shore of Corsica, Italy, Algeria and Tunisia (notably in Zembra-Zembretta and Cap Blanc). They are particularly developed in the Eastern Mediterranean (Boudouresque, 1997).

The *Neogoniolithon* reefs are built by the calcareous rhodophyte *Neogoniolithon brassica-florida* (Harvey) Setchell & L.R. Mason, 1943. They are very widespread in the Mediterranean, and in Tunisia they develop mainly along the spit that closes the El Bibane lagoon, about 30 km in length. The environmental conditions, very calm mode, high temperature and salinity, favor the formation of these reefs, because they limit interspecific competition and grazing of *Neogoniolithon brassica-florida* by herbivores (Boudouresque, 1997).

2.2. Species threats and their impacts on coastal Ecosystems

During the Messinian crises (5 to 6 million years ago), the Mediterranean dried up with the disappearance of most of its communities. Following these crises, the communities of the Mediterranean had to be reconstituted from the Atlantic. Thus, Atlantic species, entering the Mediterranean, evolved to give rise to several species and varieties. The endemic species are therefore the descendants of certain immigrants. This is a recent endemism or neo-endemism manifested at the specific level (Afli, 2024b). The rate of endemism is very high in the Mediterranean compared to other regions of the world. Globally, the Mediterranean Sea presents a very high endemism rates, since 20-30% of species are considered endemic to this sea (Capapé, 1986; Stehmann & Bürkel, 1986; Fredj & Maurin, 1987; Fischer et al., 1987; Bradaï, 2000; Afli, 2024a, b).

Endemic marine species have not been the subject of specific inventories in Tunisia, and the few reports made were mostly reported accidentally. As a result, the inventory carried out in this work required extensive research in scientific articles, doctoral theses and scientific reports. Thus, the list below is not exhaustive and the endemic species in Tunisia would be significantly more numerous (Afli, 2024a, b).

Climate change, primarly rising temperatures, has exacerbated the combined effects of all these disruptive factors on habitats and species (Ben Rais Lasram et al., 2010a, b; Ounifi-Ben Amor et al., 2016; Afli, 2023b). Certain species that form essential habitats in the Mediterranean, such as *Posidonia* meadows and calcareous algae of the coralligenous, have declined, notably due to the overall warming of the waters (Mannino et al., 2017; Ghanem, 2018; Afli, 2023b). Furthermore, the resistance of the species themselves and the resilience of ecosystems to harmful factors, such as acidification and eutrophication, are weakened by rising water temperatures (Zenetos et al., 2010; Numa & Troya, 2011; Ounifi-Ben Amor et al., 2016; Afli, 2023b).

The warming of the Mediterranean Sea has also facilitated the bioinvasion of tropical exotic species from the Red Sea and also the Atlantic, which often possess a strong capacity for exclusion, predation, and competition against native species (Lootvoet et al., 2010; Afli, 2024a, b).

3. Relationship between habitat, patrimonial species and coastal tourism

Tourism in Tunisia is relatively an old activity; it has developed since the country's independence (1956). It is mainly located on the coast (95% of tourist activities), notably on the East coast between Nabeul and Sfax (more than 50%) (Krakimel, 2003), but also the islands of Djerba (SE) and Tabarka (NW). The tourism sector in Tunisia contributes on average 6–8% of the GDP, 18–20 % of foreign exchange earnings, and employs around 400,000 people. The overall capacity of tourism in Tunisia is around 241,000 beds. However, the number of tourists has fluctuated markedly from year to year, mainly since the revolution (January 2011). For example, the number of entries of non-residents during the period from January 1 to July 10 was 3,637,718 in 2010; 4,148,142 in 2019 and 1,366,958 in 2020 (B-H, 2021). However, the evolution between 2010 and 2019 was not steady and experienced ups and downs, depending on several factors, including the political and security situation of the country.

Over several decades, tourism activity has had negative effects on coastal ecosystems. The construction of hotels along the littoral and the occupation of beaches have certainly a negative impact on habitats and biodiversity in general (Lootvoet et al., 2010). According to the MedWetCoast program, 35% of species (all taxa combined) are threatened on the coast of Tunisia. This has affected certain specific ecosystems, sensitive and/or rich in biodiversity (Krakimel, 2003).

In general, in Tunisian tourist areas (Tabarka, Hammamet, Sousse, Monastir and Djerba), phanerogam meadows (*Posidonia* and eelgrass) and algae are absent in shallow depths (swimming areas). They are often large and relatively in good condition at medium depths, like the seagrass beds on the East of the island of Djerba and in the Gulf of Hammamet (Hattour & Ben Mustapha, 2013). In the Gulf of Gabès (Southern Tunisia), *Posidonia* meadows were the densest compared to the whole Mediterranean (Ramos-Esplá et al., 2011). In general, the *Posidonia* meadows in Tunisia have declined due to several factors, including tourism. Siltation caused in particular by discharges of phosphogypsum (Gulf of Gabès), trawling activities, organic pollution, and maritime constructions have all contributed to the general decline of *Posidonia* meadows (Hattour & Ben Mustapha, 2013). It is practically the same for macroalgae that grow in the intertidal or even the mediolittoral, like *Cystoseira* spp. On the other hand, other algae appear to be more spared since they live further offshore such as *Laminaria*.

The 237 Tunisian coastal wetlands (e.g. lagoons, sebkhas, salt marshes, swamps, wadis, chotts) which communicate with the sea and/or between them contribute in general to improving the biodiversity of the Tunisian coasts (Ministère de l'Environnement et de l'Aménagement du Territoire, 2001; CAR/ASP & INAT2002).

It should be noted that among the wetlands, only the coastal lagoons have been the subject of several studies.

They are seven in number and represent the most productive wetlands. They are the seat of a high and characteristic biodiversity. Most Tunisian lagoons are subject to various sources of pollution (e.g. urban and industrial discharges, town planning), and some lagoons are subjected to significant fishing activities. As for tourism, it has negative impacts especially

on lagoons close to tourist areas or beaches, such as the lagoons of Ghar El-Melh and Boughrara.

In Tunisia, the 62 islands and islets host a remarkably high biodiversity. Some islands are more important in terms of biodiversity than others (Boudouresque et al., 1996). The Galite archipelago is made up of a set of islands and islets. La Galite is the only inhabited island in the archipelago, and no waste or sewage collection structure currently exists.

The archipelago is frequented mainly by boaters. With a view to preserving the supposed habitat of the monk seal (which has been completely extinct since the 1970s), the island of Galiton in the West has been classified since July 1980, by order of the Ministry of Agriculture, as a "Strict Nature Reserve". In 1995, a decree from the Ministry of Agriculture banned fishing in the 1.5 MN band around the islands.

The archipelago is home to a large number of rare, endemic and threatened species and it can, therefore, be considered of major importance in terms of biodiversity: the brown algae *Cystoseira stricta*, endemic, bio-indicator of pure waters; the calcareous red algae *Phymatolithon calcareum* (Pallas) W.H. Adey & D.L. McKibbin which indicates the presence of a maerl facies, very widely threatened on the Mediterranean; the large Mediterranean mother-of-pearl (nacre), which is considered endangered in many areas around the Mediterranean; two gastropods, the Mediterranean Conch and *Astrea rugosa*; the large black limpet, a rare and very endangered “Atlantic” species, a bio-indicator of the coasts of the Western Mediterranean.

The red lobster is the object of targeted fishing which remains the main fishing activity of the archipelago. The Galite archipelago is relatively protected from the impacts of tourism (although it is said that the disappearance of the monk seal is due to hunting tourists) due to the distance to the coast and the poor shelter (Krakimel, 2003).

The archipelago of Zembra-Zembretta is highly important for biodiversity, mainly for flora (four threatened species are reported, two of which are endemic). Zembra Island is included in UNESCO's MAB "Biosphere Reserves" list, and the "Zembra and Zembretta Islands National Park" was established in 1997.

Among the 200 species of benthic fauna listed, we can cite the orange madrepore, the newt and fluted gastropods, the giant limpet (or ferruginous) *Patella ferruginea* which is an endemic species that is particularly threatened in the Mediterranean (Krakimel, 2003). For the impact of tourism, the Zembra-Zembretta archipelago is subject to strong pressure from underwater hunting, which has certainly a negative effect on biodiversity in general and on endemic species in particular.

The Kuriat Islands are located facing the town of Monastir. They are two small flat islands, low and 2 km apart. Off the Northern and rocky part of the two islands, maerl formations, at very shallow depths, are very rare and very vulnerable. The Kuriat Islands are an important site for some seabirds. Most interestingly, these islands are one of the most important and endangered loggerhead sea turtle *Caretta caretta* nesting sites in the Mediterranean. Tourism has a significant effect on these islands, as they are very popular with tourists.

As a result, the Kuriat Islands constitute a fragile and vulnerable ecosystem. Efforts have been made by Tunisia to promote environmentally friendly tourism (national strategy for sustainable coastal tourism). As for the coralligenous, it is an important hotspot of biodiversity in the Mediterranean. Being located further

offshore, in depths greater than 20-30m, the coralligenous is spared from the nuisances caused by tourism, except spearfishing and trawling which affect these biogenic constructions (Afli, 2023b).

Biological invasions (introduction of alien species, some of which are invasive) have been accentuated in recent decades with the increase in human activities (e.g. trade, navigation, port activities, and maritime traffic). They are considered by many international organizations, including IUCN, as the second cause of biodiversity loss, just after habitat destruction. Endemic species are, arguably, affected by the presence of invasive species (Ounifi-Ben Amor et al., 2016; Mili et al., 2020).

Thus, legal and regulatory structures were created; in particular the creation of the Coastal Protection and Planning Agency (APAL, responsible for applying the State's policy on coastal protection, in general, and the public maritime domain, in particular) and the elaboration of development plans for tourist areas (Krakimel, 2003).

In this context, a network of Marine and Coastal Protected Areas, mainly located in island environments was created (the Galite archipelago, the Kneis islands, the Kuriat islands, the Zembra and Zembretta islands, the coast of Cap Negro at Cap Serrat). Protected areas are an effective way to conserve rare and endemic species (Abdulla et al., 2008).

The objectives of the creation of this network in Tunisia are to (i) guarantee the protection of marine environments and rare, threatened and endemic species; (ii) contribute to the sustainable development of coastal areas, in particular through the controlled development of ecotourism; (iii) contribute to raising public awareness for the protection of biodiversity (Afli, 2023b).

5. Conclusion

Several factors affect biodiversity, and most often act concurrently. These include climate change, urban and industrial discharges, excessive fishing, tourism and biological invasions. Invasive species thrive at the expense of native species, especially endemic ones (Ounifi-Ben Amor et al., 2016; Mili et al., 2020; Afli, 2023b, 2024a, b). They compete with them and even exclude some of them. Especially since certain endemic species form ecosystems rich in biodiversity and host many endemic species such as *Posidonia* and *Cystoseira* which are affected by the invasive tropical algae *Caulerpa taxifolia* (M. Vahl) C. Agardh, 1817 (Langar et al., 2002).

If the impact of nuisance factors on biodiversity in general is obvious and has resulted in the disappearance of certain endemic species such as the monk seal and the rarefaction of others, it is very difficult to be able to separate the share of the impact of tourism in relation to all other factors affecting the marine environment, except perhaps in tourist areas where the effect is palpable.

This work represents a first overview on the impact of tourism and other environmental/anthropogenic factors on biodiversity in marine remarkable habitats.

A temporal monitoring in these areas is necessary to make it possible to complete the list of present species and to mark the evolution of their status, mainly in areas under the influence of tourist activities.

This will help decision-makers and managers to adopt strategies and economic development plans that are more respectful of the environment and that will ensure the conservation of the marine biodiversity.

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