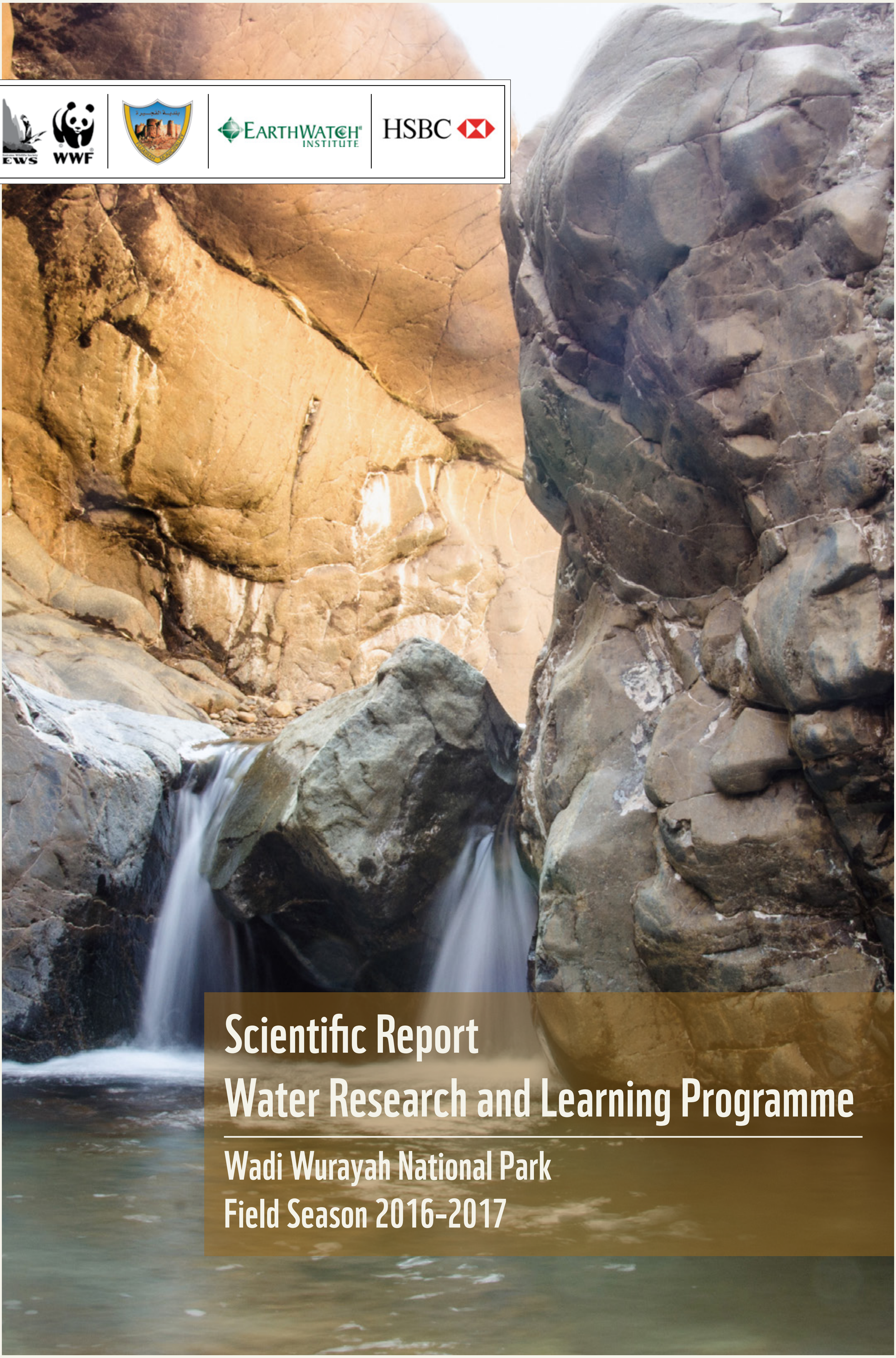

Scientific Report
Water Research and Learning Programme

Wadi Wurayah National Park
Field Season 2016-2017

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PROJECT PARTNERS

HSBC Bank Middle East Ltd.

One of the largest international banks in the Middle East and a key financial partner and supporter of Wadi Wurayah National Park since 2006, HSBC Bank Middle East Ltd. established the Water Research and Learning Programme as part of its Global Water Programme.

Fujairah Municipality

Strategic partner and driver of Wadi Wurayah National Park development. The mission of Fujairah Municipality is to provide advanced infrastructure, a sustainable environment, and excellence in services to the people of Fujairah.

Emirates Wildlife Society-WWF

Emirates Wildlife Society-WWF is a UAE environmental non-governmental organisation established under the patronage of H. H. Sheikh Hamdan bin Zayed Al Nahyan, ruler's representative in the western region and chairman of Environmental Agency Abu Dhabi. Since its establishment, Emirates Wildlife Society has been working in association with WWF, one of the largest and most respected independent global conservation organisations, to initiate and implement environmental conservation and education projects in the region. EWS-WWF has been active in the UAE since 2001, and its mission is to work with people and institutions within the UAE and the region to conserve biodiversity and tackle climate change through education, awareness, policy, and science-based conservation initiatives.

Earthwatch Institute

Earthwatch Institute is a leading global non-governmental organisation operating from offices in the United States, United Kingdom, India, Hong Kong, Japan, Australia, and Brazil. The Earthwatch Institute engages communities in environmental projects in more than 40 countries worldwide. Scientists, educators, students, corporations, and the general public are engaged in initiatives to promote the understanding of and actions necessary for a sustainable environment.

SCIENTIFIC REPORT WATER RESEARCH AND LEARNING PROGRAMME

Wadi Wurayah National Park
Field Season 2016-2017

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1. INTRODUCTION

The Water Research and Learning Programme (WRLP) is a 5-year environmental learning programme for Citizen Science Leaders from the Middle East initiated in 2013. This programme is funded by HSBC Bank Middle East Ltd. and is the result of a partnership between the Emirates Wildlife Society–WWF (EWS-WWF), Earthwatch, HSBC, and the government of Fujairah in the UAE. The goal is to understand and protect a unique wadi ecosystem and to engage and inspire Citizen Science Leaders to promote and protect precious freshwater resources across the Middle East.

The Water Research Centre is located in the Wadi Wurayah National Park (WWNP), in the emirate of Fujairah. The presence of permanent water pools and streams in Wadi Wurayah gives life to a rich ecosystem within a dramatic landscape. This unique ecosystem serves as the study base of freshwater habitats to understand the ecological functioning of this arid environment and to ultimately develop relevant strategies for the conservation of the national park.

Teams of 10 to 12 employees from HSBC in the MENA region travel to WWNP to be part of the 5-day programme, where they are involved in research activities through 'feet in the field and hands in the lab' experiences while they contribute to the important data collection that this report aims.

Since 2013, over 900 volunteers from 12 different countries have participated in the WRLP. This report presents in detail the main scientific results obtained during the last field season, 2016–2017, comparing them with previous seasons'.

2. GENERAL OBJECTIVES

The ambitious objectives of the scientific research set at the beginning of the WRLP in 2013 are as follows:

1. Describe the physicochemical components and factors of variation
2. Describe the biodiversity components (species diversity, relative abundance, population size, etc.) and their spatiotemporal variations
3. Understand the relationships between the physicochemical characteristics of the habitats and their biodiversity components
4. Determine the ecological requirements and the tolerance limits of key species (plants, insects, toads, fish, etc.)
5. Assess the dispersal propensity of key species
6. Measure the impacts of human activities (agricultural practices, tourist frequentation, well construction, etc.) on water quality
7. Assess the contribution of anthropogenic freshwater habitats as biodiversity refuges
8. Develop scenarios of biodiversity drift in relation to climate change models and propose adapted conservation strategies

The research activities developed by the EWS-WWF are designed to be conducted by volunteers, without strong ecological and/or scientific background, and to provide results that will contribute in addressing these broad research objectives. In this framework, the research and monitoring programme developed with the help of the volunteers aims

- to monitor surface water parameters in relation to presence and abundance of water- dependent organisms,
- to study and monitor populations of key species, and
- to identify threats and orientate conservation actions.

As in previous years, the research programme of season 4 focused on the monitoring of water quality, wildlife populations (zooplankton, freshwater invertebrates, dragonflies, toads), and vegetation. In addition, a new research activity was developed to characterise the population of trees and quantify their densities, and one team of volunteers helped conduct a trial to make the required adjustments in the protocol. The research consisted in the monitoring programme of tree species in the Wadi Wurayah National Park based on tree mapping. The objective of this research is to understand the distribution of the different tree species and its relation to habitat characteristics.

3. THE SURVEY SITES

The geological characteristic of Wadi Wurayah has created a unique hydrogeological system that allows runoff water from the upper catchment to emerge as springs in areas where impermeable and permeable rock layers meet. The different freshwater habitat types found in the park vary from riffle and stream to waterfall, all spring-fed with water flows that alternate between being underground and on the surface throughout the wadi. The selection of the locations where surveys were conducted was based on the different habitat types. Surveys were conducted in two distinct areas: the waterfall and the main wadi, which is the main branch of Wadi Wurayah. In both areas, four and five sampling locations

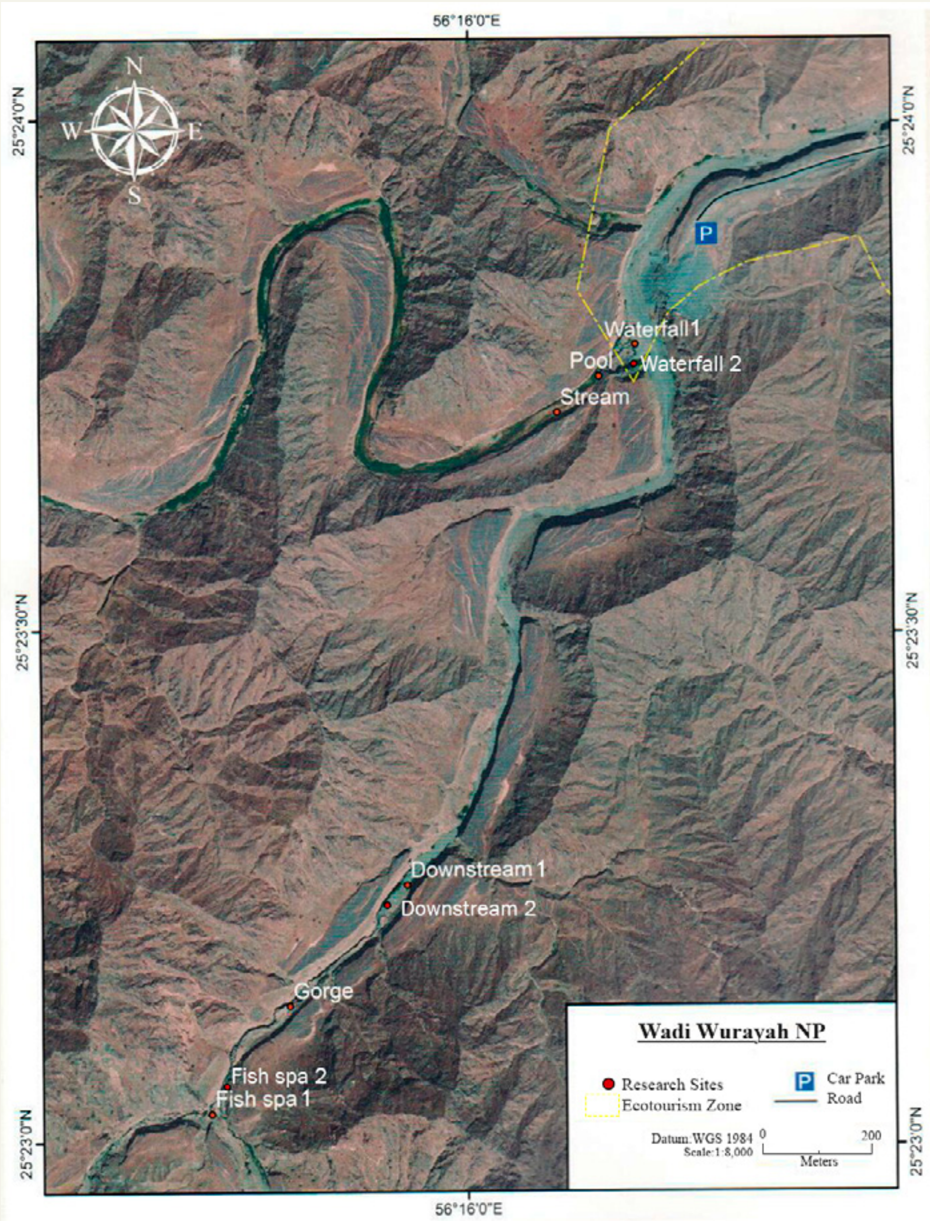

Figure 1: Map of the sampling sites in Wadi Wurayah National Park

were selected: waterfall 1, waterfall 2, pool, and stream for the waterfall Area, and downstream 1, downstream 2, gorge, fish spa 1, and fish spa 2 for the main wadi (Figures 1 and 2).

Figure 2: Habitat characteristics of the nine sampling sites

Photo of the Location	Name of the Site
	**Waterfall 1** **Code:** WW1 **Latitude:** 25.396170° **Longitude:** 56.269585° **Habitat type:** Permanent pool **Substrate:** Mud **Bank vegetation:** *Arundo donax, Saccharum griffithii* **Algae:** Small mats and few attached to shore rocks
	**Waterfall 2** **Code:** WW2 **Latitude:** 25.39576° **Longitude:** 56.26954° **Habitat type:** Permanent pool **Substrate:** Bedrock **Bank vegetation:** *Arundo donax, Saccharum griffithii* **Algae:** Small amount attached to the rocks on the bottom
	**Stream** **Code:** WS **Latitude:** 25.39524° **Longitude:** 56.26829° **Habitat type:** Running water **Substrate:** Mud **Bank vegetation:** *Arundo donax* **Algae:** Scattered on the bottom

Pool

Code: WP
Latitude: 25.39584°
Longitude: 56.26904°
Habitat type: Permanent pool
Substrate: Bedrock
Bank vegetation: *Arundo donax, Saccharum griffithii*
Algae: Evenly dispersed on the bottom

Downstream 1

Code: GDS1
Latitude: 25.387382°
Longitude: 56.265550°
Habitat type: Permanent pool
Substrate: Gravel
Bank vegetation: *Arundo donax, Nerium oleander*
Algae: Attached to the shore

Downstream 2

Code: GDS2
Latitude: 25.386812°
Longitude: 56.265058°
Habitat type: Permanent pool
Substrate: Gravel
Bank vegetation: *Arundo donax, Nerium oleander*
Algae: Attached to the shore

Gorge

Code: GUS
Latitude: 25.385431°
Longitude: 56.263611°
Habitat type: Running water
Substrate: Gravel
Bank vegetation: No vegetation
Algae: No algae

Fish Spa 1

Code: GFS1
Latitude: 25.383437°
Longitude: 56.262241°
Habitat type: Permanent pool
Substrate: Gravel
Bank vegetation: No vegetation
Algae: No algae

Fish Spa 2

Code: GFS2
Latitude: 25.383806 °
Longitude: 56.262127°
Habitat type: Permanent pool
Substrate: Gravel
Bank vegetation: No vegetation
Algae: Attached to the shore rocks and small mats attached to the bottom

The sites waterfall 2, downstream 2, and fish spa 2 were surveyed only for toads, while waterfall 1, pool, stream, downstream 1, gorge, and fish spa 1 were surveyed for water quality and dragonfly and damselfly monitoring.

4. FRESHWATER ECOSYSTEMS' HEALTH

4.1 THE EARTHWATCH GLOBAL NETWORK

Freshwater Watch is a global initiative of Earthwatch in 32 cities worldwide to monitor and assess freshwater quality and availability. It aims to establish a water quality monitoring network throughout the world; the Water and Research Learning Programme in Wadi Wurayah is part of this network.

At the Water Research Centre, citizen scientists are trained on how to conduct the Freshwater Watch and encouraged to do it on their own back home. They can measure the ecological conditions of waterbodies that might not have been previously studied, contributing in mapping the spatial extent of eutrophication.

Two of the most important factors affecting water quality are nitrate and phosphate concentrations. Excessive levels of these nutrients lead to eutrophication with algal blooms: algae float on the water surface and create a barrier that limits the exchange of gasses and light, produce many negative impacts on the freshwater ecosystem, and generally result in poor water quality.

4.1.1 The Standard Method

A global standard methodology is used for Freshwater Watch tests. Observers fill a standardised data sheet describing the ecosystem conditions, measuring concentrations of nitrate (NO_3-) and phosphate (PO_4+) using simple colorimetric tests and the levels of turbidity using a Secchi tube. Pictures 1 and 2: Volunteers performing Freshwater Watch tests

Images 1 and 2: Volunteers performing Freshwater Watch tests

4.1.2 Nitrate and Phosphate Concentrations

A total of 85 tests were conducted between October 2016 and February 2017 at four different locations in the waterfall area. Both nitrate and phosphate concentration remained mostly similar at all sites, although slightly higher in a pool behind the waterfall. This site has very low water movement, with more algae than in other pools.

For the majority of the tests measured (Table 1), the concentrations of nitrate and phosphate were low; 53% of the total nitrate tests were less than 0.2 ppm NO_3–, while 76% of the phosphate tests were less than 0.02 ppm PO_4+. The high concentrations of nitrate observed (greater than 0.2 ppm) were recorded in November 2016. Turbidity remained below 12 NTU at all sites throughout the season.

Table 1: Interseasonal variation of nitrate and phosphate concentrations expressed as the number of tests (in %) falling within a specific range of concentrations

	Nitrate (ppm)				Phosphate (ppm)		
	< 0.2	0.2–0.5	0.5–1.0	1.0–2.0	< 0.02	0.02–0.05	0.05–0.1
Oct	73	27	0	0	68	27	5
Nov	47	11	11	32	79	16	5
Dec	80	20	0	0	80	20	0
Jan	63	38	0	0	75	25	0
Feb	77	23	0	0	100	0	0

4.1.3 Comparisons Between Seasons

Comparing the distribution of range values between seasons (Table 2) highlights a relative stability in phosphate concentrations (Figure 4), but with some interannual variations in nitrate concentrations (Figure 3). Nitrate concentrations were generally lower in seasons 2 and 4 compared with those seasons 1 and 3, with a higher percentage of tests providing low concentrations, supporting the effect of the closure of the park on water quality. However, nitrate concentrations were low all throughout season 2, while in seasons 3 and 4, more variations were observed, with a higher number of tests showing a slightly higher nitrate concentration. These variations are presumably related to rainfall occurrence. Season 2 was very dry with very few precipitations, compared with season 3, which received more rainfall. Rainfall could allow the drainage of nitrates and phosphates present in the environment to surface water, leading to an increment of their concentrations.

Table 2: Interannual variations of nitrate and phosphate concentrations expressed as the number of tests (in %) falling within a specific range of concentrations

	Nitrate (ppm)					Phosphate (ppm)		
	< 0.2	0.2–0.5	0.5–1.0	1.0–2.0	2.0–5.0	< 0.02	0.02–0.05	0.05–0.1
Season 1	36	24	21	12	6	78	15	7
Season 2	92	4	2	0	2	87	11	1
Season 3	55	23	5	11	7	82	16	1
Season 4	67	20	6	7	0	79	15	6

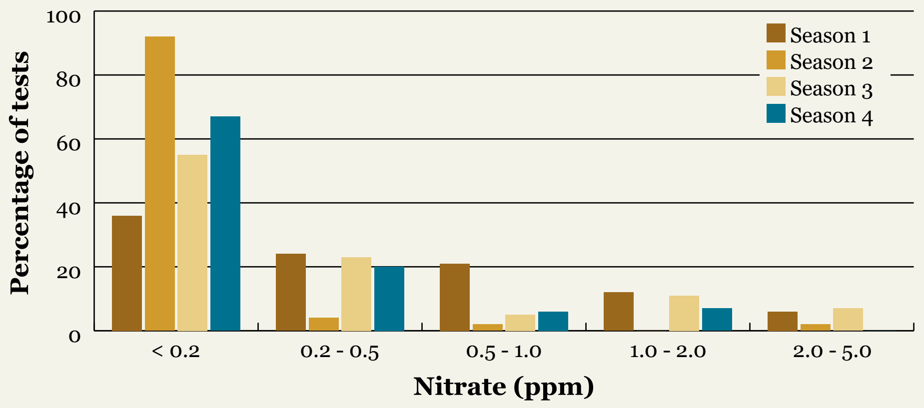

Figure 3: Interannual variations of nitrate concentrations expressed as the number of tests (in %) falling within a specific range of concentrations

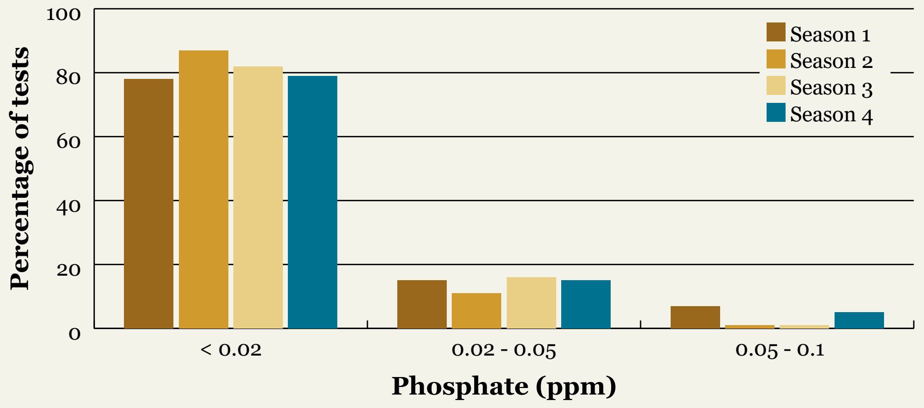

Figure 4: Interannual variations of phosphate concentrations expressed as the number of tests (in %) falling within a specific range of concentrations

With the disappearance of diverse sources of pollution (littering, leftovers, etc.), nitrate and phosphate concentrations have dropped to the normal level for unpolluted and healthy freshwater. Low turbidity is also a good indicator of the health of the ecosystem. These results support the beneficial effect of the closure of the park to public for the improvement of water quality.

4.2 WATER QUALITY MONITORING PROGRAMME

Water quality monitoring is fundamental in the management of wetlands and their ecosystem's health. Freshwater sustains biodiversity, and its quality affects human health directly. All living organisms depend on water availability; at the Wadi Wurayah National Park, many species are linked more or less directly to the freshwater ecosystem; thus, any disturbance could compromise the survival of some of them, causing an alteration in the entire ecosystem. For that reason, EWS-WWF has developed a monitoring programme that has been carried out since 2013 to understand the variations of different freshwater parameters. By knowing the range of natural variations of these parameters, thresholds can be defined, setting alert levels on the ecosystem's health.

The monitoring programme is run weekly and monthly, depending on the parameters and the amplitude of their variations. Analysis of seasonal and interannual variations helps detect trends; parameters that fall outside the range of threshold values could indicate some unbalance in the system, stimulate further investigations to identify its causes, and ultimately provide adequate management to re-establish the natural balance and ensure the sustainability of the ecosystem.

The purpose of the water quality monitoring programme is to determine the physicochemical parameters of different waterbodies in Wadi Wurayah to understand their natural spatiotemporal variations and ultimately to establish threshold values of variations.

4.2.1 Measurements of Water Quality Parameters

A total of 17 environmental parameters (temperature, pH, ammonia, nitrite, nitrate, phosphate, dissolved oxygen, salinity, conductivity, total dissolved solids, turbidity, hardness, alkalinity, iron, chloride, redox potential, and biochemical oxygen demand) were measured from October 2016 to February 2017 at six sampling locations. Eight of them were measured in situ, using a handheld instrument, the YSI ProDSS. This instrument has been used since 2015, providing standardised measures of freshwater parameters. Other parameters require collecting water samples and performing tests in the laboratory of the Wadi Wurayah National Park headquarters (Tables 3 and 4).

Table 3: Summary of methods for the determination of water quality parameters measured and frequency of measurements

Parameter (units)	Accuracy	Method	Instrumentation	Measured	Frequency
Temperature (°C)	±0.2°C	Temperature sensor	YSI ProDSS	In situ	Once a week
Dissolved oxygen (mg/L and % saturation)	0 to 200%: ±1% of reading or 1% saturation, whichever is greater 0 to 20 mg/L: ±0.1 mg/L or 1% of reading, whichever is greater	Optical sensor	YSI ProDSS	In situ	Once a week
pH (pH units)	±0.2 pH units	pH electrode	YSI ProDSS	In situ	Once a week
Salinity (g/L)	±1.0% of reading or ±0.1 ppt, whichever is greater	Conductivity sensor	YSI ProDSS	In situ	Once a week
Conductivity (µS/cm)	0 to 200 mS/cm	Conductivity sensor	YSI ProDSS	In situ	Once a week
Total dissolved solids (mg/L)	Calculated from specific conductance and a user-selectable TDS multiplier (0.30 to 1.00; default 0.65	TDS sensor	YSI ProDSS	In situ	Once a week
Redox potential	±20 mV	ORP electrode	YSI ProDSS	In situ	Once a week
Turbidity (nephelometric turbidity units, NTU)	N/A	Secchi tube		In situ	Once a month
Ammonia (mg/L)	N/A	Colorimetric method	Hanna Instruments	In lab	Once a month
Nitrite (mg/L)	N/A	Colorimetric method	Hanna Instruments	In lab	Once a month
Nitrate (mg/L)	N/A	Colorimetric method	Hanna Instruments	In lab	Once a month
Total hardness (mg $CaCO_3$)	N/A	EDTA titration	Hanna Instruments	In lab	Once a month
Alkalinity (dKH)	N/A	Acid titration	Hanna Instruments	In lab	Once a month
Chloride (ppm)	N/A	Acid titration	LaMotte	In lab	Once a month
Iron (ppm)	±2% FS	Colorimetric method	LaMotte	In lab	Once a month
Phosphates (ppm)	±2% FS	Colorimetric method	LaMotte	In lab	Once a month
Biochemical oxygen demand (mg/L)	±0.2% FS (550% air saturation) ±1 digit (with 1.25 PE membrane at 10˚C)	BOD-5 APHA 5210-B	Hach/Polyseed/YSI Pro Plus	In lab	Once a month

N/A Information not available

Table 4: Mean and SD of the environmental freshwater parameters measured at six locations from October 2016 to February 2017

Parameters (units)	Number of samples	Waterfall area			Main wadi		
		Waterfall	Pool	Stream	Downstream	Gorge	Fish spa
Temperature (°C)	16	24.45 ± 1.46	23.6 ± 2.6	23.7 ± 2.5	23.71 ± 2.38	22.48 ± 1.35	26.38 ± 1.9
pH (pH units)	16	8.07 ± 0.31	7.91 ± 0.37	7.92 ± 0.31	8.47 ± 0.38	8.63 ± 0.29	8.24 ± 0.34
Salinity (g/L)	16	0.31 ± 0.01	0.3 ± 0.01	0.3 ± 0.01	0.25 ± 0.03	0.25 ± 0.03	0.24 ± 0.03
Conductivity (µS/cm)	16	622.47 ± 32.63	581.53 ± 35.73	586.8 ± 27.79	465.96 ± 30.86	466.69 ± 13.89	498.65 ± 39.08
Total dissolved solids (mg/L)	16	426.13 ± 16.72	413.1 ± 20.48	399.51 ± 28.34	326.78 ± 11.37	322.42 ± 8.68	323.45 ± 41.97
Dissolved oxygen (mg/L)	16	8.02 ± 0.41	7.81 ± 0.4	5.74 ± 1.15	9.03 ± 0.68	8.53 ± 0.25	6.6 ± 0.81
Dissolved oxygen (% saturation)	16	94.66 ± 5.59	86.95 ± 4.18	65.55 ± 12.78	99.86 ± 6.05	98 ± 1.74	81.01 ± 8.66
ORP (mV)	16	182.4 ± 23.03	178.11 ± 31.19	180.14 ± 30.07	159.89 ± 27.64	142.33 ± 41.04	163.96 ± 21.61
Turbidity (NTU)	6	<12	<12	<12	<12	<12	<12
Ammonia (mg/L)	6	<0.5	0.5	0.5	0.5	0.5	0.5
Nitrite (mg/L)	6	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Nitrate (mg/L)	6	<10	<10	<10	<10	<10	<10
Total hardness (mg $CaCO_3$/L)	6	265 ± 42.68	261.5 ± 37.15	279.17 ± 61.46	214 ± 32.27	212.2 ± 35.79	211 ± 31.5
Alkalinity (dKH)	6	9.31 ± 2.09	9.2 ± 1.58	8.88 ± 1.19	7.65 ± 1.4	7.48 ± 1.43	8.55 ± 2.04
Chloride (mg/L)	6	102.4 ± 27.3	86.8 ± 4.6	93.4 ± 17.2	77.2 ± 8.6	69 ± 12.8	86.8 ± 24.7
Iron (mg/L)	6	0.02 ± 0.02	0.02 ± 0.02	0.01 ± 0.01	0.03 ± 0.06	0.03 ± 0.04	0.01 ± 0.01
Phosphates (mg/L)	6	0.5 ± 0.58	0.25 ± 0.5	0.5 ± 0.58	0.75 ± 0.5	0.5 ± 0.58	1.25 ± 0.5
Biochemical oxygen demand (mg/L)	2	2.34 ± 0.41	2.22 ± 0.36	2.25 ± 0.16	2.63 ± 0.48	2.61 ± 0.08	2.39 ± 0.53

Water temperature

Water temperature is a physical property that is mainly influenced by air temperature, sunlight exposure, groundwater inflows, and turbidity. At the same time, it influences chemical factors such as conductivity, salinity, pH, and dissolved oxygen, among others. Moreover, temperature plays an important role for aquatic organisms, directly affecting their metabolism functions and behaviour. During the survey, the temperature varied from a minimum of 17.4°C in February to a maximum of 29.8°C in October (Figure 5). The highest average temperature in season 4 was registered in November (25.3°C), and the lowest in February (21.7°C). Over the years, we have observed a relative stability where the highest temperature is reached in October and the lowest in February. Spatial variations occur because of the habitat characteristics of the different waterbodies, such as sunlight incidence and differences in water flow.

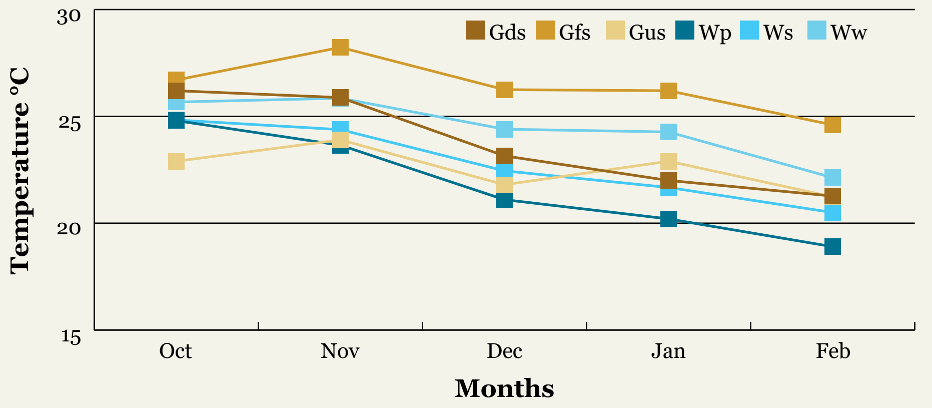

Figure 5: Monthly variation of the average temperature per location measured from October 2016 to February 2017

Turbidity

A cloudy appearance or coloration of a waterbody is a visual indication of pollution. Turbidity is a measure of water clarity in relation to the amount of suspended solids contained in the water column. However, this is not a direct measure of total suspended solids (TSS). High turbidity has negative effects on waterbodies, by increasing the temperature and depleting dissolved oxygen.

Turbidity measures were consistently <12 NTU at all sites during all four seasons, which means that the water is very clear. This season, no flash flood, which is the major cause of increased turbidity, occurred. However, the effect of such event is very punctual since turbidity returned to normal levels in less than 24 hours after a flash flood.

Total dissolved solids

Total dissolved solids (TDS) refers to the sum of all ions dissolved, not bigger than 2 microns (0.0002 cm), including the electrolytes that compound the salinity. For 'clean' water, the TDS concentration is approximately equivalent to the salinity. Depending on the ionic properties (presence of arsenic, cadmium, nitrate, and others), excessive total dissolved solids can produce toxic effects on fish and fish eggs (Scannell et al. 2001, Figure 6). The total dissolved solids in aquatic organisms keep the cell density balanced. Low levels of TDS can make the cells swell, and high levels would shrink them, causing them trouble by moving in the column of water. TDS can also be related to alkalinity and hardness (Thompson 2006).

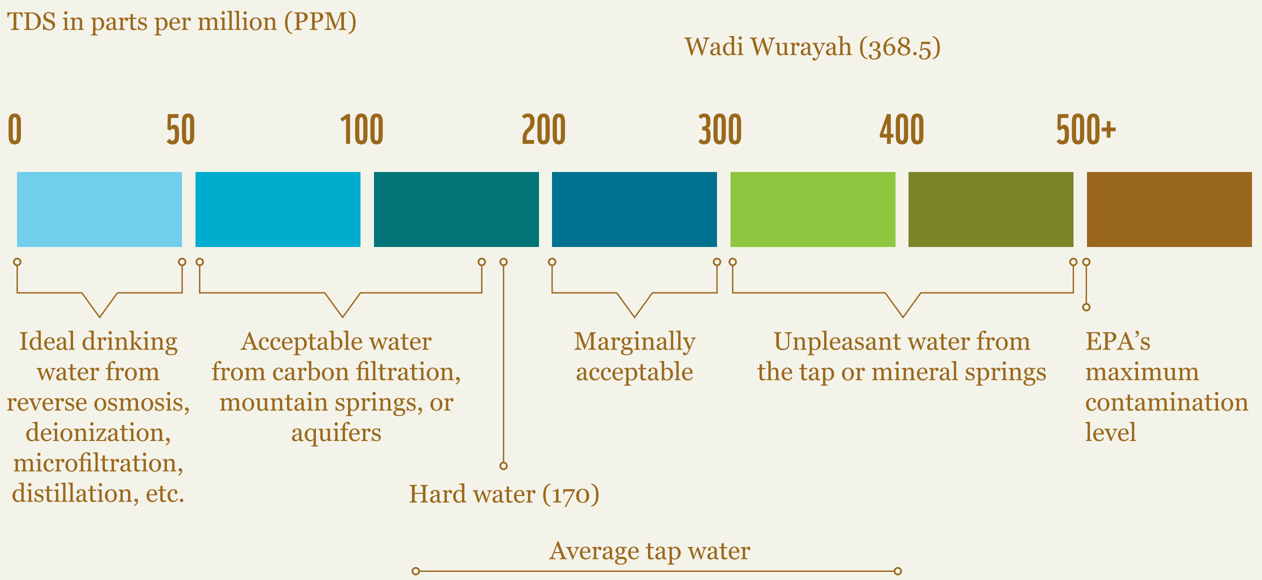

Figure 6: Diagram of the levels of TDS by the US EPA (http://www.tdsmeter.co.uk/abouttds.html)

TDS is mainly influenced by the origin of the water and the characteristics of the waterbodies. The samples in the waterfall area presented higher average values (426.13 ± 16.72 mg/L, 413.10 ± 20.48mg/L, 399.51 ± 28.34) compared with the values obtained in the main wadi (326.78 ± 11.37mg/L, 322.42 ± 8.68 mg/L, 323.45 ± 41.97mg/L).

Conductivity

Conductivity is the ability to pass electrical flow and depends on the negative ions present in the water such as chlorides, nitrates, and phosphates, among others. The temperature also affects the conductivity of the water. For this reason, it is reported as specific conductance at 25°C. In Wadi Wurayah, conductivity is mainly influenced by the geology; streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionise, and streams that run into areas with clay soils tend to have higher conductivity (APHA 1992). In this regard, we observed that conductivity is higher in the waterfall area (622.47 ± 32.63 µS/cm, 581.53 ± 35.73 µS/cm, 586.80 ± 27.79 µS/cm) than in the main wadi (465.96 ± 30.86 µS/cm, 466.69 ± 13.89 µS/cm, 498.65 ± 39.08 µS/cm). Conductivity should remain constant and within the values obtained over the years of research (min. reported 371 µS/cm and max. reported 672 µS/cm); significant changes can be indicators of pollution.

Salinity

Salinity is defined as the total concentration of all dissolved salts in water (Wetzel 2001), and it is correlated to TDS and conductivity levels. On average, salinity in the waterfall area is higher (mean=0.31 g/L) than that in the main wadi (mean=0.25 g/L) (Figure 7).

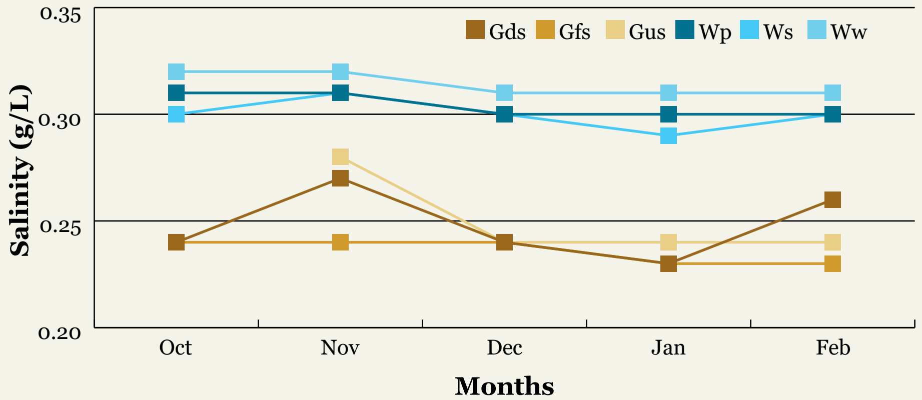

Figure 7: Monthly variations of the average salinity per location measured from October 2016 to February 2017

Chloride

Chloride (Cl-) values ranged from 80 to 150 mg/L. The lowest value was recorded at downstream and is the lowest value ever recorded throughout the four seasons (54 mg/L). The chloride concentrations in the waterfall and the pool had higher average values than those in other locations, but also with higher standard deviations, indicating important seasonal variations (Table 4). Once more, the geology composition and the chemistry of rocks upstream are presumed to be the main determinants of water chemistry. Chloride is one of the components of salts; its concentration is directly correlated with salinity. No clear trends appear yet in annual or intersite variations (Figure 8).

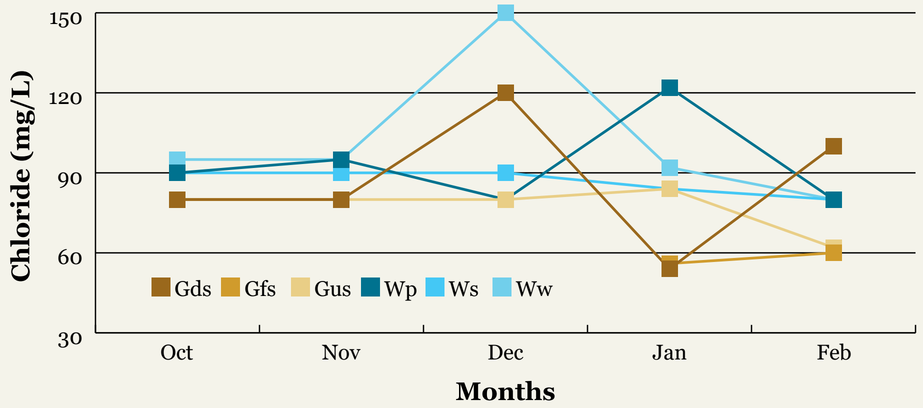

Figure 8: Monthly variations of the average chloride per location measured from October 2016 to February 2017

pH

The pH is the ‘power of hydrogen, which consists in the molar concentration of hydrogen ions (H+). It quantifies how alkaline or acidic a liquid is. Wadi Wurayah waters are considered ultrabasic because their pH is on average greater than 8. The mineral composition of surface freshwater depends on the rocks and soils that this water comes in contact with, while circulating underground, before reaching the surface. The average pH in the waterfall area is 7.97 pH units and 8.44 pH units in the main wadi.

The higher values of pH in the main wadi compared with those in the waterfall area should be linked to differences in the mineral composition of upstream rocks (Figure 9). Values of pH varied rather consistently among all sites throughout the season, with a slight increase in October, followed by 3 months of decrease from November to January, and then a new increase in February. Interpreting these monthly pH variations requires some more investigations.

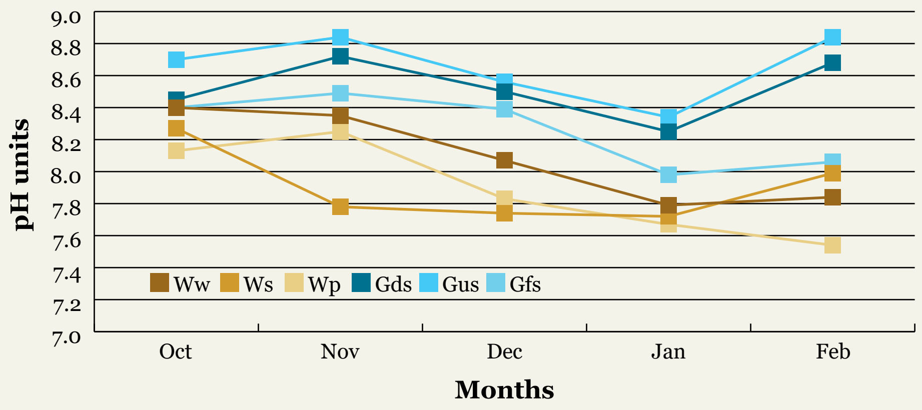

Figure 9: Monthly variations of the average pH per location measured from October 2016 to February 2017

Dissolved Oxygen

Dissolved oxygen (DO) refers to the noncompound oxygen (O2) present in the water; it can be expressed in percentage or in milligrams per litre. It is essential for the development of aquatic organisms, which have different oxygen requirements from one species to another. Different physical characteristics of the waterbodies can influence the quality of gas exchange, resulting in higher or lower dissolved oxygen concentrations. The levels obtained in this season ranged from 3.98 to 10.79 mg/L. The highest results were observed in downstream at the main wadi, which occasionally reached supersaturation with dissolved oxygen concentrations exceeding 100%. The lowest levels of dissolved oxygen were recorded at the stream of the waterfall area, where an important drop was recorded between October and November (Figure 10). This drop was not recorded in other locations, neither for any other water parameters. Low dissolved oxygen levels are often associated with the presence of decaying organic matter, or pollution by some nutrients. However, none of these were recorded at the stream in the waterfall area, but we observed a bloom of vegetation that has decreased the size of this waterbody. Continuation of the monitoring programme is necessary to understand the causes of variations.

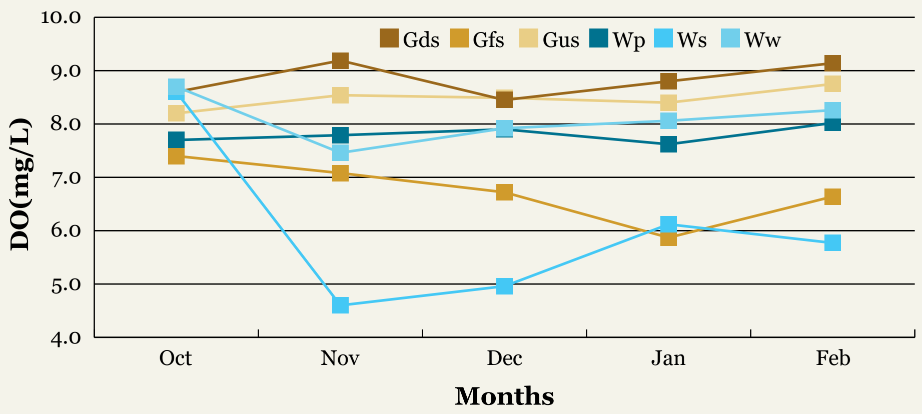

Figure 10: Monthly variations of the average dissolved oxygen per location measured from October 2016 to February 2017

Nitrogen

Ammonia (NH3), nitrites (NO2–), and nitrates (NO_3-) compound the nitrogen cycle, which is essential in the ecological functioning of a waterbody, from the synthesis of the nitrogen that is utilised for the photosynthesis to its assimilation by other organisms higher up in the food chain. A level of ammonia higher than 0.53 mg/L is considered toxic for freshwater organisms and can cause a collapse of the waterbody's life. The levels of ammonia at all sites remained on average below 0.5 mg/L. In only one occasion in February, the level of ammonia exceeded 1 mg/L in three locations in the main wadi, possibly in relation to rainfalls during that month. Levels came back to normal below 0.5 mg/L in March. Nitrites and nitrates were below 0.2 and 10 mg/L, respectively, at all sites through the season. The levels of toxicity for ammonia vary as a function of pH values and temperature (Table 5). On average, the temperature in downstream is 23.7°C, and pH is 8.5. Under these conditions and according to the table, ammonia becomes toxic, above 0.23 mg/L. Our measures (0.5 mg/L) are exceeding this threshold, but we did not record any evidence of toxicity in the fauna of this waterbody. These threshold values were assessed for freshwater ecosystems in the United States and may not be valid in the wadi environment. It is necessary to keep monitoring the main waterbodies to detect any abnormal variations in nitrogen levels, understand the levels of toxicity, and take conservation actions accordingly.

Table 5: Criteria for total ammonia for the protection of aquatic life at different water temperatures (EPA 1985). Values highlighted in yellow represent the threshold of ammonia toxicity under the lowest and highest pH and temperature recorded in WWNP waters.

	Ammonia concentration ($mg\ l^{-1}$)						
pH	0°C	5°C	10°C	15°C	20°C	25°C	30°C
6.50	2.50	2.40	2.20	2.20	1.49	1.04	0.73
6.75	2.50	2.40	2.20	2.20	1.49	1.04	0.73
7.00	2.50	2.40	2.20	2.20	1.49	1.04	0.74
7.25	2.50	2.40	2.20	2.20	1.50	1.04	0.74
7.50	2.50	2.40	2.20	2.20	1.50	1.05	0.74
7.75	2.50	2.20	2.10	2.00	1.40	0.99	0.74
8.00	1.53	1.44	1.37	1.33	0.93	0.66	0.47
8.25	0.87	0.82	0.78	0.76	0.54	0.39	0.28
8.50	0.49	0.49	0.45	0.44	0.32	0.23	0.17
8.75	0.28	0.28	0.26	0.27	0.19	0.16	0.11
9.00	0.16	0.16	0.16	0.16	0.13	0.10	0.08

Alkalinity

Alkalinity is the buffer capacity or ability of a solution or waterbody to resist pH changes. Because of this, organisms are protected from sudden pH changes. In the surface water, alkalinity is mostly due to calcium carbonate (CaCO3) being leached from rocks and soil. On average, alkalinity is higher in the waterfall area (9.11 ± 0.39 dKH) than in the main wadi (7.89 ± 1.03 dKH). Further studies on geological chemistry need to be done to determine the source of the higher levels of this parameter at the waterfall.

Total hardness

The sum of calcium and magnesium hardness is known as total hardness; the term comes from the fact that carbonates mixed with soap makes it hard to create a foam. On average, calcium carbonate (CaCO3) concentrations ranged from 168 to 360 mg/L CaCO3 with consistency along with alkalinity. The waterfall area contains a higher value (267.13 ± 24.05 mg/L CaCO3) than the main wadi (211.08 ± 10.47 mg/L CaCO3). A high quantity of calcium and magnesium can affect the efficiency of osmoregulation and respiration of aquatic organisms, especially invertebrates. Meanwhile, fishes are more tolerant. Also, algae seem to prefer hard waters. We did not observe drastic changes in the trends of this parameter that could affect biodiversity.

Iron

Iron is the fourth most abundant element on earth, but its concentration in water is low due to its low solubility (Xing et al. 2011). This element influences algal productivity. When iron concentration increases from 0.1 to 1 mg/L, algal community in lakes shifts from green algae to cyanobacteria (Morton et al. 1974). On average, iron concentrations in the waterfall area were 0.01 ± 0.05 mg/L and 0.02 ± 0.03 mg/L in the main wadi. It never exceeded 1mg/L, which is the lower limit for freshwater before it can be considered polluted.

Phosphate

Phosphorus is naturally present in rocks. During the weathering process, phosphorus is released in the form of phosphate ions, which are very soluble in water. They are assimilated by plants and are an essential element of the Krebs cycle and the process of energy storage in living organisms. Therefore, phosphorus is a growth-limiting nutrient for plants and animals. In well-oxygenated waters the levels of phosphates are low; and unlike nitrogen, phosphorus is retained in the soil. Phosphate concentrations did not exceed 1 mg/L at all locations, except for a single measurement (2 mg/L) in November at the fish spa.

Biochemical oxygen demand (BOD)

This standard quality test evaluates the ability of the elements and bacteria that are present in the water to use the available dissolved oxygen at a frame time of 5 days. The test is performed under controlled conditions to ensure the accuracy of the results. BOD determines the degree of pollution of the water (Table 6). The average value of BOD across the six locations was 2.41 mg/L, which stayed within the range of 'clean water with little organic waste', indicating that WWNP is currently in a state of nonanthropogenic contamination.

Table 6: Interpretation of BOD levels

BOD Level	Status
1–2 mg/L	Clean water with little organic waste
3–5 mg/L	Moderately clean water with some organic waste
6–9 mg/L	A lot of organic materials and many bacteria
>10 mg/L	Very poor water quality; large amounts of organic waste

Redox potential

Redox potential (ORP) is measured to determine the oxidising or reducing potential of a water sample. It can indicate possible contamination and the presence of pollutants, such as high concentrations of metals and strong oxidising or reducing agents. ORP is a nonspecific measurement; that is, the measured potential is reflective of a combination of the effects of all the dissolved species in the medium. Because of this factor, the measurement of ORP in relatively clean environmental water (ground, surface, estuarine, and marine) has limited value unless a predominant redox-active species is known to be present.

Measured values ranged from a minimum of +52.2 to a maximum of +226.3 mV. ORP readings remained positive, indicating that the water in Wadi Wurayah contains an oxidising agent (able to acquire electrons) but has a small oxidation potential.

Referring to a classification of water types according to the relationship between pH and ORP (Figure 11), with an average ORP of 168.4 mV and pH of 8.2, waterbodies in Wadi Wurayah are within the normal range of unpolluted freshwater body.

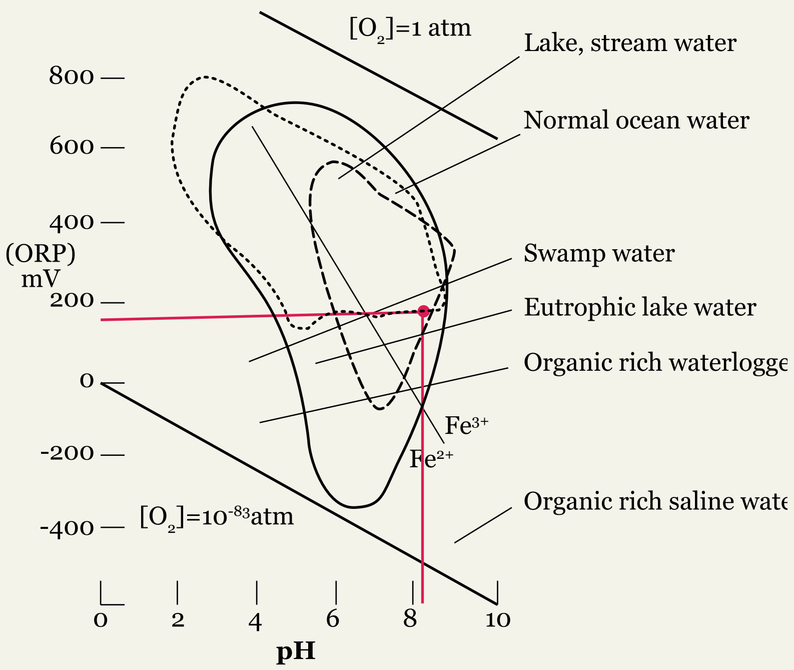

Figure 11: pH-ORP phase diagram for a selection of water types. The red line indicates where WWNP waterbodies stand according to our average measured values of pH and ORP (adapted from Langmuir 1997).

4.2.2 Interannual Variations

EWS-WWF has been monitoring water quality parameters in Wadi Wurayah for 4 years. Analysis of seasonal and interannual variations will start providing reliable information to detect trends over time (Table 7).

Table 7: Water parameters measured in the waterfall area from 2013 to 2017 (Mean ± SD)

Parameter	Season 1	Season 2	Season 3	Season 4
Temperature (°C)	22.9 ± 1.86	23.4 ± 2.99	25.6 ± 3.57	24.4 ± 1.46
pH (pH units)	8.82 ± 0.17	8.58 ± 0.92	8.48 ± 0.17	8.07 ± 0.31
Salinity (g/L)	0.27 ± 0.05	0.31 ± 0.02	0.32 ± 0.02	0.31 ± 0.01
Conductivity (µS/cm)	549.88 ± 129.62	611.73 ± 37.35	641.09 ± 56.61	622.47 ± 32.63
Total dissolved solids (mg/L)	243.50 ± 38.7	421.98 ± 27.19	427.04 ± 23.51	426.13 ± 16.72
Dissolved oxygen (mg/L)	10.03 ± 0.12	7.09 ± 0.81	8.49 ± 0.82	8.02 ± 0.41
Dissolved oxygen (% saturation)	X	82.60 ± 10.37	95.85 ± 5.13	94.66 ± 5.59
ORP (mV)	X	X	96.80 ± 21.17	182.40 ± 23.03
Turbidity (JTU/NTU)	2.29 JTU*	<5 JTU*	<5 JTU*	<12 NTU
Ammonia (mg/L)	X	0.21 ± 0.29*	<0.05	<0.5
Nitrite (mg/L)	X	0.03 ± 0.01*	<0.05	<0.2
Nitrate (mg/L)	0.59 ± 0.33*	0.84 ± 0.41*	<0.5	<10
Total hardness (mg $CaCO_3$/L)	X	226.68 ± 36.19	239.14 ± 37.34	265.00 ± 42.68
Alkalinity (dkH)	8.79	8.31 ± 1.6	8.79 ± 1.19	9.31 ± 2.09
Chloride (gpg)	2.24 ± 0.78	4.98 ± 0.68	8.12 ± 4.92	5.45 ± 0.1
Iron (mg/L)	0.75 ± 0.07	<0.02*	<0.02*	0.02 ± 0.02
Phosphates (mg/L)	X	<0.02*	<1*	0.5 ± 0.58
Biochemical oxygen demand (mg/L)**	X	X	1.22 ± 0.18	2.34 ± 0.41

*This value was obtained using a different methodology.
**BOD test was implemented starting in season 3.
X – Value unavailable—the parameter was not measured.

An overall comparison of water quality parameters between years provides indications of possible trends. However, no statistical analysis has been performed yet to test their significance.

Water temperature has been increasing since season 1 (Figure 12). Since the beginning of the survey, the maximum water temperature registered was 31.6°C on 11 October 2015, while air temperature was 30.5°C; and the minimum registered water temperature was 17°C on 4 January 2015, while air temperature was 18.2°C.

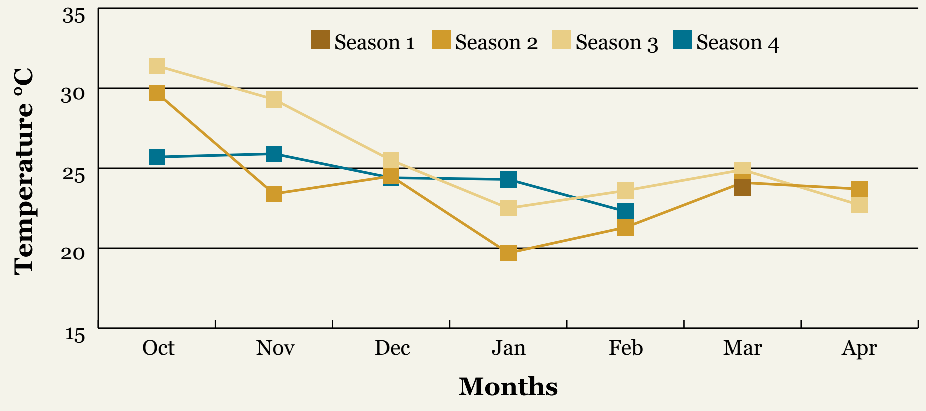

Figure 12: Interannual variations of average monthly temperature at the waterfall

Higher values of pH were recorded during the first season; however, they were measured with a different and possibly less reliable equipment (Pocket Multiparameter – PSC Testr 35), compared with those in following years. In season 2, the YSI Pro Plus, equipped with an electrode sensor, periodically calibrated to ensure the accuracy of the readings, was used. From season 3 onward, pH was measured using the YSI ProDSS, equipped with an Ag/AgCl electrode sensor in gelled electrolyte, also periodically calibrated. The values of pH were similar in the second and third seasons but much lower (acid) in the fourth season (Figure 13). Since pH is known to vary according to temperature (lower pH with higher temperature), we might suspect that the lower pH recorded in season 4 might be linked to the higher recorded temperatures. Additional analysis will be performed to test the statistical significance of correlations between these parameters.

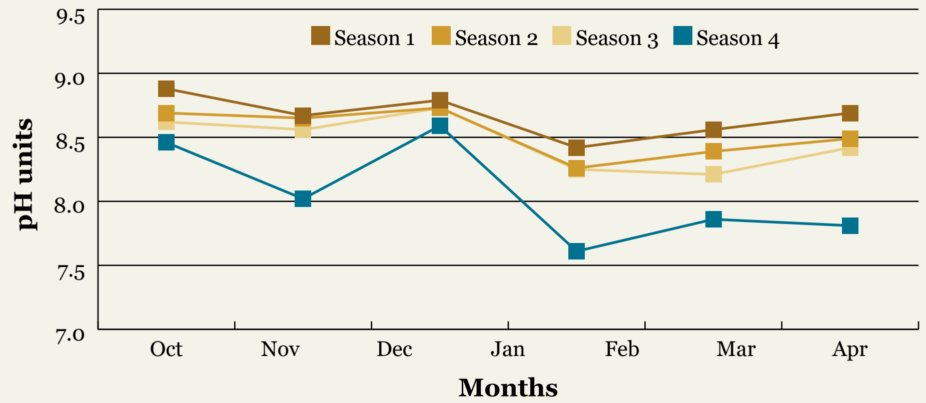

Figure 13: Interannual variations on the average pH per month in the waterfall

Apparent variations of dissolved oxygen (DO) concentrations could be due to the use of different methodologies and instrumentations throughout the four seasons. DO was measured using the Winkler titration (LaMotte) in season 1, the handheld water meter YSI Pro Plus with an electrochemical sensor in season 2, and the YSI ProDSS with a more accurate optical probe in the last two seasons.

Alkalinity and hardness seem to be increasing over the years. As for other parameters, further investigations need to be done to test the statistical significance of these variations, study the possible reasons, and monitor the effects. Conductivity, total dissolved solids, and chloride also present variations over the years, but no clear trends of increase or decrease can be detected so far.

ORP is a parameter that has been monitored only for the last two seasons. Monitoring of this parameter should be continued in the following years to detect any trends or changes in the health of the ecosystem.

Levels of ammonia did not exceed 0.53 mg/L, which is considered the lowest level, above which it becomes toxic for aquatic organisms. Nitrate and nitrite concentrations also did not exceed the levels of toxicity, which were above 10 mg/L and 1 mg/L, respectively. Overall, the nitrogen cycle stayed balanced in this waterbody throughout the 4 years of monitoring.

4.2.3 Indicators of Recreational Water Quality

Escherichia coli (E. coli) is a gram-negative, facultative anaerobic bacterium that is part of the group of coliforms. These bacteria are present in the lower area of the intestine of warm-blooded animals and are transmitted to the water through faecal disposes. Their presence in a waterbody can be an indicator of faecal contamination.

Faecal-oral transmission is the major route through which pathogenic strains of the bacterium cause diseases in humans, such as gastroenteritis, urinary tract infections, and neonatal meningitis. The most common symptoms are abdominal cramps, diarrhoea, and fever.

E. coli and coliforms should continue to be monitored because their presence is not constant, and high concentrations of *E. coli* are a health concern. For this reason, should the park be reopened to the public, recreational use should be restricted until the levels decrease. The US Environmental Protection Agency (1986) recommended limiting E. coli in recreational waters (full body contact waters) to 126 cfu/100 mL (colony forming units per 100 millilitres of water) or less.

The concentration of E. coli was tested once a month from October 2016 to February 2017 at six sampling locations. Water samples were collected and transferred to the laboratory. An amount of 1 mL was inoculated into a 3M Petrifilm Plate and incubated at 35°C for 48 hours. After this period, colonies were counted.

Presence of *E. coli* was observed in three locations (Table 8): in the waterfall (30 cfu/100mL) in November and December and in downstream (67 cfu/100mL) only in November. After December, *E. coli* was absent in all locations. However, *E. coli* was present in the gorge in November and December at high levels, exceeding the recommended levels for recreational use.

The large amount of droppings from rock pigeons that nest in the gorge could explain these high *E. coli* concentrations. During the second week of December, a few individuals were found dead, and the species was not recorded there anymore in January and February. *E. coli* also disappeared during that same period.

Table 8: Monthly variations of *E. coli* (cfu/100 mL) per location from November 2016 to February 2017

	Waterfall area			Main wadi		
	Waterfall	Stream	Pool	Downstream	Gorge	Fish spa
Nov	30	0	0	67	267	0
Dec	30	0	0	0	533	0
Jan	0	0	0	0	0	0
Feb	0	0	0	0	0	0

The presence of coliforms in the waterbodies varied between months without any obvious pattern of variations (Table 9). The levels were high, above the US EPA–recommended levels for recreational water, 200 faecal coliforms per 100 mL (US EPA 1986). Coliforms as group do not give enough information about the risk of illness for bacterial transfer through the water, but studies conducted by the US EPA in the '60s did link health issues to coliform presence above 2300 cfu/100mL. For this reason, using this water for recreational purposes is not yet recommended until the levels drop to below 200 cfu/100 mL, particularly in the waterfall area that might be open to the public in the future.

Table 9: Monthly average variations of coliforms (cfu/100 mL) per location from November 2016 to February 2017

	Waterfall area			Main wadi		
	Waterfall	Stream	Pool	Downstream	Gorge	Fish spa
Nov	8100	5433	3100	5867	700	67
Dec	8300	3967	12000	8967	7967	900
Jan	4433	4033	2933	2033	167	1233
Feb	3800	1700	3500	1467	2567	4467

Concentrations of E. coli have decreased over the years (Table 10) presumably owing to reduced and controlled human presence around waterbodies along with physical changes induced by flash floods. Concentrations of coliforms have also decreased (Table 11) but have not yet reached a safe level. This improvement of water quality is a demonstration of the natural restoring process of the waterbodies under controlled and restricted access.

Table 10: Interannual average variations of E. coli (cfu/100 mL) per location

Locations	2014	2015	2016	2017
Downstream		8611.3	620	0
Fish spa		0	0	0
Gorge		633.3	1246.6	0
Pool		0	6.6	0
Stream		0	0	0
Waterfall	11791	0	18	0

Table 11: Interannual average variations of coliforms (cfu/100 mL) per location

Locations	2014	2015	2016	2017
Downstream		17078	5178	1750
Fish spa		2866	4461	2850
Gorge		13311	5028	1367
Pool		2189	6922	3217
Stream		5311	7367	2867
Waterfall	19541	17722	11189	4117

5. FRESHWATER ECOSYSTEMS' BIODIVERSITY

5.1 ZOOPLANKTON

Zooplanktons are small free-floating aquatic microorganisms that drift with water currents for their movement. Freshwater ecosystems are productive areas with rich zooplankton populations. Zooplankton is a vital component in freshwater food webs, as it forms a link between the phytoplankton community and larger species, such as fish and invertebrate predators. It is composed of primary consumers (which eat phytoplankton) and secondary consumers (which feed on other zooplankton species). Planktonic populations have long been used as ecological indicators (Webber et al. 2005).

Following the research conducted during the previous field season in zooplankton communities, which investigated different methodologies, the objectives of this fourth season were to estimate zooplankton diversity (richness and abundance) and to compare their spatiotemporal variations.

5.1.1 Sampling Methodology

Zooplankton samples were collected from October 2016 to March 2017 on a monthly basis from six different waterbodies at the waterfall area and the main wadi.

Five litres of water were collected from the surface of waterbodies and filtered through a long conical plankton net (mesh size: 100 µm; mouth diameter: 13 cm). The net was held vertically by hand. In the laboratory, samples were poured into a 7 × 27 × 43 cm white tray, where all living organisms were captured using a pipette and counted. Identification was performed, under 40 × magnification using a Swift binocular microscope, according to the 'Practical Guide to Identifying Freshwater Crustacean Zooplankton' (Witty 2004).

5.1.2 Variation in Zooplankton Diversity and Abundance

As in the previous season, only two species were captured and identified: the cyclopoid Cyclops sp. and one cladoceran species of the family Chydoridae. However, it is not excluded that specimens of similar general appearance, and attributed to one species, could hide cryptic species, with subtle identification criteria. Other organisms present in the plankton samples included mayflies, stone flies, and mosquito larvae. Cyclops sp. was the most abundant species and was more abundant at sampling locations in the waterfall area than in the main wadi (Figure 14).

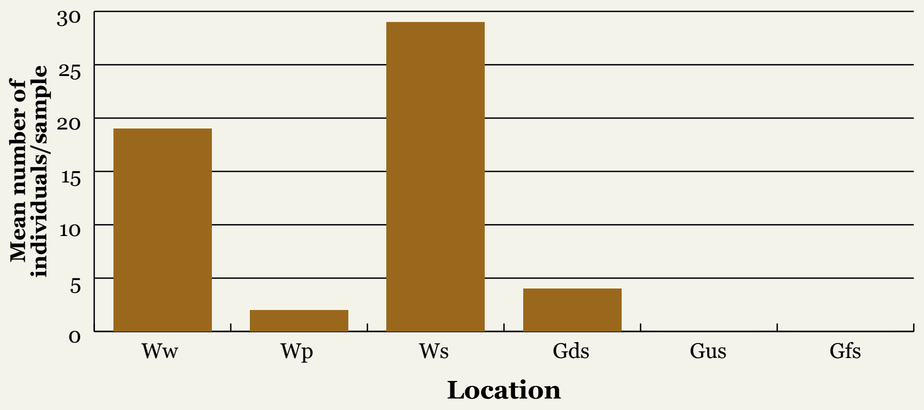

Figure 14: Intersite variation in *Cyclops* sp. abundance

The highest number of Cyclops sp. (Figure 15) was found at the start of the season in October–November. The species was not detected in December–January but reappeared in February–March in much lower numbers. Only two specimens of the cladoceran Chydoridae were recorded in February.

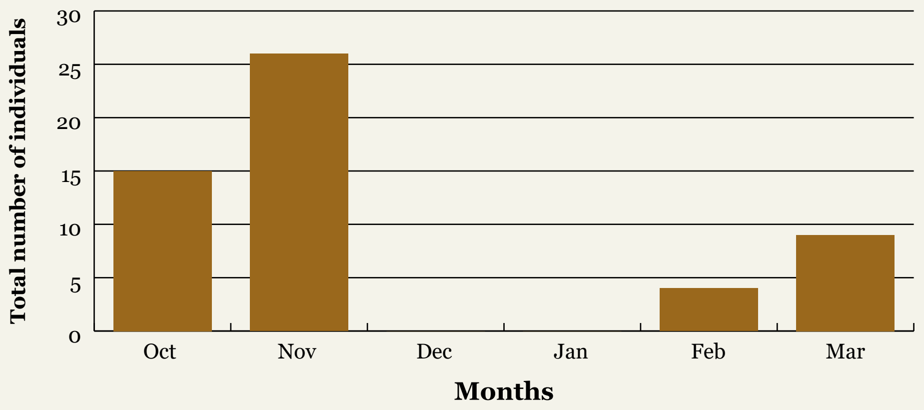

Figure 15: Monthly variations in *Cyclops* sp. abundance

Cyclops sp. was the only species recorded in all seasons (Table 12). Cladoceran was found in the last two seasons, while *Daphnia* sp. was found only in season 2.

Table 12: Interannual variations in zooplankton communities per sample (mean ± SD); X: species not recorded

Class	Order	Family	Species	Season 2	Season 3	Season 4
				Mean ± SD	Mean ± SD	Mean ±SD
Branchiopoda	Cladocera	Daphniidae	Daphnia sp.	0.06 ± 0.53	X	X
		Chydoridae	Unidentified	X	0.14 ± 0.92	0.05 ± 0.23
Copepoda	Cyclopoida	Cyclopidae	Cyclops sp.	2.3 ± 5.4	2.3 ± 5.3	5.5 ± 3.8

5.2 FRESHWATER INVERTEBRATES AS BIOINDICATORS

In a healthy waterbody, most of the pollution-sensitive invertebrates should be present. A sign of good water quality is reflected in the different taxa present in a waterbody. Freshwater invertebrates are commonly used as indicators of changes in water quality and can provide important information on natural or man-made disturbance level. Different invertebrate taxa tolerate organic pollution to a lesser or greater extent, and their responses can be used to indicate water quality (Hodkinson and Jackson 2005). The purpose of this study is to characterise the macroinvertebrate fauna and its spatiotemporal variations.

5.2.1 Sampling and Identification

Sampling of freshwater invertebrates was performed from November 2016 to February 2017. A total of 12 samples were collected at two different waterbodies within the waterfall area.

Sampling was standardised by running a D net (0.5 mm mesh) in the middle point of the waterbody, drawing an 8 shape 10 times. The content of the net was emptied in a 7 × 27 × 43 cm white tray, and all living organisms were collected and sorted by appearance. Specimens were counted and identified following *The Freshwater Name Trail: A Key to the Invertebrates of Ponds and Streams* (Orton and Bebbington 1996). Most taxa were identified to species level, but several groups had to be placed in a higher taxonomic level. Analyses were performed at the order taxonomic level.

5.2.2 Diversity and Abundance

From the 12 samples collected, 7 different orders were represented (Table 13). The most abundant taxon was Hemiptera, or true bugs (50.7%), followed by Ephemeroptera, or mayflies (18.5%); Odonata, or dragonflies and damselflies (16%); Caenogastropoda, or molluscs (6.9%); Diptera, or true flies (3.8%); Plecoptera, or stone flies (2.5%); and the least abundant, Coleoptera, or beetles (1.6%).

The two sampling locations were selected to represent two different habitat types: waterfall 1 has stagnant water with vegetation, while the pool has flowing water without vegetation. The waterfall 1 presented all taxa except Diptera and Plecoptera, and the pool presented all taxa except Coleoptera.

Odonata was the order with the most species found, *Anax* spp., *Trithemis* spp., *Urothemis thomasi Zygoptera* spp., *Paragomphus* spp. (Table 14).

Table 13: Number of specimens collected in each taxonomic order per sample site with percentages between brackets

Taxon	Waterfall 1	(%)	Pool	(%)	Total	(%)
Number of samples	6		6		12	
Caenogastropoda	10	(8.3)	15	(6.2)	25	(6.9)
Coleoptera	6	(4.9)	0	(0)	6	(1.6)
Diptera	0	(0)	14	(5.8)	14	(3.8)
Ephemeroptera	6	(4.9)	61	(25.2)	67	(18.5)
Hemiptera	42	(34.7)	142	(58.7)	184	(50.7)
Odonata	57	(47.2)	1	(0.4)	58	(16)
Plecoptera	0	(0)	9	(3.7)	9	(2.5)
Total	**121**		**242**		**363**	

Table 14: Number of Freshwater invertebrates identified at different levels

Class	Order	Suborder	Family	Species	n
Gastropoda	Caenogastropoda			*Melanoides tuberculata*	25
Insecta	Coleoptera		Dytiscidae		6
	Diptera		Culicidae		14
	Ephemeroptera			Mayfly spp.	67
	Hemiptera		Notonectidae	*Enithares lineatipes*	7
			Naucoridae	*Heleocoris minusculus*	177
	Odonata	Anisoptera	Aeshnidae	*Anax* spp.	6
			Gomphidae	*Paragomphus* spp.	35
			Libellulidae	*Trithemis* spp.	11
				Urothemis thomasi	1
		Zygoptera		Damselfly spp.	5
	Plecoptera			Stone fly spp.	9

Image 3: *Anax* sp. (early instar)

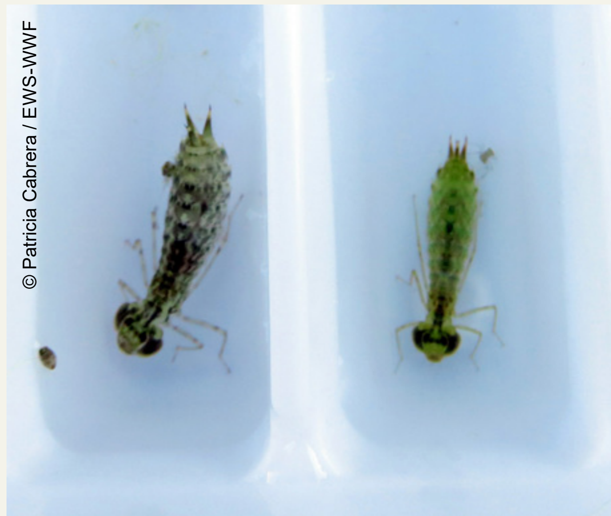

Image 4: *Anax* sp. (late instar)

Image 5: *Paragomphus* sp.

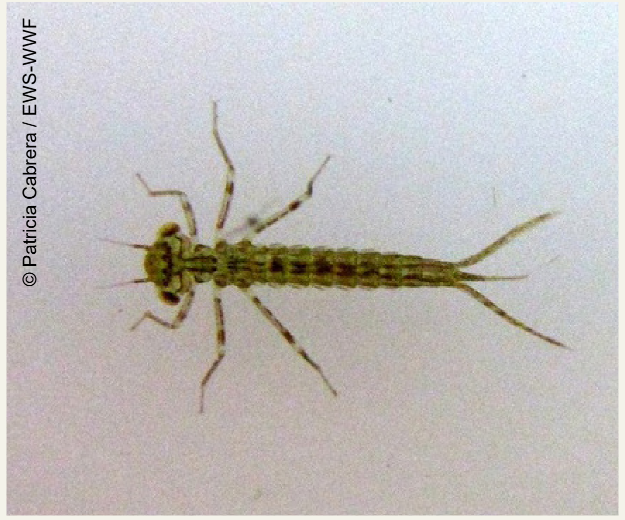

Image 6: *Damselfly* sp.

Image 7: *Trithemis* sp.

Image 8: *Urothemis thomasi*

5.2.3 Interannual Variations

There were some differences in the composition of freshwater invertebrates surveyed during the two seasons (Figure 16). Hemiptera, Ephemeroptera, and Odonata remained the most abundant order; Plecoptera was less abundant; and while Caenogastropoda, Diptera, and Coleoptera were more abundant in season 4.

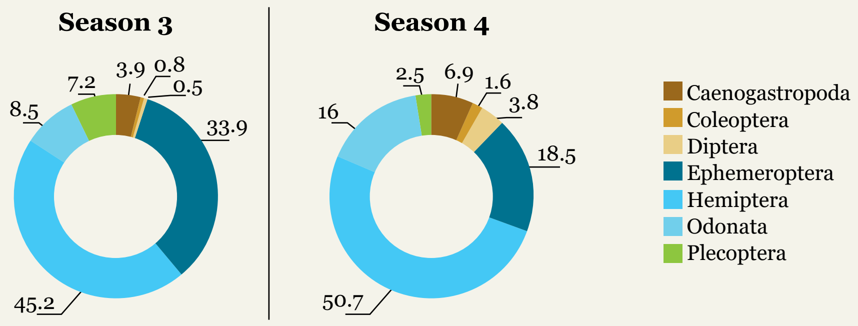

Figure 16: Comparison of the percentage composition of invertebrates between seasons 3 and 4

5.3 ODONATA POPULATION STUDIES

The insect order Odonata (dragonflies and damselflies) is often used as an indicator of ecosystems' health and conservation management. Species diversity and abundance in odonate communities are generally considered a good indicator of water quality as odonates depend on water throughout their whole life cycle (Corbet 2004). Each species has a different level of tolerance to environmental conditions, such as water temperature, dissolved oxygen, pH, and so on. As predators, either when adults or during their larval stage, odonates' existence is linked to prey availability; their numbers and diversity reflect the conditions of the whole aquatic ecosystem.

Out of the 30 odonate species known in the UAE, 25 have been recorded in Wadi Wurayah, which is a positive indicator of the health of the freshwater ecosystem and water quality. However, to maintain this ecological equilibrium and diversity, we need to understand what the species' requirements are, how their life cycle is linked to environmental conditions, and what the amplitude and cycle of variations in population abundance are.

5.3.1 Species Diversity

During the first two seasons, important effort has focused on collecting data on odonates' species diversity, abundance, and behaviour. Point counts were performed for 15 minutes in preselected areas of 10 m radius. In season 3, the monitoring protocol was adjusted to reduce the field survey effort requirement and the spatiotemporal constraints. The standardised survey methodology involved the record of all odonates seen throughout the six sampling sites; notes on both sex and behaviour (sitting, flying, chasing another Odonata, mating, laying, etc.) were taken. This new methodology aims to explore the reliability of the presence-absence methodology to document trends in odonates' population, where less survey effort is applied (Judas 2016).

In total, 500 odonate individuals of 20 species were recorded from October 2016 to March 2017 in 73 point counts. Species diversity varied between months (Figure 17), from a minimum of 8 species recorded in January and February to a maximum of 16 in March. The number of species recorded per point count varied from 1 to 11 individuals, and the monthly average of species recorded was 3.3 ± 1.9 per point count.

Species diversity was higher in the pools (waterfall, pool, and downstream), where the average number of species was 3.5 ± 1.9, compared with that in the streams (stream, fish spa, and gorge), where the average number of species was 2.9 ± 1.9 (Figure 18).

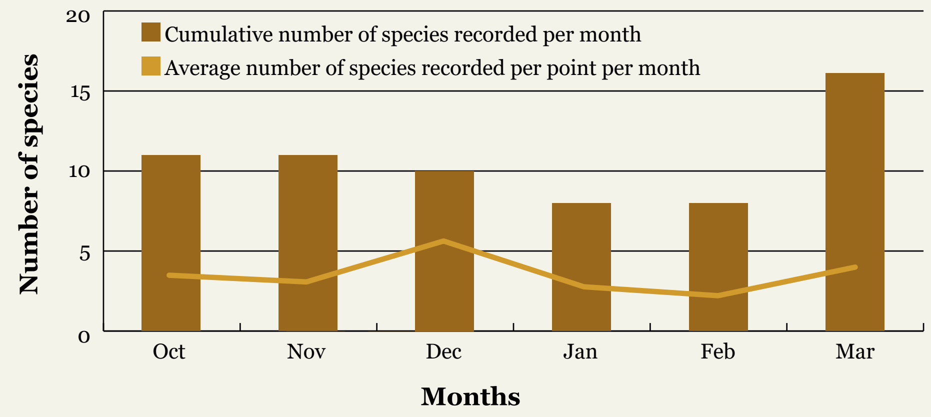

Figure 17: Monthly variation of odonate species diversity from October 2016 to March 2017

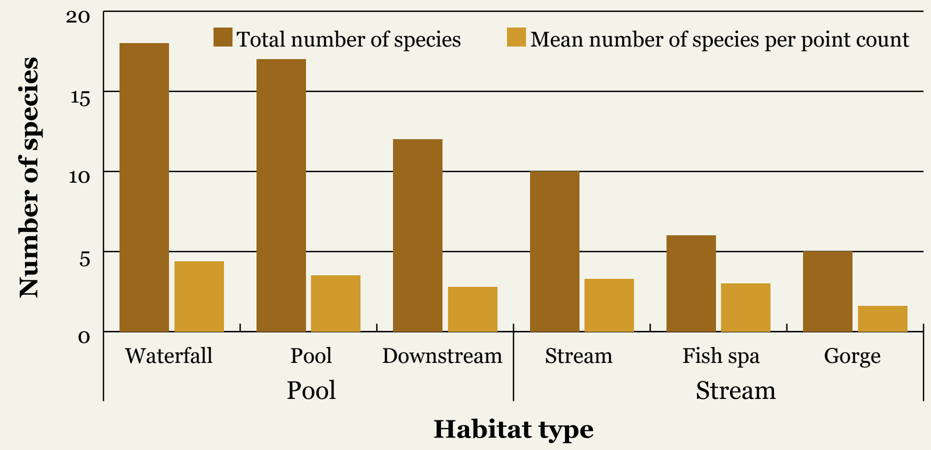

Figure 18: Variation of odonate species diversity per location from October 2016 to March 2017

The data collected highlight some patterns in species occurrence (Table 15). While some species such as *Anax imperator, Crocothemis erythraea, Crocothemis sanguinolenta, Diplacodes lefebvrei, Ischnura evansi,* and *Trithemis arteriosa* were observed throughout the fielding season, some others such as *Arabicnemis caerulea, Arabineura khalidi, Orthetrum chrysostigma, Paragomphus sinaiticus, Pseudagrion decorum*, and *Zygonyx torridus* were absent in the colder months of December and January.

Table 15: Presence or absence of individual species from October 2016 to March 2017; dark blue indicates that the species was present in all 6 months, lighter blue indicates that the species was present in 3–6 months, lightest blue indicates that the species was present in 1–2 month(s), and white indicates that the species was not recorded.

Species	Oct	Nov	Dec	Jan	Feb	Mar	N months of presence
Anax imperator	1	1	1	1	1	1	6
Crocothemis erythraea	1	1	1	1	1	1	6
Crocothemis sanguinolenta	1	1	1	1	1	1	6
Diplacodes lefebvrei	1	1	1	1	1	1	6
Ischnura evansi	1	1	1	1	1	1	6
Trithemis arteriosa	1	1	1	1	1	1	6
Anax parthenope	0	1	1	0	0	1	3
Arabicnemis caerulea	1	1	0	0	0	1	3
Orthetrum sabina	1	1	1	0	0	0	3
Pantala flavescens	1	1	1	1	0	1	5
Anax ephippiger	0	0	0	1	0	0	1
Arabineura khalidi	1	0	0	0	0	1	2
Orthetrum ransonnetii	0	0	0	0	0	1	1
Orthetrum chrysostigma	0	0	0	0	1	1	2
Paragomphus sinaiticus	0	0	0	0	1	1	2
Pseudagrion decorum	0	1	0	0	0	0	1
Trithemis annulata	0	0	1	0	0	0	1
Trithemis kirbyi	0	0	0	0	0	1	1
Urothemis thomasi	0	0	0	0	0	1	1
Zygonyx torridus	1	0	0	0	0	1	2
Ischnura senegalensis	0	0	0	0	0	0	0
Orthetrum abbotti	0	0	0	0	0	0	0
Paragomphus genei	0	0	0	0	0	0	0
Sympetrum fonscolombii	0	0	0	0	0	0	0
Tramea basilaris	0	0	0	0	0	0	0
Total number of species	**11**	**11**	**10**	**8**	**8**	**16**	**20**

5.3.2 Interannual Variations

Species diversity and abundance showed a positive trend across the four seasons (Table 16). Of the 25 species recorded in WWNP, 18 were recorded in season 1, 19 in season 2, and 20 in seasons 3 and 4. While considering the frequency of occurrence across the season, expressed as the number of months during which each species was recorded, only three species were present throughout season 1, compared with 7, 5, and 6 species in seasons 2, 3, and 4, respectively.

Caution needs to be taken while interpreting the results. This increase of species encounters could indicate a regular increase in species abundance, which would be a good sign for the overall health of the Wadi Wurayah ecosystem. However, the skills of the observers have improved over the years, and the survey methodology has been slightly modified in season 3, which might affect the observed trend.

Table 16: Presence or absence of individual species during the four seasons of the survey; dark blue indicates that the species was present 6–7 months, lighter blue indicates that the species was present 3–6 months, and lightest blue indicates that the species was present 1–2 month(s).

	Total months present			
Species	**Season 1**	**Season 2**	**Season 3**	**Season 4**
Anax imperator	7	7	7	6
Trithemis arteriosa	7	7	7	6
Crocothemis erythraea	2	7	7	6
Crocothemis sanguinolenta	1	7	7	6
Ischnura evansi	2	7	7	6
Orthetrum chrysostigma	7	7	6	2
Arabineura khalidi	5	6	6	2
Pantala flavescens	4	7	6	5
Trithemis kirbyi	6	6	5	1
Arabicnemis caerulea	3	5	6	3
Diplacodes lefebvrei	1	3	6	6
Zygonyx torridus	4	4	3	2
Paragomphus sinaiticus	3	3	4	2
Orthetrum sabina	2	3	3	3
Orthetrum ransonnetii	4	0	4	1
Pseudagrion decorum	0	3	3	1
Urothemis thomasi	0	2	4	1
Trithemis annulata	1	1	0	1
Anax ephippiger	0	0	4	1
Anax parthenope	0	0	1	3
Ischnura senegalensis	0	0	2	0
Paragomphus genei	2	0	0	0
Orthetrum abbotti	0	1	0	0
Sympetrum fonscolombii	1	0	0	0
Tramea basilaris	0	0	0	0
Total species	**18**	**18**	**20**	**20**

The total number of species varied throughout the seasons along the years (Figure 19). Species diversity was consistently higher in March and April with a maximum of 17 species in April and lower in January and February with a minimum of 3 species in February. The monthly average number of species recorded per point count varied from 1 to 12 with an overall average of 3.6 ± 2 species per point count (Figure 20). The minimum monthly average number of species was recorded in February of season 1 (1.33 ± 0.82) and the maximum monthly average in October in season 3 (5.73 ± 2.33).

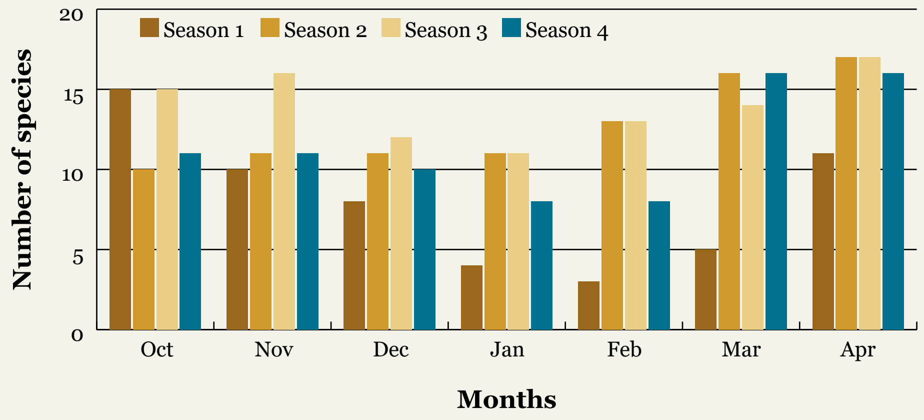

Figure 19: Seasonal and interannual variations in Odonata's species diversity from October 2013 to March 2017. No data were collected between May and September.

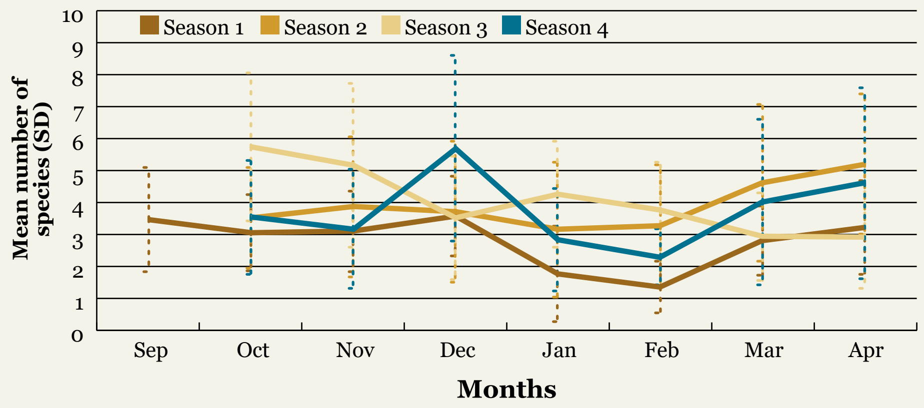

Figure 20: Monthly variations of the average number of species per point count from September 2013 to March 2017

5.3.3 Breeding Records

Different stages of the mating process were recorded during the entire survey (Table 17) and are defined as follows: Precopulatory tandem (T)—in Zygoptera, this is when the male appendages grasp the prothorax of the female, while in Anisoptera, the head of the female is grasped. Copulation (C)—the male transfers the sperm to the female. Ovipositing (O)—the female lays her eggs.

In season 4, only 7 species were recorded in a reproductive behaviour compared with 6, 12, and 13 species in seasons 1, 2, and 3, respectively. The record of breeding activities during the whole survey showed seasonal variations. The maximum number of species breeding was highest in October and April with 9 species recorded in both cases, which correlates to the highest species diversity. During the whole survey, the only species that was breeding in all months, from September to April, was *Trithemis arteriosa*, while species such as *Anax ephippiger, Diplacodes lefebvrei, Orthetrum ransonnetii, Paragomphus sinaiticus, Trithemis annulata,* and *Zygonix torridus* exhibited breeding behaviour for only 1 month.

Table 17: Odonate species' breeding activity per month from October 2016 to March 2017. Letters highlighted in yellow indicate breeding behaviour recorded in season 4.

Species	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Anax ephippiger								O
Anax imperator		O	C			O	O	
Arabicnemis caerulea		C	C					CO
Arabineura khalidi	C	C						
Crocothemis erythraea	C	O	CO	CO		CO	O	O
Crocothemis sanguinolenta					O			T
Diplacodes lefebvrei		C						
Ischnura evansi		O	CO	C	C	C		O
Orthetrum chrysostigma			C				C	
Orthetrum ransonnetii								O
Orthetrum sabina		O	O					
Pantala flavescens		O	O	O	O			
Paragomphus sinaiticus								O
Trithemis annulata								O
Trithemis arteriosa	O	CO	CO	CO	O	O	O	TCO
Zygonyx torridus				O				

5.3.4 Dragonfly Tagging

The technique of mark-release-recapture (MRR) is a powerful method for monitoring populations (Thompson et al. 1998). This method has been used in Wadi Wurayah since 2013, allowing us to mark 844 individuals of 14 species. This technique was implemented in Wadi Wurayah to estimate survival rates, population abundance, and dispersal of dragonflies. Among all the dragonflies caught and marked in seasons 1 and 2, *Trithemis arteriosa* was by far the most captured and recaptured species, representing 58% of all captures and 73% of all recaptures. For this reason, all efforts of capture were focused on this species in seasons 3 and 4. Morphometric measurements taken in seasons 1 and 2 were discontinued in seasons 3 and 4 to minimise the time for handling the specimens.

Dragonflies are caught using classic butterfly nets. Each dragonfly is then held on a magnetic board by placing a magnet on the left forewing and the right hindwing (Figure 16 shows a marked male). A four-digit number incremented by 1 at each new capture is written with a permanent marker on the right forewing. For each captured individual, date, time, and location are recorded along with the tagging identification number.

Image 9: Marked *Trithemis arteriosa*

Overall, 77 *Trithemis arteriosa* (96% males and 4% females) individuals were marked from October 2016 to February 2017, in 28 sessions that lasted 20 min on average. The number of marked individuals varied monthly, from a minimum of 5 marked individuals in February to a maximum of 23 in November 2016. Numbers of marked individuals also varied according to years (Figure 21). However, these differences are presumably more related to trapping effort and success of capture rather than to variations in population abundance.

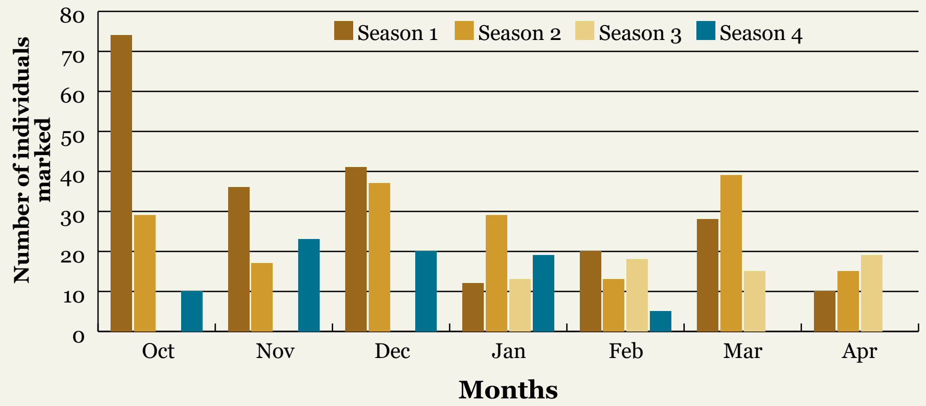

Figure 21: Seasonal and interannual variations in numbers of *Trithemis arteriosa* marked from October 2013 to February 2017.

The low recapture rate (18.2%) reveals an important turnover of the population either because of low survival rates, high dispersal, or a combination of both. The maximum time for recapture was recorded in this season, 201 days; this individual was marked in April 2016 and recaptured in October of the same year, being the first record of a recaptured dragonfly that was captured in a previous season (Table 18).

Table 18: Recapture rate and time to recapture of *Trithemis arteriosa* per season

Season	Capture	Recaptured at least once	Recaptured > once	Recapture rate	Time to recapture (in days)		
					Mean	Min	Max
S1	231	37	5	16%	14.1 ± 16.9	1	85
S2	179	27	6	15.1%	7.2 ± 6.8	1	22
S3	65	18	5	27.7%	5.4 ± 5.4	1	15
S4	77	14	2	18.2%	20.7 ± 52.3	2	201
Total	552	96	13	17.4%			

5.3.5 Exuviae Collection

During the aquatic larval stage, odonates experience several processes of irreversible changes in morphology, physiology, and behaviour, called metamorphosis. The latter is the moult that produces the adult dragonfly or damselfly. The exoskeleton that remains after the moult of the last larval stage is called exuviae. They are found hanging on rocks or in the vegetation around waterbodies where adults have laid their eggs and larvae have grown. The collection of exuviae provides important information to quantify population abundance and seasonal patterns and proves without a doubt that a species is breeding in the area. Exuviae were collected by hand during field activities from October 2016 to March 2017 at six sampling sites. They were placed in a container labelled with the date and site of collection and identified in the laboratory.

Image 10: Emergence of a damselfly

Image 11: Exuviae of *Anax* sp.

A total of 81 exuviae from 9 species were collected, of which 25 of 4 species could be identified at the species level (Table 19). In season 4, the highest number of exuviae was collected in October, whereas in season 2, the highest number was in March and April, indicating possible interannual variation in the peak period of emergence. On the other hand, the monthly variations of species diversity assessed from the exuviae did not perfectly correlate with species diversity recorded by presence or absence records on point counts. These differences might occur because of breeding period and the duration of the development of the larval stage.

Table 19: Number of exuviae collected per species and per month and comparison with species diversity

Species	Oct	Nov	Dec	Jan	Feb	Mar	Total
Anax sp.	17	3			1	1	22
Crocothemis sp.	2		1		1		4
Paragomphus sinaiticus	1					1	2
Paragomphus sp.				1	2		3
Trithemis arteriosa	19						19
Trithemis sp.	20	1			1	1	23
Urothemis thomasi	1						1
Zygonix torridus	1	1			1		3
Zygoptera sp.	3					1	4
Total number of exuviae	64	5	1	1	6	4	81
Number of species	9	3	1	1	5	4	9
Flying adult species diversity	11	11	10	8	8	15	19

5.4 TOAD POPULATION STUDIES

Wadi Wurayah is inhabited by the only two species of native amphibians in UAE, the Arabian toad (*Sclerophrys arabica*) and the Dhofar toad (*Duttaphrynus dhufarensis*). Although both species are listed as least concern by the International Union for Conservation of Nature (IUCN Red List 2015), their survival depends on the availability of surface waters. The Arabian toad, more dependent on permanent surface water than the Dhofar toad (Soorae et al. 2013), is much more abundant, or at least visible, in the park. These differences in ecology and dependence to water make these two species an excellent model for studying the effects of climate change on the Hajar Mountains ecosystems and for determining how different breeding strategies can favour (or not) a species. The purpose of this study is to

1. characterise and monitor toads' populations,
2. assess toads' abundance and their spatiotemporal variations,
3. document the species' morphometry, and
4. assess individual movements, survival, population size, and dynamics.

5.4.1 Methodology: Point Count and Tagging

Toads were captured from October 2016 to February 2017 at nine different sampling sites. They were visually searched and captured using hand nets within a 20 m diameter area for 26 min on average and placed in a bucket partially filled with water.

Toads' measurements included snout-to-vent length (SVL), which is defined as the distance between the tip of the head and the end of the cloaca (to the nearest 0.1 mm); rear leg length (RLL), which is the distance between the foot and the end of the cloaca (to the nearest 0.1 mm); and body weight (to the nearest 0.1 g). At all locations, water quality parameters and meteorological conditions were recorded.

Following the criteria adopted by Pyke (2005), toads whose SVL exceeded 40 mm were fitted with passive integrated transponder (PIT) tags, allowing detection using a portable handheld reader. PIT tags (biocompatible glass-encapsulated tags, 134.2 kHz radio frequency 8.4 mm, Biomark) were loaded in a disposable needle and injected subcutaneously into the postdorsum position.

5.4.2 Population Abundance

A total of 617 Arabian toads were counted in 101 point counts distributed among nine sampling sites. The average number caught per point count was 6.1 ± 7.8 (min–max 0–36, n=101). No Dhofar toads were found.

Toads' abundance showed important variations in time and between locations (Table 20). The number of toads in the waterfall area was significantly lower (0.75 ± 1.2) than that in the main wadi (10.7 ± 6.6). Downstreams 1 and 2 had the highest abundance. Toads' abundance was lower at the start and the end of the season and highest during the coldest months of December and January.

Table 20: Number of toads caught per point count (mean ± SD) according to month and sampling location; (–): no point counts performed, (0) no toads found

	Waterfall area				Main wadi					Mean
	Waterfall 1	Waterfall 2	Pool	Stream	Downstream 1	Downstream 2	Fish spa 1	Fish spa 2	Gorge	
Oct	0.5 ± 0.7	0	0.5 ± 0.7	1 ± 1.4	30	36	4.3 ± 1.5	5	–	**6.8 ±11.9**
Nov	0.7 ± 1	–	0.2 ± 0.5	0.7 ± 1	8	15.5 ± 6.4	2.5 ± 0.7	1.5 ± 2.1	17.5 ± 0.7	**4.2 ± 6.5**
Dec	1	0	0.3 ± 0.6	1	15.3 ± 8.1	18 ± 2.8	4	16	14	**8.4 ± 8.3**
Jan	1 ± 1.73	0	0.5 ± 0.7	1	18.3 ± 2.9	23.5 ± 2.1	8.7 ± 2.5	1	12.5 ± 2.1	**8.4 ± 8.7**
Feb	2 ± 2.4	0	0.4 ± 0.5	0	5 ± 5.7	4.7 ± 4.9	10 ± 3.6	5.5 ± 4.9	11 ± 3.6	**4.6 ± 5**
Mean	**1.2 ± 1.6**	**0**	**0.4 ± 0.5**	**0.7 ±0.8**	**13.2 ± 9.1**	**15.4 ± 10.7**	**6.8 ± 3.8**	**5.1 ± 5.6**	**13.2 ± 3.4**	**5.1 ± 7.8**

5.4.3 Variation in Body Size

All the 617 Arabian toads captured were measured and released. The average body weight was 2.5 ± 2.4 g (min–max 0.5–17 g), the average body length was 27.7 ± 5.7 mm (min–max 18.8–57 mm), and the average rear-leg length was 23.9 ± 4.9 mm (min–max 15.8–47.2 mm).

The average size of the toads varied in time and location (Table 21), with the bigger toads found in the waterfall area (6.3 ± 3.5 g) and the smallest in the main wadi (2.2 ± 1.89 g). The bigger toads were found in November (3.3 ± 3.7 g), which fit with the breeding records in December.

Table 21: Body weight of toads caught per point count (mean ± SD, n= 617) according to month and sampling location; (–) no point counts performed, (0) no toads found

	Waterfall area				Main wadi					Mean
	Waterfall 1	Waterfall 2	Pool	Stream	Downstream 1	Downstream 2	Fish spa 1	Fish spa 2	Gorge	
Oct	10	0	5	1.9 ±0.1	2.8 ± 2.2	1.4 ± 1.2	2 ± 2.4	1.4 ± 0.4	–	**2.1 ± 2**
Nov	10.3 ±3.8	–	5	4.7 ±1.2	6.1 ± 4.1	2.5 ± 1.5	3.3 ± 3.8	1.9 ± 0.1	2.4 ± 0.9	**3.3 ± 3.7**
Dec	5 ± 2.8	0	5	4	3.2 ± 3.4	1.6 ± 0.5	2.1 ± 2.1	2.1 ± 0.4	1.9 ±1.5	**2.3 ± 2.2**
Jan	5.7 ± 1.5	0	8	2.7 ±1.2	2.7 ± 2.1	1.3 ± 0.6	2 ± 0.8	1	2.1 ± 1.1	**2.1 ± 1.7**
Feb	7.9 ± 4	0	3.3 ± 3	0	2.5 ± 3	1.3 ± 0.3	2.3 ± 0.8	3.3 ± 2.7	2.9 ± 1.6	**2.9 ± 2.4**
Mean	**7.7 ± 3.6**	–	**5.1 ± 2.4**	**3.4 ±1.5**	**3.1 ± 3.5**	**1.6 ± 1**	**2.2 ± 1.5**	**2.3 ± 1.6**	**2.4 ± 1.4**	**5.5 ± 2.4**

5.4.4 Toad Tagging

Toad capture occurred in 617 occasions. On 583 captures (94.5%), individuals had an SVL < 40 mm and were not tagged. On 17 occasions (2.7%), individuals that had an SVL ≥ 40 mm were tagged. The 17 remaining capture occasions (12 recaptures (2%) and 5 captures) which had an SVL ≥ 40 mm were found at non-tagging locations (0.8%).

The average number of toads tagged per point count was 0.3 ± 0.5 (min–max 0–3, n=44). Of the 17 toads tagged this season, only 6 individuals were recaptured—2 were tagged this season, and the other 4 were tagged during the previous season. For the last ones, the maximum number of recaptures was 9, the average time between the first recapture and the last recapture was 390 ± 100 days, and the maximum time recorded was 475 days.

Toad tagging was performed only in two locations in the waterfall area (waterfalls 1 and 2) and two in the main wadi (downstreams 1 and 2). There was no dispersal of toads between the waterfall area and the main wadi. Only one individual in the main wadi moved in several occasions from downstreams 1 and 2 (40 m distance).

The number of toads tagged in season 4 decreased because majority of the toads captured were too small to be tagged. The recapture rate also considerably decreased from 43.9% in season 3 to 11.7% in season 4 (Table 22). This decrease might be explained by lower breeding activity in relation to inadequate environmental conditions (few rainfalls), involving less adult-size toads. Testing this hypothesis will require more trapping occasions and complex analysis.

Table 22: Comparison of the number of toads tagged per season

	Season 3	Season 4	Total
Toads tagged	82	17	99
Toads recaptured	36	2	39
Recapture rate	43.9%	11.7%	39.4%

5.4.5 Breeding Records

Presence or absence of eggs and tadpoles has been recorded from October 2016 to February 2017, as well as toads' vocalisations. Eggs were recorded only once at the end of November 2016, while tadpoles and vocalisations were recorded only once at the end of February. The low numbers of breeding records this season are possibly linked to the low amount of rainfall and the absence of any flash floods that could create temporary pools. The high number of toadlets found this year might indicate that toads have been breeding during summer 2016.

5.4.6 Interannual Variation

Abundance showed important seasonal and interannual variations. The average number of toads per point count was calculated per month and compared between seasons (Figure 22). Abundance appeared to be highest in December–January in season 4 (8.4 ± 8.4; n=35), while in season 3, the highest abundance was in October–November (8.3 ± 3.4; n=23). In contrast, the lowest abundance of the three seasons was in January–February in season 3 (0.64 ± 0.96, n=25).

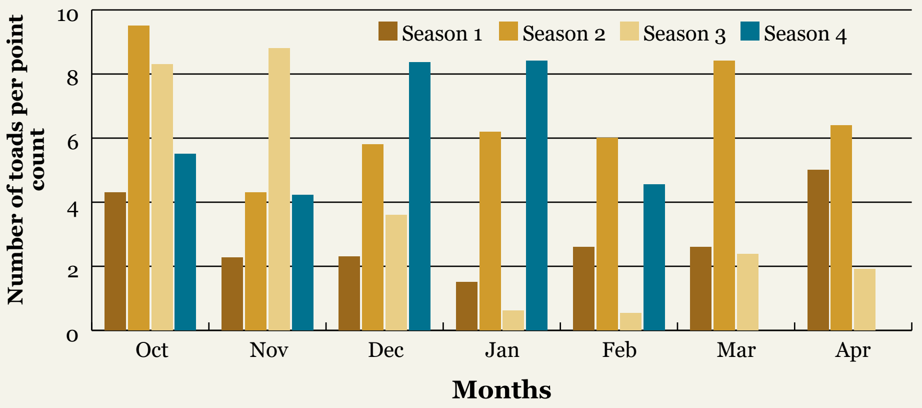

Figure 22: Seasonal and interannual variations in toads' abundance from October 2013 to February 2017. Toad abundance is measured as the monthly average of the number of individuals per point count. No data were collected between May and September.

The number of point counts performed in season 4 was similar to that in previous seasons except in season 2 (Table 23). The total number of toads counted in season 4 has been the highest of the four seasons. Important differences on the size of toads are highlighted during the whole survey. The average size of toads have been decreasing since the start of the programme. The bigger toads were found in season 1 (7.2 ± 3; n=333), decreasing in seasons 2 and 3 (5.1 ± 3.1; n=517 and 5.3 ± 2.6; n=354, respectively); and the smallest toads were found in season 4 (2.5 ± 2.4 g; n= 617). These differences in population abundance and age structure might be due to change of weather, as per the whole survey, we have experienced different weather conditions along the years (i.e., rainfall and flash floods) that have affected the physicochemical characteristics of the habitat in Wadi Wurayah, remodelling the structure of the pools and streams, which seems to be conditioning the behaviour of this species.

Table 23: Interannual comparisons of toad point counts, number of toads caught, and body measurements

	Season 1	Season 2	Season 3	Season 4
Total number of point counts	114	76	106	101
Total number of toads caught	333	517	354	617
Average weight (g)	7.2 ± 3	5.1 ± 3.1	5.3 ± 2.6	2.5 ±2.4
Average body length (mm)	41.8 ± 6.8	36.6 ± 8.4	39 ± 6.2	27.5 ± 5.6
Average leg length (mm)	51.3 ± 10.1	31.5 ± 7.8	34.5 ± 6	23.9 ± 4.9

6. MONITORING OF TERRESTRIAL HABITATS

6.1 VEGETATION STUDY

The vegetation study aims to identify and implement methodologies to assess the vegetal biomass and productivity in the WWNP. These two environmental parameters are critical in assessing the carrying capacity of the park for herbivores. An assessment of how much food is available for herbivores and how that availability may vary in time and space would enhance the design of the reintroduction strategy for the Arabian tahr (*Arabitragus jayakari*) and the mountain gazelle (*Gazella gazella*) within the park, as well as provide direction for an adaptive management of the park. Biomass estimation can also be used to assess carbon sequestration in these ecosystems. In addition, vegetation surveys will help researchers understand and monitor flora species phenology.

6.1.1 Pilot Study

The pilot study, initiated in 2015, was continued with the assistance of WRLP volunteers to develop a protocol for measuring and monitoring vegetation, looking for the most efficient, reliable, and least time-consuming method. These methodology requirements are set to maximise the possibility of implementing vegetation monitoring in the long term while providing reliable indices of environmental changes. The protocol aims to assess relative abundance, species density, and biomass.

6.1.2 Sampling

The main initial objective of the study was to measure the density of the most abundant species found in the wadi. The species selected was *Heliotropium brevilimbe* (family *Boraginaceae*). The sampling technique consisted in randomly selecting 10 m^2 quadrats distributed over four different habitats (gravel ground, slope, terrace, and wadi bed). Geographic location (GPS coordinates), substrate, and percentage of vegetation cover were recorded for each quadrat. Then all *Heliotropium* individuals were counted; and their maximum height, length, and width were measured to assess the volume of each individual. The number of stems in each growth/reproductive stage (seedling, vegetating, flowering, seeding, or dry) was also recorded.

Image 12: *Heliotropium brevilimbe*

Image 13: Volunteers sampling vegetation

A total of 48 quadrats were sampled in different habitats by teams of five volunteers and their field guide. Sampling five quadrats lasted 2 hours on average.

A total of 32 samples of *Heliotropium* were randomly selected from the four habitats; effective height, width, and length for each individual were measured. The samples were then clipped, placed in paper bags, and dried in a forced-air oven at 60°C until weight stabilised after approximately 48 hours to assess their biomass.

6.1.3 Species Phenology

Vegetation phenology on each quadrat was assessed by quantifying the percentage of stems in different growth-reproductive stages. During the sampling period, most parts of the vegetation were in either immature or vegetating stage. The vegetation appeared predominantly in vegetative development (green stage) in all habitats (72% in gravel ground, 76% on slopes, 67% on terrace, and 78% in wadi beds). Ratio of flowering was quite similar in all four habitats (8% in gravel ground, 9% on slopes, 12% on terrace, and 10% in wadi beds). The main difference appeared in the proportion of fruiting plants, which was slightly higher on slopes (26%) than on gravel grounds (8%) and in wadi beds (14%) and absent on terraces (0%). The percentage cover of *Heliotropium* was found higher on gravel ground (4%), while it was found lower than 2.5% in the other three habitats as was 2.1% on slopes, 1.3% on terrace, and 2.5% in wadi beds (Figure 23).

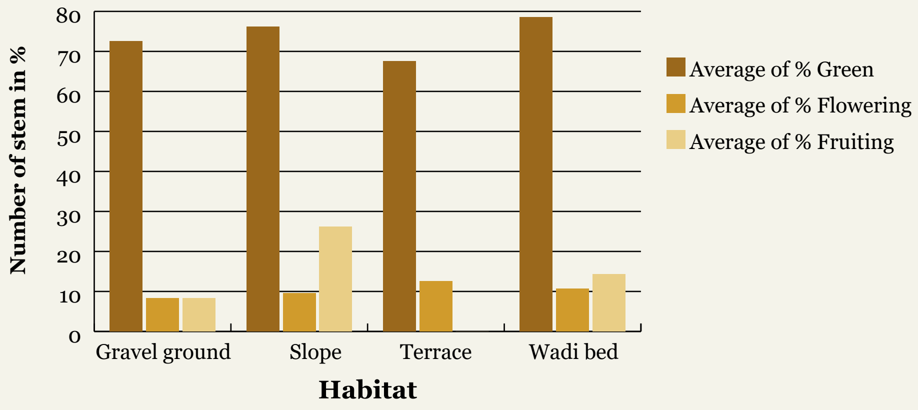

Figure 23: Distribution of growth-reproductive stages of the vegetation in four different habitats

6.1.4 Biomass

The average height of the 32 samples of *Heliotropium brevilimbe* collected in the field was 26.2 ± 13.2 cm, for an average fresh weight of 53.6 ± 38.1 g and an average volume of 0.17 ± 0.14 m3. The dry weight represented 54% ± 56% of the fresh weight; that is, 46% of its weight was water. The volume of each sample was calculated as the volume of a half sphere, whose radius was the average of height, width, and length of each specimen.

To assess the biomass of *Heliotropium* on each quadrat, given that the records taken in the field were the number of specimen and their volume, we looked at how dry weight and volume from the 32 collected specimens were correlated using linear and power regressions (Table 24). Dry weight and volume were poorly correlated using linear regressions. The power regression provided a slightly better correlation, and the equation y = 0.1132x0.4566 was used to assess the dry weight of each *Heliotropium* individual measured on the quadrat (Figure 24).

Table 24: Correlations between volume and dry weight

Regressions		Dry weight – volume
Linear	Trend line equation	y = 5E-05x + 19.977
	R^2	0.12
Power	Trend line equation	$y = 0.1132x^{0.4566}$
	R^2	0.3958

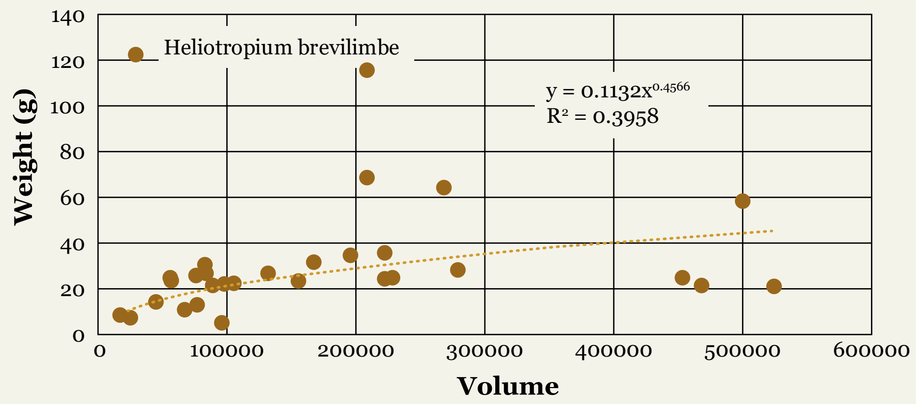

Figure 24: Correlation between volume and dry weight (g) for 32 samples of *Heliotropium brevilimbe*

Summing the estimated weight of individuals, the average dry weight of *Heliotropium brevilimbe* per 100 m² quadrat was 0.10 ± 0.10 kg (Table 25). By extrapolation, the biomass of *Heliotropium brevilimbe* was 10 ± 10 kg per ha, or about 0.01 t/ha. In comparison, the highest biomass measured on earth is 228 t/ha in the tropical forests of South America.

Table 25: Biomass of *Heliotropium brevilimbe* assessed on 100 m² quadrat and extrapolated per ha in four habitats in Wadi Wurayah

Heliotropium brevilimbe	Gravel ground	Slope	Terrace	Wadi bed	Total
N	12	12	12	12	48
Dry weight (kg)/quadrat (Mean ± SD)	0.13 ± 0.11	0.07± 0.1	0.08 ± 0.09	0.1± 0.1	0.1± 0.1
Dry weight (kg)/ha (mean ± SD)	13 ± 11	7 ± 10	8 ± 9	10 ± 10	10 ± 10

6.1.5 Carbon Sequestration

This biomass assessment can also be converted into an assessment of carbon store. For woody biomass, it is estimated that 50% of it is carbon. The carbon contents of *Heliotropium brevilimbe* is not exactly known, but applying the same ratio of 0.5 provides a figure of 0.005 t/ha of carbon store.

6.2 CONCLUSIONS AND REMARKS

Compared with the last season, some changes were made in assessing plant biomass per species. The approach is to measure the exact biomass of a limited number of specimens, for which morphometric measurements are also taken. Measuring plants in the field is easier and quicker to perform than measuring their weight, which has to be done in the laboratory. Assessing plant weight by taking a few selected measures in the field would allow increasing sample size and obtaining more accurate assessment of the biomass, without having to cut the vegetation. In previous seasons, the height of each individual was compared with its weight, while in this season, the volume of each individual was calculated from three dimensional measurements, considering that each plant can be assimilated to a half sphere, and then calculating the correlation between volume and weight. The volume and dry weight of *Heliotropium brevilimbe* correlated poorly. The irregular shape of plants that did not match a half sphere presumably partially explained these poor correlations. Moreover, several plant samples had well-developed woody stems that increased their weight compared with other plants samples. Additional investigations have to be conducted to obtain better assessment of plant biomass from morphometric measurements of samples.

More time and effort must be dedicated to assess all four habitats, track seasonal changes, and collect abiotic environmental data, such as temperature, humidity, light, wind, soil moisture, and composition on sampling sites to investigate the relationships between environmental conditions and flora biodiversity, phenology, and biomass. These sampling methods may also be extended to a study of the grazing pressure of feral goats in the park. This information is necessary for future adaptive management programmes.

7. DISCUSSION AND PERSPECTIVES

Since September 2013, 93 teams of volunteers have participated in the WRLP, contributing to collect a large amount of data. Over the years, new research activities have been added, and methodologies have been improved, helping us develop efficient protocols to monitor biodiversity in the Wadi Wurayah National Park.

The water quality monitoring programme has been substantially improved by integrating proper instrumentation and methodologies to measure water parameters. Water quality specialists of Fujairah Municipality have been contacted to provide guidance, and the next step will be to revise our protocols and cross-check the results we are able to obtain using simple test kits with the results a more advanced equipment provides. A new sensor for the handheld water meter will be added to get accurate results on turbidity measurements. The continuity of the water quality monitoring programme is fundamental for detecting abnormalities that could affect the health of this valuable ecosystem or for understanding all natural variations that determine the ecological functioning of the ecosystem.

Although there are no major concerns about the quality of water in Wadi Wurayah, the presence of harmful bacteria still persists in some waterbodies, exceeding the recommended levels for use as recreational waters. Even if those levels keep on decreasing, their monitoring should continue to guarantee a safe recreational use for the public in the future.

Only three different taxa of zooplankton were identified. Cyclops sp. is the most abundant species found in the waterbodies; however, a change in the protocol might bring interesting information about the other two species that have been observed but are by far less abundant.

This year, the sampling of freshwater invertebrates focused on the two most diverse sampling sites that were identified in the previous season. Odonata was the taxon with the highest species diversity, although not all individuals could be identified to the species level. In the future, we will put more efforts on identifying them.

The study of the Odonata population has gone through some changes since the beginning. Modification of the protocols has brought interesting results. The survey effort applied has been minimised and did not affect the quality of the results. It allowed more time for performing new research activities while ensuring continuity in the ongoing research activities. Recorded species diversity has increased since the beginning, and the recapture rate and average time of recapture of the marked species *Trithemis arteriosa* have improved compared with those in seasons 1 and 2.

Toad population showed important annual variations in abundance and population structure, while relations with environmental factors are not yet understood. This underlines the importance of the continued monitoring of these populations to better understand their dynamics. Tagging toads also provided interesting preliminary results, with the recapture of individuals that were tagged in the previous season. The PIT tag methodology appeared promising for monitoring toad populations, but the relatively low recapture rate highlights the need to implement the methods for a longer period.

The pilot study for vegetation monitoring explored a sampling technique that can be applied by nonscientists once proper demonstration is provided and their work supervised. The technique started providing interesting new and original results but also indicated where improvements are required, especially while designing protocols for different activities. So far, only two species have been investigated; other most common species will also be measured following a similar protocol in the future.

The study of the freshwater and terrestrial ecosystems in the WRLP will contribute to achieving the goal of preserving the biodiversity in WWNP, which requires a thorough understanding of how diversity and abundance might be affected by different management strategies.

With the closure of the WRLP, a new programme has been designed to continue the research in Wadi Wurayah: the Climate Research and Learning Programme (CCRLP). This programme follows the same objectives of the WRLP, but with a focus on climate change. The research aims to understand the ecological functioning of the freshwater ecosystem; how species, habitats, and environmental conditions are interrelated; and how changes in environmental conditions can affect species and habitats. Four new research activities will be carried out:

Two different field research activities have been developed to monitor birds' populations: point counts, where teams of volunteers will identify and count bird species in a specific area for 15 minutes, and individual focal observations, where the behaviour and activity of some birds of selected species will be measured according to temperature variations.

In the study of the nocturnal life of bats, volunteers will be able to listen to their echolocation calls. Bat surveys will be done with the help of bat detectors to quantify bats' activity in relation to environmental conditions (temperature, humidity, moonlight, etc.).

How do variations in temperature affect the growth and development of tadpoles? Volunteers will help answer this question by counting and measuring tadpoles that are raised in a controlled environment. Toad eggs will be collected from the field and placed in aquariums with five different temperatures.

Already tested with volunteers this year, the last new research activity is tree mapping. Volunteers will identify and locate trees on Google Earth maps to assess tree density. The challenge will be finding the trees using a GPS and completing a form to describe them.

8. REFERENCES

APHA, 1992. Standard methods for the examination of water and wastewater. 18th ed. American Public Health Association, Washington, DC.

Corbet, P. S., 2004. *Dragonflies: Behaviour and ecology of Odonata* (revised edition). England: Harley Books, 829 pp.

EPA, 1985. Ambient water quality criteria for ammonia. EPA-440/5-85-001, United States Environmental Protection Agency, Washington, D.C.

Hodkinson, I. D., and Jackson, J. K., 2005. Terrestrial and aquatic invertebrates as bioindicators for environmental monitoring, with particular reference to mountain ecosystems. *Environmental Management* 35 (5):649–666.

IUCN, 2016. IUCN red list of threatened species. Available online at: http://dx.doi.org/10.2305/IUCN.UK.2004.RLTS.T54574A11169048.en

Judas, J., 2016. Wadi Wurayah National Park: Scientific research report 2013–2015. EWS-WWF report, 115 pp.

Langmuir, D, 1997. *Aqueous environmental chemistry*. New Jersey: Prentice-Hall. Available online at: http://appslabs.com.au/ph%20and%20orp%20in%20water.htm

Morton, S. D., and Lee, T. H., 1974. Algal blooms-possible effects of iron. Environmental Science and Technology 8:673–674.

Orton, R., and Bebbington, J., 1996. The freshwater name trail: A key to the invertebrates of ponds and streams. The Field Studies Council, UK.

Professional plus water quality instrument—specifications. Available online at: https://www.airmet.com.au/assets/documents/product/156/file_1439354527_864.pdf

Pyke G., 2005. The use of PIT tags in capture-recapture studies of Frogs: A field evaluation. Herpetol. Rev. 36:281–285.

Scannell, P. W., & Jacobs, L. L., 2001. Technical report: No. 01-06. Effects of total dissolved solids on aquatic organisms. Alaska Department of Fish and Game, Division of Habitat and Restoration. Available online at: http://www.adfg.alaska.gov/static/home/library/pdfs/habitat/01_06.pdf

Soorae, P., Els, J., Gardner, D., and El Alqamy, H., 2013. Distribution and ecology of the Arabian and Dhofar toads (*Duttaphrynus arabicus* and *D. dhofarensis*) in the United Arab Emirates and adjacent areas of Northern Oman. Zool. Mid. East 59(3): 229–234.

Thompson, W. L., White, G. C., and Gowan, C., 1998. Monitoring vertebrate populations. San Diego: Academic Press.

Thompson, K., 2006. AWWA Research Foundation, WateReuse Foundation, & Water Quality Association. Characterizing and managing salinity loadings in reclaimed water systems. N.p.: American Water Works Association.

US Environmental Protection Agency, 1986. Ambient water quality criteria for bacteria, 18 pp. Available online at: https://www.regulations.gov/#!documentDetail;D=EPA-HQ-OW-2007-0808-0001

Webber, M., Edwards-Myers, E., Campbell, C., and Webber, D., 2005. Phytoplankton and zooplankton as indicators of water quality in Discovery Bay, Jamaica. *Hydrobiologia* 545 (1):177–193.

Wetzel, R. G., 2001. Limnology: Lake and river ecosystems (3rd edition). San Diego, CA: Academic Press.

Witty, L. M., 2004. Practical guide to identifying freshwater crustacean zooplankton. Cooperative Freshwater Ecology Unit, Laurentian University, Ontario, Canada, 2nd edition. Available online at: http://www3.laurentian.ca/livingwithlakes/wp-content/uploads/2012/06/Zooplankton-Guide-to-Taxonomy.pdf

Xing, W., & Liu, G. 2011. Iron biogeochemistry and its environmental impacts in freshwater lakes. Fresenius Environmental Bulletin, 20(6), 1339–1345.

YSI ProDSS Multiparameter Sampling Instrument, Available online at: https://www.ysi.com/File%20Library/Documents/Specification%20Sheets/YSI-ProDSS-W83-03-0715-Spec-Sheet.pdf

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