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REVIEW ARTICLE

Tunisian reservoirs: diagnosis and biological potentialities

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Abstract – Due to scarcity, irregular rainfall and increasing water demand, several reservoirs have been built in recent decades in Tunisia to meet water needs for essential uses, which is generally done without analysis of their capacity to maintain a high quality of aquatic life and equitable distribution of water resources. Currently, 90% of available water resources are already mobilized and climate change exacerbates the country's aridity which makes it difficult to monitor water needs. With a view to contributing to their effective management and setting future directions for controlling and improving inland fish productivity, a comparative limnological study was carried out on 8 artificial reservoirs that were stocked with mullet fry. This study, based on a review of existing data, provides information on the availability and quality of inland water resources in relation to international standards and the biological potential (plankton, fish and other organisms) of these reservoirs. The satisfactory water quality for aquatic life, as well as the significant growth and production of introduced species associated with the rearing of mullet fry, clearly show that, despite several problems, Tunisian reservoirs represent an important potential that still needs to be developed. To this end, we recommend to improve the fishing techniques and the stocking of mullet fry. In addition, the strengthening of fishermen's groups, the encouragement of private initiative and the quality control of water and fish meat are highly requested.

Keywords: Water resources / quality of water / biological communities / mullets / fisheries

1 Introduction

In semi-arid regions, often all water resources including precipitation, surface water, and groundwater are mobilized to cope with human demands. Surface waters are remarkably variable in time and space generating water stress crippling economic and social life (Margat, 1981; Servat and Mahé 2009).

Tunisia is a country with a temperate Mediterranean climate, strongly influenced by the proximity of the sea and the desert, and characterized by a pronounced aridity, which limits water resources, that increases from the north to the south (Peel et al., 2007). Since antiquity, Punic and Roman times, the mobilization and transfer of surface water in Tunisia has been a common practice due to the scarcity and irregularity of precipitation. Indeed, the hydraulic vestiges of different historical epochs, such as the aqueduct of Carthage from the Roman period (120–130 AD) restored by the Hafcides in the 13th century (Chanson-Jabeur, 2005), Aghlabids basins in Kairouan (Mahfoudh, 2009) or Khriga (foggaras) irrigation system built in the 13th century by Ibn Chabbat in southern Tunisia (Remini et al., 2010; CDCGE, 2015), testify the importance of these practices.

Over the last century, the mobilization of surface and groundwater in Tunisia has become a necessity because of an increasing demand for water and the unequal distribution of water resources in time and space. Different types of reservoirs have been built mainly in the north and center of the country and others are underway or planned (ITES, 2014). Compared

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to natural ecosystems, artificial water bodies are marked by significant human influences considering that the hydraulic regime has been fundamentally modified and managed by humans, transforming running water into calm water and thus generating very significant ecological changes (Beuffe et al., 1994; Baudot et al., 1997).

Eutrophication, which is becoming increasingly important due to the natural processes of soil erosion, low vegetation cover and anthropogenic actions, namely agricultural practices (hyper fertilization) and industrial and urban discharges, leads to the emergence of new nuisances (Beuffe et al., 1994; Chorus and Bartram, 1999). Indeed, eutrophication was ranged in 1997 by the International Lake Environment Committee (ILEC, 1997) as the fourth of six major risks that may affect lakes and reservoirs around the world. In Tunisia, this phenomenon seems to favor the proliferation of prokariotic phytoplankton, potentially toxic cyanobacteria (Ben Rejeb Jenhani et al., 2006; Fathalli, 2012), and aquatic plants. Moreover, siltation of reservoirs in Tunisia is also a permanent threat to their useful life span, since their storage capacity is continuously decreasing depending on the intensity of siltation (Ben Mammou and Louati, 2007; Louati, 2010). The durability of these hydraulic retention structures, and consequently surface water, is conditioned by a revision of the current approach of water and soil conservation in the concerned watershed.

In Tunisia, since the 1960s, various freshwater fish have been introduced into reservoirs to diversify livestock given that autochthonous fish fauna is poorly diversified (Kraiem, 1983; Djemali, 2005). These introductions together with the stocking of a large number of reservoirs with mullet fingerlings, have contributed to the development of extensive inland fish farming and to the development of regional socio-economic activities (Losse et al., 1991; Hadj Salah, 2002). The significant growth of introduced species in the water reservoirs, especially mullet, clearly show that the Tunisian reservoirs represent an important potential that must be further developed (Mili et al., 2016).

These hydraulic installations are man-made aquatic environments representing new ecosystems for Tunisia that should be exploited and properly managed to secure both resources and forms of exploitation. The main goals of this study are (i) to review the environmental and ecological conditions in these reservoirs whether they are favorable to support fish growth and suitable for the production of healthy products (ii) to assess the carrying capacity for mullets, both in terms of abundance as well as in terms of biomass, and (iii) to assess the availability of reliable data on the distribution and biomass of fish stocks necessary to ensure their effective management.

To this end, the present paper, essentially based on published data (except fisheries statistics), will make the point on the water availability and quality, in order to assess the biological potentialities of eight reservoirs belonging to four hydrological basins with permanent water body supporting an extensive mullet farming activity. This synthesis will guide the decision makers to implement an effective management of these reservoirs compatible with inland fish farming. The lack of well-established monitoring of these man-made environments has led us to use the results of a variety of different scientific studies and reports.

2 Water resources in Tunisia: improvements and constraints

Since 1975, strategies and master plans for northern, central and southern waters of the country were developed to implement infrastructures for mobilization, transfer and exploitation of available water resources. Now 40 reservoirs, 237 hillside dams and 902 hillside lakes have been built mobilizing more than 90% of surface waters. Currently, the possibilities of extending mobilizable resources have reached their limits, and it will be difficult to keep up with the rapid evolution of water demands in the different sectors (Ben Boubaker, 2016).

The latest assessment of conventional water resources, conducted in 2010, shows about 4.67 km^3/year which 2.63 km^3/year are surface waters (ITES, 2014). However, these resources remain far below those of neighboring countries such as Morocco and Algeria with 29 km^3/year and 17 km^3/year, respectively (Seddik, 2015).

In the north, the largest reservoirs are interconnected to facilitate consumption of water for households, industry and irrigation agriculture and alleviate the over-exploitation of ground-waters. The waters are transferred through channels and pipelines to developing areas, especially the greater Tunis metropolitan area and the eastern coast of the country close to Sfax (Seddik, 2015). Some transfer axis from dams and aquifers, in central Tunisia, supply the irrigated areas of the Sahel and Sfax drinking water and others from Chott Fejjej and Jeffara aquifers serving the South East of the country (Fig. 1). Indeed, the integration of the total water supply through interconnections has made it possible to compensate certain local deficits and to improve the quality of salt-laden water by mixing it with a water of lower salinity (more than 50% of the country's water resources have a salinity higher than 1.5 PSU). These transfers, managed by the SECADENORD and SONEDE governmental companies, provide an equitable distribution for a large part of the territory (ITES, 2014).

However, silting of reservoirs is causing a reduction in their storage capacity that remains a major problem despite the redevelopment and maintenance works (e.g. heightening of dams and desilting). These have been undertaken by some structures in order to delay their replacement, including the Sidi Salem and the Nebhana dams cases (ITES, 2014). Concentrations of suspended solid particles exceeding 100 g/L were recorded during the floods of the Mejerda and Zeroud rivers located in the north and the center of the country, respectively (Ben Mammou and Louati, 2007). Thus, assuming the same climatic conditions as currently prevailing, the storage capacity of Sidi Salem reservoir, which is fed by the Mejerda river, will be reduced by 40% and 57% in 2030 and 2050, respectively. The storage capacity of Sidi Saad's, which is fed by Zeroud river, will be reduced by 67% and 95% in 2030 and 2050, respectively (ITES, 2014). According to Louati (2010), the loss of storage capacity in Tunisia is estimated at 17% of their initial capacity. This problem affects in a similar way all countries in the Maghreb. It is estimated annually at 0.5% to 1%, 0.7%, 0.5% respectively for Tunisia, Algeria and Morocco (GEORE, 2001; Boumediene, 2011, Ben Mammou and Louati, 2007).

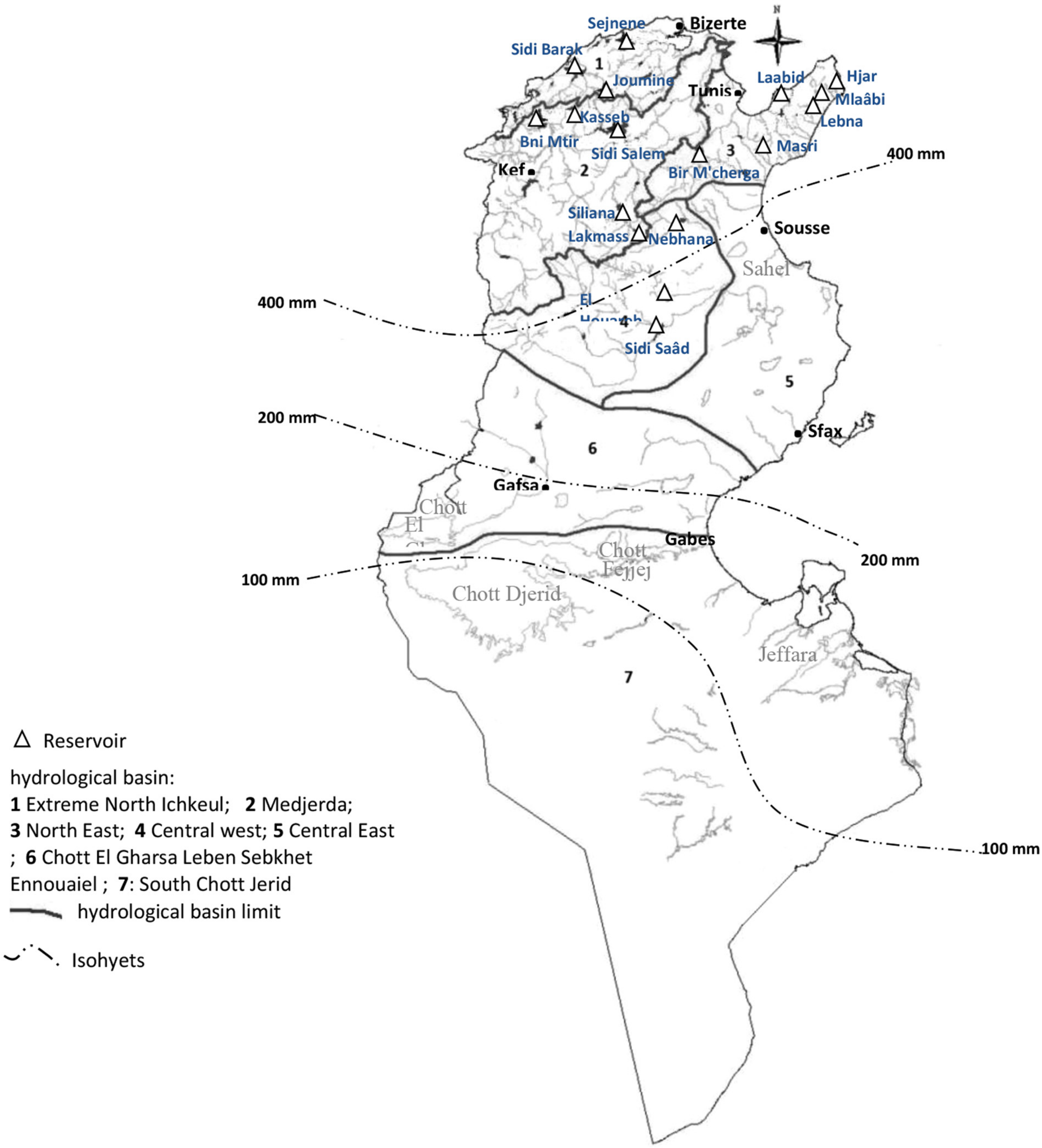

Fig. 1. Location of Tunisian reservoirs, hydrological basins and annual average isohyets (Ben Mammou and Louati, 2007; modified).

3 Space and environment

3.1 Hydro-climate

The average volume of surface water, annually available in Tunisia, is strongly modulated by the prevailing rainfall, which varies among regions. In the north, rainfall ranges from 400 mm/year along the Medjerda valley to 1500 mm/year in the extreme northwest. In the center, south of Tunisian Dorsal, it ranges between 200 and 400 mm/year, while in the southern regions of the country, rainfall events are less frequent representing amounts of about 50–200 mm/year (Fig. 1). Most wet precipitation in Tunisia occurs during short periods of heavy rainfall, which causes strong runoff with excessive erosion of soils. Rainfall events insufficiently recharge groundwater and produce violent flash floods. It rains on average 70 days/year in the north, 40 days per year in the center and 20 days per year in the south (ITES, 2014; Henia and Benzarti, 2006).

Table 1. Characteristics and uses of some Tunisian reservoirs stocked with mullet's fry.

Hydrological basins	Reservoirs	Geographic coordinates	Impoundment	Main supply	Catchment area (km^2)	Volume (10^6 m^3)	Area (Ha)	Rainfall (mm/year)	Uses
North East	Lebna (L)	N36°44′01″ E10°55′08″	1986	Lebna river	189	29	732	550	Irrigation, fish farming
	Bir M'cherga (BM)	N36°30′36″ E10°00′38″	1971	Méliane river	1260	52.9	705	500	Irrigation, fish farming
Extreme North Ichkeul	Joumine (J)	N36°59′23″ E09°36′59″	1983	Joumine river	418	130	651	740	Drinking water Irrigation, fish farming
	Séjnène (S)	N37°10′42″ E09°28′25″	1994	Séjnène river	376	138	790	900	Drinking water, Irrigation, fish farming
Madjerda	Sidi Salem (SSM)	N36°35′27″ E 09°23′51″	1981	Medjerda river	18000	555	4 300	450	Drinking water Irrigation, fish farming electric energy
	Beni Mtir (BMt)	N 36°43′10″ E 08°44′10″	1953	El lil river	103	57.2	299	1200	Drinking water Irrigation, fish farming electric energy
Central west	Nebhana (N)	N36°03′34″ E09°52′34″	1965	Nebhana river	855	66.55	530	430	Irrigation, fish farming
	Sidi Saâd (SS)	N35°25′31″ E09°41′50″	1981	Zeroud river	8950	209	1710	400	Irrigation, fish farming

Tunisia is among the countries that are particularly vulnerable to climate change (Dahech, 2013; Laignel et al., 2012). Climate change in Tunisia will exacerbate the aridity that currently affects two-thirds of the territory. Compared to the period 1961–1990, climate projections by 2050 mention a decrease in precipitation between 2% and 16% and an increase in average temperatures between 1.4 and 2.1 °C (Touzi and Ben Zakour, 2015). This situation must encourage better management of water storage in reservoirs, especially surpluses in rainy years, which are still not under control, to minimize losses and ensure wider distribution.

3.2 Typology

Most of the Tunisian reservoirs are earth type and are classified in large dam, hill and lake reservoirs according to their capacity and height dike. These are located mainly in the wettest area of the territory (Fig. 1) in four major hydrological basins, i.e., (i) the Extreme North Ichkeul basin, (ii) the Medjerda basin, (iii) the North-East basin and (iv) the Central-West basin) located in the north and center of the country (Tab. 1 and Fig. 1). These water bodies are supplied by rivers, the majority of which are characterized by intermittent water flows that occur only during and shortly after the rare and heavy rainfall events. The inputs of rivers into the reservoirs vary depending on the catchment area and the extent of the rain (intensity and duration). Downstream of the dams the water flows are modulated by the management of the dams and sediment transport is reduced due to retention of sediments in the reservoirs. The Medjerda, which is the principal river of the territory with a perennial flow, has been equipped with the largest dam in the country, i.e., Sidi Salem reservoir. This hydraulic installation has led to a reduction of sediment transport from the upper basins to the coastal zone which may have strong and long-lasting effects on coastal geomorphology and ecosystems (Kotti et al., 2018). This reservoir receives many tributaries and has a very variable flow rate ranging from 1 m^3/s to 1000 m^3/s (Tab. 1). On the other hand, in the center of the country, smaller and intermittent rivers flow towards the south where the water evaporates in salt marshes or sebkhas (Plante, 2006).

In order to develop the economies of inland areas and to provide an alternative source of animal protein, especially in the disadvantaged regions, twenty-seven among the 40 currently constructed reservoirs are stocked with fry mullets (CTA, 2015). The selection of reservoirs is based on their importance in terms of their capacity, surface area, the presence of fish stock, the existence of a certain infrastructure and the proximity of large urban and rural settlements which are favorable factors for the development of fish farming, fisheries and local markets (Losse et al., 1991). Since 1991, and following the Tunisian-German cooperation project which established the basis of fishing activity in the Tunisian reservoirs, the authorities have adopted a stocking rate of 500 mullet's fry per hectare (IFREMER, 2005). Currently, the annual quota of mullet's fry is allocated to water bodies according to the request of groups of fishermen or concession holders and the availability of fry. Most of the time, the amount of fry caught by the governmental Technical Center of Aquaculture (CTA) is insufficient to cover the demand.

Table 2. Means annual of physic-chemical parameters in some Tunisian reservoirs stocked with mullet fingerlings.

	Hydrological basins												Aquatic life	Irrigation	Raw waters for consumption
	North East		Extreme North Ichkeul				Medjerda				Central west				
	L	BM	J		S		SSM		BMt		NB	SS			
References	a	b	c	d	c	e	c	f	c	g	h	i	CEC (1978)	FAO (1994)	INNORPI (2014) NT 09.13
Cond μS/cm			690		629	621	3250	1700	247			3734		3000	2500
T (°C)	19.7	20.3	22.4	20.08	22.5	20.54	22.4	20	22.6	16.9	21	23.97	22		
O2 (mg/ L)	8.7	9.02		15.6		7.78		8.6		4.58	4.6	8.26	5–9		
pH	8.49	8.5	8		7.9	7.49	7.9	8.07	7.5	8.12	8.1	8.1	6.5–9	6.5–8.4	5.5–9
Turb (NTU)			11.1		19.3	3.56	12.7	4.22	74.5			6.14	10		5000
NO_3^- (mg/L)	0.72	1.69	6.5	4.7	3.4	0.49	12.7	1.2	3	0.15	0.198	1.6		10	100
NO_2^- (mg/L)	0,07	0.08	0.01		0.01	0.007	0.01	0.23	0.01	0.039	0.046	0.05	0.01–0.03		
NH_4^+ (mg/L)	0.58	0.3	0.05	0.074	0.05	0.025	0.05	0.18	0.1	0.03	0.059	0.03	0.04–1.0	5	4
PO_4^3 (mg/L)	0.09	0.16		0.13						0.053	0.044			2	
P_T (mg/L)	0.18	0.23	0.5	0.95	0.5	0.034	0.5	0.1	0.5	0.057	0.060	0.027			0.7
SO_4^{2-} (mg/L)			108	134.7	79	135.78	574	500	39			1335.93		960	500
Na^+ mg/L			55	41.8	62	67.64	507	220	25.1			506.09		920	200
K^+ (mg/L)			4	2.63	4.6	1.73	14.6	7.2	2.7			15.56		2	
Ca^{2+} (mg/L)			68	47.78	53	52.18	183	167	27			386.87		400	200
Mg^{2+} (mg/L)			19	21.26	16	9.77	65	38	7.9			105.03		60.75	100
Cl^- (mg/L)			81	83.64	95	75.65	664	237	37			742.30		1062	500
F^- (mg/L)			0.4		0.3	0.08	0.9		0.3				1.2		1.5
Fe (mg/L)				0.06		0.06							0.03		3
Zn (mg/L)			0.005	0.009	0.005	0.006	0.005						0.03		5
Cu (mg/L)			0.005	0.006	0.005	0.0072	0.005						0.002		3
SAR			1,52	1.26	1.91	2.24	8,19	3.99	1.09			5.88		15	

L: Lebna; BM: Bir Mcherga; J: Joumine; S: Sejnene; SSM: Sidi Salem; BMt: Béni Mtir; NB: Nabhena; SS: Sidi Saâd.
a: El Herry, 2008; b: Fathalli, 2012; c: Ben Rejeb Jenhani et al., 2017; d: Limam, 2003; e: Zouabi Aloui and Gueddari, 2009; f: Ben Othmen, 2003; g: Sellami et al., 2010; h: Sellami et al., 2016; i: Bouden, 1995.

3.3 Water quality assessment

The reservoirs are relatively warm lakes, characteristic of the Mediterranean climate (Vollenweider, 1982) with average annual temperatures between 20 °C and 22 °C, which nevertheless remain favorable for aquatic life. A North-South gradient of water temperature arising mainly from the combined effects of latitude, maritime influence, relief and Sirocco (hot and dry Saharan wind) is also observable. During periods of high summer temperatures and low wind intensities, thermal stratification occurs and affects environmental factors and thereafter aquatic food web (Lemmin, 1995; Ndebele-Murisa et al., 2010). Excepting Bir Mcherga and Nebhana where no stratification was reported, an ephemeral stratification is established during the spring-summer at Sidi Salem, Joumine, Sejnène, Lebna et Sidi Saad reservoirs which is generated essentially by increased water temperature and low wind energy. This stratification is quickly disrupted by the effects of strong and repetitive winds, currents, internal waves and water extractions frequent in summer (Mouelhi, 2000; Limam, 2003; El Herry, 2008; Fathalli, 2012).

Potential of hydrogen (pH) did not show significant variations. It oscillates between 7.5 and 8.5. The conductivity seems to be affected by the lithology of the hydrological basins and the prevailing climatic conditions (precipitation, evaporation and temperature). In fact, in the extreme north, Ichkeul reservoir has the lower conductivity indicating a less mineralized water, considered as higher quality, than in the Medjerda and Central West hydrological basins.

Average concentrations of major ions in most reservoirs are acceptable and complying generally with the quality standards required by INNORPI (2014) and FAO (1994) for bulk waters intended respectively for consumption and irrigation. However, Sidi Saad and Sidi Salem reservoirs are exceptions, which are characterized by considerably higher sulfate, sodium and chloride concentrations, exceeding the different prescribed limits. With reference to the United States Salinity Laboratory Staff (1954), and taking into account the electrical conductivity and the sodium adsorption ratio (SAR) estimated from the concentrations of sodium, calcium and magnesium ions expressed in equivalents per million, the waters from all dam reservoirs are suitable for irrigation and have no effect on soil structure. High-dose of trace metals Copper and Zinc may cause acute toxicity to most aquatic organisms and for renal dialysis patients (Gaujous, 1995). But their concentrations in Tunisian reservoirs are consistent with international standards for drinkability and aquatic life. Iron levels in Joumine and Sejnane reservoirs failed to comply with the CEC standard but are compatible for bulk water intended to consumption.

Nitrogen and phosphorous have been identified as the major nutrients governing primary production and phytoplankton biomass (Pourriot and Meybeck, 1995; Capblancq and Decamps, 2002). The variation in their concentration from one site to another is due to the variability of the inputs from watersheds, biological activities and biogeochemical processes inside reservoirs. Despite the variability of the N/P mass ratios, it appears that the waters are principally phosphorous limited

Table 3. Trophic status of some Tunisian reservoirs stocked with mullet's fry.

Hydrological basins	Reservoirs	Carlson and Simpson, 1996		Burns and Bryers, 2000		OCDE, 1982				References
		TSI_C	Trophic status	TSI_B	Trophic status	Chl a	Trophic status	PT	Trophic status	
North East	L	52.57	Eutrophic	4.55	Eutrophic	1.21	Oligotrophic	180	Hypertrophic	El Herry, 2008
	BM	64.52	Eutrophic-hypereutrophic	5.70	Supertrophic	6.86	Mesotrophic	230	Hypertrophic	Fathalli, 2012
Extreme North Ichkeul	J	62.59	Eutrophic-hypereutrophic	5.48	Supertrophic	3.38	Mesotrophic	950	Hypertrophic	Limama, 2003
	S	53.55	Eutrophic	4.57	Eutrophic	0.66	Oligotrophic	218	Hypertrophic	Bel haj Zekri, 2003
Madjerda	SSM	55.79	Eutrophic	4.73	Eutrophic	5.11	Mesotrophic	100	Eutrophic	Ben Romdhane, 2015
	BMt*	54.36	Eutrophic	4.66	Eutrophic	4.94	Mesotrophic	57	Eutrophic	Sellami et al., 2010
Central west	N	52.86	Eutrophic	4.68	Eutrophic	5.20	Mesotrophic	60	Eutrophic	Sellami et al., 2016
	SS*	55.66	Eutrophic	4.81	Eutrophic	6.8	Mesotrophic	55	Eutrophic	Sellami et al., 2010

L: Lebna; BM: Bir Mcherga; J: Joumine; S: Sejnene; SSM: Sidi Salem; BMt: Béni Mtir; NB: Nabhena; SS: Sidi Saâd.
TSI_C: Carlson and Simpson index 1996; TSI_B: Burns and Bryers index 2000.
* Values calculated from Chl a and P_T (Sellami et al., 2010).

($N_T/P_T > 7$, Redfield, 1958). This is the case for the vast majority of surface waters in temperate regions. Bni Mtir, Joumine Nebhana reservoirs show very low mass ratios indicating a possible limitation by nitrogen. Even if the use of N/P ratio remains highly debatable, because the instantaneous measurements of both nutrients do not take into account the innumerable possibilities of recycling and replenishment (Barroin, 2004), this ratio may be useful for predicting the types of algae that may develop (Ryding and Rast, 1994) a low N_T/P_T ratio appears to favor the dominance of cyanobacteria in temperate lakes (Smith, 1983). The process based on the N/P ratio to estimate the probability of nitrogen-fixing cyanobacteria encounters the difficulties mentioned above. According to Horne and Commins (1987), the production of nitrogenase, enzyme of nitrogen fixation, is independent of the value of the N/P ratio: it is sufficient that the concentration of the total mineral nitrogen falls below 50–100 μg/L. Thereby, a prediction of a probable evolution in the composition of algae communities based only on the ratio of available nitrogen and phosphorus concentrations is not feasible (Reynolds, 1998).

The assessment of the trophic level of a lake is commonly used to characterize the effects of nutrients on water quality or to describe the trophic potential of a body of water (Ryding and Rast, 1994). For this, different methods: Carlson and Simpson (1996), Burns and Bryers (2000) and OCDE (1982), and different indicators (chlorophyll a, Secchi depth, total phosphorus and total nitrogen), most commonly used in lakes and reservoirs, were selected to assess the trophic level of water reservoirs (Tab. 3). The trophic state indexes of Carlson and Simpson (1996) and Burns and Bryers (2000) calculated from authors's data (Tab. 3), appear concordant and varied respectively between a minimum (52.57–4.55 observed at Lebna) and a maximum (64.52–5.70 at Bir M'cherga) indicating for all reservoirs an eutrophic status to a tendancy to hypereutrophic or supertrophic, especially for Bir M'cherga and Joumine dams. On the other hand, according to OCDE (1982), and with reference to total phosphorus, the reservoirs reveal as well an eutrophic or hypereutrophic status, which is not the case with chlorophyll a indicating a predominantly mesotrophic status. This assessment may partly explain the development of cyanobacteria blooms, which are increasingly frequent in water reservoirs (El Herry, 2008; Fathalli, 2012; Sellami et al., 2016). However, the prediction of algae proliferations cannot be based on a simple relationship to the amount of available nutrients. It is also necessary to consider the functional diversity of the algae as well as socio-economical processes in a dynamic view of the management of continental waters (Capblancq and Decamps, 2002).

Overall, the studied reservoirs can be considered as well-oxygenated where annual averages vary between 7.7 and 15.6 mg/L, except for Bir M'cherga (BM) and Nebhana (NB) where they are around 5 mg/L. These averages conform to the criteria established by the World Health Organization (WHO, 1996, 2004) and the Commission of European Committees (CEC, 1978) standards and are considered good and sufficient for human consumption and aquatic life. However, towards the bottom of the lakes and at specific dates during the summer-autumn period, pronounced depletions of dissolved oxygen (OD) have been reported in several reservoirs (Project Report, 2006; Mouelhi, 2000; Fathalli, 2012; Ammar et al., 2015; Ben Romdhane, 2015; Hajlaoui, 2017). This trend to

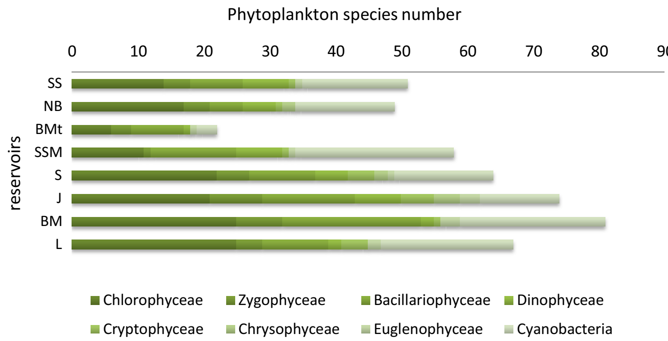

Fig. 2. Species number in phytoplankton classes present in some freshwater reservoirs stocked by mullet's fry in Tunisia (Limam, 2003; Bel Haj Zekri, 2003; Ben Rejeb Jenhani et al., 2006; El Herry et al., 2008; Fathalli 2012; Sellami et al., 2012 ; Ammar et al., 2015; Ben Romdhane, 2015); L: Lebna; BM: Bir M'cherga; S: Séjnène; J: Joumine; SSM: Sidi Salem; BMt: Beni Mtir; NB: Nebhana; SS: Sidi Saâd.

anoxia, that could harm aquatic life, especially fish population (Abrantes et al., 2006; Twoney et al., 2002; Brönmark and Weisner, 1992), results from oxygen demand for the active degradation of organic matter and the bacterial decomposition linked to phytoplankton blooms die-off. Additional factors such as lack of rain, particularly observed in 2016–2017 where whole dams have accumulated less than 50% of their capacity (ONAGRI, 2017), may be involved in degradation of water quality and occurrence of cyanobacterial blooms induced by potentially toxic taxa (*Microcystis aeruginosa*, *Planktothrix agardhii*, etc.). Intensification of these sporadic phenomena with massive fish mortalities have just been reported in Mlaabi, Sidi Saad and Hjar dams (unpublished data). Unavailability of toxin data prevents us to highlight the real causes of this phenomenon.

4 Biological potentialities

4.1 Plankton communities

Phytoplankton as a primary producer has the main role in the aquatic trophic web, feeding a wide range of animals from microscopic zooplankton to gigantic whales (Behrenfeld et al., 2005). It is also considered as a good indicator of water quality and descriptor of the trophic status of lakes (Hakanson and Boulion, 2002).

Investigations conducted in some Tunisian reservoirs revealed the presence of 185 phytoplanktonic species spread over classes: Dinophyceae, Euglenophyceae, Cryptophyceae, Chrysophyceae, Zygophyceae, Bacillariophyceae, Chlorophyceae and Cyanobacteria branch. The last two groups were the most diversified each with 51 and 52 species, respectively. Bir M'cherga one of the main fish-farming reservoir in Tunisia (DGPA, 2010), had the largest species richness with 81 identified species (Fig. 2). Quantitatively, phytoplankton density in this reservoir was also very important and reached 14.6×10^6 and 17.47×10^6 individuals/L in 2005 and 2006, respectively (Fathalli et al., 2010; Fathalli, 2012). Also, phytoplankton biomass estimated by chlorophyll a content showed that Bir M'cherga and Sidi Saâd reservoirs presented the highest level of chlorophyll a recorded in Tunisian reservoirs, with annual average of 6.8 $\mu g\,L^{-1}$ (Fathalli, 2012; Sellami et al., 2010). Massive developments of phytoplankton were considered as a nuisance for water usages like drinking water, irrigation, fish farming or recreation (Pearl, 1988). Since 2004, some episodic fish die-offs, affecting all species indiscriminatingly, have been reported in Bir M'cherga, particularly between March and June (Ammar et al., 2015; Ben Rejeb Jenhani et al., 2012). Recently, the same problem of fish mortality was noted in Sidi Saâd (Unpublished data).

In fact, the expansion of urban areas associated with more and more intensive agricultural pressure promote the progressive eutrophication of surface water, which contributes to the deterioration of water quality and leads to symptomatic changes such as water coloration and harmful algal blooms (HAB) occurrence (Dauta and Feuillade, 1995). Cyanobacteria are the most commonly bloom-forming taxon in freshwater. They can produce toxic secondary metabolites including hepatotoxins, which have carcinogenic potential, neurotoxins and lipopolysaccaride endotoxins (Carmichael and Falconer, 1993; Carmichael, 2001).

Tunisian reservoirs revealed the presence of 55 species of cyanobacteria comprising mainly filamentous strains. Sixteen of them have been cited in the scientific literature as potentially toxic (Tab. 4). The first report of cyanobacterial blooms was signaled in 2008 in Hjar and Lebna reservoirs, located in the north-east of Tunisia It was confirmed as hepatotoxin-containing blooms by molecular tools (Ben Rejeb Jenhani et al., 2010). In April 2017, a precocious bloom was observed in the same hydrological basin in Mlaabi reservoir (data not shown). Compared to neighboring countries, Morroco and Algeria, toxic cyanobacterial blooms are still less frequent and intense in Tunisia (Oudra et al., 2002; Amrani, 2016). Most of these blooms were generated by the potentially toxic species *M. aeruginosa*, the most involved cyanobacterium in incidents of human and animal poisoning over the world. In Tunisia, this taxon was represented by *M. aeruginosa* and *M. wesenbergii*.

The invasive potentially hepato/neurotoxic *Cylindrospermopsis raciborskii*, which was firstly recorded in tropical to subtropical climate regions, was reported for the first time in Tunisia in October 2004 (Fathalli et al., 2010). It was observed in Bir M'cherga. This species confirmed as non-toxic (Fathalli et al., 2011) was observed, later, in Nebhana and Sidi Saâd reservoirs, located in the center of the country (Fathalli et al., 2015). *Planktothrix*, one of the most frequent hepatoxic microcystins producers (Kurmayer et al., 2005), was represented in Tunisian freshwater by the species *P. agardhii* that was recorded at five different reservoirs (Joumine, Bir m'cherga, Sidi Salem, Nebhana and Sidi Saâd) which also proved to be nontoxic (Fathalli et al., 2011).

Cyanobacteria dominance increases especially during the summer–autumn period. Fathalli (2012) reported that cyanobacterial development in Bir M'cherga was negatively correlated with the N_T/P_T ratio. This shows that high cyanobacterial proliferations periods often coincided with the lowest N_T/P_T values. In fact, Tunisian reservoirs have become progressively more enriched during last decades. The extent of eutrophication in Tunisian water bodies has been highlighted in previous studies, showing that these ecosystems present an increasing productivity continually stimulated by fertilizing contributions caused by important anthropisation

Table 4. Inventory cyanobacteria species in some Tunisian reservoirs stocked with mullet's fry.

	Hydrological basins							
	North East		Extreme North Ichkeul		Madjerda		Central west	
	L	BM	J	S	SSM	BMt	NB	SS
Aphanothece c.v. brevis					x			
Aphanothece clathrata							x	
Eucapsis sp.					x			
Merismopedia glauca	x		x	x				
Merismopedia elegans				x	x			
Merismopedia miniata					x			
Merismopedia sp.		x	x	x		x		
Microcytis aeruginasa	x	x	x	x	x		x	x
Microcytis wesenbergii	x				x		x	
Microcytis sp.					x		x	x
Chroococcus sp.	x	x		x			x	x
Chroococcus limneticus					x			
Chrococcus turgidus	x							
Coelomoron sp		x						
Gloeothece sp.							x	x
Snowella sp.	x	x						
Snowella atomus	x							
Synechococcus elongatus		x		x				
Synechocystis aqualis	x							
Anabaena sp.	x		x		x		x	x
Anabaena circinalis					x			
Aphanizomenon sp.		x						
Arthrospira plathensis					x			
Cylindrospermopsis raciborskii		x					x	x
Borzia trilocularis	x							
Limnothrix sp.		x						
Limnothrix redekei					x			x
Leptolyngbya sp.							x	
Lyngbya sp.		x			x	x		x
Nostoc sp.							x	
Oscillatoria articulata			x	x				
Oscillatoria chlorina	x	x	x	x	x			
Oscillatoria geminata					x			
Oscillatoria homogenea		x	x	x			x	x
Oscillatoria lacustris		x			x			x
Oscillatoria limnitica	x		x	x				
Oscillatoria planctonica	x	x	x	x	x			x
Oscillatoria pseudogeminata		x						
Oscillatori simplissima	x							
Oscillatoria sp.	x	x	x	x	x	x	x	x
Oscillatoria tenuis	x	x		x	x			
Phormidium sp.	x			x				
Planktolyngbya subtilis								x
Planktolyngbya limnitica		x						
Planktothrix agardhii		x	x		x		x	x
Pseudanabaena catenata	x	x		x	x			x
Pseudanabaena constricta	x	x			x		x	
Pseudanabaena limnitica		x			x			
Pseudanabaena sp.			x					x
Raphidiopsis curvata					x			
Romaria sp.							x	
Hydrococcus rivularis	x							

L: Lebna; BM: Bir M'cherga; S: Séjnène; J: Joumine; SSM: Sidi Salem; BMt: Beni Mtir; NB: Nebhana; SS: Sidi Saâd; bolt: Potentially toxic. List established from following references (Ben Rejeb Jenhani et al., 2006; El Herry et al., 2008; Fathalli et al., 2015; Fathalli 2012; Sellami et al., 2012; Ammar et al., 2015; Ben Romdhane, 2015).

and dryer climate (Mouelhi, 2000; Turki, 2002; Ben Rejeb Jenhani et al., 2006; Fathalli et al., 2006; El Herry et al., 2008; Fathalli 2012; Ammar et al., 2015; Ben Romdhane, 2015).

In Tunisian freshwater, the occurrence of cyanotoxins has been confirmed for the first time in 2003, at Hjar reservoir in North-East of the country, revealing three variants of Micocystins MC: MC-LR, MC-RR, MC-YR (El Herry et al., 2007). In Lebna, toxin concentrations reached 5.57 µg MC-LR equivalent per liter, suggesting that three morphospecies of *Microcystis* and the filamentous species *O. tenuis* that occurs in the same period, were toxigenic. In this water body two variants of MC (MC-LR and MC-YR), were identified (El Herry et al., 2008). Ben Rejeb Jenhani et al. (2006) report that Hjar, Mlaabi and Lebna hydrosystems were characterized by the highest levels of toxins with 7.45, 1.04 and 5.57 µg MC-LR equivalent per liter, respectively. The cyanotoxins concentrations detected in bulk waters of the three above-mentioned dams, exceeded the guideline value for MC-LR ($1\,\mu g\,L^{-1}$) established by the WHO (1998) for drinking water. Thus, the highest values of toxicity in Tunisian freshwaters were recorded at the north-east hydrologic basin characterized by high anthropogenic activity. This region which represents 8.5% of the whole area of Tunisia, concentrates 45% of urban population, 49% of industrial employment, 36% of tourism capacity and 30% of irrigable surface (Cherif, 2003).

Although cyanobacterial toxicity has been well studied worldwide, investigations on the bioaccumulation of MCs in aquatic organisms are less common (Larson et al., 2014). In the natural environment, MCs, the most important toxins in freshwater, are accumulated in a wide range of aquatic animals, including fish (Magalhães et al., 2003; Mohamed et al., 2003), shrimps (Chen and Xie, 2005b), gastropods (Zhang et al., 2007) and bivalves (Chen and Xie, 2005a) and are found in both the viscera and also in the edible muscle/foot (Jia et al., 2014). It has been reported by several authors that MCs concentration in muscle was highest in omnivorous fish, followed by phytoplanktivorous fish, and was lowest in carnivorous fish (Zhang et al., 2009; Larson et al., 2014; Amrani, 2016). However, Chen et al. (2005) found that most toxins are located in the inedible parts, which means that removing the hepatopancreas, digestive tract, and gonads before consumption could decrease the risk of intoxication.

This information is lacking in Tunisia despite its practical importance for public health protection.

In freshwater ecosystems, zooplankton plays a key role as efficient filter feeders on the phytoplankton and as a food source for other invertebrates and fish (Lampert, 2006; Li et al., 2009; Preuss et al., 2009; Saha and Bandyopadhyay, 2009). In Tunisian reservoirs, a total of 87 zooplankton species were found. Rotifers, the most diversified group with 52 species, are followed by cladocerans with 22 species. Sidi Salem, the largest reservoir in Tunisia, had the most important zooplankton specific richness with 9 copepoda, 12 cladocera and 31 rotifera species (Fig. 3).

The composition and dynamics of the zooplankton community is affected by interspecies competition and selective predation pressures. Sellami et al. (2012) showed that phytoplankton, as well as planktivorous fish species, is an important factor responsible for the succession of zooplankton community, the cyanobacteria being the group with major impact. Indeed, the dominance of inedible cyanobacteria lead to a very low species diversity of zooplankton in this water body (Sellami et al., 2012). In Nebhana reservoir, during May and June, the abundances of cladocerans and rotifers were low abundances and negatively correlated with cyanobacteria abundance, (Sellami et al., 2016). It has been reported that cyanobacterial blooms cause direct decline in numbers of large cladocerans (Ger et al., 2014). It can reduce the reproduction rate of rotifers and both growth and reproduction of cladocerans (Arnold, 1971; Haney, 1987). The susceptibility of cladocerans to mechanical and chemical interference from cyanobacteria was well established (Lürling, 2003; Gustafsson and Hansson, 2004; Wood, 2014).

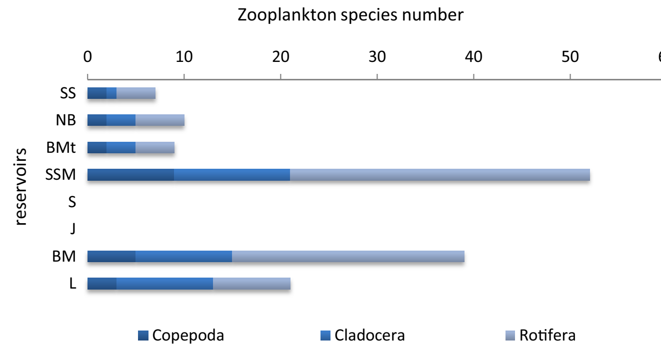

Fig. 3. Species number in zooplankton groups present in some freshwater reservoirs stocked by mullet's fry in Tunisia (Mouelhi, 2000; Ammar, 2006; Souga, 2007; Sellami et al., 2010, 2012, 2016); L: Lebna; BM: Bir M'cherga; S: Séjnène; J: Joumine; SSM: Sidi Salem; BMt: Beni Mtir; NB: Nebhana; SS: Sidi Saâd.

4.2 Fish assemblages

Because of the aridity of the climate stemming from irregular rainfall and the absence of natural permanent freshwater bodies (rivers and lakes), the endemic Tunisian freshwater fish biodiversity is low and limited to two families of Cyprinidae and Anguillide including barbel *Barbus callensis*, minnow *Pseudophoxinus callensis* and European eel *Anguilla anguilla*. In order to promote fisheries in a large number of reservoirs and provide high-quality proteins and economic resources for people living in the surrounding areas where unemployment is generally high, fish species have been introduced in a few Tunisian reservoirs. These included both marine fish species that are autochthonous in the Tunisian coastal zone as well as freshwater fish species native from Eastern Europe and Western Asia (Zaouali, 1981). After the 1990s, this activity was extended to most large reservoirs (Losse et al., 1991). Among the allochthonous freshwater species, we may mention roach *Rutilus rubilio* (L.), rudd *Scardinius erythrophthalmus*, carp *Cyprinus carpio* (L.), catfish *Silurus glanis* (L.), pikeperch *Sander lucioperca* (L.), blackbass *Micropterus salmoides*, tilapia *Oreochromis niloticus* (L) and grass carp *Ctenopharyngodon idella* (L). Among the autochthonous marine species we may cite mullets *Mugil cephalus* and *Liza ramada* (L.) which are captured at juvenile

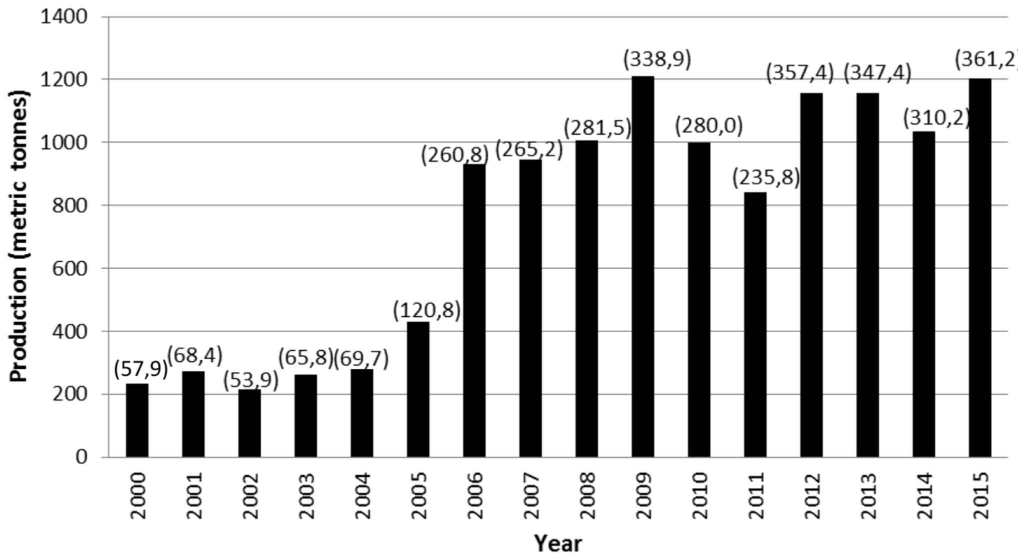

Fig. 4. Freshwater fish production in Tunisian reservoirs from 2000 to 2015 (Statistics DGPA). Values between brackets represent mullet's production per year.

stage in the mouth of the Tunisian wadi. These mullets are euryhalines species but are unable to reproduce in freshwater. On one hand, fish seeding must be renewed every year, but on the other hand, the acclimatization risk is null. Manipulating ecosystems by introducing carnivorous, even with high economical interest, is widely regarded as detrimental and can never be considered risk free (Vitule et al., 2009). The largest reservoir of Sidi Salem located in the North West of Tunisia has seen its population of barbel decreasing concomitantly with the increase of pikeperch population (Djemali, 2005). However, this carnivorous species allow the transformation of autochthones invaluable fishes (*Phoxinella*, barbel) into exploitable biomass, of excellent nutritional quality and commercial value (Steenfeldt et al., 2015). Mullets species are omnivorous and constitute an excellent low risk alternative to the introduction of carnivorous to enhance fish production.

Freshwater fish production in Tunisia increased significantly since 2006 to exceed 1200 metric tons (Fig. 4). However, this production represents only 1% of the national marine fish catch. In Tunisia, freshwater fishing is generally a secondary activity for people. In fact, these fishermen are mainly farmers who livelihoods are based on terrestrial agricultural activities; and fishing activities allow them only to improve their incomes (Hadj Salah, 2002). In order to increase freshwater fish production, it is particularly interesting to develop mullets production and in particular *M. cephalus* which show the best growth performances and can reach high length (0.78–1 m) within a few years, resulting from their inability of reproducing (Djemali et al., 2017). Yearly, the mullet production represents between 25 and 30% of the landed freshwater fish biomass.

Since twenty years, freshwater fishing in reservoirs became a source of employment for rural populations and showed growing importance. There is a critical need for reliable fish biomass estimates to ensure their effective management (Djemali et al., 2009), but acoustic surveys to estimate MSY present fairly limited results because they were obtained only for a single season. Year-round studies highlighted significant seasonal changes in fish biomass (Djemali et al., 2017; Djemali and Laouar, 2017), but more efforts have to be carried out for further estimation and to establish mid- or long-term trends. In the eutrophic shallow reservoir of Bir-Mcherga, located in northern Tunisia, with untargeted common carp, fish biomass peaked in autumn with average value reaching $355 \pm 162\,\mathrm{kg\,ha^{-1}}$ (Fig. 5) of which 14% was constituted by mullets (*M. cephalus* and *L. ramada*) (Djemali et al., 2017). In this reservoir *M. cephalus* is the most targeted fish species so fishermen use gillnets with specific mesh size and techniques. During autumn, from the dyke to the tributaries, fish biomass distribution was not governed by depth and was the most abundant in the upstream areas (Fig. 5). In Joumine reservoir, located in the extreme north of the country, fish biomass peaked during summer with an average value of 140 ± 37 kg/ha of which 35% (i.e. 49 kg/ha) was constituted by the two species of mullet (Djemali and Laouar, 2017) (Fig. 6). This shows that the environmental and ecological conditions in this reservoir support the growth of the mullets although promoting fisheries targeting mullets requires that juvenile mullets are released regularly. Nevertheless, the above-mentioned mullet's biomass was obtained using professional gillnets which efficiency in freshwaters for fish sampling is affected by fish species and size.

In the deep Tunisian reservoirs of Kasseb, Joumine and Sidi el Barak, low mullets landing is mainly due to the use of unsuitable artisanal fishing gears consisting in gillnets with a low height (<7 m), which are fixed near the banks. Deep-water angling in the context of recreational activity or netting might be a better way for the exploitation of the mullet's stocks in the deeper areas of these reservoirs. During September, mullet's landing increases (DGPA, 2012) and fishermen have attributed

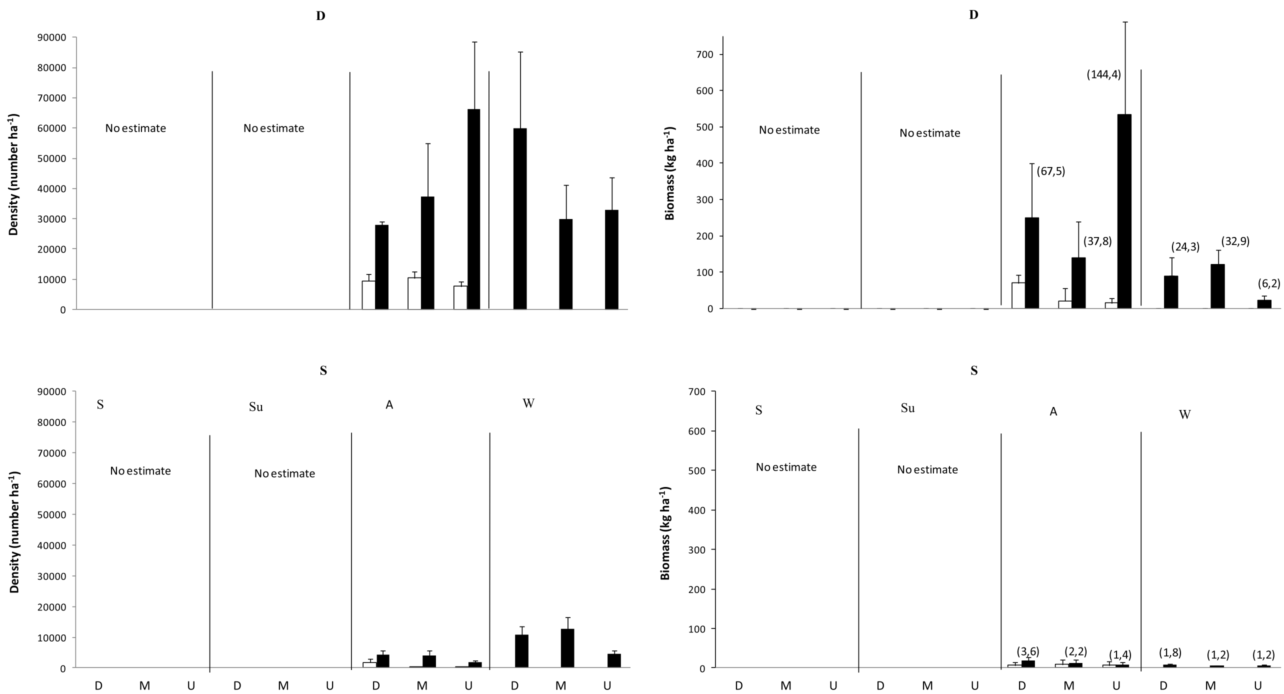

Fig. 5. Mean fish biomass and density measured in the layer between 0 and 3 m (D) and in the layer deeper than 3 m (S) sampling in three zones (u = upstream; m = middle; and d = downstream) of the Bir M'cherga Reservoir sampled in four seasons. The white bars correspond to day surveys and black bars correspond to night surveys. Error bars show standard deviations. Seasons are shown in each panel, abbreviated as follows: spring = S, summer = SU, Autumn = A and winter =W. Values between brackets represent mullet's biomass.

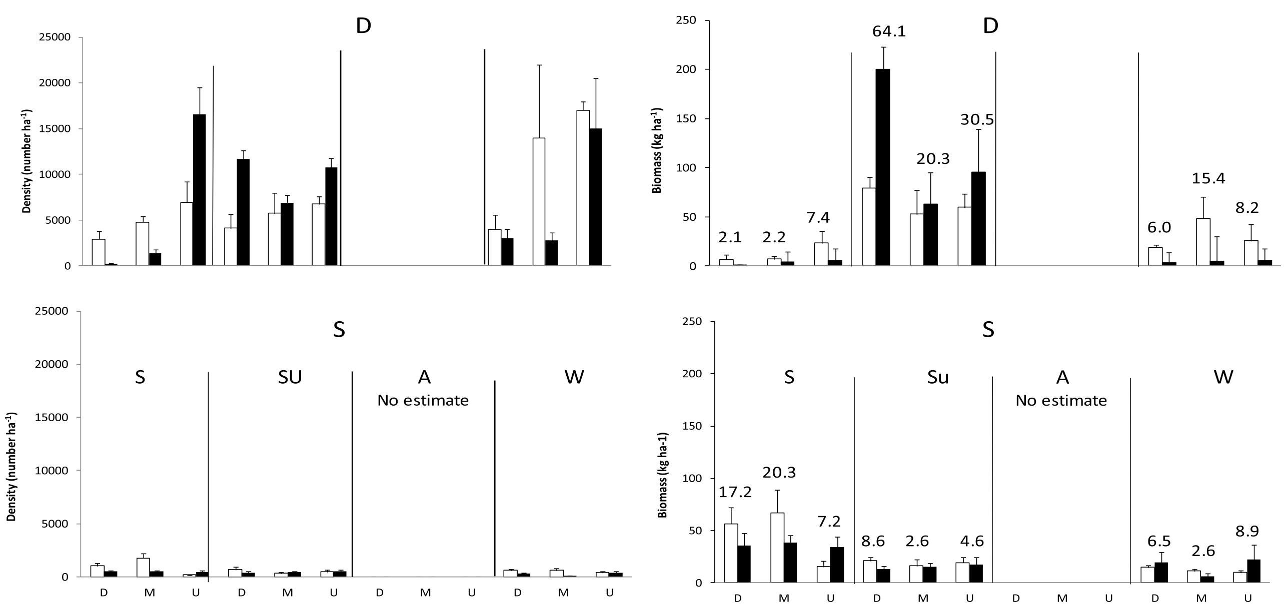

Fig. 6. Mean fish biomass and density measured in the layer between 0 and 3 m (D) and in the layer deeper than 3 m (S) sampling in three zones (u = upstream; m = middle; and d = downstream) of the Joumine Reservoir sampled in four seasons. The white bars correspond to day surveys and black bars correspond to night surveys. Error bars show standard deviations. Seasons are shown in each panel, abbreviated as follows: spring = S, summer = SU, Autumn = A and winter =W. Values between brackets represent mullet's biomass.

this phenomenon to increased water turbidity with the first rains of August-September making their nets less visible to fish. However, higher catch rates is linked to high fish growth during warm months and to higher vulnerability of mullets during spawning period despite there is no oocytes emission (Djemali and Laouar, 2017).

Capture-based enhancement of mullet fisheries is highly influenced by the fry and fingerlings manipulation during

Table 5. Inventory of macrophytes, algea and invertebrates in some Tunisian reservoirs stocked with mullet's fry.

	Hydrological basins							
	North		Extreme North		Madjerda		Central	
	L	BM	J	S	SSM	BMt	NB	SS
Macrophytes								
Potamogeton pectinatus	x	x						x
Potamogeton pusilus		x						
Chara sp.		x						x
Myriophyllum sp.		x						
Phragmite sp.	x	x						x
Thypha sp.								
Filamentous Algae								
Chaetomorpha sp.		x						
Crustaceans								
Atyaephyra desmarestii	x	x			x		x	x
Paleomonetes varians 199		x						
Potamon algeriensis		x			x		x	x
Insect larvae								
Odonates		x						x
Chironomids		x			x			
Ephemeroptera								
Tubifex					x			
Gastropods								
Lymnaea sp.							x	
Eobania sp.					x			

L: Lebna; BM: Bir M'cherga; S: Séjnène; J: Joumine; SSM: Sidi Salem; BMt: Beni Mtir; NB: Nebhana; SS: Sidi Saâd. List established from following references (Boumaiza et al., 1986; Losse et al., 1991; Dhaouadi-Hassen et al., 2004).

transfers. Moreover, during transfer, fish are exposed to some environmental variations, especially salinity, temperature and dissolved oxygen, which may lead to physiological perturbations negatively affecting survival, growth and physiological quality of the future adult (Khériji et al., 2001). The success of stocking also depends from the species knowing that *M. cephalus* has greater impact per introduced fish than *L. ramada* (Snovsky and Ostrovsky, 2014). The most interesting study concerning mullet stocking success was performed in Hawai (USA) and showed that the size at release, season and habitat are the main factors impacting mullet recaptures in the fishery (Leber et al., 2016). Taking into account the surface of the Tunisian reservoirs and the commercial value of grey mullet it has been estimated necessary to stock 10 millions of fingerlings per year but the "Centre Technique de l'Aquaculture" which controls stocking programs, is unable to transfer more than 8 millions of fingerlings per year due to a high fluctuation of the stock in time and space. The more frequent periods of dryness and the overfishing of wild mullets are among the factors explaining the increasing scarcity of wild mullet juveniles available which is now limiting current capture-based mullet fisheries. Hence, Tunisian authorities have to encourage culture-based fisheries enhancements to improve mullet production, especially as the intent is to promote a highly prized species (Aizen et al., 2005).

4.3 Other documented organisms

In aquatic environments, macrophytes provide shelter, feeding and nesting area for various species of vertebrates and invertebrates (insects, crustaceans, molluscs, fish, birds, etc.). In reservoirs, the macroflora is poorly studied: when it exists it is mainly represented by reed stands (Thyphaceae, Poaceae) on the banks and farther, in the deeper zone, we find *Potamogeton* (Potamogetonaceae) and *Myriophyllum* (Haloragaceae). Filamentous algae such as *Chaetomorpha* (Cladophoraceae) are also reported (see Tab. 5). According to Losse et al. (1991), macroflora in Sidi Salem and Nebhana is absent. With the exception of Bir mcherga, Sidi Saad, Lebna et El Houareb reservo`irs, most of the reservoirs in Tunisia are poor in both submerged and emerged macrophytes which may affect diversity and abundance of water birds. The reasons for this remain unknown so far. The species richness of aquatic birds increases with the abundance of the aquatic vegetation (Losse et al., 1991). Insects that constitute a large part of the macrozoobenthos of freshwater habitats around the world have been very well studied in Tunisian running waters (rivers) where checklists are often updated (Touaylia et al., 2010, 2011; Boumaiza, 1994). However, in water bodies only a few indications are available on insects. The crustaceaen *Atyaephyra desmarestii* has also a wide distribution in both running and stagnant continental waters. It was reported in Sidi Salem, Lebna and Sidi Saad reservoirs, i.e., three distinct bioclimatic areas with high differences in salinity (average values 1.37, 0.7 and 2.8‰, respectively) thus confirming its euryhaline status (Dhaouadi-Hassen, 2003). Similarly, research on Molluscs was carried out only on running water (Khalloufi and Boumaïza, 2005, 2007, 2009; Khalloufi et al., 2011).

5 Conclusion and future directions

This review attempts to bring together information about dam reservoirs in Tunisia from a wide range of disparate studies which, nevertheless, yielded valuable and useful information. In reference to national and international standards the majority of the reservoirs have good water quality. The high trophic status of all reservoirs could be explained by the gradual aging of the retaining structures associated with a permanent external nutrient load that is mostly subject to increase (pollution) and by extended periods of drought. This assessment revealed a frequently negative evolution of these environments, causing an increase in the frequency of potentially toxic cyanobacteria blooms and in massive fish mortality affecting even the most robust and adapted species (Cyprinidae) to the lack of oxygen in the deeper zones.

Toxic cyanobacterial blooms which are not as frequent and intense as in the neighboring countries are so far not a matter of concern, but may become so with the increasing eutrophication. A comprehensive investigation of the MCs concentrations in various organs of various freshwater fish from various reservoirs has never been conducted in Tunisia despite its practical importance for public health. Considering this fact, it is relevant to monitoring fish and other aquatic animals from water bodies with toxic cyanobacteria species for assessing any potential risks to human health.

Data on benthic invertebrates and macrophytes, apart from some occasional indications, are almost absent for inland water bodies and deserve to be studied in order to elucidate how the functioning of these reservoirs should influence the inland fisheries, Thus, a long-term monitoring of water quality and biotic integrity of nectonic, planktonic and benthic communities should be considered for an efficient management of these new artificial hydrosystems already old.

In Tunisia, inland fishing seemed marginal compared to the inshore fishery that is practiced along the coast. However, the introduction of new species associated with mullet fry rearing operations has clearly increased the potential for fish production in the reservoirs and can therefore be considered as profitable. Indeed, the productions reached these last years show clearly that inland reservoirs, with their environmental conditions, are well suited for these activities and represent a significant potential that must be further developed. Thereby, mullet's biomass estimates in Tunisian reservoirs show that environmental and ecological conditions support their growth.

Despite the efforts made by the authorities, the quantities produced are still below the forecasts of the economic and social development plans. So, for a better management policy for this fish resource, multidisciplinary studies should be considered to explain the variability of production both interannual and between dams. Consequently, future studies should use more than one sampling technique in order to limit sampling bias of the abundance, species composition, size structure and spatio-temporal distribution of fish. To ensure the sustainability of the development of fisheries activity in Tunisian inland waters there is a need for periodic stocking of mullet's fry for a larger number of reservoirs therewith encouragement of private initiative. Also, the lack of a reliable system for collecting inland fisheries statistics is a major handicap for the development of this sector contravenes an objective analysis of the situation.

Thereby, improvement of fishing techniques and stocking of mullet fry, strengthening fishermen's groups, control of illegal fishing, monitoring of water and fish meat quality are recommended for the development of the sector. Also, from an ecosystem perspective, it is imperative to ensure the consistency of all fisheries management measures with the conservation of living resources and their environment. Harmonization of the interventions of all actors will protect the resource and ensure its sustainability.

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