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Rivers' natural reservoirs: new inputs to the classification of Mediterranean and Saharan wetlands

Lacs de barrages naturels de rivières: apports nouveaux à la classification des zones humides méditerranéennes et sahariennes

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Abstract. This article is dedicated to natural reservoirs, widely distributed ecosystems in North Africa but poorly studied. Their hydrological and ecological characteristics are insufficiently highlighted in existing wetland typologies; that's why we recommend to assign them to new wetlands' types. Generally named *gueltas*, these reservoirs have a common genesis model, based on natural dams that block river beds. Four types of gueltas are identified: (1) *landslide lakes*, mountainous reservoirs created upstream of voluminous landslides that block deep valleys; (2) *river gueltas*, river beds blocked by small deposit thresholds, generally installed by tributaries; (3) *dune gueltas*, generated upstream to active Saharan dunes; (4) *estuarine gueltas*, due to fluviomarine dikes transforming estuaries into large 'saltwater ponds'. These standing waters are built in river beds, and their characteristics and communities are highly fashioned by floods, both in their composition and functioning. The river gueltas are widely distributed in North Africa, while other reservoirs are poorly represented, some of them being threatened. Permanent reservoirs, in both mountains and desert, host endemic fishes, while river gueltas are conservatories of fish during dry seasons. Considering these originalities and values, several Moroccan gueltas have been classified in Ramsar sites, hoping they would benefit from future studies.

Keywords: Wetland classification, Landslide-dammed Lakes, Fluvial Gueltas, Dune-dammed Gueltas, Ecosystem Values, North Africa.

Résumé. Cet article est consacré aux lacs de barrages naturels, écosystèmes largement distribués en Afrique du Nord mais encore mal étudiés. Leurs caractéristiques hydrologiques et écologiques ne sont pas suffisamment mises en évidence dans les typologies existantes des zones humides ; c'est pourquoi nous recommandons de les affecter à de nouveaux types d'écosystèmes aquatiques. Généralement appelés gueltas, ces réservoirs ont un modèle de genèse commun, qui réside en l'endiguement de lits d'oueds par des processus naturels. Quatre types de gueltas sont identifiés : (1) lacs de glissement de terrain, réservoirs montagneux créés en amont de glissements de terrain volumineux qui bloquent des vallées profondes ; (2) gueltas fluviales, lits fluviaux bloqués par des dépôts accumulés en forme de seuil bas, généralement acheminés par des affluents ; (3) gueltas dunaires, générées en amont des dunes sahariennes actives ; (4) gueltas estuariennes, en amont de digues fluviomarines transformant les estuaires en grands 'plan d'eau salés'. Ces eaux stagnantes sont construites dans les lits des rivières et leurs caractéristiques et communautés vivantes sont fortement façonnées par les inondations, tant dans leur composition que dans leur fonctionnement. Les gueltas fluviales sont largement distribuées en Afrique du Nord, tandis que les autres types de réservoirs y sont peu représentés, certains d'entre eux étant menacés. Les réservoirs permanents, qu'ils soient en montagne ou dans le désert, abritent des poissons endémiques, tandis que les gueltas fluviales sont des conservatoires de poissons pendant les saisons d'étiage. Compte tenu de ces originalités et ces valeurs, plusieurs gueltas marocaines ont été classées dans des sites Ramsar, en espérant qu'elles bénéficieront de futures études.

Mots-clés: Classification des zones humides, lacs de glissements de terrain, gueltas fluviales, gueltas dunaires, gueltas estuariennes, valeurs patrimoniales, services écosystémiques, Afrique du Nord.

INTRODUCTION

Natural dam reservoirs correspond to basins that occupy river beds upstream of natural dams; they are widespread in the world (Costa and Schuster 1991, Strom A. 2010) and can develop at any level of the river system, from the mountain streams to the estuarine zones. In most of the existing studies on these wetlands, the main targeted themes are their genesis and the risks generated by their dams failure (Costa & Schuster1988, Ermini *et al*. 2006, Evans2006, Geertsema *et al*. 2006, etc.) and more rarely their geomorphological characteristics (Korup 2004, Tacconi Stefanelli *et al*. 2015 ...). Studies that make a clear link between the biocenoses of these aquatic ecosystems and their genesis are practically absent, knowing that this link was indirectly mentioned (i.e. Panouse 1963, Bernatchez 2001, Delling & Doadrio 2005, Snoj *et al*. 2011).

In arid regions, these basins appear as standing waters over a long period of the year, but their hydro-sedimentary characteristics are dependent on highly contrasted fluvial dynamics. While some dams are permanent, resulting from consolidated high dams, many others are submersible by high waters (floods or large swells), or even broken by strong flash-floods, after which they can be rebuilt in a natural way.

Living communities of the natural reservoirs are highly variable in both their composition and their dynamic, mainly depending on nature, position, origin and age of these wetlands. All these features are poorly highlighted in the typology schemes designed for Palearctic wetlands (Devillers & Devillers-Terschuren 1996, Devillers *et al.* 2001, Davies *et al*. 2004, Evans 2012). Indeed, in North Africa, several studies (Gayral 1954, Morgan 1982, Morgan & Boy 1982, Dakki 1985-1987, El Agbani *et al*. 1992, El Alami & Dakki 1998, etc.) have revealed that inland wetlands have specificities that don't allow them to be incorporated in such typologies.

However, natural reservoirs are frequently positioned in these typologies, ignoring their status of *lacustrine/ palustrine ecosystems*, but located in *river* or *estuarine systems*. This creates ambiguity, which is particularly acute for the estuarine and small riverine reservoirs, strongly shaped by the

contrasting hydrological regime of the North-African *wadis* and whose dams can be temporarily broken. On the other hand, mountain lakes with permanent dams seem to find their place easily in the lacustrine system, but their biocenoses are very original, mainly due to their recent genesis, and deserve to be distinguished from the other lakes. This justifies the need of new criteria to adapt these typologies to the North African area, where inland waters have pronounced Mediterranean characters (Giudicelli *et al*. 1985, Dakki 1987). In the two past decades, a new typology has been elaborated especially for Mediterranean wetlands (Farinha *et al*. 1996); it was borrowed from a classification designed for the North American wetlands (Cowardin 1979), but based on universally applicable criteria. Despite its flexibility, this typology is considered by some ecologists as unable to cover all types of North African wetlands.

In North Africa, natural dam reservoirs are commonly called *gueltas* (or *gueltate* and *gueltat* as their plural is pronounced) or *tamdas* or *thamdas*, the two names having an Amazigh origin; these names rarely designate lakes, marshes and ponds other than reservoirs on streams. Each guelta, even of small size, bears a name that evokes its locality or one of its distinctive characteristics, such as shape, color, depth, etc. (e.g. Guelta Kahla, Tamda Tametrocht).

This article presents and describes different categories of these ecosystems, through Moroccan representative examples, which were inventoried from the Atlas Mountains and the Saharan rivers, without ignoring their wide distribution in North Africa.

OVERVIEW OF MOROCCAN NATURAL RESERVOIRS

A brief description of the known natural reservoirs in Morocco revealed that they have similar characteristics (position on the streams/rivers, functioning, and genesis). Despite this convergence, they have been classified into four different categories of inland and coastal wetlands; these are presented hereafter, through well illustrative Moroccan examples that have been located on a map (Fig. 1).

All these categories can be subdivided into different types, but the available studies on gueltas are relatively meager and the subdivisions are proposed only when they are clearly justified.

Landslide-dammed lakes (Landslide lakes)

These are reservoirs whose genesis is due to large landslides that have blocked a river bed, transforming its upstream side into a lake/pond. In humid regions, with high river flow, the lifecycle of this obstacle could vary from days to a few years (Ermini *et al*. 2006, Evans *et al*. 2006, Miller *et al*. 2018). But in arid regions, due to the low stream flow, the landslide would be, on the contrary, consolidated thanks to fine sediments drained from the watershed. This is the case of the Moroccan landslide dams, which have limited watersheds and could unlikely be collapsed or overflowed by waters. On the contrary, these dikes may have groundwater losses through which the lake's water would supply the downstream watercourses via high flow springs.

Four high-altitude Atlas wetlands, easily recognized on satellite images, have been identified as typically representative of North African landslide lakes: Ifni Lake, Tamda Anghomer, Izourar Lake and Tamda Tametrocht (Fig. 2). These lacustrine formations are specific to narrow-bottomed deep valleys, where steep slopes can generate large landslides, whereas the narrow bed of the stream allows the accumulation of this scree as a high dike. These steep slopes are also a potential source of materials that would contribute, along with river inputs, to the gradual filling of these lakes.

This means that lacustrine depressions (karstic, tectonic, etc.) whose genesis took place outside of this kind of valleys, are not considered as natural reservoirs, although some of these formations are partly shaped by natural dikes. This is the case of some natural lakes of the Middle-Atlas (Afennourir, Afourgagh, (Awa, etc.).

Depending on the duration of their seasonal submersion, these lakes are subdivided into three categories: permanent, semi-permanent and intermittent.

Permanent landslide lakes

Two High-Atlas landslide lakes are permanent: Ifni Lake on the upper Tifnoute valley (tributary of the Oued Souss), and Tamda Anghomer (or n'Ounaghmar), on the Ounila valley (upper tributary of the Dr'a river).

Ifni Lake is located at 2323 meof altitudm, in a glacial valley occupying the southern slope of the Toubkal Mountain (Fig. 2); its genesis is due to a large landslide which obstructs the valley (Dresch 1938, 1941, Boulhol 1941). Fed mainly by melting snow and sub-lake springs, this lake can cover up to 35 hectares, for a depth of 65 m; but it is permanently submitted to water losses (through the scree dam), that feed the upper Tifnoute. These losses lead to a significant reduction in the size of the lake, without ever drying it out.

Tamda Anghomer is located on the southern slope of the Central High-Atlas, at 2664 m ofealtitudm, where it occupies the high valley of Ounila stream. Dominated by Jbel Zarzamt (3113 m) to the south and Jbel Ounaghmar (3581 m) to the north, this valley was blocked by a landslide detached from the latter mountain during the Middle Quaternary (Couvreur 1981) and which created this wetland (Fig. 2 & 3).

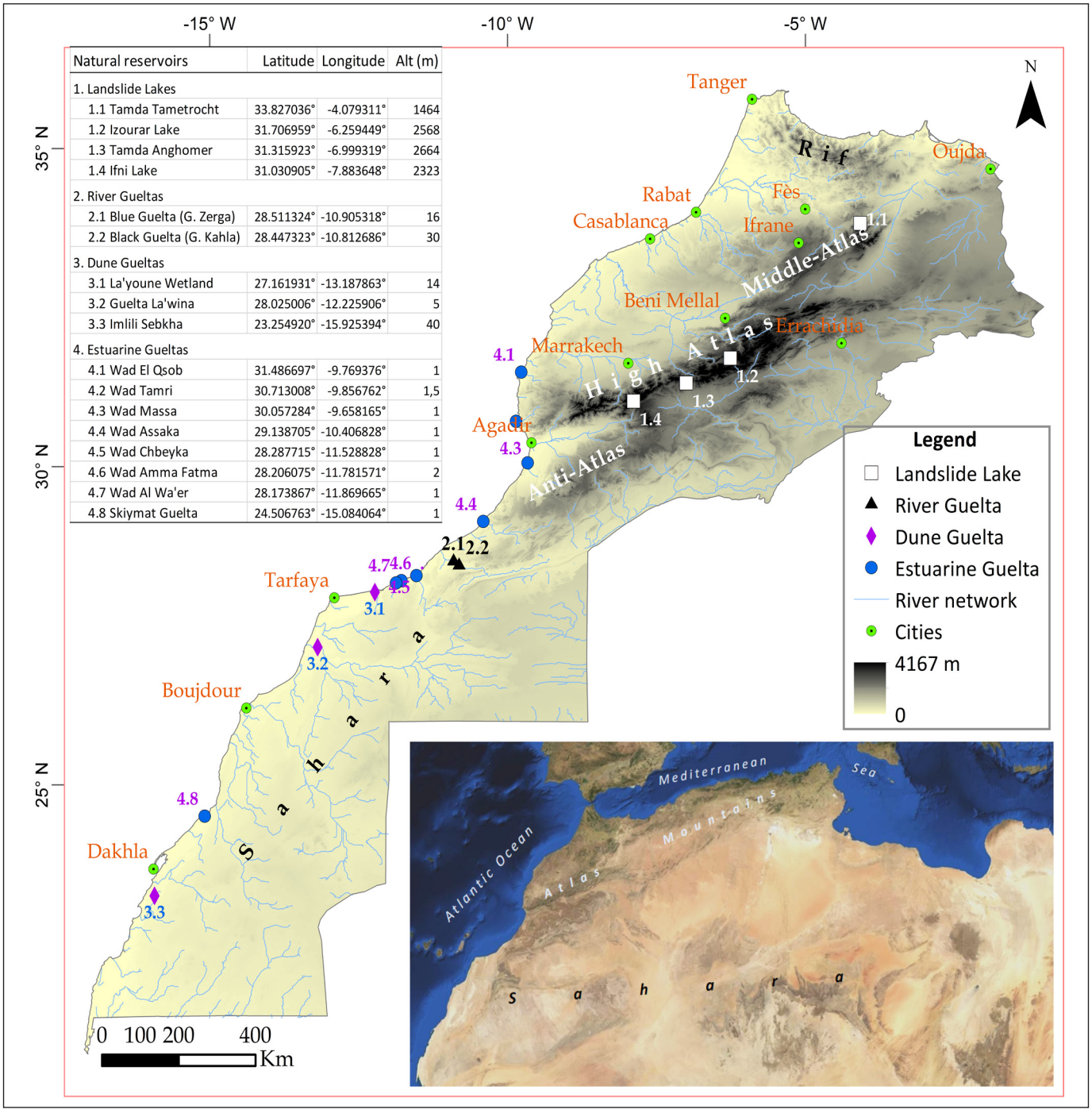
This permanent freshwater lake is mainly supplied by snowmelt, knowing that upstream, the valley has a very small and relatively dry watershed, with rare marks of runoff. The water depth in the lake is highly variable and often suffers from severe summer lowering, but the lake has never been totally dry.

Immediately downstream of the impermeable rock barrier, the river is supplied only by melting snow and dries up in the summer, as well as a temporary pond whose connection to the lake is improbable. It is only 500 meters below this dam, with the outcrop of the Triassic clays, that resurgences supply the stream. The lake's contribution to this hydrology remains to be determined.

Semi-permanent landslide lakes

This type of wetland can be illustrated by an example of a typical Middle-Atlas lake, the Tamda Tametrocht (Guelta Tamda), which can be drained consequently to dry winters and more especially to prolonged droughts.

This lake is located in the eastern Middle-Atlas, 1464 m above sea level, on the upper Oued Ighrane, south of Meghrawa (hinterland of the city of Taza). It has an elongated shape, following the deep valley where it took place, consequently to a big landslide that blocked this valley during the Middle to Recent Quaternary (Fig. 2 and 3). This chaotic dam still provides zones of water infiltration, responsible for emptying the lake in case of low upstream inflows (El Fellah 1994), knowing that these inflows result from both rainfall and snowmelt.



Natural reservoirs	Latitude	Longitude	Alt (m)
1. Landslide Lakes			
1.1 Tamda Tametrocht	33.827036°	-4.079311°	1464
1.2 Izourar Lake	31.706959°	-6.259449°	2568
1.3 Tamda Anghomer	31.315923°	-6.999319°	2664
1.4 Ifni Lake	31.030905°	-7.883648°	2323
2. River Gueltas			
2.1 Blue Guelta (G. Zerga)	28.511324°	-10.905318°	16
2.2 Black Guelta (G. Kahla)	28.447323°	-10.812686°	30
3. Dune Gueltas			
3.1 La'youne Wetland	27.161931°	-13.187863°	14
3.2 Guelta La'wina	28.025006°	-12.225906°	5
3.3 Imlili Sebkha	23.254920°	-15.925394°	40
4. Estuarine Gueltas			
4.1 Wad El Qsob	31.486697°	-9.769376°	1
4.2 Wad Tamri	30.713008°	-9.856762°	1,5
4.3 Wad Massa	30.057284°	-9.658165°	1
4.4 Wad Assaka	29.138705°	-10.406828°	1
4.5 Wad Chbeyka	28.287715°	-11.528828°	1
4.6 Wad Amma Fatma	28.206075°	-11.781571°	2
4.7 Wad Al Wa'er	28.173867°	-11.869665°	1
4.8 Skiymat Guelta	24.506763°	-15.084064°	1

Figure 1. Location of natural reservoirs chosen as examples in this article.

Intermittent landslide lakes

Izourar Lake is a good representative of this type of formation; it was formed in a highly incised valley (Assif Arous), 2568 m above sea level, upstream of a large landslide (3 km long and 200 m thick), forming a 2 km bridge between Jbels Ouaoulgouzate and Azourki (Fig. 2 & 3). This dam, consisting of scree consolidated in a limestone matrix, is deposited on groise formations, attributed to the Ancient Quaternary (Couvreur 1981). In addition to the coarse materials provided by the sloping mountains, this wetland receives finer, reddish and clay-rich materials.

This lake has a near-flat bottom, which is quickly filled with water during snowing periods and thunderstorms; but despite its large floodable area (at least 110 hectares), it undergoes a rapid summer emptying after what appears as a vast silty plain, with some herbaceous spots.

Indeed, the rock mass that constitutes the dam is infiltrated by the waters of the lake, which emerge at the foot of the dam, among the springs filling the stream of Aït Bou Guemmaz.

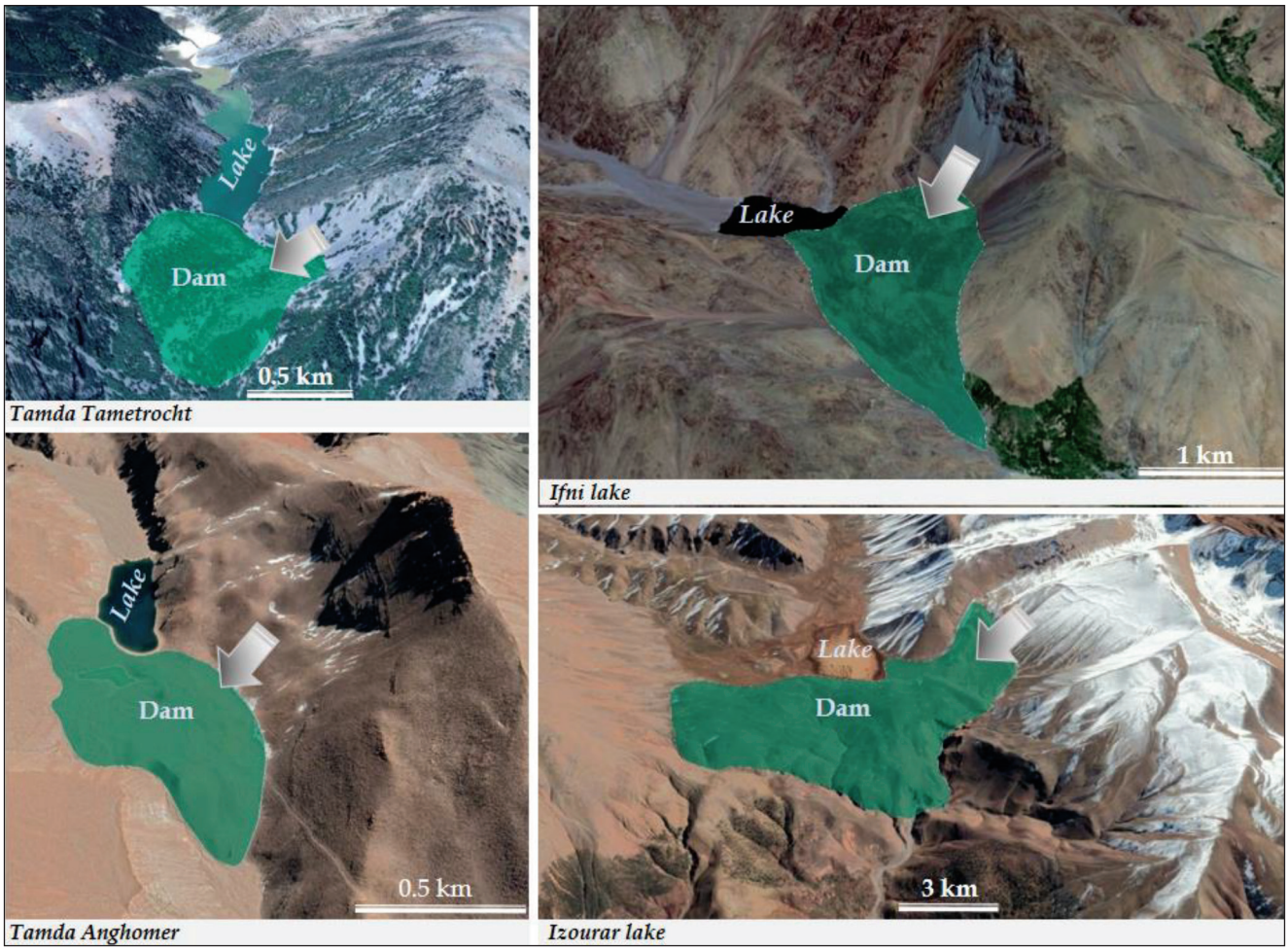


Figure 2. Landslide lakes: four typical examples from Moroccan Atlas Mountains, illustrated on satellite images.

Figure 3. Landslide lakes: three typical examples from Moroccan Atlas Mountains, illustrated by photos.

Fluvial gueltas

These correspond to ponds that occupy the river beds and whose genesis is linked to the formation of a permanent sedimentary threshold, often consisting in coarse materials pebbles and blocks) consolidated by fine deposits.

Thanks to medium resolution satellite images, these basins are easily identifiable in the river landscape, especially during the dry season; they are either permanently or intermittently supplied with upstream waters, and often from the river underflow. They show no flow for long periods, but they can have an outlet through which the flow is often temporary.

Fluvial gueltas are one of the striking features of the North African rivers, strongly shaped by the seasonal (or even inter-annual) hydrological contrast. There are thousands of them, in both pre-Saharan rivers and more wet Northern regions, especially in medium and piedmont rivers, with medium to low slopes. They are also frequent in the Saharan Mountains (Bouvet & Le Berre 1985, Le Berre 1989, Durant & Renoult 2012 …), where they are often assigned to oases.

Most of these gueltas develop at meanders or waterfalls foot, where the river provides a double dynamic of erosion (digging) and sedimentation (sediment bar building). They are also common upstream of confluences, where sediment dams are deposited in the form of colluvium by lateral tributaries; this latter case is well illustrated in the lower Dr'a (Fig. 4 & 5).

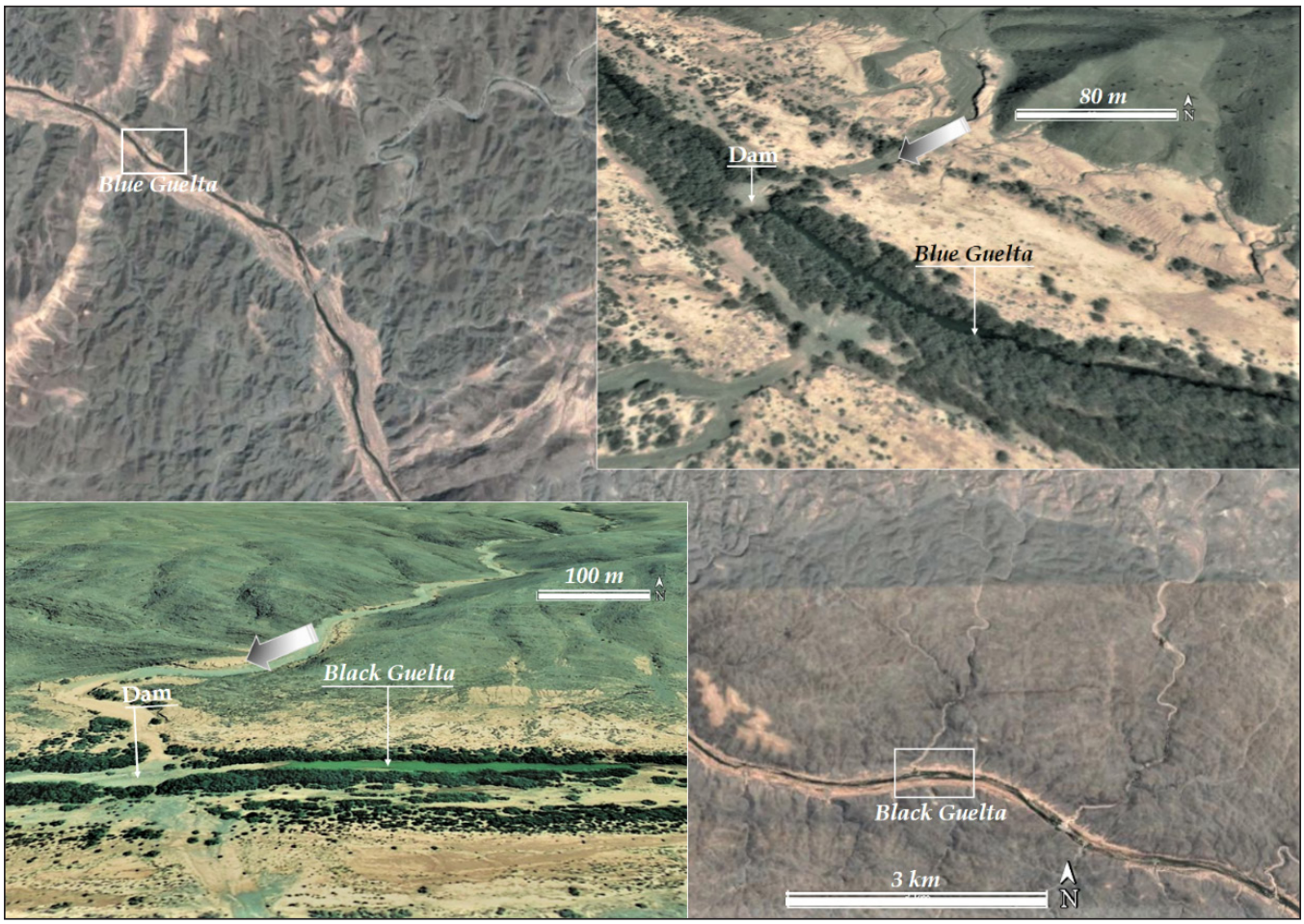


Figure 4. Genesis of the river gueltas: Representative examples from the Lower Dr'a, intermittent river, dammed by alluvial deposits brought by tributaries.

Figure 5. Blue Guelta, on the Lower Dr'a River (South Morocco), a typical representative of permanent fluvial gueltas.

It should be pointed out that certain gueltas can be supplied by the underflow waters, but the great resurgences that emerge in some river beds are not considered to be gueltas if they show a high flow, preventing water stagnation.

Dune dam gueltas (dune gueltas)

These are stagnant waters generated in large river beds,yas a result of their containment by active sand dunes; these gueltas are specific to Saharan areas, where these dunes are frequent and the flow of rivers is intermittent, even random. Dune dams can have heights between 10 and 60 m and kilometric dimensions; however, despite their large extension, some of these dams can be broken following large floods, allowing a sudden emptying of the guelta they've generated. This rupture usually lasts only a few weeks, since the dunes are quickly renewed, but the reconstitution of the gueltas depends on the rainfall and the water inflows from upstream or potential water tables underlying these gueltas. Among several dune gueltas identified in North Africa, only the well-known examples are considered in this work; they can be subdivided in two subtypes.

Permanent dune gueltas

The Sebkha of Imlili (or Sebkhat Imlili), in the Dakhla region, provides a typical example of these gueltas. It corresponds to an elongated depression, with a sandy bottom, very weakly inclined and bordered by cliffs or sand banks, which are no other than the steep banks of a large river (Fig. 6). The existence of this vast guelta is essentially due to a sandy dam, installed on this river during the Holocene age. This dam is considered permanent, in the sense that it cannot be broken by any large flood under the actual climate. This is justified by the length of the river section filled by sand (about 20 km) and by the height of these dunes (15-25 m over the guelta bottom), but probably also by a potential consolidation of the sand, especially in depth. This guelta is distinguished by the permanence of its water, which emerges through several tens of 'wells' (Qninba *et al*. 2009), where a permanent water

biocenosis survives, under insular conditions for several millennia. Water remains present in almost all of these water holes, knowing that they can be filledy alternatively, and in flood periods, the overflowing water ensures surface communication between them.

The La'youne wetland, which occupies the river bed of Assakia El Hamra, is a dune-dammed reservoir, shaped as an elongated permanent marsh (Fig. 7). Only exceptional floods of this river can lead to a rupture of the sandy dam, and these floods lead to partial emptying of this wetland to the ocean. After few dayg, the dunes quickly recover.

There is reason to wonder whether the permanence of this water is not mostly due to the urban wastewaters, directly discharged into the river, with a secondary role of groundwater, accumulated during floods. However, the sand dam and the contributions of this river are rather in favor of this permanence thanks to an underground water table; furthermore, the city of La'youne wouldn't be established if not thanks to perennial emergences, as indicated by its name (La'youne) which means springs.

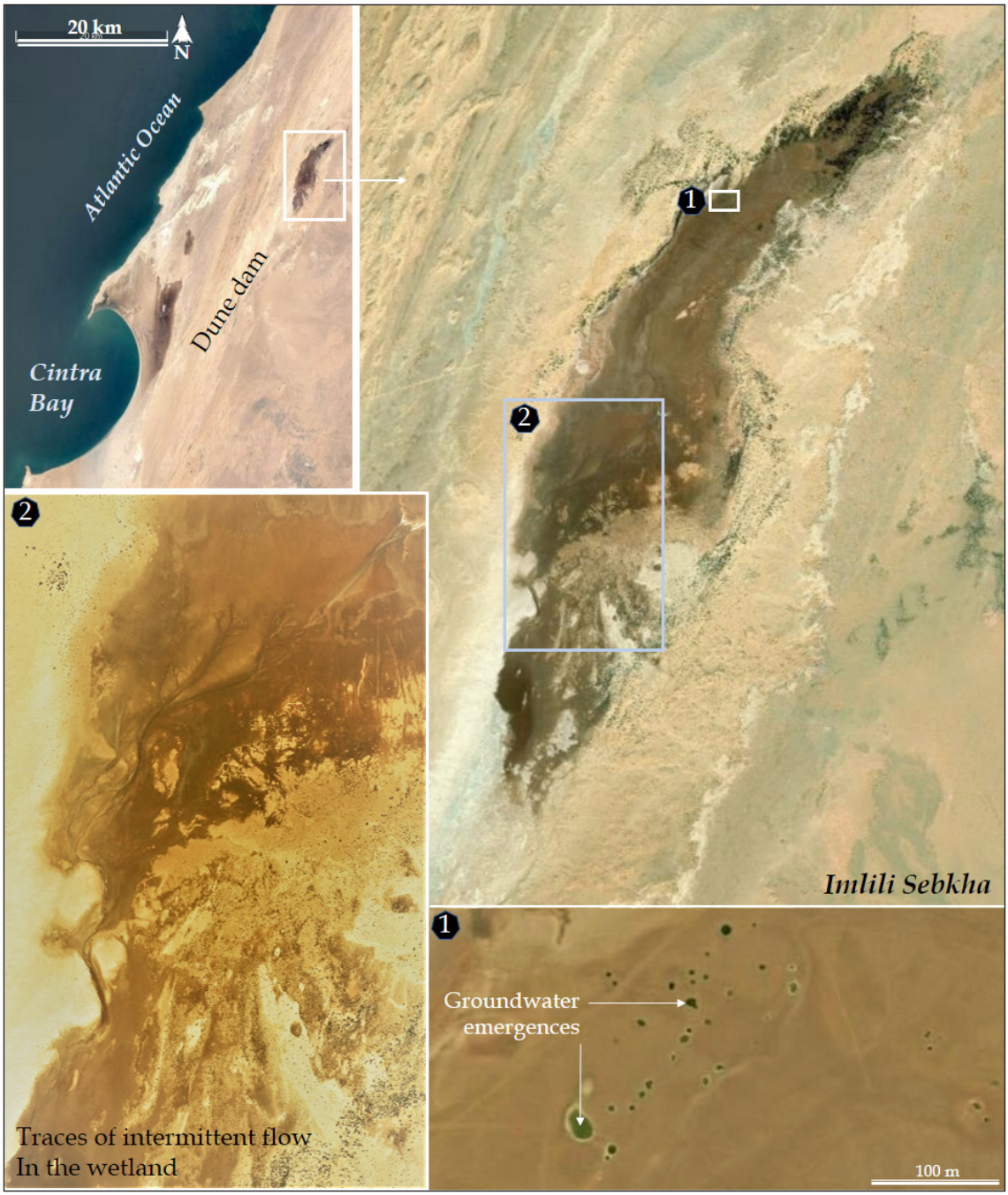


Figure 6. Imlili Guelta/Sebkha, south-east of Dakhla, as it appears on satellite images: 1. groundwater discharge wells, 2. flow channels indicating the slightly inclined bed of the wetland.

Intermittent dune gueltas

This type is represented by the Guelta La'wina, located on the terminal course of the Oued Awedri, near the Khnifiss Lagoon (Fig. 8), some 70 km west to Tarfaya. The sandy dam responsible for this guelta can be broken during exceptional floods; this occurs when the water reaches the top of the dune and incises a narrow flow channel, which expands rapidly, triggering an enormous flow of water and sand to the Khnifiss Lagoon mouth. In windy Saharan regions, these gueltas can remain dry for several years and it is only thanks to the floods that they are submerged.

Guelta La'wina is close to the Atlantic coast and its bottom altitude is only 3-6 m, however, it is unlikely that the stormse can break the sand dune and water inflow to the guelta from the sea.

Figure 7. La'youne Wetland: dune dam broken by the great flood of October 2016 (top) and its reconstruction in few weeks (bottom).

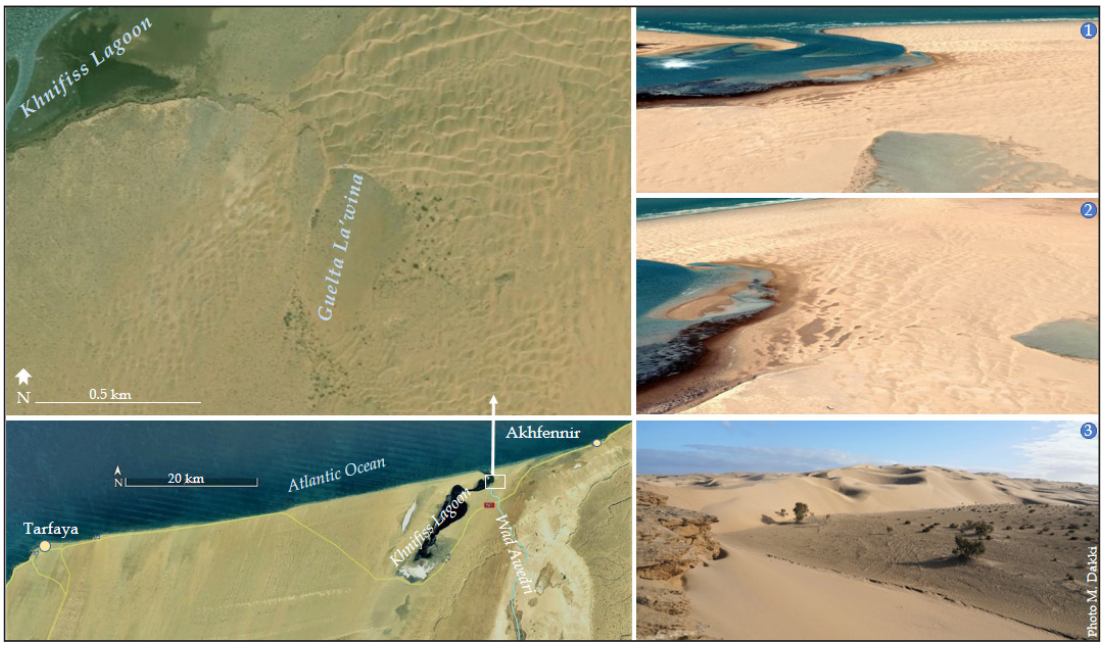


Figure 8. Guelta La'wina on Wad Awedri (South Morocco) and its dammed outlet in the Khnifiss Lagoon. Left: location of the guelta, Right: tilted images of the dune dam from South (1) and West (2) and photo of the guelta and dune dam (3).

Estuarine Gueltas (temporarily open/closed estuaries)

These are saline wetlands that occupy river mouths, where riverine and marine waters intermittently overlap, due to natural sediment bars built across the river mouth. These bars are generated in rivers which summer flow is insignificant or null, more especially if they are exposed to long droughts. Indeed, on the Atlantic coast, the marine sediment influx to the coast is a continuous phenomenon, as well as the wind, which transport these sediments to the river mouth, leading to the progressive construction a dam. These phenomena are intermittently or occasionally opposed by the great river floods that can lead to the river mouth breaching, making it more or less exposed to tidal currents. But these floods bring fluvial deposits that generally contribute to consolidate the estuarine dams, which height cad reach several meters in the Southern arid zones of Morocco (Massa, Chbeyka, El Wa'er, etc.). Apart from periods of great floods, these gueltas are occasionally supplied with inland waters, whereas they undergo great losses by evaporation. In the Sahara, mouth breaching needs very exceptional rain.

Five different examples of estuarine gueltas are reported below, from arid and Saharan zones (Fig. 9-12): Wad Tamri on the High-Atlas coast (Fig. 9), Wads Massa, Assaka and Al Wa'er in the Anti-Atlas and Pre-Sahara coast (Fig. 10) and Quasi-permanent guelta of Qninba *et al*. 2020, on the Saharan coast (120 Km north of Dakhla).

Figure 9. Estuarine guelta (intermittently open/closed estuary) of Wad Tamri, Atlantic High Atlas (photo M. Dakki).

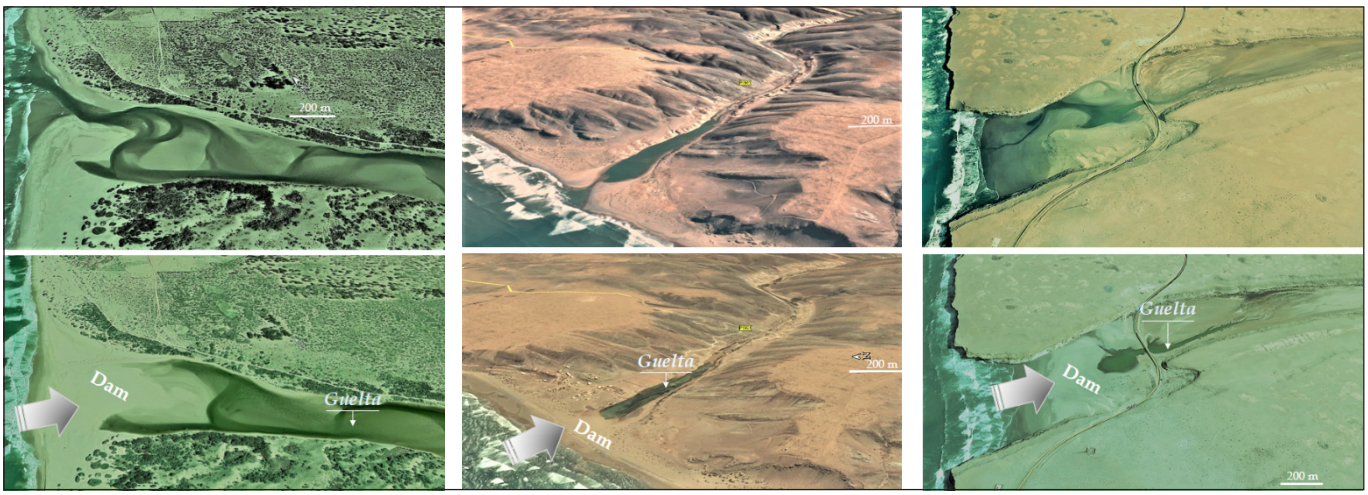


Figure 10. Estuarine gueltas (intermittently open/closed estuaries): examples from Anti-Atlas and Pre-Saharan coasts: Massa (left), Assaka (centre) and Al Wa'er (right).

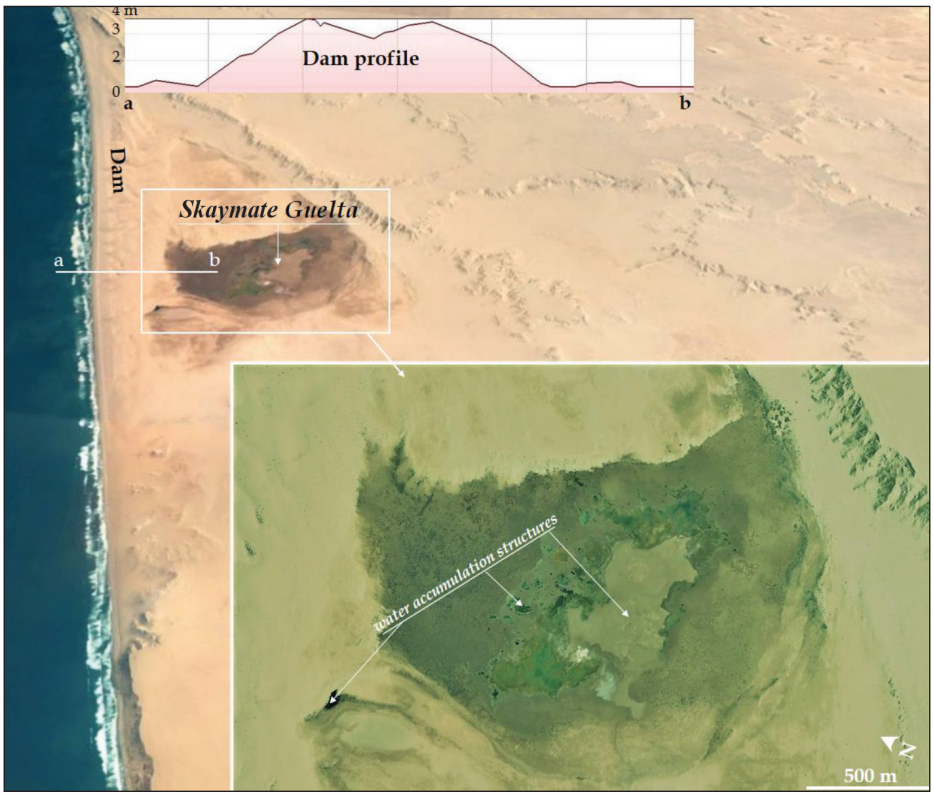


Figure 11. Skaymate estuarine guelta, on the Saharan coast: a-b: profile 'ocean-guelta', showing the quasi-permanent consolidated dam and irregular bottom of the guelta.

Figure 12. Saline permanent/semi-permanent shallow waters of the Skaymate estuarine guelta, Saharan coast.

TYPOLOGICAL POSITIONS AND ECOLOGICAL SPECIFICITIES OF THE GUELTAS

The natural reservoirs were defined above as original ecosystems in reference to their current hydrological functioning, but also to their genesis model, both linked to rivers' dynamic. This originality must be reflected in wetland classifications by assigning them to particular types, which can be confirmed both by mesological and biological criteria.

Despite their location in river beds, these ecosystems show over more or less periods, even permanently, stagnant waters, characterized by the total absence of apparent flow, which can be limited to brief periods of flood. Nevertheless, despite these common characteristics, natural reservoirs differ greatly, depending on the context they occupy. The descriptions provided above allow to classify the North African gueltas into three major wetland systems.

The ***fluvial gueltas*** are practically shaped by floods, which impose a massive and frequent downstream drift of living communities, after which they gradually recover. Because of their location practically within river beds (Fig. 4 & 5) and their resilience to the strong influence of floods, these gueltas

must be classified in the riverine system; however, due to the absence of rheophilic communities, they should form a distinct category from all river habitat types defined to date.

Animal communities that inhabit these ecosystems have a typical composition (compared to those of the same river), clearly dominated by planktonic or nektonic organisms (algae, crustaceans, insects, etc.). In addition, most of the fluvial gueltas host river fish, including Barbels and Tilapia (Qninba *et al*. 2012) an, even eels (Qninba *et al*. 2011) that attests of their permanent presence and their high role as a conservatory of these fishes during the dry periods.

The ***landslide lakes'*** hydrology is highly dependent on snow and its melting rate, or even sub-lacustrine resurgences. This is especially true for lakes with very small catchment areas (Ifni, Anghomer, Izourar). For lakes with larger river basin, such as Tamda Tametrocht (Fig. 2), floods are mainly related to autumn and winter rain. These can cause a rapid rise of the lake level, sometimes with high turbidity and habitat modifications, at least at the entrance of the streams.

This means that according to their physiography, landslide gueltas can be classified among lacustrine ecosystems, as already done; but their living communities show low specific richness and a very simple trophic chain. These characteristics have been well verified in the permanent lake of Ifni, whose plankton revealed only one Algae and one Crustacean alongside a Fish (Panouse 1963, Dumont *et al*.1973). This poverty can be linked to two facts: (1) these communities are inherited from local rheophilic biocenosis, of which very few species could have conquered the new lake environment; (2) the isolation of these lakes in the mountains reduces their chances of being populated by natural chorological processes, especially since this isolation is only a few millennia old (Dresh 1938, 1941).

In the permanent lake of Ifni, as well as in the Tamda Anghomer, the recent insularity has not led to a speciation among plankton, but genetic criteria has shown that the Ifni trout is a particular form. Described by Delling & Doadrio (2005) as endemic species (*Salmo akairos*) of this lake, and attributed to an Atlantic lineage (Bernatchez 2001, Snoj *et al*. 2011), this has still controverted status (Tougard *et al*. 2018). However, we assume that such specialization already started in the upper parts of the two rivers before the lake creation.

These ecological particularities support our proposal to assign to these lakes the specific type of 'landslide reservoirs', well widespread across the world. This assignment explicitly integrates historical criteria into the typology.

The ***dune gueltas***, at least those of the southern Morocco and southern Algeria, have a nearly flat, sandy and more or less salty bottom, characteristics that lead to qualify some of them as *sebkhas*. They are classified as stagnant waters, but given their presence on the course of large intermittent rivers, they can be classified among river natural reservoirs. They thus follow the elongated shape of the host river and undergo the influence of its floods, some of these being very violent. Although rare, these floods play a decisive role in the functioning of such gueltas, since they feed the underground water table and can break the sandy dam and reshape the entire ecosystem. Given these characteristics, dune gueltas operate very differently from mountainous landslide lakes and fluvial gueltas, justifying their classification as a special type, distinct from these two categories.

Ecologically, large floods cause alteration of the flora and fauna communities, by potentialtsand drift, a rupture of the sandy dam (i.e. Guelta La'wina and La'youne Wetland). In the Guelta of Imlili, the permanence of the water, due to an impassable dam, allowed the maintenance of a relatively rich community (Himmi *et al*. 2019), that's been occupying the wetland since several millennia, under extreme insularity conditions. This has led to the specialization of a fish population of *Coptodon guineensis*, attested by a certain dwarfism and genetically confirmed (Agnèse *et al*. 2018).

In the Assakia El Hamra wetland, despite its presumed permanence, the flora and fauna are expected to be relatively poor (see i.e. Ramdani 1988, Hammada *et al*. 2002), given the habitat instability caused by flooding. This poverty is more accentuated in the temporary guelta of La'wina, where water duration is often short and the sandy bottom is constantly reshaped by the wind. This makes it an unstable habitat, but when flooded, its bottom can show high biological activity, with an almost continuous aquatic bed, densely populated by limnophilous invertebrates. A dozen of species have been found in this guelta, including seven planktonic crustaceans, mostly halophilous and widely distributed (Ramdani 1988). Large numbers of birds occupy this guelta when flooded (Parker & Dakki 1988), indicating the high density of its fauna, as food for birds.

In ***estuarine gueltas***, the rhythm of both submersion and salinity fluctuation is related to water inflows of the rivers, knowing that the ocean waves can exceptionally overflow the sediment dams. During long periods, these inputs are absent or low, but when they are violent, they can fill the guelta in a way to break its sedimentary dam. This can make the guelta quite empty and create potential biological exchanges between it and the sea, through an estuarine zone, which length decreases when its slope increases; these exchanges are generally brief, knowing that the sedimentary dams are recovered a few weeks after the flood.

Estuarine ecosystems with intermittent opening to the sea have been reported in several regions of the World, as southeastern coast of South America (Pintos *et al*. 1991, Bonilla *et al*. 2005, Netto *et al*. 2012, Moreira *et al*. 2014), Southern Asia (Ranasinghe & Pattiaratchi 2003), Australia (Roy *et al*. 2001), New Zealand (Lill *et al*. 2012) and California (Elwany *et al*. 2003, Zuzuki *et al*. 2002, Matsubu *et al*. 2107). Nevertheless, they are particularly abundant in South Africa, where they represent more than 70% of the estuaries (Whitfield 1992, Perissinotto *et al*. 2010, etc.).

Because of their intermittent connection with the sea, they were classified as '*temporarily open/closed estuaries*', according to Whitfield (1992). This wetland's type has been characterized using both abiotic components (Snow & Taljaard 2007, Taljaard *et al*. 2009, etc.) and living communities (Whitfield *et al*. 2012, Nozais *et al*. 2005, James *et al*. 2007, Perissinotto *et al*. 2010, Tweddle & Froneman 2015, Scharler *et al*. 2020, etc.).

In the Atlantic coast of southern Morocco, and likely on the Arabian Sea coast (Bruun 1978, Al Mahfadi & Dakki *in press*), some of these estuaries are disconnected from the sea for several years (e.g. Guelta Skaymate, in the Moroccan Saharan coast). They are most of the time functioning as saline natural reservoirs, and this specificity is reflected here by considering them as a subtype (estuarine gueltas) of the temporarily open/closed estuaries. Indeed, referring to the South African studies, the living communities of these saline gueltas, still poorly known, are supposed to be deeply configured by the long isolation time both from the sea and

the upstream course, and their characteristics may greatly vary from one guelta to another.

It's not surprising that these ecosystems are relatively rare on the Mediterranean coast, where the low tide energy don't allow to build high sediment bars across the stream mouths.

PATRIMONIAL VALUES AND SERVICES OF THE GUELTAS

This chapter aims to pointpout if the assignment of new wetland types to the natural reservoirs has any implication in their conservation (i.e. ranking them in habitat Red-Lists or as protected areas). This was possible by using the Ramsar criteria for identifying wetlands of international importance (Ramsar 2012) and which translates representativeness and rarity of wetlands, their components, functional values and their services.

Relating to their rarity, the landslide lakes and the dune gueltas should be considered as threatened ecosystems, knowing that they have few representatives in each world region, both at type and subtype levels.eOn the other hand, there are thousands of fluvial gueltas, but their representativeness (as semi-permanent/permanent ecosystems) is progressively decreasing, due to recurrent drought crises. Their hydrological functioning suggests to subdivide them into different subtypes, some of which being probably in low number. The genesis schemes of the gueltas strengthen this criterion, in the sense that they involve particular mechanisms (geologic, sedimentary and eolian), the understanding of which is apt to enrich the scientific knowledge about wetlands.

As well as all stagnant waters, natural reservoirs play a significant role in mountain groundwater recharge and in river flow regulation, which is well demonstrated for some mountain lakes .e.g. Tametrocht, Ifni and Izourar lakes) and Saharan gueltas (La'youne and Imlili wetlands). The first ones give place to great perennial springs, while the second ones are responsible for filling great underground reservoirs.

Ecologically, some permanent gueltas (Ifni Lake and Sebkhat Imlili) host fish populations showing more or less advanced specialization and endemism. For their part, most of the river gueltas, despite their small size, serve during the long dry season (when the water flow is often interrupted) as exclusive habitats for fish. On another hand, the famous Nile crocodile exists in a highly fragmented Saharan population, mainly thanks to several gueltas in Mauritania, Tchad and Egypt (Brito *et al*. 2011), whereas its presence in the Maghreb southern margin ended in Morocco, during early 1950s (Monteil, 1951, Le Berre 1989, Brito *et al*. 2011).

This role of 'biodiversity conservatory' seems to be confirmed by other biological components of the river gueltas (Bouvet & Le Berre 1985, Le Berre 1989).

Large gueltas host important waterbird populations, both migratory and breeding. On the Atlantic coast, this role is played by almost all estuarine gueltas (Oueds Tamri, Massa, Assaka, Chbeyka, Al Wa'er, Skaymate, etc.) and by some dune gueltas (La'youne and La'wina wetlands). This justifies the integration of these wetlands into the international network of waterbird census (Dakki *et al*. 2002).

Translated into conservation assessment criteria, this role has made it possible to register several Moroccan gueltas as Ramsar sites (Dakki *et al*. 2011, Ramsar 2018, 2019). Among the breeding populations that give conservation value to such sites, it's worth mentioning some remarkable species, such as the Bald Ibis *Geronticus eremita*, in its last natural colony in the world, the Marbled Teal *Marmaronetta angustirostris*, the Common Pochard *Aythya ferina*, the Greater Flamingo *Phoenicopterus roseus*, the Eurasian spoonbill *Platalea leucorodia*, the Ruddy shelduck *Tadorna ferruginea*, etc.

In addition to these roles of maintaining biodiversity and natural functions, gueltas provide social services related to their physiography, hydrology or location. Indeed, most of them are used for livestock watering,ha role that is particularly important during the summer. Through this service, the mountain lakes participate in the sustainability of transhumance, which is an ancestral but declining activity in a large part of North Africa; this role is amplified in the Lake of Izourar by using it as a summer pastoral area by a large number of sheep herds.

Several gueltas, located in the mountains or in the desert, constitute landscape components of great aesthetic value, thus offering tourism opportunities, which already benefits local groups. For their part, fluvial gueltas, due to their physiography, are widely used for the irrigation of agricultural terraces, both as pumping basins and for the capture of *seguias* (diversions).

This importance was at the origin of the classification of certain gueltas in the Master Plan of Moroccan Protected areas and/or as Ramsar Sites (cf. Dakki *et al*. 2011, Ramsar 2018, 2019).

CONCLUSION

Despite their importance, the North-African natural reservoirs have been subject to very few ecological studies; this low scientific interest is likely due to the laty discovery of this importance. Indeed, the river gueltas exist in river beds, to which a high number of studies have been dedicated; but ecologists consider the gueltas out of their domain, mainly because their flora and fauna are uncommon in running waters.

The landslide lakes and the dune gueltas were probably neglected because of the poverty of their flora and fauna, even this characteristic constitutes an originality that should be better studied. However, some of these wetlands benefited from some studies only because of their endemic fishes.

By considering gueltas as separate categories in wetland typologies, we hope encouraging researchers to work towards the discovery of all the ecological aspects related to these particularities. Living communities and ecosystem functioning should be considered as prior targets in these studies, including refining their inventory and classification.

The indications provided here-above on the values and services of the natural reservoirs are also favorable to research strengthening for identifying more representatives that deserve the status of protected areas. In this context, it should be pointed out that the distinction of these ecosystems in different types gives them the opportunity to be better estimated in possible projects of red lists of habitats, knowing that they were practically invisible in past typologies.

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