The Nile

Monographiae Biologicae

VOLUME 89

Series Editor

H. J. Dumont

Ghent University, Department of Biology, Ghent, Belgium
Henri.Dumont@UGent.Be

Aims and Scope

The Monographiae Biologicae provide a forum for top-level, rounded-off monographs dealing with the biogeography of continents or major parts of continents, and the ecology of well individualized ecosystems such as islands, island groups, mountains or mountain chains. Aquatic ecosystems may include marine environments such as coastal ecosystems (mangroves, coral reefs) but also pelagic, abyssal and benthic ecosystems, and freshwater environments such as major river basins, lakes, and groups of lakes. In-depth, state-of-the-art taxonomic treatments of major groups of animals (including protists), plants and fungi are also elegible for publication, as well as studies on the comparative ecology of major biomes. Volumes in the series may include single-author monographs, but also multi-author, edited volumes.

For other titles published in this series, please visit:
www.springer.com/series/6304

Henri J. Dumont
Editor

The Nile

Origin, Environments, Limnology and Human Use

Springer

Editor
Henri J. Dumont
Ghent University
Department of Biology, Limnology Unit
K. L. Ledeganckstraat 35
9000 Gent
Belgium
Henri.Dumont@UGent.Be

ISBN 978-1-4020-9725-6 e-ISBN 978-1-4020-9726-3

Library of Congress Control Number: 2009926488

Cover illustrations:
Front cover: Tissisat Falls on the Upper Blue Nile in Ethiopia, isolating Lake Tana from the rest of the Blue Nile System (Photograph by Ferdinand Sibbing).
Back Cover: Photo 1: Fish traps opposite a papyrus swamp on Lake Victoria (Photograph by Frans Witte).
Photo 2: The Shoebill, a large piscivorous bird typical of the Upper Nile Swamps (Photograph by Pat Morris).
Photo 3: The Equatorial Nile in Southern Sudan, meandering through a savanna landscape (Photograph by Jack Talling)

Printed on acid-free paper

springer.com

Preface

What have we learnt about the Nile since the mid-1970s, the moment when Julian Rzóska decided that the time had come to publish a comprehensive volume about the biology, and the geological and cultural history of that great river?

And what changes have meanwhile occurred in the basin? The human population has more than doubled, especially in Egypt, but also in East Africa. Locally, industrial development has taken place, and the Aswan High Dam was clearly not the last major infrastructure work that was carried out. More dams have been built, and some water diversions, like the Toshka lakes, have created new expanses of water in the middle of the Sahara desert. What are the effects of all this on the ecology and economy of the Basin?

That is what the present book sets out to explore, 33 years after the publication of "The Nile: Biology of an Ancient River". Thirty-seven authors have taken up the challenge, and have written the "new" book. They come from 13 different countries, and 15 among them represent the largest Nilotic states (Egypt, Sudan, Ethiopia, Uganda, and Kenya). Julian Rzóska died in 1984, and most of the co-authors of his book have now either disappeared or retired from research. Only Jack Talling and Samir Ghabbour were still available to participate again. With his huge Nilotic experience of more than half a century, Talling offered to write a brief overview of (biological) research on the Nile. But his chapters in Rzóska's book turned out to be still remarkably up to date. His 1976 paper on the physical and chemical limnology of the Nile is here reprinted with minimal changes. His second contribution, on Nile phytoplankton, required more updating. It was revised with the assistance of colleagues from Egypt and the Sudan, mainly to accommodate the effects of eutrophication, now increasingly affecting the basin, but especially Egypt and Lake Victoria.

Samir Ghabbour preferred to write a new paper, although 30 years of time had changed little to his insights in the origin of Nilotic oligochaetes.

I tried to save some of the structure that Rzóska had imposed on his book, though not necessarily giving all subjects the same weight, and not in the same order. Thus, the geological development of the basin is treated immediately after my introductory chapter. One of the two contributors to that section, Martin Williams, was not among the authors of Rzóska's monograph. Martin had spent 2 early years of his carrier (1962–1964) mapping soils along the Nile in the Sudan. In 1975, he spent a year in the CNRS lab of Hugues Faure in Paris, when Julian Rzóska came on a visit. Julian probably judged him "too young" to be a contributor to his book. Instead, he asked him to review drafts of the geological chapters. Only 4 years later, Martin published his influential book "The Sahara and the Nile", with Hugues Faure as a co-editor. With a number of his students, he has continued to work on the Nile Basin ever since.

I have tried to single out a number of building blocks of the Nile system, and asked experts of each of them to write a synoptic paper about them. Eleven such environments, either specific lakes, or groups of lakes, or swamps, or even mountain chains supplying runoff to the Nile, have been included. As to chapters dealing with biota, their ecology and biogeography, my choice has perhaps been idiosyncratic, but it was also dictated by available expertise and level of background knowledge. I hope that the reader will find it easy to come to the conclusion that the Nile, more than other rivers like the Niger, Congo, and even the Logone-Chari, has had a tumultuous history, and, after the drying up of the Sahara, continued to link "deep" Africa to the Mediterranean. Biologically, it may not be the richest and most diverse of African river basins, but it is certainly the most fascinating!

The Nile is also the home of millions of people, and as their number keeps increasing, so does their influence on the river. Aspects related to that could not be neglected in this book, and so Tony Allan, winner of the 2008 Stockholm Water Prize, made an updated analysis of what John Waterbury had called "the Hydropolitics of the Nile" in the early 1970s. Martin Williams concludes the volume with a brief paper on what he perceives to be man's long-term impact on the river.

Ghent, Belgium and Guangzhou, China Henri J. Dumont

Contents

Part I Origin

Part II Major Nilotic Environments

Part III Climates and Hydrology

Part IV Limnology and Biological Diversity

Part IV Human Use

Contributors

Ali, Osman M. M.
Institute of Environmental Studies, University of Khartoum, Sudan
osmirghani@yahoo.co.uk

Allan, John Anthony
Geography Department, King's College, London and SOAS, London
Ta1@soas.ac.uk

Camberlin, Pierre
Centre de Recherches de Climatologie, UMR 5210 CNRS/Université de Bourgogne, 6 Boulevard Gabriel, 21000 Dijon, France
camber@u-bourgogne.fr

Cumberlidge, Neil
Department of Biology, Northern Michigan University, Marquette, Michigan 49855-5301, USA
ncumberl@nmu.edu

Dejen, Eshete
Fishery and Other Aquatic Life Research Center, P.O. Box 794, Bahir Dar, Ethiopia
dejeneshete@yahoo.com

De Graaf, Martin
WA Marine and Fisheries Research Laboratories, P.O. Box 20, North Beach, Western Australia 6920
Martin.DeGraaf@fish.wa.gov.au

Dumont, Henri J.
Department of Biology, Ghent University, Ledeganckstraat, 35, B-9000 Ghent, Ghent, Belgium Henri.Dumont@UGent.Be

Eggermont, Hilde
Department of Biology, Ghent University, Ledeganckstraat, 35, B-9000 Ghent
hilde.eggermont@ugent.be

El-Moghraby, Asim I.
Hydrobiological Research Unit, University of Khartoum, Sudan
asim_mog@yahoo.com

El-Shabrawy, Gamal, M.
National Institute of Oceanography and Fisheries, Fish Research Station,
El-Khanater, El-Kharia, Cairo, Egypt
Elshabrawy_gamal@yahoo.com

El-Sheekh, M.
Botany Department, Faculty of Science, Tanta University, Tanta 31527, Egypt
mostafaelsheekh@yahoo.com

Ferdinand A. Sibbing
Experimental Zoology Group, Wageningen Institute of Animal Sciences,
Marijkeweg 40, 6709 PG Wageningen, The Netherlands
Nand.Sibbing@wur.nl

Fishar, Mohamed R.
National Institute of Oceanography and Fisheries, Fish Research Station,
El-Khanater El-Kharia, Cairo, Egypt
mfishar@hotmail.com

Ghabbour, Samir I.
Department of Natural Resources, Institute of African Research & Studies,
Cairo University, 12613 Giza (Cairo), Egypt
ghabbour_samir@hotmail.com

Green, Jim
17 King Edwards Grove, Teddington, Middx. TW11 9LY, UK
jgreen711@btinternet.com

Hamza, Waleed
Biology Department, Faculty of Science – United Arab Emirates University,
P.O. Box 17551 Al-Ain, UAE
w.hamza@uaeu.ac.ae.

Johnson, Thomas C.
Large Lakes Observatory and Department of Geological Sciences,
University of Minnesota Duluth, Duluth, MN 55812, USA
TCJ@d.umn.edu

Lehman, John T.
Department of Ecology and Evolutionary Biology
Natural Science Building, University of Michigan, Ann Arbor,
MI 48109-1048 USA
jtlehman@umich.edu

Malala, John O.
Kenya Marine and Fisheries Research Institute (KMFRI), Lake Turkana Station,
P.O. Box 205, Kalokol, Kenya
jomalala@yahoo.com

Mkumbo Oliva C.
Lake Victoria Fisheries Organization, P.O. Box 1625, Jinja, Uganda
ocmkumbo@hotmail.com

Rabeh, Saleh Ahmed
National Institute of Oceanography and Fisheries (NIOF),
Inland Waters and Aquaculture Branch, El-Qanater Research Station,
Greater Cairo, Egypt
drsaleh_rabeh@hotmail.com

Russell, James M.
Geological Sciences, Brown University, P.O. Box 1846,
Providence, RI 02912, USA
james_russell@brown.edu

Sinada, Faisal
Hydrobiological Research Unit, Department of Botany, Faculty of Science,
University of Khartoum Sudan
fsinada@gmail.com

Sobhy, Emad M. H.
National Institute of Oceanography and Fisheries, Fish Research Station,
El-Khanater El-Kharia, Cairo, Egypt
emadsobhy@yahoo.com

Stewart, Kathlyn M.
Canadian Museum of Nature, P.O. Box 3443, Station D, Ottawa,
K1P 6P4, Canada
kstewart@mus-nature.ca

Sutcliffe, John V.
Heath Barton, Manor Road, Goring on Thames, nr Reading RG8 9EH, UK
j.v.sutcliffe@talk21.com

Taha, Ola E.
National Institute of Oceanography and Fisheries, Fish Research Station,
El-Khanater El-Kharia, Cairo, Egypt
drolataha@yahoo.com

Talbot, Michael R.
Geological Institute, Bergen University, Allegt 41, Bergen 5007, Norway
michael.talbot@geo.uib.no

Talling, Jack F.
Formerly: Hydrobiological Research Unit, University of Khartoum, Sudan
Now: Hawthorn View, The Pines, Bongate, Appleby, Cumbria CA 16 6 HR, UK
jaidtalling@btinternet.com

Van Bocxlaer, Bert
Research Unit Palaeontology, Department Geology and Soil Science,
Ghent University, Krijgslaan 281 (S8), B-9000 Ghent, Belgium
bert.vanbocxlaer@ugent.be

Van Damme, Dirk
Research Unit Palaeontology, Department Geology and Soil Science,
Ghent University, Krijgslaan 281 (S8), B-9000 Ghent, Belgium
dirk.vandamme@ugent.be

Van Damme, Kay
Department of Biology, Ghent University, Ledeganckstraat, 35, B-9000 Ghent
kay.vandamme@ugent.be

Van Oijen, Martien
National Museum of Natural History, P.O. Box 9517, 2300 RA Leiden,
The Netherlands
oijen@naturalis.nl

Vijverberg, Jacobus
Netherlands Institute of Ecology (NIOO-KNAW), Centre for Limnology,
Rijksstraatweg 6, 3631 AC Nieuwersluis, The Netherlands
j.vijverberg@nioo.knaw.nl

Williams, Martin A. J.
Geographical & Environmental Studies, University of Adelaide,
Adelaide 5005, Australia
martin.williams@adelaide.edu.au

Witte, Frans
Institute of Biology Leiden, Leiden University, P.O. Box 9516, 2300 RA Leiden,
The Netherlands, National Museum of Natural History, P.O. Box 9517,
2300 RA Leiden, The Netherlands
F.Witte@biology.leidenuniv.nl

Zahran, Mahmoud A.
Plant Ecology, Department of Botany, Faculty of Science,
Mansoura University, Mansoura, Egypt
Zahrancabi2001@yahoo.com

A Description of the Nile Basin, and a Synopsis of Its History, Ecology, Biogeography, Hydrology, and Natural Resources

Henri J. Dumont

Abstract Following a description of the Nile, the longest river of the world (ca 6,800 km) and its basin (2.9×10^6 km^2), including its various "source" lakes, some brief notes on its main neighbours (Congo and Logone-Chari) and their history are given. The biota of the basin are moderately diverse, and endemism tends to be low, except in some of the "old" source lakes. The situation is complicated by the fact that at least two of these lakes (Victoria and Tana) dried out around or slightly before the beginning of the Holocene, and thereafter, speciation (especially of cichlid fish) may have happened at an unusually great speed.

In general, the Nile offers a pathway for African species to extend from the tropics to a Mediterranean climate and spill over into the Levant and Arabia. Such incursions may have happened many times across history, with some of the older "waves" using the Red Sea (before its opening to the Indian Ocean) rather than the Nile.

Currently, as elsewhere in the world, invasive species in the Nile are becoming more and more common, although the oldest cases (some Ponto-Caspian cnidarians) may date back to the end of the nineteenth century. The water hyacinth *Eichhornia* has invaded the Nile basin in at least three different zones.

Since early pharaonic times, man has interfered with the river and its flow regime, in an effort to control the yearly "flood of a hundred days", but large-scale damming only started in the nineteenth century, and culminated with the construction of the Aswan High Dam in the 1960s, reducing the river to a giant irrigation canal. More recent developments include the construction of the Toshka lakes diverticle to Lake Nasser, a project with an uncertain future.

The river and its lakes are important fisheries resources; the various dams are generating large amounts of power, and fossil hydrocarbon deposits are under development in at least three zones of the basin. This may contribute to river pollution, which is still a local phenomenon, except in Lake Victoria, which suffers from eutrophication, and in Egypt, that combines a population explosion (almost four doublings in the last century) with a substantial industrial development.

H.J. Dumont (✉)
Animal Ecology, Biology Department, Ghent University, Ledeganckstraat, 35, B-9000 Ghent,
e-mail: Henri.Dumont@UGent.Be

H.J. Dumont (ed.), *The Nile: Origin, Environments, Limnology and Human Use*,

1 Introduction

The Nile monograph by Rzóska (1976) was entitled “biology of an ancient river”. Whether the Nile is indeed an ancient river is, however, a matter of taste. Rather, one could conceive the Nile as a puzzle, to which at times pieces were added, while at other times pieces were subtracted. This happened all along its history, including the late Pleistocene. In its present form, the delta, for example, is not much more than 6,000 years old. On the other hand, surely a river (or a series of consecutive rivers) existed in North-East Africa since it emerged from the Tethys Sea at the end of the Mesozoicum. Talbot & Williams and Williams & Talbot (2009) summarize the current views on the various stages of the drainage systems that ultimately became the Nile as we know it.

As usual, we know more as we approach the present, and the Pleistocene history of the River is, in broad lines, well established even if some parts of the basin (e.g. the evacuation pathway of the Blue Nile across geological time) still invites more research work (Talbot & Williams; Williams & Talbot, 2009).

The twentieth century stood witness to the progressive, and ultimately, the complete regulation of the Nile. Population growth and economic expansion, especially in the lower Nile valley, continue to increase the demand on the water resource, a process that has been underway for about five millennia, but risks to reach a climax soon. The river is therefore more than a complex ecological jewel: it is a multi-purpose renewable resource that should be wisely managed, however difficult this may be.

2 A Description of the Nile Basin (Fig. 1)

With an approximate length of ca 6,800 km (Said, 1981), the Nile is the longest river in the world (Ibrahim, 1984). The nineteenth century quest for the source(s) of the Nile is a heroic chapter in the history of the exploration of the African continent, and it was long thought that Lake Victoria (see further) was its ultimate source. Yet, that lake itself is fed by rivers that arise further south, the most important of which is the Kagera. Until recently, it was believed that its tributary, the Luvironza, that springs in Tanzania at ca 4° S, was the Nile’s ultimate “source”. However, a revised length estimate of 6,718 km was established in 2006, when a British–New Zealand expedition found that the tributary of the Kagera River arising furthest to the south is the Rukarara. It springs in the Nyungwe forest, Rwanda.

The Nile is the only permanent river that manages to cross the Sahara, the largest desert in the world, and reach the Mediterranean Sea, yet its early beginnings are in a montane equatorial climate, and it traverses a series of climatic zones before reaching its delta. Its basin orientation is unique among the major rivers in the world in that it runs almost perfectly from south to north, discharging at 31° N (Fig. 1). Each climate zone which it crosses shows considerable variability in precipitation and run-off (Camberlin, 2009), but over more than half its length

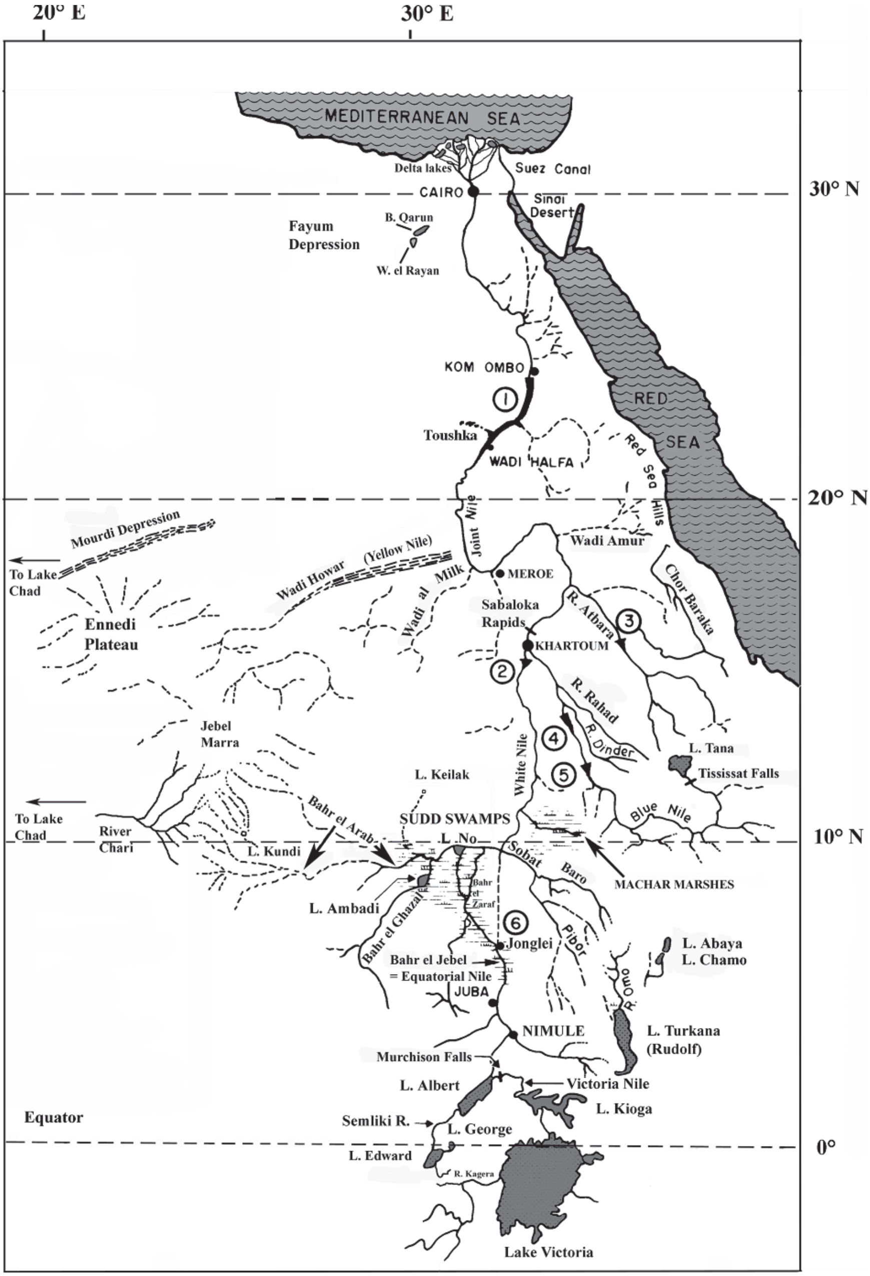

Fig. 1 The Nile Basin. All specific environments dealt with in this volume are shown. The possible zones of contact between Nile and Chad, north and south of Jebel Marra, are also indicated

it receives less than 150 mm of rain per annum. Its basin is relatively narrow and small (2.9×10^6 km^2) compared to that of most other large rivers of the world (the Congo, ca 4×10^6 km^2 according to Bailey, 1986; the Amazon, ca 7×10^6 km^2 according to Sioli, 1984).

The Nile basin covers the whole of Egypt and the Sudan, except for the short rivers that drain the Red Sea Hills towards the red Sea. Most of these are wadis that only discharge water for few days after rare desert rains. For both countries, the Nile is a vital economic resource (see further) and the need to secure access to sufficient water has dominated their political agenda since times immemorial (Allan, 2009). The basin also covers about one third of Ethiopia (Tudorancea & Taylor, 2002), the whole of Uganda, and part of Kenya, Tanzania, Congo, Rwanda and Burundi.

Conventionally, the Nile is divided into a number of sub-basins: the White or Equatorial Nile and its source lakes, the Blue Nile and Lake Tana, and the Main Nile. The River Atbara is often considered a separate, although small, sub-basin. Presently not or hardly active is the so-called Yellow or Desert Nile, comprised of the valleys of the Wadi Howar and the Wadi El Milk. Around 6,000 BP, these watercourses significantly augmented the total discharge with water coming from the Nile-Chad divide (Jebel Marra, the Tabago and Meidob hills, and the Eastern Ennedi – see further) (Kuper & Kröpelin, 2006).

The entire White Nile sub-basin has a surface area of ca 3.8×10^5 km^2. It is best known for the large, reputedly ancient lakes on the plateau in the south of its drainage area. Of these, Lake Victoria is the largest. With a surface area of 7×10^4 km^2, it is second in size only to the Caspian Lake in West Asia and Lake Superior in North America (Lehman, 2009). The White Nile also drains a sizeable part of the Western Rift, including lakes Albert and Edward (Green, 2009). Both obtain much of their water from the high mountains of the Rwenzori (Eggermont et al., 2009). A second source of water are the Virunga highlands, which rose as a volcanic plug across the rift valley between 9 and less than 3 million years ago (Kampunzu et al., 1998). This deleted Lake Kivu from the Nile basin. The Virunga volcanoes also blocked the course of a number of smaller rivers (Beadle, 1981), and created the Kigezi lakes to the north. They are renowned for their scenic beauty, but are also of great biological interest (Green, 2009). The outflow of these lakes eventually finds its way to either Lake Victoria or Lakes Albert-Edward.

Lake Victoria is not a rift lake, but a huge, saucer-shaped depression with marshy shores (Beadle, 1981; Lehman, 2009). Its maximum depth (ca 70 m) is modest and it is therefore sensitive to fluctuations in precipitation, to the point of occasionally drying out, as happened around 12,500 BP (Johnson et al., 1996, 2000). Historical deviations in lake level with an amplitude of more than 4 m have been recorded, and fluctuations of 2 m within less than a decade are not exceptional (Beadle, 1981; Lehman, 2009).

The origin of the lake is described by Lehman (2009). It is about 400,000 years old, and was created by uplift of the western side of the East African Rift valley. Uplifting and tilting reversed the direction of flow of the previously westwards flowing rivers Kagera, Katonga and Kafu, that began to fill the Victoria depression and transformed the Kyoga area from a river to a river-lake. Probably, for some time, a series of river-lakes existed in the Victoria cuvette too, together forming the cradle for the speciation of an endemic fauna. For the overflow to the north (at Jinja) to function, a precipitation threshold is required that was not reached at several occasions in the late Pleistocene. Johnson et al. (1996) show that the basin was closed around 18,000 BP and again at 14,200 BP (Stager & Johnson, 2008), and fell dry completely about two millennia later. Lake Victoria is famous for an "endemic" flock of haplochromine cichlid fish (Witte et al., 2009). The number of species is still debated, because many are so closely related as to raise doubts about their full species status. Lévêque (1997) estimates their number at about 200, but according to Witte et al. (2009), there might be as many as 500.

A man-made ecological disaster made Lake Victoria a global news item in the 1990s, viz. the consequences of the intentional introduction of the Nile perch, a large carnivorous centropomid fish that contributed to the collapse of many endemic haplochromines as they fell prey to it (for details, see Lehman, 2009; Witte et al., 2009).

The Victoria Nile leaves the lake near Jinja in the north, crossing the Owen falls (now Nalubaale) (ca 30 m high), flowing rapidly for the next 70 km, to slow down upon reaching the dendritic swamp-lake Kyoga. Next it turns west to join Lake Albert in the western rift almost exactly at the same point where the Albert Nile leaves that lake to flow north. But first it crosses the Karuma and Murchison (or Kabalega) falls, which are part of a biogeographic barrier that prevents rift biota from migrating up to Lake Victoria. Nile perch occurs naturally in Lake Albert, but was stopped from migrating upstream by these falls (Green, 2009).

The western rift section of the Nile consists of Lakes Edward, Albert, George and a number of smaller lakes and rivers that drain into them. The rivers draining the Rwenzori Mountains, locally rising to above 5,000 m, are short, steep, and fed partly by direct precipitation, partly by glacial melt-water (Eggermont et al., 2009). The Rwenzori, the mountains of the moon, rose as part of the rifting process, around 10 million years ago, in late Miocene–early Pliocene times. Originally, the water that collected on the floor of the rift formed a single water-body, (Palaeo) Lake Obweruka. In the early Pleistocene, this lake, that was rich in endemic biota, broke up in two parts, Lakes Lusso and Kaiso, which were the predecessors of lakes Albert and Edward. Currently, Albert and Edward are separated by a drop in altitude of about 300 m and connected by the Semliki River. A series of rapids constitutes a barrier to faunal exchange between both.

Lake Kivu, or a predecessor of it, originally belonged to the same series. If not part of Lake Obweruka, it was at least connected to it, until it was isolated by the Virunga volcanoes, a series of eight huge volcanoes that rose between 9 and less than 3 million years BP and intermittently remained active to the present time. Evidence for this is found, at the molecular level, in the fact that Kivu cichlids form one superfloc with Lake Albert-Edward-Victoria endemics, not with those of Lake Tanganyika, to which Lake Kivu now evacuates excess water via the Panzi falls and Rusisi River (Verheyen et al., 2003).

Oddly, the Nile leaves Lake Albert near the point where it entered it, a swampy delta. The total drop in altitude between Lakes Victoria and Albert is ca 515 m, and the influence of Victoria water into the (more saline) Lake Albert is hardly felt. The Albert Nile, as it is now called, flows steadily northwards through flat country until it reaches Nimule. It then works its way through a narrow gorge rich in rapids, and is joined by a couple of affluents from the SE, including the Aswa, that drains a zone to the north of Lake Kyoga.

When the Nile emerges from the Nimule rapids, it has left Uganda and has entered the Sudan, where it is known as the Bahr el Jebel (bahr = sea, lake or river; jebel = mountain). It flows across a hilly tract, dropping in level for about 1 m per km across the next 150 km. North of Mongalla, it reaches the great swamps of southern Sudan, known as the Sudd (= blockage). The Sudd is a vast stretch of permanent (ca 7,000 km^2) and seasonally (ca 90,000 km^2) flooded marshland. More than rapids and cataracts, it long constituted a barrier to human penetration from the north. As well the pharaohs as the Romans failed to cross it. The Bahr el Jebel flows in a braided channel, although one river rapidly and permanently separates from it, the Bahr el Zeraf. Numerous lakes are found all along the swamps, with the largest ones (Lake Ambadi, Lake No) situated near the junction of the Bahr el Jebel with a tributary coming from the west, the Bahr el Ghazal (Green & El-Moghraby, 2009). The Bahr el Ghazal becomes a seasonal stream west of the city of Wau. It drains the hills at the confines between the Sudan and the Central African Republic. From the north, it receives a tributary, the Bahr el Arab, that is also partly seasonal, partly permanent and drains the eastern flanks of the Chaine des Bongos in the Central African Republic and the south of Jebel Marra. A number of lakes, such as L. Kundi and L. Keilak are part of its drainage (Green, 2009). At the tripoint Chad-Central African Republic-Sudan, in the area of the town of Birao, the Nile and the upper Logone-Chari are very close. This is one of two corridors across which temporary faunal exchange may have taken place during humid spells of the Pliocene–Pleistocene–Holocene.

Just south of Malakal, the White Nile receives another major tributary from the East, the Sobat, with a basin of 224,000 km^2, including some huge swamps (the Machar marshes). Of its two major branches, the Paro (or Baro) springs in western Ethiopia. The upper reaches of its southern branch, the Pibor, contain the extensive Lotigipi swamps, across which Lake Turkana used to overflow to the Nile until mid-Holocene times (Johnson & Malala, 2009). Lake Turkana (formerly Rudolf) (Kenya) and the Omo catchment (Ethiopia and Kenya) in the Eastern Rift are part of the White Nile sub-basin. Currently, the Turkana basin is closed, but around 7,000 BP, the lake rose by some 80 m and Lakes Abaya and Chamo, as well as the current salt pan – then lake – Chew Bahir (formerly Stephanie) in the Eastern (Gregory) Rift evacuated towards it (Adamson & Williams, 1980; Tudorancea & Taylor, 2002). In spite of a degree of salinisation since the closing of their basins, the fauna of Lakes Turkana, Abaya and Chamo has maintained a strong Nilotic character (e.g. the fish and zooplankton: Witte et al., 2009; Dumont, 2009). The Turkana basin is a relatively recent addition to the Nile basin. Until mid-Pliocene times, the Palaeo-Turkana, then a (mainly) riverine system, emptied in the Indian Ocean (Van Damme & Pickford, 2003). At that time, the marine stingray *Dasyatis* managed to migrate up to the lake (Feibel, 1988; Stewart, 2009).

From Malakal to Khartoum, a stretch of about 730 km, no further tributaries enter the While Nile, but at Khartoum (378 m asl) the Blue Nile (known in Ethiopia as the Abbay) joins from the east, at a place called the Mogran (the "elephant's trump", presumably after the shape of the elongated island present at the junction). The Blue Nile, with a basin area of 325,000 km^2, flows out of Lake Tana (1830 m asl) in the central Ethiopian highlands (Vijverberg et al., 2009). It is itself fed by about 60 short rivers all around it. In contrast to the While Nile the profile of the Blue Nile is very steep once it has left the East African plateau, and its flow is torrential (Morris et al., 1976). After leaving the lake at its southern extremity, and cascading over the Tissisat falls, it forms an elaborate loop, running first south, then west, through a spectacular gorge that is up to 2 km deep, and has eroded away some 100,000 km^3 of material (Talbot & Williams, 2009). When it touches the Sudan plain, after some 900 km, its altitude is 464 m asl (at Roseires). In its remaining course to Khartoum, it only drops for another 75 m, working its way through a fossil floodplain, the Gezira, largely built from sediment extracted from the Abbay gorge.

Between Khartoum and the Mediterranean delta, only one partially active tributary, the Atbara, joins the Nile, some 310 km north of Khartoum. The discharge of the Atbara is seasonal, and after the summer floods the lower course gradually dries up, but during the flood, its contribution to total Nile discharge is sizeable (Sutcliffe, 2009).

Between Khartoum and Aswan in Egypt, the Nile describes a giant "S", meandering around the lava fields of the Bayuda Desert. It follows a well-defined bed, punctuated by rapids or "cataracts". Before man's interference, there were six such cataracts, two of which have now disappeared under Lake Nasser-Nubia. The fourth cataract, near Kerma, will disappear as soon as the Meroe dam, now under construction, will become operational. The cataracts seriously impeded navigation of the Nile south of Aswan, and long hindered travel and economic exchange between "Egypt" and "Nubia".

To the west of the Nile, currently defunct but at times during the Holocene a major stream, is the Wadi Howar or Yellow Nile, that used to empty close to the mouth of that second "desert river", the Wadi el Milk. The bed of the lower Wadi Howar, several kilometers wide, is currently obstructed by sand dunes. Its upper course drains the hills of North Darfur (the Meidob and Tabago hills, the north part of Jebel Marra, and the south flank of the Ennedi). Until ca 7,000–6,000 BP, this hydrologic network was intermittently active. Van Neer (1988, 1989) found not less than 18 species of fossil Nilotic fish in Holocene river deposits here (see also Stewart, 2009). As well, Neolithic man settled the whole area, to retreat to the Nile valley and the hills only as the climate became drier after 6,000 BP (Kuper & Kröpelin, 2006). The zone north of Jebel Marra and as far north as the Mourdi depression is the second one where contact and exchange between Nile and Chad biota may have taken place.

Adamson & Williams (1980) state that the Jebel Marra volcano began to rise in the Miocene, and volcanism continued into the quaternary (which would also be valid for the more northerly situated Meidob hills), thereby deleting some 60,000 km^2 of catchment from the Nile basin. Previously eastward-draining rivers (towards Wadi Howar) were suddenly reversed to the west, and the contact Nile-Chad was rendered more difficult, while the divide between Nile-Congo and Chad-Congo remained unaffected.

Just north of Cairo, the Nile builds a flat, triangular delta of ca 25,000 km^2. Somewhat south of Cairo, a left-bank diverticle leads to the Fayum depression, of Pliocene age, in which Lake (Birket) Qarun and the artificial Wadi El Rayan lakes are situated. The Fayum channel, a natural overflow during exceptionally high floods, was artificially maintained since the Middle Kingdom, and the lake, called Lake Moeris, became the centre of a prosperous agricultural area. Originally a deep lake, with surface situated well above sea level, its level has now fallen to about −40 m, and the water has evolved from fresh to hypersaline in less than two centuries (El-Shabrawy & Dumont, 2009a).

The delta is composed of two branches, Rosetta and Damietta (but many more in the past few millennia) and has traditionally been one of the important agricultural areas of Egypt (currently also a source of natural gas and oil – see further). It did not exist as such until the end of the Flandrian transgression, and started building not more than some 6,500 years ago; however, it rapidly expanded afterwards (Hamza, 2009). Four shallow brackish lakes (Idku, Maryut, Borullus and Manzalla) at its northern extremity slowly individualized from a delta-wide salt marsh during historical times, as sediment was deposited at the head of the delta at a rate of about 1 cm per century. Currently, the sand spit separating the lakes from the sea is being eroded, a complex phenomenon but to which the lack of sedimentation since the Aswan dam stopped the summer floods certainly contributes much (Hamza, 2009; Dumont & El-Shabrawy, 2007).

3 Nile Biogeography and Taxon Richness

Per unit area, the taxon richness of the Nile can only be described as mediocre, and so is the degree of endemism of its biota. This contrasts with the fact that particular lakes in the catchment may be centers of radiation for particular animal groups. Cases in point are the species flocks of haplochromine cichlids in Lake Victoria and cyprinids in Lake Tana, two lakes that are usually considered as “ancient”, yet dried out around the onset of the Holocene. In the case of Lake Victoria, the connotation arose that the several hundreds of endemic haplochromines evolved in less than the last 12,000 years. To many evolutionary biologists, such a “speciation at lightning speed” is inconceivable. Some (Fryer, 2005) therefore maintain that the lake cannot have dried completely, although Slater & Johnson (2008) argue that the evidence is incontrovertible.

The controversy is likely to continue for some time (Nagl et al., 2000), but it is worth noting that many haplochromines may have speciated long before the lake dried out. A dry terminal lake does indeed not mean that the rivers emptying in it are dry too, except perhaps in their lower courses. Some cichlids endemic to Lake Kivu seem to have survived a “boiling” of the lake by lava from the Virunga volcanoes by retreating into rivers as well (Dumont, 1986). In fact, the "Victorian" rivers Kagera and Katonga are rich in lakes and swamps that may have served as refuges (Mwanja et al., 2001). The endemic mollusks of Lake Victoria (Van Damme & Van Bocxlaer, 2009) suggest exactly that scenario, and the similarity between the mollusk fauna of Lake Turkana and Lake Victoria suggests that the "retreat" area may have been the foot of Mount Elgon. It may also be useful to attract attention to the fact that even in the Sahara, in conditions of precipitation of less than 30 mm per annum, permanent water may persist in sheltered localities (Dumont, 1979). Around twenty species of fish, including cichlids and cyprinids, have survived here in rock pools or "gueltas" since the last pluvial (Le Berre, 1989; Lévêque, 1990). Their origin is mixed. Some are of northern (Mediterranean) origin (e.g. *Barbus biscarensis*), others of Afrotropical orgin (e.g. *Barbus anema*), and they meet in the central Saharan mountains of Ahaggar and Tassili-n-Ajjer. In spite of their isolation, which lasted for a minimum of 6,000–12,000 years, they show no sign of speciation.

The Lake Tana endemics (mainly *Barbus* and *Labeobarbus*, and thus Cyprinidae and not Cichlidae as in the lakes on the East African plateau) as well likely speciated in rivers away from the lake, and only colonized the lake when it was flooded after a period of drought (Lamb et al., 2007; Vijverberg et al., 2009): one *Labeobarbus,* morphologically close to the ancestral form of the Tana species flock, still has riverine habits. Endemism on the Ethiopian plateau is significantly higher than elsewhere in the Nile basin, including the East African plateau, and it is again mostly in riverine, not lacustrine animals (e.g. gomphid dragonflies: Dumont, 2009). Furthermore, the ancestry of these endemic species (there is no endemism at higher taxon levels) can be traced to two origins: the so-called Afromontane region (East Africa between Kenya-Uganda and South Africa), and the Palaearctic.

In brief, although the species flocks of endemic fish and to a lesser extent of molluscs and copepods of Lakes Victoria, Edward-Albert, Tana, and even Turkana remain impressive, the available evidence does not provide conclusive proof that all this speciation happened in the last 12,000 years. We may never know how long it really took for these faunas to evolve, but chances are that their cradle was in rivers, and that only the final radiation took place in lakes afterwards.

The Ethiopian plateau is relatively species-poor, yet it is the most important, but not the only, focus of aquatic palaearctic relicts (some still identical to their northern populations, others clearly speciated, suggesting more than one wave of immigration). For these to reach Ethiopia, a significant drop in temperature was perhaps more important than a higher humidity in the now arid to hyperarid deserts north of it. A plausible age for at least some of these relicts is therefore the last glacial maximum. Support for this idea is found in the fact that they do not stop on the Ethiopian plateau, but extend to high mountains further south such as Mount Elgon, Mount Kenya, the Drakensberg, and even the Mediterranean zone of the Cape Province. Conversely, several species with a South African range reach their limit of northern extent either in the great lakes area or on the Ethiopian plateau. Van Damme and Van Bocxlaer (2009) provide examples among the molluscs. One peculiar endemic fish of the Ethiopian plateau is *Nemacheilus abyssinicus*. It mainly lives in rivers although few specimens have been found in Lake Tana

(Dgebuadze et al., 1994; Vijverberg et al., 2009). It belongs to a family with an otherwise exclusive European-Asian range. The nearest site where two congeners can be found is the Levant (in and around Lakes Kinneret and Hula) (Ben Tuvia, 1978; Dimentman et al., 1992).

A second focus of palaearctic species is the Egyptian Nile, although the majority of species living there are Afrotropical elements that use the Nile flow to reach northwards. Spectacular examples are found among the megafauna, often linked to historical anecdotes, such as the hippopotamus that killed pharaoh Menes (see further). Many more examples can be found in various contributions in this book, in aquatic insects and zooplankton (Dumont, 2009), but the fish fauna (Witte et al., 2009), and the molluscs (Van Damme & Van Bocxlaer, 2009) are no doubt the most convincing, since these two groups have a fossil record (for fish, see Stewart, 2009). Palaearctic elements in the lower Nile often have circum-mediterranean ranges, or extend from the (semi)arid belt of Middle Asia to North Africa and sometimes the Iberian Peninsula (Irano-Turanian species). In the case of some dragonflies and fairy shrimp, these species are not found in the Nile valley itself, but west and east of it, often in oases in the western desert (Siwa, Kharga…) and in Sinai, which may reflect the presence of superior competitors in the river itself. In some cases, we know what these superior competitors are: in the freshwater crabs, for example (Cumberlidge, 2009), the tropical family Potamonautidae extends to the Nile delta, with two widespread species *Potamonautes niloticus* and *P. berardi*. East and west of it, but not in the river valley itself, the Eurasiatic family Potamonidae is found, with *Potamon potamobius* in Sinai and the Jordan valley, and *Potamon fluviatile* in the Maghreb. The situation with Nile fish is, of course, similar.

In contrast, African species spilling over from the Nile valley to the Levant via Sinai and from here even further north and west is common. Probably the best known case is that of the Papyrus, *Cyperus papyrus*, which established itself in the valley of the River Jordan (Lake Hula) and even extends to Sicily. Other examples occur among fish, mollusks, annelids (Ghabbour, 2009), crustaceans, and insects. Some that became established in the Jordan-Litani valleys have relict populations in the Sinai desert even today.

In the south, exchange of aquatic biota with Arabia across the street of Bab el Mandeb was possible before the street opened, some 4.5 million years ago, but appears to have been group-selective. There is little evidence that fish made the crossing (no cichlids naturally occur in Arabia although *Tristramella* is endemic of the Levant, see further), and most Arabian cyprinids are related to species of the Levant). In zygopteran dragonflies, the African genus *Pseudagrion* has six known species in south Arabia, of which one is endemic (*P. arabicum*) but related to an African congener (*P. kersteni*) that is also ancestral to the levantine *P. syriacum* (see further). It still occurs rather commonly in Yemen, vertically segregated from *P. arabicum* (Schneider, 1987). The others are wide-ranging African species, except the oriental *P. decorum* that is, however, limited to Oman. Several *Azuragrion* also managed to cross from Africa to Arabia, but the reverse movement seems to have been made by no zygopterans and by only few anisopterans, including the oriental *O. taeniolatum*, that has meanwhile speciated in north-east Africa to *O. kollmanspergeri* (Dumont & Verschuren, 2005). Among African anisopterans, at least five African species of *Trithemis* are found in south Arabia; one endemic aeshnid (*Aeshna yemenensis*) is again a close relative of an African species. In contrast to the Nile valley, where endemism is at the species level at best, there are also two endemic genera of damselfies in South Arabia (*Arabineura* and *Arabicnemis*). They are derived from African ancestors, and are clearly older than the current Nile fauna. Like *Tristramella*, they are unrelated to the Nile fauna and their origin should be sought in the Red Sea rift which, prior to the opening of Bab el Mandeb, was a river valley rather than a sea.

In the north, the Sinai "gate" leads into the Jordan valley, where three *Pseudagrion* are found, of which only one is shared with south Arabia, but as a different subspecies (*P. sublacteum mortoni*), while another species (*P. syriacum*) is endemic to the Jordan-Litani valleys. The third species, *P. torridum*, has relict populations in the Sinai desert, and extends to Lake Hula in the north Jordan valley (presumably as a subspecies). Among African-derived libellulids, three endemic subspecies are found: *Rhyothemis semihyalina syriaca, Urothemis edwardsi hulae*, and *Crocothemis sanguinolenta arabica* (see Kinzelbach et al., 1987, for a distribution map). In fish, the comparison turns out differently in the details, but the major lines are similar: as stated earlier, no cichlids are native to Arabia (although some exist in Iran, so their absence from Arabia might be secondary). However, several are known from the Jordan valley, and, as in the dragonflies, some species are widespread nilotic taxa (*Sarotherodon galilaeus*, *Tilapia zillii*, *Oreochromis niloticus*, *Clarias gariepinus*), while others have speciated. Among cichlids, at least three endemic species occur, *Astatotilapia flavijosephi* and two species of the endemic genus *Tristramella*, *viz. T. sacra* and *T. simonis* (Ben Tuvia, 1978). Like *Arabineura* and *Arabicnemis*, *Tristramella* might be a relict of Miocene age. In addition to these Africa-derived elements, a rather large number of Palaearctic cyprinids, some of which endemic, exist here. It is to be noted that the non-speciated Levantine fish are identical to species currently surviving in the Sahara desert.

Faunal exchange across Sinai may have occurred in several waves in the late Pleistocene–early Holocene. Taxa that have speciated may be considered to belong to older waves than those that did not. However, this might not be as straightforward as it seems since some species, genera or families may take longer than others to evolve. Haplochromine cichlid fish, for example, are currently considered capable of rapid speciation (even if perhaps less rapid than sometimes assumed), while *Sarotherodon* and *Tilapia* are "slower". On the other hand, in libelluline dragonflies, three relict pockets are known where the same two species, *Urothemis edwardsi* and *Rhyothemis semihyalina* co-occur. Only in the Lake Hula refuge do these show signs of (sub)speciation, not in a site (Wadi Darbaat) in Dhofar, South Arabia (Schneider & Dumont, 1997), and not in the wetlands of El Kala, Algeria. Of two models (simultaneous sequestration of the relicts and a different rate of evolution, versus a similar rate of evolution, but a different time of arrival time) it is unclear which one to choose. In conclusion, it seems that progress in this domain must await the discovery of DNA markers suitable for the derivation of a trustworthy molecular clock.

Physically, the basin from which the Nile is currently best isolated is that of the biologically much richer Congo. This separation came in the form of the deletion of the entire lakes plateau area from the Congo basin, near the end of the Miocene (Talbot & Williams, 2009), when the current great lake's area was uplifted and so tilted that it started to drain towards the north instead of the west. Compounded by strong climatic fluctuations, a suite of impressive extinctions of pre-existing faunas (fish: Stewart, 2009; molluscs: Van Damme & Van Bocxlaer, 2009) followed, all along the Pliocene. The result, still tangible today, is an impoverishment of the Nile vis-à-vis the Congo, and a quasi-complete difference between both faunas (Fish: Witte et al., 2009a; Molluscs: Van Damme & Van Bocxlaer, 2009; Crabs: Cumberlidge, 2009; Odonata: Dumont, 2009).

There remains the question of the relatedness of the biota of the Logone-Chari basin, The Niger, and the Nile. When biogeographers use the term "Nilotic", they refer to a fauna and flora that extend from the Senegal and Niger to the Logone-Chari and Nile basins, the connotation being that the origin of this assemblage is situated in the Nile valley. This is almost certainly wrong (Van Damme & Van Bocxlaer, 2009). True, of the ca 115–130 fish species that are found in the main Nile, some 74–80 are shared with Lake Chad and the Logone-Chari (Greenwood, 1976; Lévêque, 1997; see also Witte et al., 2009). Similar figures can be given for molluscs, and, among planktonic crustaceans, the only place where the calanoid copepod *Thermodiaptomus galebi* is found outside the Nile basin is in Lake Chad. These data argue for a recent connection between both basins, even if a double caveat is in order: (1) there definitely exist species that are not shared between both basins, and (2) the Logone-Chari fauna is richer than that of the Nile. Van Damme & Van Bocxlaer (2009) therefore suggest that the refuge zone for this fauna during dry periods of the Pliocene–Pleistocene was not the Nile but the upper Logone-Chari, situated in an equatorial climate and thus relatively well shielded from droughts. A third argument is that, if the connection between the basins had been long-lived, some indication would be found in the geomorphology of the divide. This is not the case.

On the other hand, the altitudinal flora and fauna of Jebel Marra contain numerous relicts of tropical biota that must have required much more precipitation than today to become established there (Wickens, 1976; Dumont, 1988). The age of these relicts is probably early Holocene. The most probable areas of contact between the basins are either the upper Bahr el Arab south of Jebel Marra, the upper reaches of the Wadi Howar and Mourdi depression north of Jebel Marra and the Ennedi plateau.

4 Invasive Species

Currently, an unprecedented wave of animal and plant invasions is creating havoc worldwide in the ecosystems they overwhelm. In contrast to earlier decades, when species introductions were often intentional, many of the present invasions are accidental or follow from an ever-more intense international traffic. In the aquatic realm, aquarium trade and ballast water are two important vectors. Another stimulus is the construction of canals, that link previously unconnected river systems. This has not happened on a large scale in Africa so far, but in Europe and Western Asia it has created a water network that extends from the Volga to the Rhine.

Biological invasions have probably been triggered by man since prehistoric times, and many probably go unnoticed unless they cause major disruptions in the receiving ecosystems. Some well-documented cases go back to the nineteenth century, including a notorious one, involving the Nile hyacinth, *Eichhornia crassipes*. It appears that the neotropical Nile hyacinth has been introduced to the Nile three times independently. In the lower Nile, around Cairo and in the delta, hyacinths were introduced during the last decades of the nineteenth century, as ornamental plants (Zahran, 2009). They escaped and rapidly became a nuisance in thousands of kilometers of irrigation channels. The problem persists to the present, and fears have been voiced that, now that the regulated Nile at times resembles more a lake than a river, *Eichhhornia* may migrate upstream. Zahran (loc. cit.) cites one isolated finding of few plants just below the Aswan dam in 1986, but no further spread has occurred since.

The second focus is the While Nile in southern Sudan. Here, the first plants were seen around the mid-1950s. They rapidly expanded afterwards and currently are found over more than 1000 km of river, from the Sudd to Jebel Aulia dam. Major river blockages have occurred, and at times, Jebel Aulia reservoir is completely covered in hyacinths. The infestation probably came from the Congo, where it had started a few years earlier than in the While Nile.

The third and most recent focus is Lake Victoria, where it was first sighted in 1989. It quickly developed huge floating mats and occasionally clogs the lake outflow and power generating system (Lehman, 2009).

Among fish, the most widespread intentionally introduced species is *Gambusia* sp., intended at combating mosquitoe larvae in the irrigation systems. This is moderately successful, even if the fish also feeds on zooplankton. Yet, no major disturbances seem to have been created by it.

Among the crustaceans of the plankton, some delta lake copepods are suspected to be invaders. This is the case of *Acanthocyclops trajani*, of presumed American origin, and currently the most abundant copepod of the delta (Dumont, 2009). Van Damme & Van Bocxlaer (2009) cite several species of invasive mollusks. Again, none seem to cause much ecological damage, although some may facilitate the transmission of parasitic diseases such as bilharzia (shistosomiasis). Among decapods, two freshwater crayfish species have been intentionally introduced to combat precisely some bilharzia-transmitting snails. Although these species have created additional problems by their burrowing habits and although their diets turned out to be broader than suspected, the balance of their effects is not entirely negative: they have proven comestible to man and are well accepted by the local population (El Shabrawy & Fishar, 2009).

A most surprising finding has been that, of the few species of cnidarians that live in the Nile, more than half are invasive (Dumont, 2009). The medusa-forming hydroid

Moerisia lyonsi, described in 1906 and long considered endemic of Birket Qarun, is really a mesohaline species that cannot have lived in the lake in earlier centuries, because its water was too fresh. In the twentieth century, it disappeared, because the water was becoming too salty. It is a synonym of a Caspian species. Curiously, at about the same time as *Moerisia lyonsi* a second hydroid, *Cordylophora caspia* was also first found in lower Egypt. This is an extremely euryhaline animal, that adapted to the Nile and managed to work its way upstream as far as the sudd, before the major dams were in place (Rzóska, 1949). Both species are of Ponto-Caspian origin, and it is well possible that they were introduced together, but how and when this happened is unknown.

5 The Nile as a Multipurpose Natural Resource

5.1 Hydrology and River Damming

After the confluence of the Blue and White Niles, the river flows for over 3,000 km through a desert landscape, and is only augmented seasonally by the Atbara, 300 km North of Khartoum. From Aswan to Rosetta (Rachid) it crosses 1,200 km with no drop of extra water, but plenty of evaporation and some infiltration. Northern Sudan and Egypt are therefore totally dependent on the Nile for their freshwater needs, and their politics reflect that (Allan, 2009). Sutcliffe (2009) discusses the hydrology of the Nile. It is difficult to decide what to emphasize: the regularity of the "hundred days" of summer flood, bringing an abundance of water and fertile silt, or the uncertainty of the variations of that flood, with occasional failures, or, alternatively, floods so high that they drowned much of the valley. Surely, the predictability of the river rising by about 7 m in the lower Egyptian summer must originally have been interpreted as a divine intervention in human affairs. Consequently, the pharaohs were held accountable for failed floods which, if repeated, could lead to famine and political turmoil.

The mythical pharaoh Menes, founder of the first dynasty around 5,100 BP, who may or may not correspond to a single person and is known under a variety of names, lived at a time of high Nile floods. His life, and the centuries that followed, coincided with high rainfalls in the Sahel, creating prosperity in Egypt (Williams & Talbot, 2009). During his long reign of more than 60 years, the first large-scale cereal agriculture in the valley prospered. Among other things, he is remembered for having been killed by a hippopotamus; but he also founded the city of Memphis, and as part of that effort, dammed part of the Nile to create an artificial lake, the first known act of basin irrigation. Since building was mainly using wood and bricks, nothing of this dam remains. Remarkably, Egyptian engineers and architects did not develop skills in river flow manipulation beyond basin irrigation, but rather focused their talents on building temples, palaces and tombs, culminating with the pyramid of Cheops around 4,550 BP. Thus, when about a thousand years later a severe drought occurred, the Egyptians could not react rationally, and the old kingdom collapsed.

The Egyptians never moved beyond basin irrigation; in contrast, they developed skills in canal building. In the days of pharaoh Menes, Lake Moeris (now Birket Qarun) in the Fayum was fed by a natural overflow of the Nile. Around 4,300 BP, as the Nile levels began to fall, the waterway between Moeris and Nile was not allowed to dry out but was actively maintained, and the pharaohs of the 12th dynasty are known to have used the lake as a regulator of Nile flow, useful to store excess water (El-Shabrawy & Dumont, 2009).

For the idea that variation in discharge of a river can be brought under control by dam building, and extend the irrigation period, we have await the late nineteenth century AD, a period when the full geography of the Nile basin was finally clarified and its climatic forcings adequately understood (Camberlin, 2009). That the entire basin, save Ethiopia, came under British colonial rule, facilitated the deployment of comprehensive management initiatives. But it was under the Mohammed Ali dynasty, which was also the time of the construction of the Suez Canal, that the first barrages were constructed near Cairo, and on the Rosetta and Damietta branches of the delta. The main incentive was that cotton had become the new cash crop, and by elevating the river level, and digging an intricate network of secondary, tertiary, etc. canals, agricultural yields received a first boost (Waterbury, 1979). However, the technical level of river damming did not differ much from what pharaoh Menes had attempted 5,000 years earlier.

After 1882, the situation rapidly changed: strong population growth in Egypt (three doublings between 1820 and 1970, and a fourth one underway) fueled a thirst for water that continues to the present, at first mainly for agriculture, later increasingly for industrial use. As the need for perennial irrigation rapidly consumed the full flow of the Nile during low flow, a real dam was constructed at Aswan, with a storage capacity of 1×10^9 m^3. Its height (and capacity) soon needed to be raised, in 1907–1912 and 1929–1933, but it threatened to overflow in 1946, and plans for a high dam in addition to a series of smaller dams between Aswan and Cairo were worked out in the framework of a management plan that has become known as the Century Storage Scheme (Waterbury, 1979). The foundations for this were laid as early as 1904 by the then British Undersecretary of Public Works in Egypt, and included storage in the equatorial lakes, the building of a canal that would bypass the Sudd swamps, and damming of Lake Tana and the River Atbara.

To the exception of the Jonglei canal, most of these objectives have been achieved. The *raison d'être* of this canal is to cut down the huge loss to evaporation in the Sudd swamps, thereby gaining about 4.7×10^9 m^3 of water for downstream use, as well as to reclaim ca 100,000 ha of agricultural land. Numerous ecological and sociological objections against the canal have been voiced. The digging started in 1980 but was stopped by civil war in Sudan in 1983, after 260 out of 360 km were completed. In 2008, discussions about continuing the work were resumed.

According to a tediously negotiated agreement of 1959 between Egypt and the Sudan, the average yearly Nile discharge of about 85×10^9 m^3 per year is divided as follows: 57×10^9 m^3 for Egypt, and 18.5×10^9 m^3 for the Sudan; about 10×10^9 m^3 are lost to evaporation and infiltration.

British engineers had planned the building of large storage dams on the East African plateau and in Ethiopia, making use of existing lake basins, because evaporation would be lower there. However, once the colonial era had ended, the newly independent Egypt preferred a dam on its own territory, in the desert environment of Aswan. The high dam started to fill in 1964, and with that, full over-year storage was achieved, and the river came under full control. In the words of Hamdan (1970), it was transformed from a destructive force into a giant irrigation canal; in Waterbury's (1979) words: the Nile stops at Aswan! For a discussion of the gains and losses caused by the dam, see El-Shabrawy (2009).

When filled to capacity, the Nasser-Nubia reservoir may hold up to 160×10^9 m^3 of water, which amount to about twice the average yearly discharge of the Nile at Aswan (85×10^9 m^3). A steady year-round flow has been achieved, replacing the old summer highs and winter lows, and perennial agriculture is now widely applied.

Exceptionally, the dam may close for 2–3 weeks in winter, at which time the water level in the delta lakes may drop to a point where seawater briefly enters the delta lakes (Dumont & El-Shabrawy, 2008). During the high water levels of the late1990s, Egypt implemented the so-called New Valley or Toshka-project: from the days of the earliest conception of the High Dam, the possibility that the reservoir might overflow had been considered. The Toshka valley in the western desert was identified as a sort of "safety valve" through which excess water could be evacuated. Between 1978 and 2005, 50 km of canal and a pumping station were constructed, to yearly pump up to 5×10^9 m^3 of water into the Toshka depression, creating four lakes and irrigating some 400,000 ha of new land. However, after the exceptionally high Nile floods of 1998–2001, falling water levels have now caused these lakes to shrink. The westernmost one is rapidly increasing in salinity (El-Shabrawy & Dumont, 2009b). There is a clear danger that what happened to the Fayum will repeat itself here!

A second recent and ambitious water-diversion project is the Sinai peace canal ("El Salaam"), aimed at irrigating some 260,000 ha of land and create an artificial lake of 6,000 km^2. To this end, up to 4.5×10^9 m^3 of water is pumped through a series of ducts that pass under the Suez Canal.

Dam building in the Sudan began with the dam at Sennar on the Blue Nile in 1925, aimed at irrigating the Gezira, a large cotton-growing area. Jebel Aulia dam followed in 1937, Roseires dam in 1966, and Khasm el Ghirba dam on the Atbara in 1966 as well. The latter dam was the result of an agreement with Egypt, aimed at resettling the Nubians that had been moved from the flooded Nasser-Nubia reservoir area.

In Ethiopia downstream developments are closely monitored, and occasional tensions arise between the Upper Nile countries that, according to Allan (2009), provide water but lack power, and the Lower Nile countries that are dependent on this water but wield power. In 1992, the Nile Basin Initiative (NBI) was initiated, aimed at improving cooperation between all riparian states, but a deep-rooted suspicion