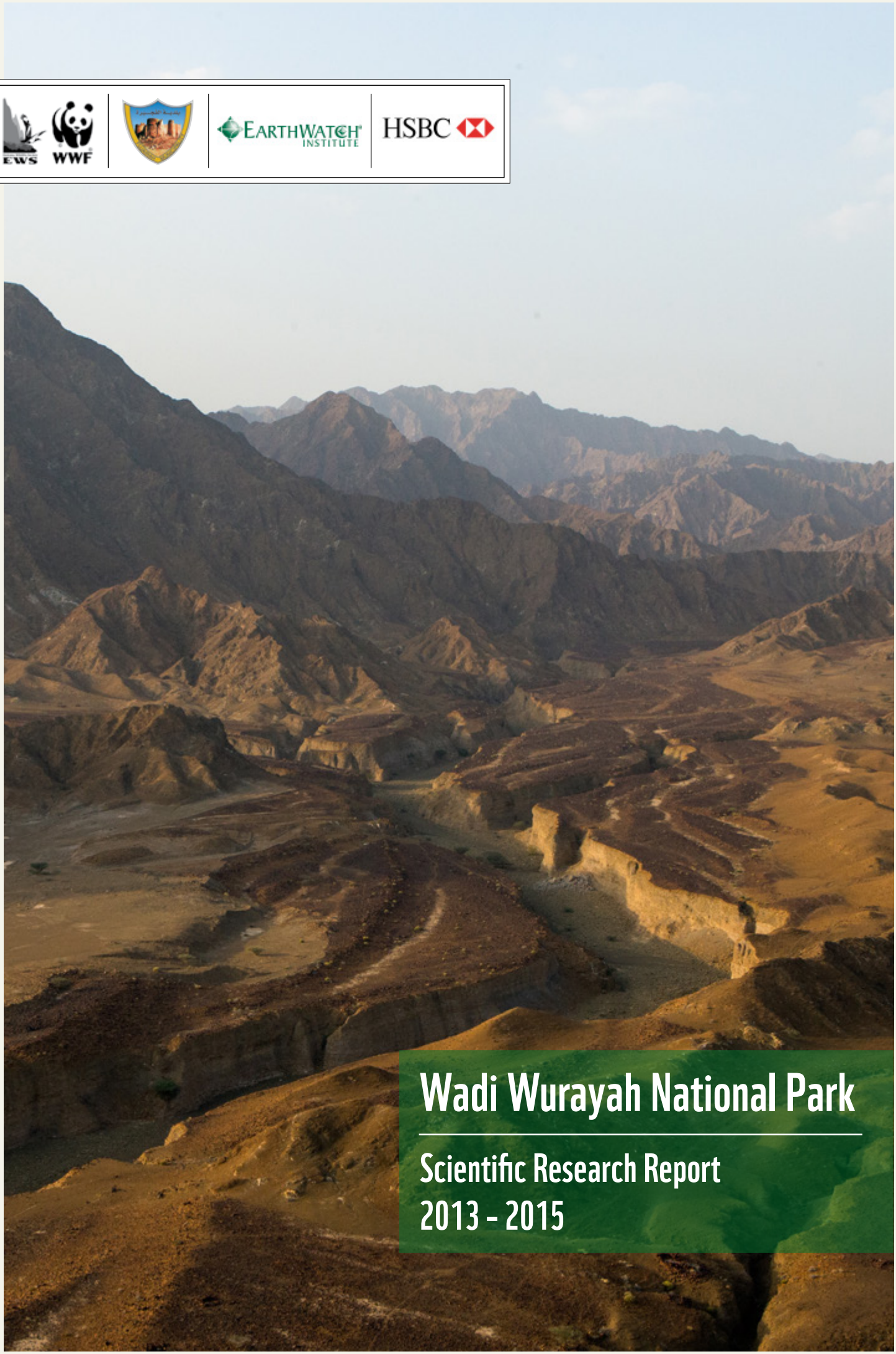

Wadi Wurayah National Park

Scientific Research Report
2013 - 2015

Lead Author:
Jacky Judas, PhD, Research Manager, WWNP - EWS-WWF

Reviewer:
Olivier Combreau, PhD, consultant

EWS-WWF Head Office
P.O. Box 45553 Abu Dhabi United Arab Emirates T: +971 2 634 7117 F: +971 2 634 1220

EWS-WWF Dubai Office
P.O. Box 454891 Dubai United Arab Emirates T: +971 4 354 9776 F: +971 4 354 9774

The Water Research & Learning Programme
P.O BOX 9777 Wadi Wurayah National Park, Fujairah, UAE

For information about the programme, please contact: info@ewswwf.ae

www.ewswwf.ae

@ews_wwf /ews.wwf wwfuae @ews_wwf

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PROJECT PARTNERS

Emirates Wildlife Society-WWF

Emirates Wildlife Society-WWF is a UAE environmental nongovernmental organisation established under the patronage of H. H. Sheikh Hamdan bin Zayed Al Nahyan, the ruler's representative in the Western Region and the 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.

Fujairah Municipality

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

HSBC Bank Middle East Ltd

HSBC Bank Middle East is one of the largest international banks in the Middle East, and, since 2006, it has been the main stakeholder and financial partner of EWS-WWF on the Wadi Wurayah National Park project. HSBC Bank Middle East has funded most of the research programmes conducted to date in Wadi Wurayah National Park.

Earthwatch Institute

Earthwatch Institute is a leading global nongovernmental organisation that engages communities in environmental projects in more than 40 countries worldwide. Earthwatch Institute is EWS-WWF's partner in the Water Research and Learning Programme in Wadi Wurayah National Park, drawing on its international experience to bring citizen scientists into the field in a safe and useful manner.

EXECUTIVE SUMMARY

In January 2013, Fujairah Municipality and the Emirates Wildlife Society in association with the World Wide Fund for Nature (EWS-WWF) signed a three-year agreement to develop the newly created Protected Area into a national park of international importance, the Wadi Wurayah National Park. The main role of Wadi Wurayah National Park is to conserve natural ecosystems and wildlife as well as the cultural values that are characteristic of this region of the Hajar Mountains. One of the first tasks that EWS-WWF undertook was the initiation of a scientific and research programme aligned with the management plan in which six major conservation targets were identified. These included the freshwater ecosystems, terrestrial vegetation and habitats, the Arabian leopard, mid-sized carnivores, endangered ungulates and birds, small mammals and reptiles.

This scientific report provides the main objectives and results for the period of 2013 to December 2015. These are articulated around two main themes: the research and monitoring programme and the description of the biodiversity in the Protected Area. An important part of the research was conducted in the framework of the Water Research and Learning Programme (WRLP), a five-year citizen science-based programme (2013-2017) elaborated as a synergic initiative between EWS-WWF, Fujairah Municipality, Earth Watch and HSBC, which provides the financial support. In addition, scientific collaborations were initiated with different research institutions, individual researchers, and universities to contribute to ecological knowledge regarding the park and the description of its biodiversity.

The guiding principle of the research effort was the development of monitoring methodologies and programmes and the identification of relevant bioindicators that were representative of the different habitats, taxonomic groups, and food web levels. The goal was to provide the management of the park with sound scientific knowledge about the state of the environment. Different criteria were taken into account while determining the indicators. They included the reliability, accuracy, and sensitivity of the measurements in the detection of changes and their costs and staff requirements (on which the feasibility of monitoring them regularly in the long term would be based).

Thus, activities involving the participation of HSBC volunteers in the WRLP were developed to determine the main bioindicators of the state of the freshwater ecosystems, which are among the main assets of the park. Indicators of the quality of freshwater have been investigated well with the regular measurement of 16 water parameters and the identification of preliminary threshold values. Variations beyond these values might provide alerts on possible environmental disturbances and stimulate additional field investigations to determine if and how human management intervention is required. Important work has been conducted on the wild toad and dragonfly populations to assess natural variations in their populations, diversity, abundance, and factors of variation. Different methods have been investigated. They have already yielded interesting results, but additional work is still necessary. The right choices of methodologies, frequencies of sampling, and required field efforts are crucial for the success of a long-term monitoring programme.

Other research fields have been investigated. They include assessments of plant biomass, tree characterisation, the description of freshwater invertebrates' populations, the relative abundance of reptiles, bird diversity variations, an owl survey with the discovery of the rare and elusive Omani owl (Strix butleri), rodent trapping, carnivore trapping, and radio-tracking.

A system for monitoring large and medium-size mammals has been defined and implemented through the deployment of a network of more than 50 camera traps, covering most of the area. The initial objective of this network of camera traps was to assess the status of the endangered Arabian tahr, which persists in the UAE in very small and fragmented populations. Three survey years did not yield any indication of the presence of the species. This strongly suggested that the species had become locally extinct since 2012 (the date of the last observations). Its reintroduction should be initiated after the securing of the area and the removal of the main suspected causes of extinction (overgrazing and poaching).

Ensuring the sustainability of conservation targets is not possible without the removal or substantial reduction of the main threats, which also need to be quantified and monitored. The quantification of most of the threats is yet to be done. A paragraph (§2.3, p.63) summarises our current knowledge of the threats and makes indications of the work to be developed.

With the increase in concern worldwide about the degradation of the environment and the unprecedented scale of loss in biodiversity, documenting the biodiversity of the park has also become a priority activity. Only comprehensive biodiversity knowledge can lead us to a better understanding of the ecosystem's functioning. Important efforts were made to document the biodiversity of the park. At the end of December 2015, they resulted in the listing of 1,146 species. A comprehensive botanical survey was conducted from 2013-2014. The Odonata (dragonflies and damselflies) community was surveyed intensively during the visit of distinguished international specialists. Moths were trapped on a monthly basis from August 2014 to October 2015. Scorpions and spiders also received the particular attention of local and foreign specialists. Last, sightings of all vertebrate species (reptiles, birds, and mammals) were systematically recorded. Although important progress has been achieved in the acquisition of WWNP biodiversity knowledge, some more studies need to be developed, particularly those of arthropods or microorganisms that have not been investigated or have been poorly investigated. It does not come as a surprise that many more species are yet to be added to the biodiversity inventory.

Although these three years have seen important progress in the development of monitoring methods and indicators and the description of biodiversity, the efforts in question should not be interrupted. The success of the environmental conservation of the park depends to a significant extent on the continuity of scientific research and the long-term sustainability of monitoring programmes.

WADI WURAYAH NATIONAL PARK

Scientific Research Report
2013 – 2015

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1. INTRODUCTION

Wadi Wurayah was declared a Protected Area on March 15, 2009, following the issuance of Law No2 of 2009 by H.H. Hamad bin Mohammad Al Sharqi, the Ruler of Fujairah. The Protected Area covers an area of 219 km², comprising a core zone of 118 km², a buffer zone of 92 km², and an ecotourism zone of 9 km² and reaching an elevation of 1,080 m (Figure 1). In January 2013, Fujairah Municipality and EWS-WWF signed a three-year agreement to develop the newly created Protected Area into a national park of international importance, the Wadi Wurayah National Park (WWNP). One of the first tasks that EWS-WWF undertook was to initiate a scientific research and monitoring programme aimed at describing the biodiversity of the area, monitoring indicator species, and more generally understanding the functioning of the ecosystems.

The main role of Wadi Wurayah National Park is to conserve natural ecosystems and wildlife and the cultural values that are characteristic of this region of the Hajar Mountains. In 2014, EWS-WWF developed a management plan for the park in which preliminary analyses of the habitats' and species' statuses and threats allowed the identification of the following six conservation targets:

1.1 CONSERVATION TARGETS AND THREATS IN WWNP

The priority conservation targets that the management plans identified follow:

- Freshwater ecosystems;
- Terrestrial vegetation or habitats;
- The Arabian leopard;
- Mid-sized carnivores;
- Endangered ungulates; and
- Birds, small mammals, and reptiles.

In addition, some cultural heritage targets which will require the development of specific research and conservation programmes were identified:

- Archaeological sites,
- Landscape & aesthetic values, and
- The traditional use of natural resources.

The main identified threats to conservation targets follow:

- Poaching,
- Overgrazing,
- Physical damage,
- Invasive species,
- Loss of spatial connectivity,
- Pollution,
- Infectious diseases,
- Interbreeding with feral and domestic animals, and
- Climate change.

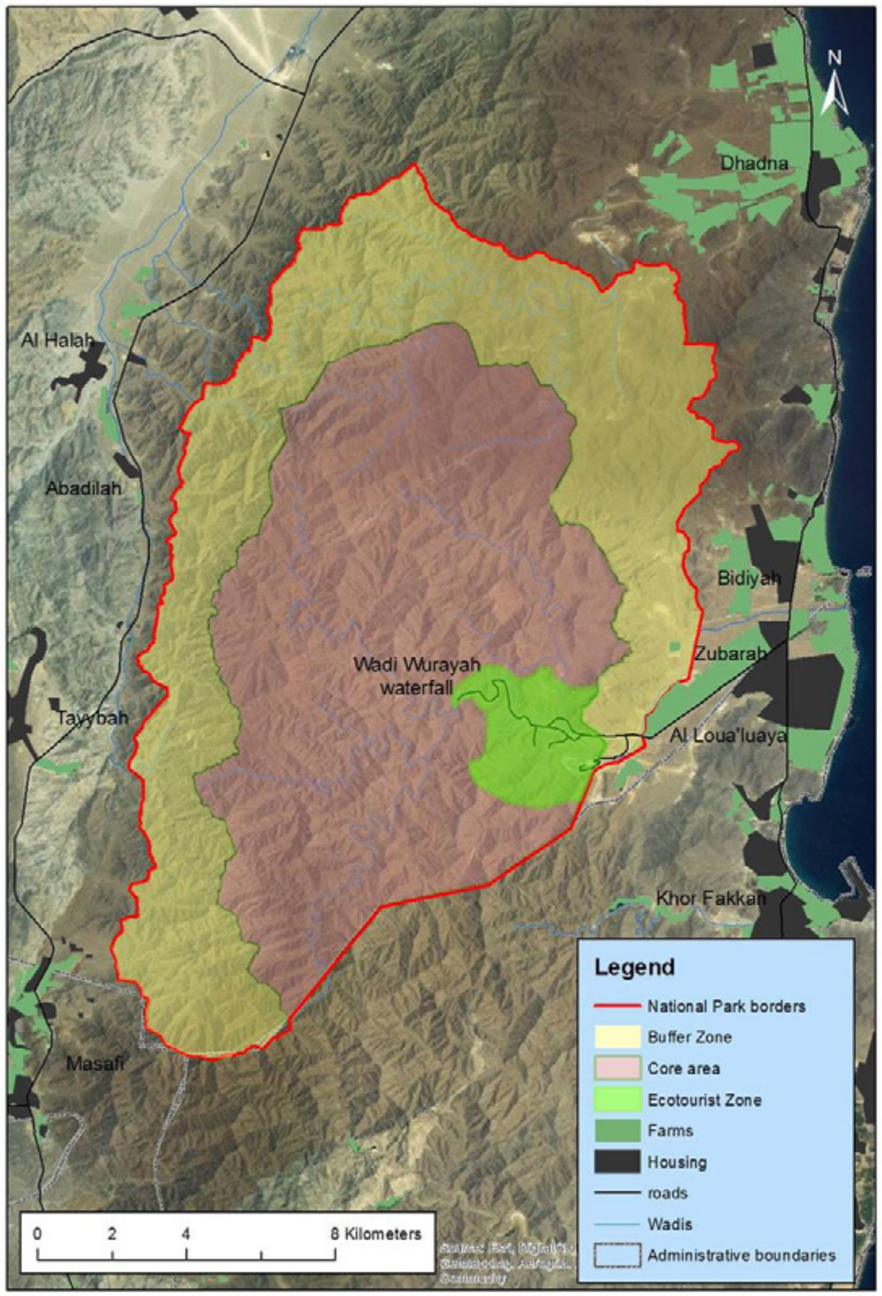


Figure 1: Map of the boundaries of Wadi Wurayah National Park, including the core area (118 km²), the ecotourism zone (9 km²), and the buffer zone (92 km²).

1.2 THE PURPOSE OF THE RESEARCH AND MONITORING PROGRAMMES

Priorities for monitoring and scientific research (fundamental research and applied research in support of conservation actions) have been defined in line with the WWNP management plan and its charter of principles. The objective is to provide robust scientific data that will help to define and adapt the conservation management plan in the park for the maintenance or enhancement of the status of the prioritised conservation targets. Ultimately, the main goal is to reduce or eliminate the threats in order to allow the natural or managed restoration of the ecosystem of Wadi Wurayah.

Preserving WWNP's natural environment and wildlife in the long term requires the consistent and standardised monitoring of different components of the ecosystem. It entails establishing indicators and defining the monitoring scheme that will best evaluate the effects of the management strategy chosen and allow for correction if needed. In parallel to the monitoring programmes, scientific research programmes need to be developed for the improved understanding of the ecosystems' functioning and the ecological requirements of all the ecosystems' components.

1.3 THE WATER RESEARCH AND LEARNING PROGRAMME

In 2013, shortly after the signing of an agreement for the development of WWNP, EWS-WWF, Fujairah Municipality, Earthwatch and HSBC signed another five-year agreement (2013-2017) to establish and operate the Water Research and Learning Programme (WRLP) in the National Park. A specific research programme associated with the WRLP was designed to focus on freshwater habitats with the following broad objectives:

- To describe the physicochemical components of the freshwater habitats, how they vary, and their main factors of variation;
- To describe the biodiversity components of the freshwater habitats (species diversity, relative abundance, population size) and their spatio-temporal variations;
- To understand the relations between the physicochemical characteristics of the habitats and their biodiversity components and to identify the keystone species which drive ecosystem processes;
- To determine the ecological requirements (including the different life history stages in relation to the hydroperiod) and the tolerance (upper thermal tolerance and resistance to drought) of (a selection of) species directly linked to the freshwater habitats (plants, insects, frogs, and fish);
- To assess the propensity of key species for dispersal and their ability to colonise new habitats and to define the limits of functional populations;

- To assess the risks and measure the impacts of human activities (agricultural practice, tourist frequentation, wells) on water quality, water availability, and the sustainability of the freshwater ecosystem;
- To assess the contribution of anthropogenic freshwater habitats as biodiversity refuges; and
- To develop scenarios of biodiversity drift in relation to climate change models and propose adapted conservation strategies (for instance, do changes in occurrence/seasonality/the volume of rain affect the breeding cycles or life-history parameters of some species?).

The Water Research and Learning Programme (WRLP) is a citizen-science programme, primarily involving volunteers from HSBC, the initial financial partner of the project (EWS-WWF 2015). Besides providing education regarding the environment, enhancing public awareness, and supporting scientific research, the aims of WRLP are as follows:

- To share the knowledge and skills necessary to understand freshwater related issues at different geographic scales,
- To introduce and explain freshwater conservation challenges in the Middle East, and
- To involve volunteers in research activities through “feet in the field and hands in the lab” experiences while simultaneously making them contribute to important data collection.
- Throughout this report, we will present the main scientific results obtained and the progress observed from 2013 to 2015 owing to the Water Research and Learning Programme.

2. RESEARCH AND MONITORING

The effective conservation of wildlife and ecosystems is dependent on the thorough knowledge of their status and health. These can be assessed by establishing and measuring indicators at regular time intervals. The indicators should ideally be representative of the different habitats and trophic levels that constitute the ecosystem. Upon the detection of changes in population trends or a species or ecosystem with a poor status, an investigation is launched to determine the mechanisms underlying these changes. This should ultimately lead into conservation actions to reverse the unwanted changes. Well-designed monitoring programmes are vital for optimising the conservation management of the park. In addition to the monitoring of bioindicators, all existing and suspected threats must be carefully controlled, quantified, and monitored in order to provide indicators of the effectiveness of the implemented management and guidance towards an adaptive management plan.

An important proportion of the research activities conducted between 2013 and 2015 has focused on defining, testing and implementing methodologies to monitor the status and health of different components of the WWNP ecosystem. The development of the monitoring programme entails the following:

- Selecting the most appropriate environmental parameters and defining the requested accuracy, frequency of measures, and methodology;
- Selecting different taxonomic groups that represent the different habitats and food web levels of WWNP and testing monitoring methods for each group;
- Defining indicators to quantify and measure the threats;
- Testing the reliability and efficiency of the different methodologies;
- Optimising the sampling effort (the staff, the budget requirements, and the sensitivity of the indices to change in the ecosystems); and
- Defining acceptable variation thresholds for all indices that do not require investigations or management interventions.

The choice of methodology is critical. It has to be robust as it is set for the long term. A good methodology produces comparable indices and trend assessments and is eventually translated into conservation management actions in case of important variations in the trends. The following factors should drive the choice of methodologies and protocols:

- The accuracy and the repeatability of the measurements;
- The sensitivity of the indicators for the timely detection of any significant ecological variations; and
- The minimising of cost, time, and staff requirements to maximise the sustainability of the monitoring programme in the long term.

Should the methodology be inappropriate, changes may be detected too late or may not be detected at all. Inconsistency or lack of rigor can considerably alter the reliability of the indices and the assessment of the trends, and they may result in the loss of time, energy, and money.

Methodological approaches that can be applied in the measurement of specific taxonomic groups are generally known. However, they are not always strictly comparable as they may be developed in different contexts, on different species, or in different habitats, subject to different environmental conditions. All these factors may affect the efficiency of the methods and the sampling efforts.

Hence, preliminary tests need to be carried out in the specific context of Wadi Wurayah National Park to compare the efficiency of methods and to calibrate the sampling effort based on the expected accuracy and sensitivity of the results. These tests may have to run for a minimum of two years for each method, taking into account inter-annual variability, before satisfactory conclusions are reached. Even so, some adjustments may be necessary in the first years of implementation as long as they do not impede the possibility of comparisons with previously collected data. Monitoring methodologies developed for WWNP will also be relevant at the country level. The Ministry of Climate Change and Environment needs to standardise indices for habitats and Protected Areas to allow the quantification of national trends, intersite comparisons, and the assessment of management effectiveness as recommended by the Convention for Biological Diversity. Most of the activities developed under the Water Research and Learning Programme with the involvement of corporate volunteers have allowed the exploration of different methodologies for population monitoring. This will ultimately contribute to the determination of the most reliable and suitable methods for monitoring population trends in the long term (Judas et al., 2014, 2015).

2.1 THE MONITORING OF THE PHYSICAL ENVIRONMENT

The subsistence of all living organisms depends on the quality of the physical environment in which they are evolving. The climatic conditions and geology of the region determine the main characteristics of the physical environment, for instance, the amount of freshwater and the elements or nutrients that are available to support the food chain (from plants to carnivores). In a global context of climate change and increasing anthropogenic pressure on ecosystems, all natural cycles are affected. The different rates of precipitation or different frequencies of occurrence of meteorological events modify the water cycle. Consequently, all other ecological cycles (that is, the nitrogen, phosphorus, carbon, and oxygen cycles), which constitute an integral part of the ecosystem's functioning, may also be disturbed. Monitoring the variation in physical parameters is crucial for understanding how the ecosystems and all their components are affected, that is, how the variations of these environmental factors affect life-history parameters of different species (survival, breeding success, dispersal).

The three main characteristics of the physical environment that need to be considered are its meteorology, hydrology, and water quality. The Ministry of Climate Change and Environment monitors meteorology and hydrology across the UAE mountains, while we mainly focus on water quality with emphasis on the following:

- Selecting the most relevant parameters for monitoring;
- Identifying methodologies, the frequency of monitoring, and the requested accuracy;
- Determining the thresholds of accepted variations; and
- Considering the automation of data acquisition and external data sourcing.

2.1.1 Meteorological records

Monitoring meteorological parameters in the long term will contribute to the assessment of the effects of climate change at the local scale. Six manual rain gauges have been deployed in the park to measure rainfall (Figure 2, Table 1). However only the one deployed at the park's headquarters could be controlled and maintained on a regular basis. Over three years, the average amount of annual precipitation recorded at the headquarters was 45.3 mm (a minimum of 7.6 mm in 2015 and a maximum of 99.6 mm in 2014) with the maximum precipitation occurring in the months of March and November (Table 2, Figure 3). Annual rainfall totals for this three-year period reveal a period of relative drought in comparison to the average annual rainfall of 179 mm recorded in Masafi from 1968 to 2004 (Tourenq et al., 2009). However, data from 2005 to 2013 are missing for comparisons, and so are records from Masafi for the same period.

Table 1: Geographic coordinates of the rain gauges deployed or planned for deployment in WWNP

Rain gauge ID	Planned latitude	Planned longitude	True latitude	True longitude	Site description
RG01	25.38927	56.30970	25.38937	56.3098	Headquarters
RG02	25.40075	56.27425	25.40140	56.27392	Donkey Plateau
RG03	25.38751	56.25821			Falling Net Plateau
RG04	25.46557	56.30169	25.47514	56.30583	Wadi Zikt
RG05	25.46977	56.20771	25.47656	56.20256	NW of Al Halah
RG06	25.44069	56.20323	25.44745	56.20055	W of Abadilah (stolen)
RG07	25.38116	56.19568			Close to Al Khulaybiyah
RG08	25.33546	56.19344			Close to Masafi

Table 2: Monthly precipitation (in mm) recorded at WWNP headquarters (raingauge RG01) from September 2013 to December 2015

Year / Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
2013									0	0	29	0	**29.0**
2014	14	5.6	47	3.2	0	0	0	0	0	0	30	0	**99.8**
2015	2.8	0	0.4	0	0	0	0	0	0	0	4.4	0	**7.6**
Average	**8.4**	**2.8**	**24**	**1.6**	**0**	**0**	**0**	**0**	**0**	**0**	**21**	**0**	**45.5**

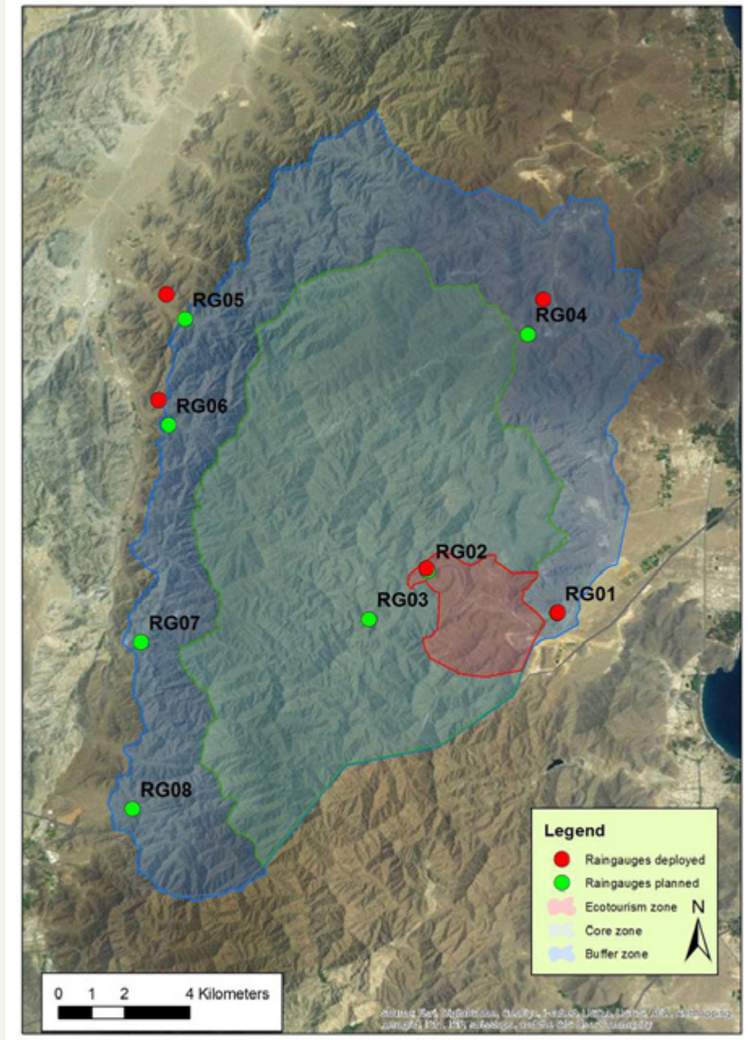


Figure 2: Distribution map of the rain gauges deployed or planned for deployment in WWNP.

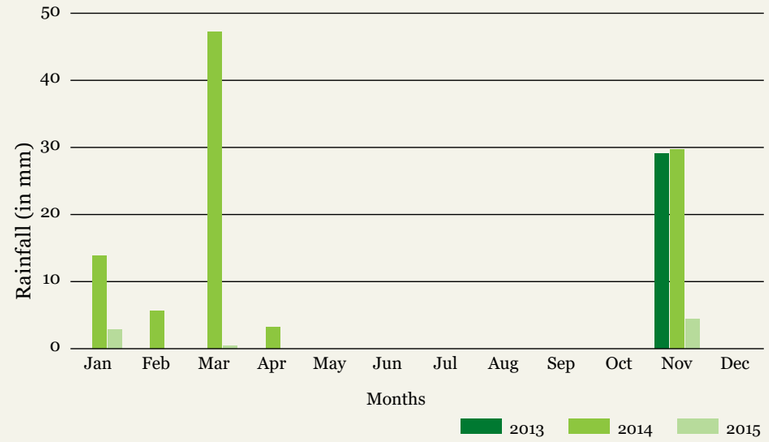


Figure 3: Distribution of rainfall events from September 2013 to December 2015 at WWNP headquarters

Meteorological and hydrological data from automatic stations deployed in WWNP and its surroundings are available at the Department of Dams in the Ministry of Climate Change and Environment's Fujairah branch. Contact has been established to facilitate the gaining of access to these data, but some follow-up will be necessary to develop an agreement between the park management and the ministry.

2.1.2 Hydrology

Monitoring the hydrology of Wadi Wurayah water basin is particularly relevant and important in the context of urban development on the eastern coast, where the freshwater supply is becoming an increasing concern. Despite the development of the desalinisation plant of Mirbah and the increase in its production capacity, waters from Wadi Wurayah are still the main source of freshwater for a number of farms and houses in the sector of Bidiyah. Increasing development along the coast (around Bidiyah in the more local context) will elevate the freshwater access requirements and exacerbate competition between different interests (agriculture, industry, housing, environmental conservation). Moreover, the increase in water consumption on the coast might drastically impact the amount of freshwater that reaches the sea, presumably impacting the coastal marine ecosystem and possibly increasing the salinity level of the underground water table. The impact of the diminution of the freshwater flow reaching the sea will need to be studied in more detail. Organising freshwater resource monitoring and understanding freshwater resource variations in the medium to long term is crucial for optimising freshwater use. The Ministry of Climate Change and Environment monitors the water table levels.

2.1.3 Water quality

Freshwater quality underlies the freshwater ecosystem balance. Any disturbance in water quality might affect an entire freshwater ecosystem and its biodiversity. EWS-WWF is developing a water quality monitoring program to detect any possible disturbance to ecosystems in a timely manner. This program focusses on quantifying the amplitudes of variation of different freshwater parameters (water temperature, pH, ammonium, nitrate, nitrite, phosphate, dissolved oxygen, salinity, conductivity, total dissolved solids, turbidity, hardness, alkalinity, iron, chloride, water flow). The natural variations of these parameters, which daily or seasonal cycles can level, allows the determination of threshold values. Variations in excess of these threshold values may indicate some imbalance, stimulate further investigations, and ultimately lead to human intervention to reestablish the natural balance and ensure the sustainability of the ecosystem. However, determining these threshold values and interpreting data from the water monitoring program requires a good understanding of the mechanisms underlying the freshwater chemical parameters and their natural variations. A significant array of technology is available to test the wide range of physicochemical water quality parameters, ranging from the very simple to the very complex but providing different degrees of accuracy and reliability in the results. It is essential to select the most suitable methods for testing the water to get the best possible results. Moreover sampling diverse pools and habitats to determine their water chemistry composition proves useful for establishing a comprehensive water quality baseline for different types of water bodies in different areas of Wadi Wurayah. To summarise, the water quality monitoring program serves the following purposes:

- To determine the physical and chemical parameters of different waterbodies in Wadi Wurayah,
- To understand their natural spatio-temporal variations,
- To assess the threshold values of variations, and
- To improve monitoring methods, data accuracy, and the precision of measurement devices.

2.1.3.1 Methodology

The testing and monitoring of freshwater parameters have been developed with the participation of HSBC volunteers. These processes explore amplitudes and causes of variations and different methods of measurement.

Sixteen physical and chemical water parameters in various water bodies (running streams and pools) have been regularly measured throughout Wadi Wurayah National Park over two October-to-April fielding seasons (2013 – 2015). Overall, ten environmental variables were measured *in situ*, while six others were tested in the laboratory using both digital devices and colourimetric tests on water samples collected from the field (Table 3).

Table 3: Summary of methods for the determination of water quality parameters in Wadi Wurayah

Parameters (Units)	Instrumentation/Method	Measured
Temperature (°C)	Temperature sensor YSI and TestR	*In situ*
Dissolved oxygen (mg/L and % saturation)	Oxygen electrode YSI	*In situ*
pH (pH units)	pH electrode TestR	*In situ*
Salinity (g/L)	Conductivity sensor YSI and TestR	*In situ*
Conductivity (µS/cm)	Conductivity sensor YSI and TestR	*In situ*
Total dissolved solids (mg/L)	TDS sensor YSI and TestR	*In situ*
Water flow (m/s)	Flow meter	*In situ*
Turbidity (Nephelometric Turbidity Units: NTU)	Secchi tube	*In situ*
Ammonium (mg/L)	Ammonium sensor YSI	*In situ*
Nitrite (mg/L)	Diazotisation colourimetric method	Lab
Nitrate (mg/L)	Nitrate sensor YSI	*In situ*
Total hardness (mg $CaCO_3$/L)	EDTA titration	Lab
Alkalinity (dKH)	Acid titration with indicator solution	Lab
Chloride (ppm)	Acid titration with indicator solution	Lab
Iron (ppm)	Colourimetric method	Lab
Phosphates (ppm)	Colourimetric method	Lab

The frequency of measurements per location changed during the second field season. In the first season, water parameters were measured for 12 randomly selected locations and averaged, whereas, in the second season, tests were conducted on a weekly basis at six predefined locations (Table 4, Figure 4).

Table 4: Description of the six waterbodies selected for the monitoring of water quality in Wadi Wurayah

Location		Latitude	Longitude	Waterbody type	Substrate	Bank vegetation
Ww	Small pool in the waterfall	25.39576	56.26954	Permanent pool	Mud	Reeds
Wp	Pool behind the waterfall	25.39584	56.26904	Permanent pool	Bed rock	No vegetation
Ws	Stream behind the waterfall	25.39524	56.26829	Running water	Gravel	Reeds
Gds	Pool before the gorge	25.39524	56.26823	Permanent pool	Sand	Reeds
Gus	Stream in the gorge	25.38752	56.26557	Running water	Gravel	No vegetation
Gfs	Pool in the fish spa	25.38514	56.26356	Permanent pool	Sand	No vegetation

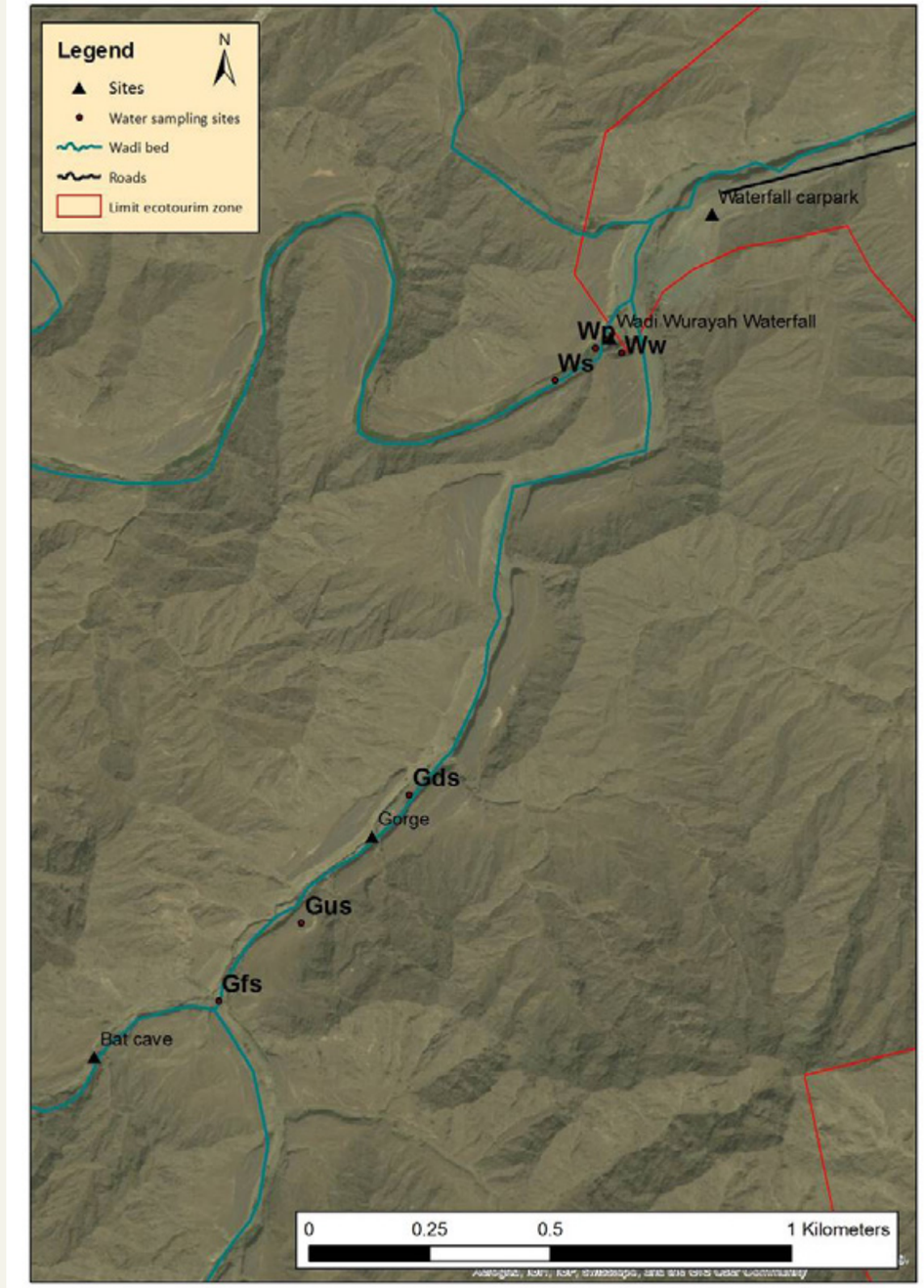


Figure 4: Map of the sampling sites selected for water quality monitoring

2.1.3.2 Measurements of physical parameters

Water temperature:

Water temperature has a major influence on chemical and biological processes, including reaction rates, water density, and dissolved oxygen content (which strongly affects many aquatic organisms). The main source of variations in water temperature is linked to the seasonal cycle and, to a lesser extent, to the diurnal cycle. The average water temperature was 24.7 ± 2.4°C for the period between January 2014 and April 2014 and 23.6 ± 2.7°C for the same period in 2015. Spatial variability occurred due to differences in water depth, the presence of macrophytes, and shading from shoreline vegetation or relief.

Water flow:

For both seasons, the average water flow speed varied from 0 m/s to 0.05 m/s in pools and never exceeded 0.17 m/s in streams.

Turbidity:

In all locations, the water remained very clear with a measured turbidity of 0 NTU (Nephelometric Turbidity Units). Turbidity increased temporarily during flash floods but returned to the normal level in less than 24 hours.

Total dissolved solids (TDS)

The TDS were, on average, 376.5 ± 50.8 ppm for the first season and 364.48 ± 46.99 ppm for the second season. These averages were calculated from measures taken at different locations. The origins of the water samples were the main influence on the variability in total dissolved solids (TDS). The three sampling locations near the waterfall presented higher average TDS values (436.41 ppm, 432.12 ppm, and 416.23 ppm) than the three sampling locations of the main branch of Wadi Wurayah (347.96 ppm, 342.45 ppm, and 339.25 ppm). This variability may be due to groundwater sources as well as the habitat extent and type upstream. In addition to intersite variability (Figure 6b) some intraseasonal variations can be observed; those would need more investigations to determine the pattern and understand its origin.

Conductivity:

Conductivity can be used as a substitute for total dissolved solids (Trebitz et al., 2007). In this regard, the same trends were observed, with higher average values in the waterfall area (622.08 µS/cm, 608.17 µS/cm, and 602.36 µS/cm) than in the gorge of the main branch of Wadi Wurayah (491.14 µS/cm, 494.05 µS/cm, and 502.82 µS/cm). The overall average conductivity was 529.43 ± 78.8 µS/cm in the first season and 539.83 µS/cm in the second season. Conductivity is generally a good indicator of productivity in freshwater ecosystems. Therefore, we can expect water bodies in the waterfall area to be slightly more productive than those in the gorge (Figure 5a).

2.1.3.3 Measures of chemical parameters

Salinity:

The average salinity from January to April was 0.25 ± 0.03 g/L and 0.27 ± 0.03 g/L for the first season and the second season, respectively. In the second season, salinity in the waterfall area was slightly higher than that in the gorge of the main branch of the wadi, with average values of 0.31 g/L and 0.24 g/L respectively. This range of salinity values is normal for fresh water (Figure 5b), but the cause of the variations is not clear yet. Salinity measurements will need to be conducted in an increased number of sampling locations presenting different characteristics (substrate, vegetation) to identify the main factors behind the variations. Salinity variations correlate with TDS and conductivity.

pH:

Wadi Wurayah's waters are ultrabasic with a relatively high pH (>8, Figure 5c), which is common in ophiolite catchment areas. The average pH was 9.02 ± 0.24 and 8.62 ± 0.31 for the first season and the second season, respectively. The maximum pH found was 9.9, and the minimum was 7.96. Apart from important and extreme variations measured in January-February 2014, which were most probably related to sensor calibration problems and were excluded from the statistics, the pH stayed relatively stable. A one-unit change in pH means a variation in [OH-] by a factor 10. Because of low precipitation, the water mostly comes from groundwater, and its composition is dependent on the geology of the catchment basin. Algae and aquatic vegetation also significantly influence the pH of fresh water. Fluctuations can result from the combined effects of photosynthesis and respiration but may also be linked to geochemical process.

Dissolved oxygen:

Rapidly moving water tends to contain more dissolved oxygen than still water (Figure 5d). Running water locations presented an average saturation of around 80%, while still water locations gave an average that was close to 70%. The photosynthetic activity of algae and aquatic vegetation can increase dissolved oxygen levels locally, even in still water. Dissolved oxygen is essential for the development of aquatic life. Different organisms have different requirements, but, in general, a high level of saturation, as was observed in Wadi Wurayah, is beneficial for a number of species and for fish respiration in particular. Dissolved oxygen concentrations seem to have increased slightly from 2014 to 2015 (Figure 6f).

Nitrogen

Concentrations of ammonia (NH_4^+), nitrites (NO_2^-), and nitrates (NO_3^-) are linked according to the nitrogen cycle. The average concentration of nitrates recorded between November 2014 and April 2015 was 1.19 ± 0.97 mg/L with an important decrease during this period (Figure 6g). Monthly average concentrations dropped from 2.36 ± 1.41 mg/L in November 2014 to 0.81 ± 0.36 mg/L in April 2015. It is interesting to note that the highest concentrations were recorded in the gorge area, with measures substantially higher there than they were around the waterfall. These higher concentrations may have resulted from sediment following the flash flood at the end of October 2014.

Alkalinity

Alkalinity is the measurement of all bases in the water, and is one of the best measures of the sensitivity of a water body to acid input in relation to the buffering capacity of the water. On average, alkalinity stayed rather constant across all locations (Figure 6i), ranging from 6.88 dKH to 8.31 dKH, qualifying the water as hard (Figure 5e). Alkalinity is measured in dKH, which means “degree of carbonate” (“Karbonathärte” in German).

Total hardness

Calcium carbonate concentrations measure the total hardness of water. Monthly average concentrations of calcium carbonate ($CaCO_3^-$) ranged from 642 mg/L to 1381 mg/L. Hardness decreased between November 2014 and April 2015. The causes of these variations are not fully understood yet but may be linked to the water sources and geochemical processes.

Chloride

Monthly average chloride (Cl^-) concentrations per site ranged from 2.78 ppm to 6.26 ppm. Intersite and intraseasonal variations have been recorded (Figure 6), but the causes of these variations remain unclear. As for salinity, research will need to focus on sampling an increased number of sites selected according to specific characteristics that are suspected to influence these variations.

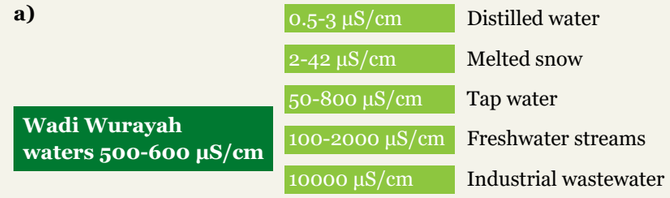
Iron

Iron concentrations were <0.02 ppm in all sites throughout the season (Figure 6l). The accuracy of the test currently used does not allow the detection of trends in the range of variations, but it is sufficient for detecting concentration increases that may prove harmful for the environment. An increase in iron of above 1 ppm would affect the algal community, shifting from the dominance of green algae to that of cyanobacteria.

Phosphate

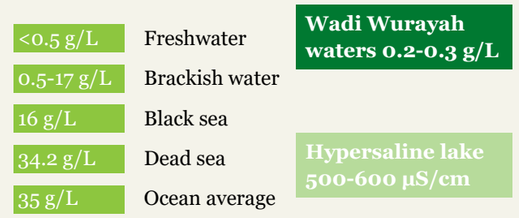
Phosphate concentrations constantly remained below <0.02 ppm (Figure 6m) as expected in the absence of major potential sources of phosphate, such as fertilisers or phosphates naturally present in the ecosystem. As for iron, the sensitivity of the test does not allow accurate measurements of variations in the range of concentrations present in the park. However, it allows the detection of any abnormal increase in concentration that may be harmful to the environment.

a)



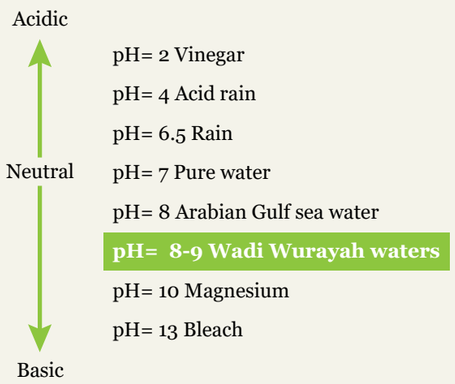
Conductivity

b)

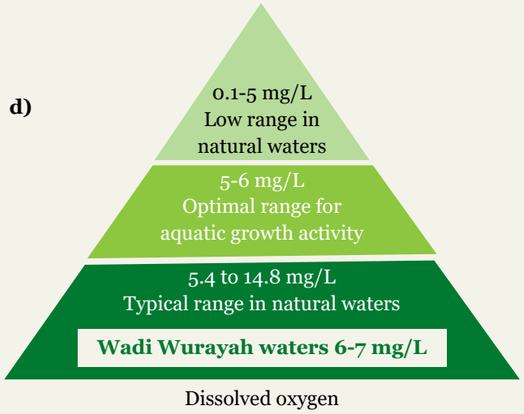


Salinity

c)



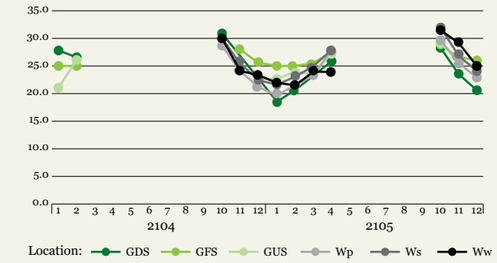
d)



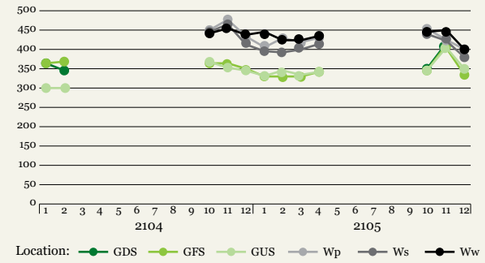
e)

Figure 5: Comparison of Wadi Wurayah water parameters with those of water of other origins: a) conductivity, b) salinity, c) pH, d) dissolved oxygen, and e) hardness

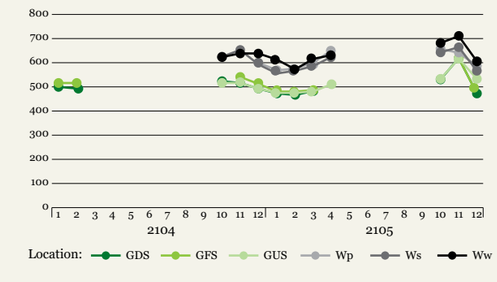
a) Water temperature (in °Celsius)



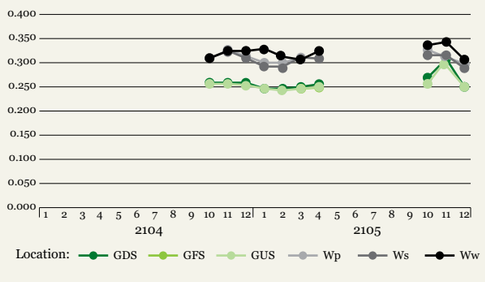
b) TDS (in mg/L)



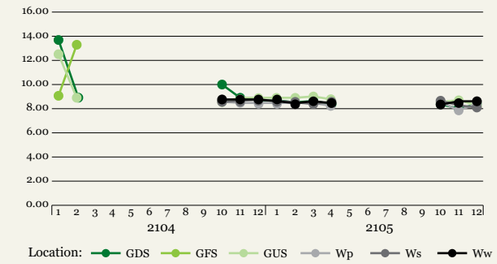
c) Conductivity (in µS/cm)



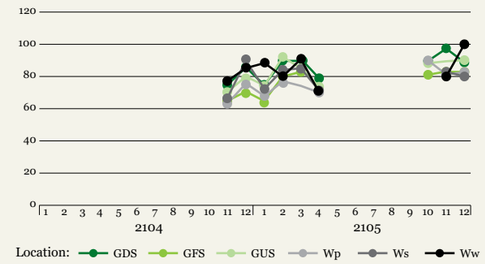
d) Salinity (in ppt)



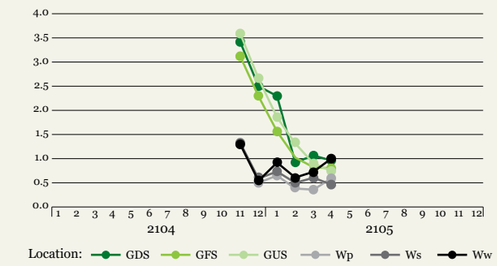
e) pH



f) Dissolved oxygen (in %)



g) Nitrate (in mg/L)



h) Ammonium (in mg/L)

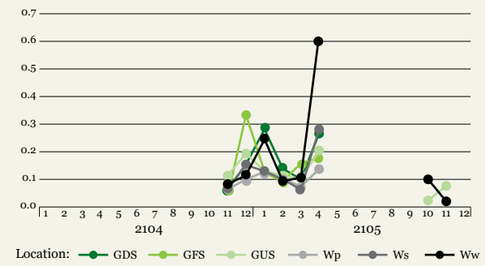
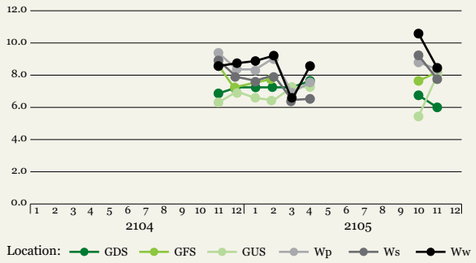
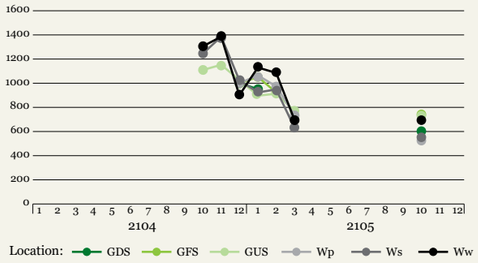


Figure 6

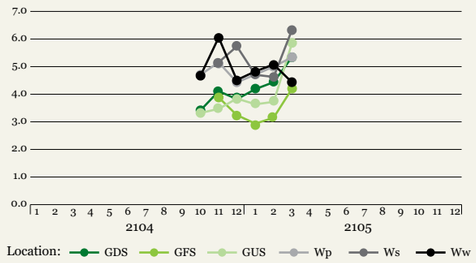
i) Total alkalinity (in ppm)



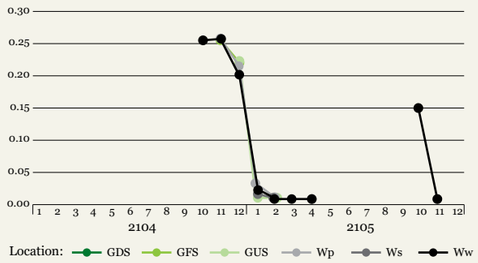
j) Total hardness (in mg of CaCO3/L)



k) Chloride (in ppm)



l) Iron (in ppm)



m) Phosphate (in ppm)

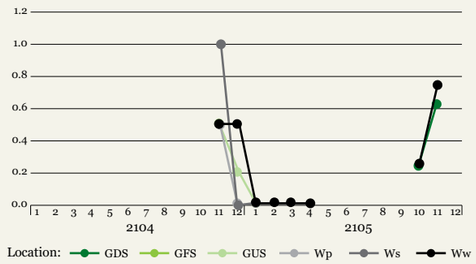


Figure 6 (continued): Variations of the different water quality parameters recorded between January 2014 and December 2015 at six different locations of Wadi Wurayah National Park (GDS: gorge downstream, GFS: gorge fish spa, GUS: Gorge Upstream, Wp: pool over Waterfall, Ws: stream upstream of waterfall, Ww: waterfall pool). Measurements were only taken between October and April for each period considered.

2.1.3.5 Measures of bacteriological parameters

Escherichia coli:

The concentration of mammalian intestinal bacteria, E. coli, was tested during the first season in order to assess the effect of not controlling the number of visitors to the park on water quality. Tests for E. coli and other coliform bacteria were performed at two locations from January to March 2014. The average concentration of E. coli was 110.95 colonies per 100 ml. Moreover, the average concentration of coliforms was 186.18 colonies per 100 ml. The concentration of coliforms in the water bodies above the waterfall in February appeared to be much lower than that in the waterfall pool, where most tourists would concentrate and swim before the closure of the park. However, the concentration of coliforms became higher in February than it was in January (two months after the park's closure). Colonies of coliforms seem to have persisted in the environment, and the increase in the air and water temperature in the late winter may have favoured their abundance. Their abundance decreased in March following the flash flood. By the end of 2015, E. coli were absent from the waterfall area, but other coliforms were detectable at low levels. Given that E. coli are pathogenic at low levels, the level of tolerance in drinking or recreational waters is null as per the recommendations of the World Health Organization (WHO, 2013). In catchment areas impacted by livestock excreta, there is a potential risk of transmission to humans. The important population of feral goats present in the park may present a potential risk, particularly after rain, when faecal elements can be drained towards the main water bodies.

Inter-annual variations

Water quality parameters measured at the waterfall in the past (Brook, 2006; Tourenq et al., 2009, 2011) were compared with the measures which the WRLP volunteers undertook in 2014 and 2015 (Table 5). The water parameters from 2006 and 2009 were from single measurements, while those from the seasons of 2013–2014 and 2014–2015 at the waterfall had been averaged for comparison.

Temperature, salinity, and nitrites (NO2 -) did not vary significantly, but pH increased slightly, as did TDS and conductivity, from 2006–2009 and 2014–2015. Iron never exceeded 1 mg/L; it remained in the normal range of values. Dissolved oxygen varied between 7.12 mg/L and 9.72 mg/L, which was within the expected range. The chloride concentration decreased somewhat after 2006; but, for the present, there is no clear explanation for this. Nitrate (NO3) concentrations have clearly decreased from 2006-2009 and 2014-2015, reaching concentrations <1 mg/L. This important decrease may be partially linked to the reduction in the human presence that followed the closure of the park to the public in December 2013. However, the higher values and regular decrease recorded in the gorge between November 2014 and April 2015 support other explanations. Generally, the closure of the park to the public had beneficial effects on Wadi Wurayah's water quality.

Table 5: Comparison of historical and recent water quality measurements at the Wadi Wurayah waterfall.

	Jan-06	2009	Mar-14	Mar-15
Temperature (°C)	-	25	24.52	24.05
pH	8.4	8.3	8.8	8.6
Salinity (g/L)	-	-	0.26	0.27
Dissolved oxygen (mg/L)	-	8.21	-	7.12
TDS (mg/L)	306	310	394	388
Conductivity (µS/cm)	474	-	539	553
NO_2 (mg/L)	<0.02	<0.02	-	<0.02
NO_3 (mg/L)	4.9	5.76	0,49	0.74
Chloride (ppm)	7.4	-	3.8	4.7
Fe (ppm)	<0.01	-	0,75	<0.02
E.coli (n colonies / 100 ml)	-	30	111	-
Coliforms (n colonies / 100 ml)	-	2,861	186	-

2.1.3.6 Assessment of thresholds

Based on the measurements and the ranges of variation of the different water quality parameters, we created an initial reference table summarising the tolerable thresholds of variation (Table 6). These thresholds may have to be reviewed based on the additional understanding of the causes and ranges of natural variation, but they should currently be sufficiently informative to focus attention on future measurements that will fall beyond the suggested thresholds.

Table 6: Suggested thresholds of tolerable variation for water quality parameters in Wadi Wurayah National Park

Parameters	Patterns of variation	Ranges of variation of monthly averages		Thresholds		Units	Points of concern
		Min	Max	Min	Max		
Water temperature	Seasonal and site-dependent	21.5	30	20	30	°C	Increase in average monthly temperature
DO	No patterns detected	50	97.7	60		%	Decrease below 60%
pH	Stable	7.7	8.9	7.5	9	pH unit	Increase or decrease beyond threshold values
Salinity	Rather stable, with possibility of slight seasonal variations	0.24	0.34	0.2	0.4	g/L	Increase or decrease beyond threshold values
Conductivity	Rather stable, with possibility of slight seasonal variations	434	711	450	700	µS/cm	Increase or decrease beyond threshold values
TDS	Rather stable, with possibility of slight seasonal variations, and site-dependence	300	470	300	470	mg/L	Increase or decrease beyond threshold values
Water flow	Variations without clear pattern	0	0.8			m/s	
Turbidity	Increase in rainfall		<5	N.A.	5	NTU	Increase >5 NTU, outside rainfall period
Ammomium	Unexplained peaks	0.025	0.603	N.A.	0.4	mg/L	Increase above 0.4 mg/L
Nitrite (NO_2^-)	Unexplained peaks	0.018	0.1	N.A.	0.1	mg/L	Increase above threshold

Parameters	Patterns of variation	Ranges of variation of monthly averages		Thresholds		Units	Points of concern
		Min	Max	Min	Max		
Nitrate (NO_3-)	Stable at waterfall, but sharp decrease in the gorge, presumably after Nov. 2014 flashflood	0.37	3.59	0.2	3.5	mg/L	Increase above threshold
Total hardness	Regular decrease from Oct. 2014 to March 2015	6.5	27	?	?	ppm	To clarify
Alkalinity	Rather stable, but slightly site-dependent	5.38	10.53	6	10	ppm	
Chloride	Seasonal variations and site-dependence	2.78	6.26	?	6	ppm	Increase above threshold
Iron	Sharp decrease after Nov. 2014, possibly in relation to flashflood	0.01	0.25	?	0.5	ppm	Increase above threshold
Phosphates	Site-dependent, unexplained variations	0	1		?	ppm	Increase above threshold
DBO							No data
ORP	Unexplained variations and site-dependent	55.4	144.37	?	?	mV	To clarify
E. coli	Link to human activities & presence of livestock	30	111	0	4	n col. / 100 ml	Increase above threshold
Coliforms		186	2,861	0	500	n col. / 100 ml	Increase above threshold

2.2 POPULATION MONITORING

The goal of the wildlife population monitoring programme is to obtain information on the statuses and population trends of several taxonomic groups, which are representative of the different habitats and trophic levels of the wadi. Taxonomic groups have been selected in line with the conservation targets of the park management plan and in accordance with the general objectives of the Water Research and Learning Programme.

Most levels of the food chain and habitats in the Protected Area have already been investigated for a selection of taxonomic groups for which monitoring methods are being developed or were intended to be developed in 2015-2016. Table 7 summarises the development of monitoring methodologies per taxonomic group.

The only level of the food chain which is yet to be investigated is that of decomposers (bacteria and micro-fungi), which plays an important role in the balance of the ecosystem but remains virtually unexplored in the park. Efforts should be made to get better coverage of habitats more than 450 m above sea level, which are logistically more difficult to access, and to generally extend the coverage of the field survey to a larger proportion of the park. For obvious logistical reasons, most field work efforts have focused on the ecotourism zone and an area with a 1-2 km radius centred on the waterfall. Work on butterflies, the small mountain bird community, owls, and bats should also be enhanced.

Table 7: Progress in the development of the monitoring programme for different taxonomic groups according to their places in the food chain and the different habitats of the park.

Food chain	Taxonomic groups	Habitats			
		Freshwater	Wadi beds	Mountains below 450m	Mountains above 450m
Decomposer	Micro-fungi	●	●	●	●
	Bacteria	●	●	●	●
Producer	Vegetation	●	O	O	●
	Trees	○	Δ	Δ	●
	Diatoms	Δ	○	○	○
Consumer I	Endangered ungulates	O	O	O	O
	Rodents	O	O	O	●
	Butterflies	●	●	●	●
	Birds	●	●	●	●
	Aquatic arthropods	Δ	○	○	○
Consumer II	Bats	●	●	●	●
	Toads	O	○	○	○
	Reptiles	O	O	O	●
	Birds	Δ	Δ	Δ	●
	Odonates	O	○	○	○
Consumer III	Carnivores	O	O	O	O
	Owls, raptors	●	●	●	●

Legend of Table 7
O Ongoing Δ Intended to start in season 2015-2016 ● For development ○ Not applicable

The overall objectives of the monitoring programme are as follows:

- To obtain reliable indices on population status and relative abundance on a yearly basis for the following groups:
    - Plants (primary producers),
    - Odonates (freshwater),
    - Toads,
    - Birds,
    - Reptiles,
    - Small mammals,
    - Carnivores, and
    - Ungulates;
- To assess population trends;
- To assess the health of the populations; and
- To provide information to local and international institutions on species' statuses (red data list).

The cumulative monitoring of the different taxonomic groups in different habitats and at different levels of the food chain will contribute to the monitoring of the park's biodiversity as a whole and encourage the ecosystems to function well.

2.2.1 Vegetation pilot study for assessing biomass and productivity

The vegetation study aims to identify and implement methodologies for assessing vegetal biomass and productivity in Wadi Wurayah National Park. These two environmental parameters are critical for assessing the carrying capacity of the park for herbivores. An assessment of the amount of food that is available for herbivores and how that availability might vary in time and space would enhance the design of the reintroduction strategy for the Arabian tahr and mountain gazelle within the park and provide direction for better park management. In addition, vegetation surveys would help researchers understand and monitor the phenology of flora species phenology.

Under the coordination of Samar Gewily and with the assistance of WRLP volunteers, a pilot study was conducted from March to May 2015 to develop a protocol for measuring and monitoring vegetation. It sought the most efficient, most reliable, and least time-consuming method. The protocol aims to assess species richness, relative abundance, and evenness in the six main habitats of the wadi, following the habitat classifications which Feulner (2014) defined. The six habitats are categorised as pool, wadi bed, wadi slope, mountain slope, gulley, and terrace.

Based on preliminary field surveys, we built a species-area curve to compare the efficiencies of two different methods: 1) increasing the size of the sampled quadrat and 2) increasing the number of 1 m^2 quadrats (Figure 7). Sampling a number of 1 m^2 quadrats appeared to be a more efficient method than sampling the same area in a single quadrat.

Of the six predefined habitats, only two (wadi bed and terrace) were sampled, in two locations each. The sampling technique consisted of describing the vegetation of 10 1 m^2 quadrats, distributed every 5 m along a 50 m line transect. The total area sampled was 30 m^2 for each habitat. A team of five HSBC volunteers and their field guide performed the sampling of each transect. Sampling 10 quadrats (one transect) took an average of 1.22 hrs. A total of 7.33 hours was spent on sampling six transects.

For each quadrat, its relative position on the line transect, the substrate, the percentage of vegetation cover, the effective height (maximum height of dense vegetation), and the species present were recorded. For each species, the percentage of cover, number of individuals, average maximum height, and number of stems in each growth/reproductive stage (seedling, vegetative, flowering, seeding, and dry) were recorded. Bird's eye view photos of the quadrats were taken for more accurate cover analysis and biomass assessment. To determine biomass from image analysis, we estimated a bulk density constant. Three samples of the five most dominant species (*Arundo donax, Nerium oleander, Tephrosia apollinea, Saccharum griffithii,* and *Asphodelus tenuifolius*) were photographed using a digital camera. The samples effective heights were measured, and they were then clipped and dried in a hot, dry place for a week until their weights stabilised.

The same species richness was found for both sampled habitats, with 18 species recorded in each. The Shannon index, which measures diversity and entropy based on the number of individuals per species, was 2.29 and 2.33 for the terrace and the wadi bed respectively; evenness was 0.79 and 0.81; and the average vegetation cover was 5.2% (1.57 m²) and 6.1% (1.82 m²) of the total area sampled per transect. Species composition and relative abundance calculated as a percentage of all species present in the habitat community differed (Figure 8). In the wadi bed, the most abundant species were *Arundo donax* (26.4%), *Saccharum griffithii* (21.1%), and *Nerium oleander* (16.5%), while, on the terrace, the most abundant species were *Tephrosia apollinea* (38.6%), *Convolvulus virgatus* (11.7%), and *Heliotropium brevilimbe* (9.7%).

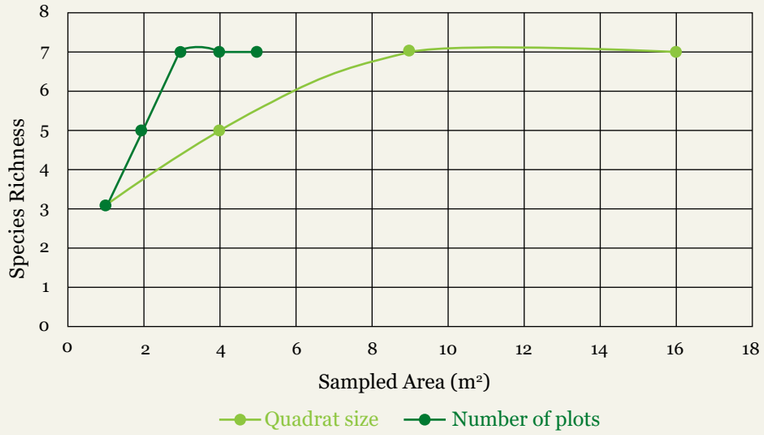


Figure 7: Average plant species richness per sampled area measured in wadi bed using 2 different methods: 1) increasing the quadrat size, 2) increasing the number of 1 m² plots (n=27)

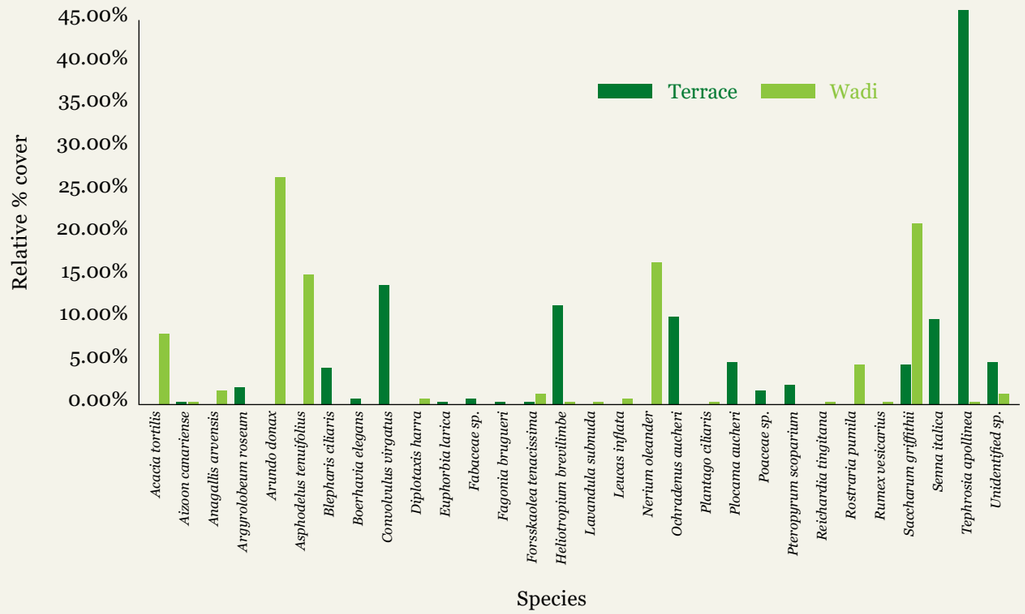


Figure 8: Relative species abundance (in % cover) recorded at six locations of two habitats (terraces and wadi beds of Wadi Wurayah National Park during a pilot vegetation monitoring study

Ground cover per species and habitat showed high variations between quadrats and transects, especially for the most dominant species, *Arundo donax, Tephrosia apollinea, Nerium oleander,* and *Saccharum griffithii* (Table 8).

On the terrace, which is a highly disturbed habitat, the most common species, *Tephrosia apollinea*, also had the highest ground coverage, with a 32% difference in cover area from the next most common species in the habitat, *Convolvulus virgatus*. The dominance of *Tephrosia apollinea* is associated with high grazing activity; since animals do not eat the plants, it outcompetes other species and dominates the habitat.

The phenology of each species was assessed by quantifying the percentage of stems in the different growth/reproductive stages. During the sampling period, most parts of the vegetation were either in the immature or vegetative stages. The pattern of distribution per stage was quite similar for the two habitats, except that a higher proportion of dry stems was present on the terrace in relation to the higher sun exposure and lower access to water (Figure 9). For both habitats, 41.7% of stems were immature, 40.6% vegetative, 8.6% flowering, 17.1% seeding, and 8.4% totally dry.

Table 8: Ground cover (mean ± SD in %) of the main species sampled in two habitats (wadi bed and terrace) of Wadi Wurayah

Species	Terrace		Wadi	
	Mean	SD	Mean	SD
Acacia tortilis	8.2	14.4	0.0	0
Aizoon canariense	0.3	0.6	0.3	0.6
Anagallis arvensis	0.0	0	1.7	2.9
Argyrolobeum roseum	1.7	3.5	0.0	0
Arundo donax	0.0	0	26.5	41.9
Asphodelus tenuifolius	0.0	0	15.2	10.7
Blepharis ciliaris	3.6	7.5	0.0	0
Boerhavia elegans	0.6	1.2	0.0	0
Convolvulus virgatus	11.7	24.2	0.0	0
Diplotaxis harra	0.0	0	0.7	0.6
Euphorbia larica	0.3	0.6	0.0	0
Fabaceae sp.	0.6	1.2	0.0	0
Fagonia bruguieri	0.3	0.6	0.0	0
Forsskaolea tenacissima	0.3	0.6	1.3	0.6
Heliotropium brevilimbe	9.8	20.2	0.3	0.6
Lavandula subnuda	0.0	0	0.3	0.6
Leucas inflata	0.0	0	0.7	1.2
Nerium oleander	0.0	0	16.6	28.9
Ochradenus aucheri	8.6	2.9	0.0	0
Plantago ciliaris	0.0	0	0.3	0.6
Plocama aucheri	4.2	8.7	0.0	0
Poaceae sp.	1.4	2.9	0.0	0
Pteropyrum scoparium	1.9	2.5	0.0	0
Reichardia tingitana	0.0	0	0.3	0.6
Rostraria pumila	0.0	0	4.7	2.9
Rumex vesicarius	0.0	0	0.3	0.6
Saccharrum griffithii	3.9	7.2	21.1	29.4
Senna italica	8.3	17.3	0.0	0
Tephrosia apollinea	38.6	70.7	0.3	0.6

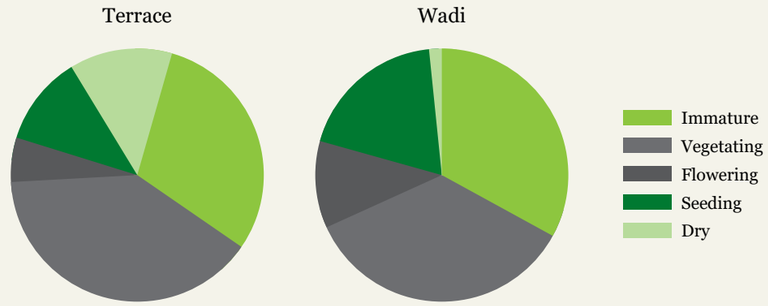


Figure 9: Distribution of growth/reproductive stages (in % of stems) of the vegetation on the terrace and wadi bed of Wadi Wurayah in April-May 2015

Differences in growth–reproductive stages were noticeable between species (Figure 10): *Acacia tortilis, Asphodelus tenuifolius, Lavandula subnuda, Convolvulus virgatus,* and *Plocama aucheri* were flowering while A. *tenuifolius* and *Ochradenus* aucheri were seeding. These species are known to flower in summer or even year round.

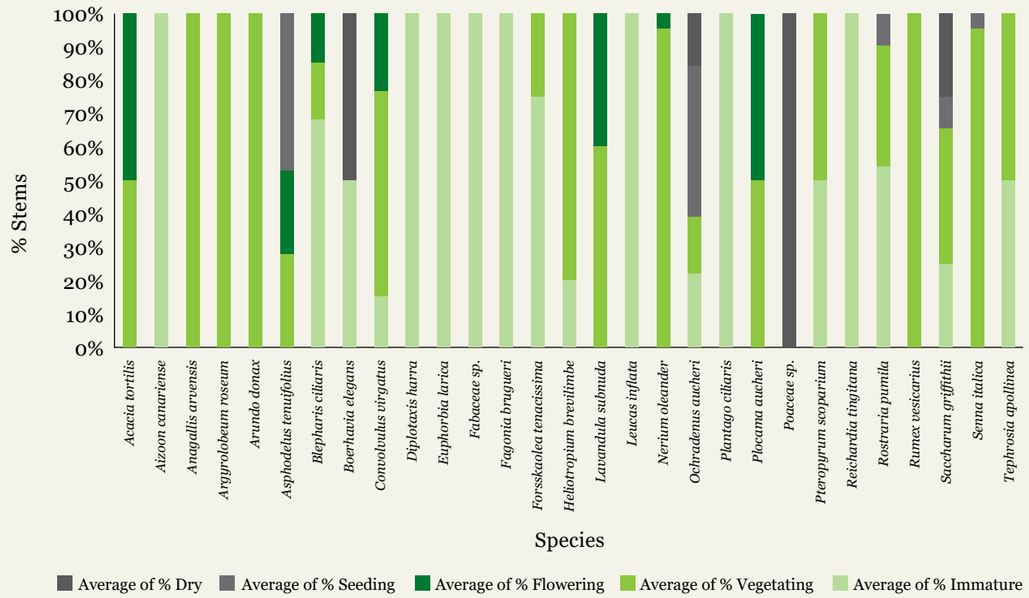


Figure 10: Growth/reproductive stages per species (in percentages of stem numbers) recorded in the terrace and wadi bed of Wadi Wurayah in April-May 2015

Pictures of quadrats and plant reference specimens (plants collected to establish a bulk density constant) were analysed using Axiovision software to measure the cover area. Using area and effective height, the volume of plants was calculated based on the cone formula ($\frac{1}{3}\pi r^2 h$). Dry mass was then divided by the volume to create a density constant of grams per cubic metre for each sample. All samples were then averaged to create a regional bulk density constant (RBDC). Subsequently, the RBDC was multiplied by the cover area and effective height for each quadrat to estimate the vegetation biomass per habitat. The bulk density constants measured for each species had low standard deviations, supporting the possibility of using them for biomass measurement as long as the cover area and height were measured consistently. The biomass on the terrace was lower than that in the wadi bed due to its lower water resources, higher sun exposure, and, possibly, the higher grazing impact of non-indigenous ungulates.

The pilot study for vegetation monitoring facilitated the determination of an efficient and reliable sampling technique that non-scientists could apply with proper demonstration and the continuous checking of their work. It also indicated where improvements were required, for instance, in the protocol for photographing quadrats. The angle (bird's eye view) at which pictures are taken and their quality are essential for accurate biomass estimation. The quantification of vegetation coverage based on the analysis of the colour spectrum with Axiovision software needs to be developed more systematically.

This approach should save time and provide more accurate results. Taking pictures of the vegetation quadrats from a lateral view may also be used advantageously to measure vegetation heights and will thus be tested. More time and effort must be dedicated to this protocol to assess all six 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 relationship between environmental conditions and flora biodiversity. These sampling methods may also be extended to a study of the grazing pressure due to feral goats in the park. This information is necessary for future adaptive management programmes. The vegetation study will also contribute to the achievement of the goal of preserving biodiversity in Wadi Wurayah National Park, which requires a thorough understanding of the impact of different management strategies on diversity and abundance.

The development of research on vegetation may also include the implementation of several exclosures to study the effect of overgrazing and the capacity of the vegetation to recover. This experiment should provide important information for habitat restoration in the park, like the rate and process of vegetation recovery, as well as the effects of grazing on plant abundance, diversity and productivity. However, it might be expected than the whole process of vegetation recolonisation, and hence the recolonisation study, can be quite long (minimum 5 years, but most probably 10-15 years).

The possibility of using remote sensing analysis to monitor vegetation growth at the scale of the National Park has been explored, but it was not possible to develop it due to the absence of staff with proper GIS competencies and access to satellite imagery. DubaiSat, which has been approached to discuss the provision of satellite imagery, could make available satellite imagery with suitable resolution (DubaiSat-2 with a 1-m PAN resolution or DubaiSat-3, which is to be launched into space in 2017). Further investigations should be conducted to define the mechanisms for obtaining access to this imagery on a regular basis and conducting the analysis. Access to the imagery could be organised through a specific agreement between local authorities and DubaiSat or other governmental organisations (the Ministry of Climate Change and Environment, the Environment Agency of Abu Dhabi, MASDAR, AGEDI, etc.).

2.2.2 Trees

Trees play a critical role in ecosystems for the benefit of humans and all other species (Picture 1). In the Middle East and North Africa, it has been suggested that trees such as *Acacia tortilis* are keystone species, which play a vital role in sustaining other species and providing some services to humans (Noumi & Chaieb, 2012). Other trees, like *Ziziphus spina-christi*, play an important role as a source of food during times of extreme drought (Saied et al., 2008). Due to this important role, it is essential to gain greater understanding of these two abundant and dominant tree species and their role within Wadi Wurayah without forgetting the other most common tree species (wadi fig (*Ficus salicifolia*), mountain fig (*Ficus johannis*), *Moringa peregrina, Acacia ehrenbergiana*, and the ghaf tree (*Prosopis cineraria*)).

Picture 1: The two most common species of trees in WWNP: *Acacia tortilis* on left and *Ziziphus spina-christi* on the right

The circumferences of *Ziziphus spina-christi* (Christ's thorn, also called Sidr in Arabic) and *Acacia tortilis* (the Umbrella Thorn Acacia, or Samer in Arabic) were measured 20 centimetres (called C20) and 1.30 metres (called CBH) from the base of each tree. All trees measured were located at the Water Research and Learning Centre. From these measurements, the diameter at 20 centimetres (D20) and the diameter at 1.30 metres from the ground (DBH) were calculated. Since most of the trees split into two or more sizable branches from one trunk, each branch was measured separately if they split below the measurement level. For example, if the trunk split into two branches 1.10 metres from the base, each branch was then measured separately at the 1.30-metre level.

In addition to this, several sections were taken from a fallen Acacia tortilis and used to estimate its age through ring counting. Three lines were drawn from the centre of the section and the rings were counted along each of the three lines. The average of the three counts was then taken to estimate the age of the tree.

In total, seven *Acacia tortilis* trees and 16 *Ziziphus spina-christi* trees were characterised (Table 9). On average, the *Acacia tortilis* had a C20 of 165 cm and a CBH of 105 cm. In comparison, the *Ziziphus spina-christi* had an average C20 of 212 cm and an average CBH of 162 cm.

For each species of tree, the diameter 20 cm above ground (D20) and the diameter 130 cm above ground (DBH) were also calculated. *Ziziphus spina-christi* had an average D20 of 67.46 cm and an average DBH of 51.5 cm. *Acacia tortilis* had an average D20 of 52.5 cm and an average DBH of 33.4 cm.

The significant variations in the circumferences and diameters of both *Ziziphus spina-christi* and *Acacia tortilis* were related to the different ages of the trees. Investigations so far have not allowed for the allocation of ages based on circumferences.

Table 9: Measurements (minima, maxima, mean ± SD) of *Acacia tortilis* and *Zyzyphus spina-christi* at the Water Research and Learning Centre

		Minimum	Maximum	Mean	SD
Acacia tortilis	CBH	52	195	105	49.4
	C20	20	318	124.7	95.2
	DBH	16.6	62.1	33.4	15.7
	D20	6.4	101.2	39.7	30.3
Ziziphus spina-christi	CBH	76	206	146.2	73.3
	C20	125	310	186.3	96.7
	DBH	24.2	65.6	46.5	23.3
	D20	39.8	98.7	59.3	17.7

CBH: circumference at body height (1.3m), C20: circumference 0.2m from the ground level, DBH: diameter at body height, and D20: diameter 0.2m from the ground level

A brief investigation into the dendrochronology (dating trees from their growth rings) of *Acacia tortilis* was conducted using cross-sections of a fallen tree. The number of rings along three equal lines were counted and averaged to approximate the age of the fallen tree. The tree cross-section had an average of 93 rings. For the accurate dating of a tree based on its rings, the tree must have a distinct growing period that events such as changes in temperature stop (Gebrekistos et al., 2013). The pattern of ring growth in arid environments with unpredictable rainfall is less clear than that in temperate countries, where growth quite strictly follows seasonal cycles. Extra care is necessary since drought conditions are known to elicit false rings or missing growth rings (Syampungani et al., 2010). Therefore, the number of rings may not reflect the true age of a tree. Rather, it is likely to reflect a minimum age.

Due to the important role of the trees of Wadi Wurayah in fixing soil and sustaining many different species, the characterisation of the tree community appears particularly important for the development of a full understanding of the ecosystem's functioning and the role of each species. Currently, only 22 trees have been characterised. Thus, there is a need for the continued characterisation of more trees, including the other tree species present in Wadi Wurayah. Furthermore, to link the characterisation measurements to the dendrochronology work (so that diameter may be used to predict age), more cross-sections of trees of different species and different apparent ages need to be taken and analysed.

Further investigations might focus on assessing trees' densities, distribution, and age classes per habitat and according to the access distance to inhabited areas or tracks. We suspect that the number of mature trees may decrease as we get closer to developed areas since they are likely to have been exploited and their populations depleted for their wood. The improvement of the habitat quality by planting native tree species and accelerating the recolonisation process may also be considered.

2.2.3 Odonata

Species diversity and abundance in odonate communities (among dragonflies and damselflies) are generally considered to be good indicators of water quality. Odonates depend on water throughout their life cycles. Adult damselflies and dragonflies lay their eggs in freshwater; the eggs hatch into predatory aquatic larvae. Each species has different levels of tolerance to aspects of its surroundings (such as water temperature, dissolved oxygen, and pH). As predators (either during the adult stage or the larval stage), their existence is linked to the availability of prey; their numbers and diversity reflect the conditions of the whole aquatic ecosystem. Out of the 29 odonate species known in the UAE, 25 have been recorded in Wadi Wurayah, which is a good indicator per se of the health of the freshwater ecosystem and of the water quality. To maintain the ecological equilibrium and diversity, we need to understand what the species' requirements are, how their life cycles are linked to environmental conditions, and what are the amplitudes and cycles of variation in population abundance are. The research and monitoring programme that the volunteers helped to develop aims to address these different questions.

2.2.3.1 Species diversity

All odonate species were systematically recorded between October and April from 2013 to 2014 and from 2014 to 2015, along with some notes on their breeding activities. Twenty-four species were recorded in the park between 2013 and 2015, including the addition of two new species to the UAE's Odonata fauna: *Urothemis thomasi* and *Orthetrum abbottii*. *Ischnura nursei*, a damselfly discovered in UAE in 2013, a week later than *Urothemis thomasi* (Feulner & Judas, 2013), has not been observed within the park, but it is present just a few kilometres south of the park border at Al Rufaysah Dam in Wadi Shi. Its may be searched for in Wurayah Dam during flooding. Only *Tramea basilaris*, which Bob Reimer recorded once in November 2011, has not been recorded again. Despite the lack of data for the period between May and September, when no field activities were organised with the WRLP volunteers, the records reveal some seasonal variations in species diversity (Figure 11). Diversity is highest in April and in October and tends to decrease between these two months to reach a minimum in the middle of winter, in January.

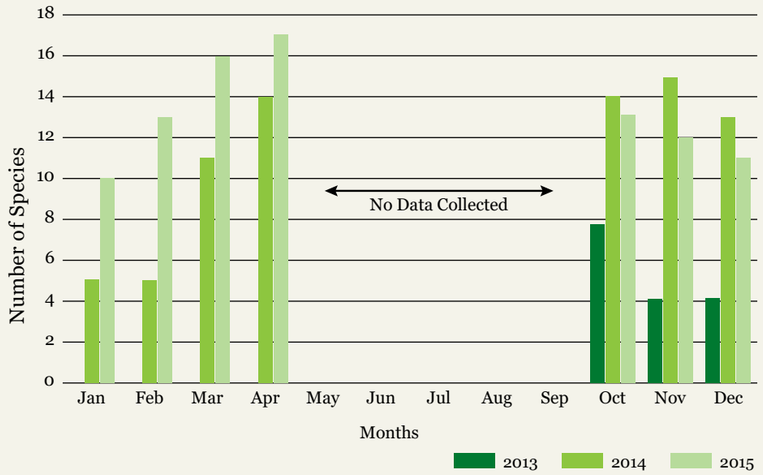


Figure 11: Seasonal and inter-annual variations of the number of Odonata species recorded per month in WWNP. Species recorded from May to September have not been included because of the low sampling effort and lack of data for the period.

2.2.3.2 Diversity and abundance on point counts

The number of individuals per point count varied from 0 to 27 individuals, with an overall average of 6.3 ± 4.1 individuals per point count (Figure 12). The monthly average was minimal in February 2014 (1.3 ± 0.6) and maximum in April 2015 (9.2 ± 5.0). The number of species recorded per point count varied from 0 to 11 with an overall average of 3.4 ± 1.9 species per point count (Figure 13), a minimum monthly average recorded in February 2014 (1.0 ± 0.0), and a maximum monthly average recorded in April 2015 (5.2 ± 2.5).

The average number of individuals per point count shows important variations between counts during similar periods (high standard deviation). With this high variability, counts of individuals would require the performance of a very high number of point counts in order to detect any significant long-term trends in the "noise" of the spatial, daily, and monthly variations. This result indicates that the counts of individuals might not be the best option for monitor population trends in the long term since it would require an important and presumably unsustainable field-survey effort.

On the other hand, the average number of species per point count shows important variability as well. Although this variable appears to be a better indicator of intraseasonal variations than the number of individuals, its measurement requires an important survey effort and does not correlate perfectly with the total number of species recorded per month (see Figure 11).

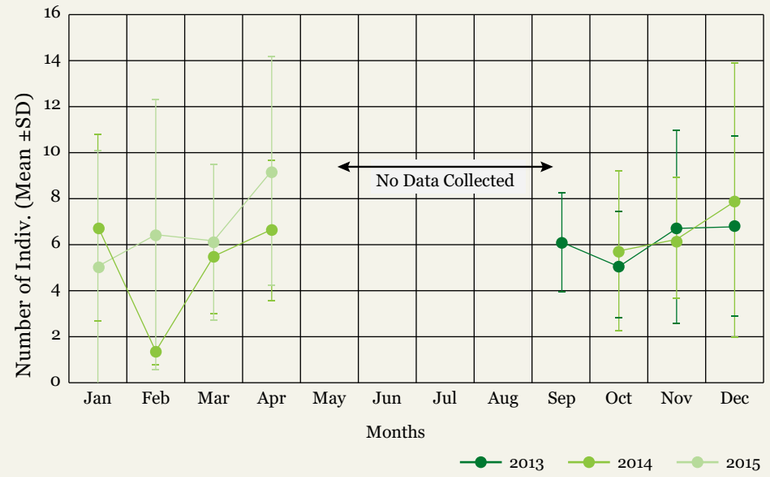


Figure 12: Monthly and annual variations in the number of individuals per point count

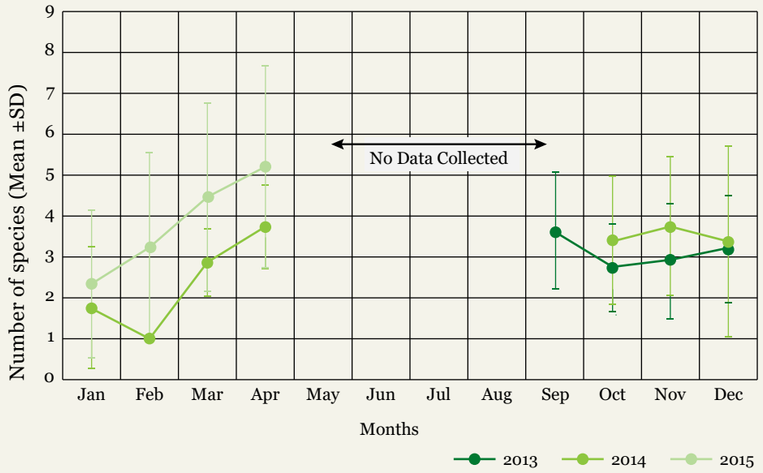


Figure 13: Monthly and annual variations in the number of species per point count

The point count method explored for the monitoring of Odonata populations in 2013-14 and 2014-15 provided important information about seasonal variations. However, it was not employed again in the third WRLP field season (2015–2016). Since the determination of the total number of species recorded per month seems to provide a reliable indicator of Odonata community variations and requires a less intense field effort, a new method based on presence/absence and integrating species detection probability is being explored for the third WRLP season. In the long term, Odonata population monitoring could be limited to recording the total number of species in October and April, and possibly in mid-summer (July), through a presence/absence model approach.

2.2.3.3 Behavioural observations on point counts

In the first two seasons (2013–2014 and 2014–2015), with systematic records of weather conditions and the distribution of point counts according to different time classes, we demonstrated that dragonfly activity increased with temperature and decreased with cloud cover (Judas et al., 2014), as well as with wind speed, humidity, and water pH (Judas et al., 2015). Activity, measured in terms of the number of individuals and number of species per unit of time was greater when point counts were conducted between 11:00 and 13:00. A future monitoring protocol should integrate these parameters to optimise the efficiency of sampling protocols and field records.

2.2.3.4 Capture-recapture by wing tagging

Dragonfly tagging was conducted to investigate the species' life span, population dynamics, and dispersal. From October 2013 to April 2015, 675 individuals of 14 species were tagged by writing individual four-digit numbers on their upper right wings with permanent black ink (Anderson et al., 2011). Eighty-six individuals of six species were controlled by visual observations at least once, giving an overall recapture rate of 12.7% (Table 10). *Trithemis arteriosa* was the most captured and recaptured species, representing 57% of all captures and 72% of recaptures. The average time to recapture was 9.4 ± 10.9 days (min–max: 1–64, n=86).

The low recapture rate and the short periods between capture and recapture reveal an important turnover in the dragonfly populations either due to low survival rates, high dispersal, or, more probably, a combination of both.

Table 10: Recapture rate and time to recapture of tagged dragonflies per species from October 2013 to April 2015

Species	n capture	n recapture	Recapture rate	Time to recapture (in days)			
				Mean ± SD	Min	Max	n
Anax imperator	17	3	18%	4.7 ± 3.2	1	7	3
Crocothemis erythraea	37	2	5%	1.0 ± 0.0	1	1	2
Crocothemis sanguinolenta	76	9	12%	12.9 ± 13.8	1	41	9
Diplacodes lefebvrei	3	0	0%				
Orthetrum chrysostigma	41	8	20%	12.4 ± 15.3	1	43	7
Orthetrum ransonetti	10	0	0%				
Orthetrum Sabina	2	0	0%				
Pantala flavescens	12	0	0%				
Paragomphus genei	1	0	0%				
Paragomphus sinaiticus	28	0	0%				
Trithemis arteriosa	383	62	16%	9.1 ± 10.3	1	64	59
Trithemis kirbyi	39	2	5%	4.5 ± 4.9	1	8	2
Urothemis thomasi	1	0	0%				
Zygonyx torridus	25	0	0%				
Total	**675**	**86**	**13%**	**9.4 ± 10.9**	**1**	**64**	**82**

The analysis of morphometric measures shows significant monthly variations in the body size of Trithemis arteriosa but not in that of any other species (Judas et al., 2014). These variations are possibly related to the availability of food in water bodies during larval growth. The lack of significant monthly variations where other species are concerned might result from lower sample sizes.

2.2.3.5 Odonata survey of the Hajar Mountains and Dhofar

Following the discovery of *Urothemis thomasi* in Wadi Wurayah National Park in June 2013 (Picture 2), EWS-WWF applied for and obtained funding from the Sheikh Mohammed bin Zayed Endangered Species Fund to conduct odonatological surveys on the Hajar Mountains and in the Dhofar region. Two surveys were conducted from October to November 2014 and from March to April 2015 in the UAE and Oman with the objectives of clarifying the status and distribution of this endangered species and gathering information on its ecological requirements. Information on the entire Odonata community and the presence of species was recorded at each of the 54 surveyed localities, along with their life stages, their behaviour, and the descriptions of their habitats and water characteristics (Figure 14). Exuviae were also systematically collected.

Altogether, 1048 observations concerning 32 species were recorded (Lambret et al., 2015). These were, namely, *Arabicnemis caerulea, Arabineura khalidi, Azuragrion nigridorsum, Ischnura evansi, I. senegalensis, Ceriagrion glabrum, Pseudagrion decorum, P. sublacteum, Agriocnemis pygmaea, Hemianax ephippiger, Anax imperator, A. parthenope, Lindenia tetraphylla, Paragomphus sinaiticus, P. genei, Orthetrum chrysostigma, O. ransonnetii, O. sabina, Nesciothemis farinosa, Crocothemis erythraea, C. sanguinolenta, Trithemis annulata, T. arteriosa, T. kirbyi, Diplacodes lefebvrii, Pantala flavescens, Tramea limbata, Urothemis edwardsii, U. thomasi, Zygonyx torridus, Rhyothemis semihyalina* and *Macrodiplax cora*.

These surveys have enhanced knowledge on the distribution of Odonata across the Hajar Mountains and in the Dhofar and Al Wusta regions. In the UAE, *U. thomasi* was only found in Wadi Wurayah, but the species was found in several new sites in the Hajar Mountains and the Dhofar and the Al Wusta regions, filling in the gap between the Dhofar region and the Muscat area. *U. thomasi* has always been found in rather low numbers during spring at relatively fresh water ponds with well-vegetated banks. However, its discovery at a brackish oasis suggests that the species might be more flexible, in terms of its habitat requirements, than expected. The survey also allowed the addition of new localities for two Arabian endemics, *Arabicnemis caerulea* and *Arabineura khalidi*, increasing their known distribution range. Important differences were noticed in the species composition of previously known localities, which were visited. Such changes may be ascribed to habitat degradation following the development of recreational activities.
Other outputs of the survey include a planned publication to describe the female *Urothemis thomasi*, as well as the description of its larva with identification criteria from other *Urothemis* species of the region (Chelmich et al., in press). Further investigations are needed to cover the UAE and Oman more intensively using two distinct approaches: (1) time-limited «expeditions» by foreign specialists and (2) continuous investigations by local people. The development of a local network of volunteers is a priority. New tools, such as the oncoming online illustrated key to Odonata larvae may help in that regard.

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Picture 2: *Urothemis thomasi*, a species new to the UAE, discovered in WWNP in June 2013

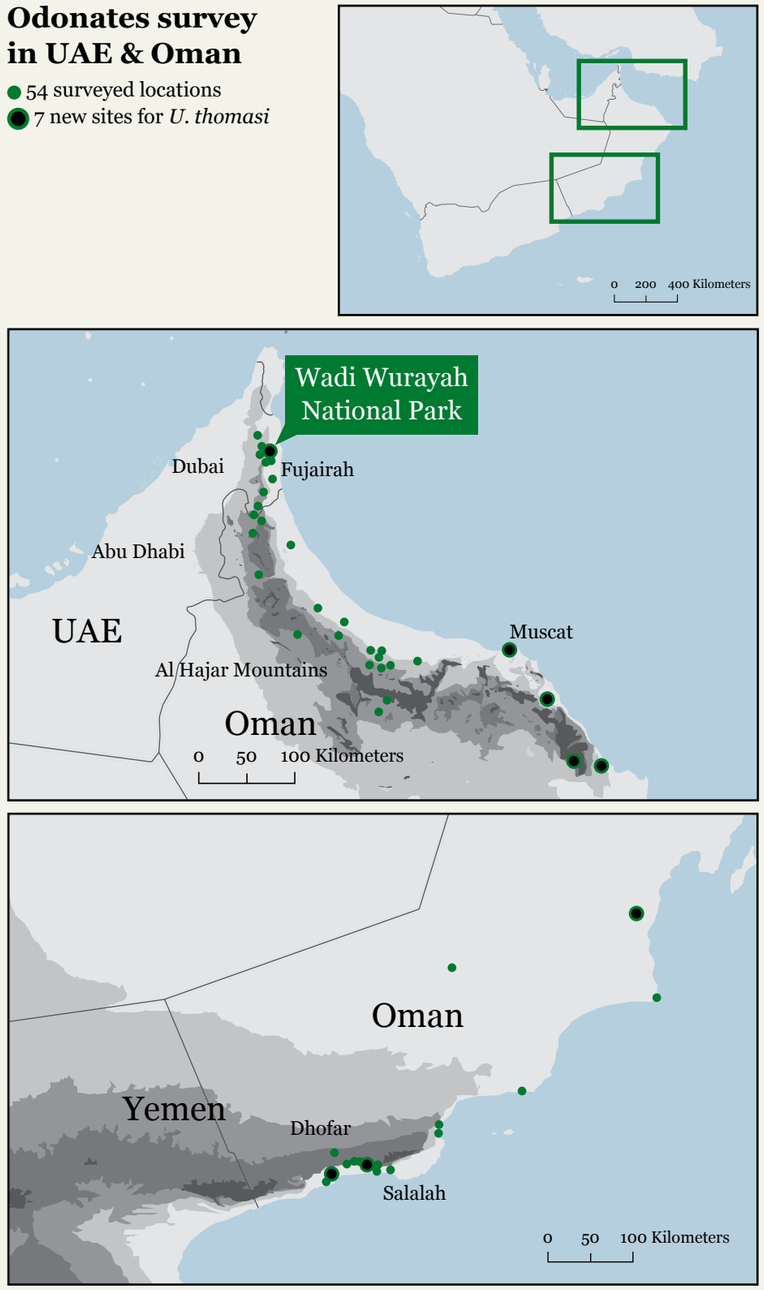

Figure 14: Distribution of sites surveyed for Odonata investigations in the Hajar Mountains, the Al Wusta and Dhofar regions, and new locations discovered for *Urothemis thomasi*.

2.2.4 Toads

Due to the nature of their lifecycles, amphibians have long been considered good indicators of ecosystem health and of good water quality; they are highly sensitive to aquatic pollution during all phases of their lives (Boyer & Grue, 1995). The two species of amphibians present in the UAE, the Arabian toad (*Sclerophrys arabica*) and the Dhofar toad (*Duttaphrynus dhofarensis*), live in the wadi. They are both secondary consumers and are linked to freshwater habitats for survival but are characterised by differences in ecology (Soorae et al., 2013). The Arabian toad, which is more dependent on the permanent presence of water than the Dhofar toad, is much more abundant, or at least visible, in the park. The Dhofar toad, which is a more opportunistic breeder, is nearly invisible all year long but appears in numbers just after rainfall to lay eggs in temporary pools. These differences in ecology and in dependence on water make the two species an excellent model for studying the effects of climate change on the Hajar Mountain ecosystems and for determining how different breeding strategies may or may not favour a species.

With the assistance of HSBC volunteers participating in the Water Research and Learning Programme, research on toads has focused on the following:

- Characterizing and monitoring the toads' population,
- Exploring methodologies to measure population trends in the long term through point counts,
- Documenting the species' morphometry and variations and the causes of those variations, and
- Quantifying the reliability of methods of assessing sampling efforts for obtaining statistically robust indicators.

2.2.4.1 Methodology

Toad population abundance was assessed by point counts from October 2013 to December 2015, except in the hottest months (May to September), when the Water Research and Learning Programme was not in operation. Toads were counted and captured within areas with radii of 10 m, centred on pools or stretches of running water, for periods of 20 minutes. Before being released, all individuals were weighed, their total body lengths (from snout to crotch) and rear leg lengths were measured. During the all point counts, the water quality and meteorological conditions were recorded and the habitat described.

2.2.4.2 Population abundance

Over the whole survey period, 231 point counts were performed, allowing the capture of 1,081 Arabian toads. No Dhofar toads were recorded in the point counts. Since the toads were not tagged, some individuals may have been caught several times. On average, 4.7 ± 4. 6 individuals (min–max: 0–34, n=231) were counted per point count. The abundance shows important seasonal and inter-annual variations (Figure 15). Since no data were collected between May and September, observations are only valid for the period of October to April. Abundance appears to be highest in October–November, decreases in mid-winter to reach a minimum in December–January, and increases between February and April. Abundance in October–December 2013 (2.6 ± 2.2, n=66) is much lower than it is in the two consecutive years during the same period (6.4 ± 5.3, n=33; 6.5 ± 3.8, n=37 in 2014 and 2015, respectively).

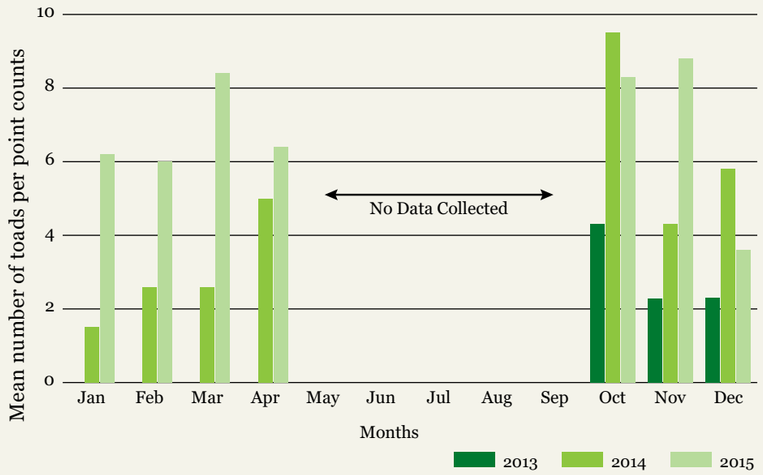

Figure 15: Seasonal and inter-annual variations in toads' abundance in WWNP from October 2013 to December 2015. Toad abundance is measured as the monthly average of the number of individuals per point count. No data were collected between May and September.

2.2.4.3 Factors of variation in the abundance of Arabian toads

Variations in water parameters (water temperature, pH, salinity, TDS, and conductivity) and meteorological parameters (air temperature, relative humidity, and cloud cover) were not correlated and did not explain the observed variations in toad abundance. Only cloud cover showed negative correllation with Odonate abundance; their abundance decreased with increasing cloud cover. Toads appeared to be more abundant in water bodies with reeds than in water bodies without vegetation (9.6 ± 6.7 (n=35); 4.1 ± 3.3 (n=17), respectively) and in running water than in stagnant water (6.9 ± 5.3 (n=37); 4.5 ± 3.9 (n=38), respectively). Arabian toads appeared to prefer running water with vegetation on banks.

2.2.4.4 Variations in occurrence according to body size

A total of 1,096 toads were captured and measured. The average weight was 5.7 ± 3.0 g (Min–max: 0.2–17.5 g, n=1071) with a body length of 38.7 ± 7.8 mm (min–max: 12.3–61.1 mm, n=1,096) and a rear leg length of 38.1 ± 12.0 mm (min–max: 0.9–75 mm, n=1,096). No clear pattern of variation was detectable in the average body size measurements, whether seasonal or inter-annual. However, the average weight and size of the toads captured in spring 2014 (January to April) appeared to be higher than those of the toads captured in the other seasons. The average weight recorded for the period January–April 2014 was 8.2 ± 2.9 g for a body size of 43.6 ± 6.3 mm, while the average weight and body size were 4.8 ± 3.2 g and 36.6 ± 8.8 for mm the period of September to December 2014 and 5.2 ± 2.9 g and 36.8 ± 8.1 mm for the period January to April 2015 (Table 11). A higher proportion of larger individuals may have been present during this period, having come to the water bodies to breed. The observation of eggs and tadpoles during this period supports this (see §2.2.4.5, p. 46).

Table 11: Variations in the average weight and body size of Arabian toads per season

Weight (in g)						
Year	Jan–April			Sept–Dec		
	Mean	SD	n	Mean	SD	n
2013				6.0	2.6	193
2014	8.2	2.9	141	4.8	3.2	195
2015	5.2	2.9	300	5.1	2.6	216
Body length (in mm)						
	Jan–April			Sept–Dec		
	Mean	SD	n	Mean	SD	n
2013				40.1	7.0	196
2014	43.6	6.3	141	36.6	8.8	217
2015	36.8	8.1	300	38.6	6.5	216

Values significantly higher than those in other seasons are red in colour

No correlation was found between the occurrences of toads per class of size and meteorological parameters. Where water quality parameters were concerned, a negative correlation was found between salinity, conductivity, TDS (all strongly interdependent), and the average body size of toads. However, it is much less clear at this stage why and how these water quality parameters would influence the relative abundance of toads of different size or if this is just a data artifact.

Arabian toads appear to have different habitat choices according to their sizes. Toads were sorted into three classes of body mass. The proportions per class were then compared between habitats to investigate whether smaller or bigger toads tended to prefer different habitats or to segregate per habitat. The smallest toads appeared to be more abundant, proportionally, in water bodies with running water and no vegetation than in water bodies with stagnant water and no vegetation, whereas the largest toads were more abundant in water bodies with running water and reeds but less abundant when there was no vegetation. Medium-size toads appeared to be more abundant in water bodies with stagnant water independent of the bank vegetation.

2.2.4.5 Breeding records

The presence or absence of eggs and tadpoles was recorded from February to April and September to December 2015 as were the toads' vocalisations. Eggs were only recorded once, at the beginning of December 2015, while tadpoles were noticed from the end of February to the beginning of April as well as in mid-December. Vocalisations were also regularly heard all through March and once at the end of April 2015.

It is worth mentioning that, despite the lack of records of Dhofar toads during point counts, few individuals have been recorded episodically far away from water (at the WWNP headquarters and on terraces). Following flash flooding and when the dam filled up with water, a concert of Dhofar toads was audible at the dam as early as one day after rainfall.

2.2.4.6 Conclusion and remarks

The toads' abundance showed some marked seasonal and inter-annual variations, but habitats or other environmental variables do not explain these variations clearly yet. Water quality parameters and local meteorological conditions did not seem to play a large role in the abundance of toads. These apparent variations will require more complex analysis and further field investigations. The distribution of toads per class of sizes appears to be an interesting variable to investigate for monitoring populations.

To better understand population dynamics, EWS-WWF initiated an individual PIT tagging programme in the third WRLP field season to obtain data on the movement, growth, and survival of individual toads throughout their life cycles. Preliminary trials of post-dorsal subcutaneous injections of electronic PIT tags were conducted successfully on four Arabian toads in May 2015, and 60 more individuals were tagged between September and December 2015 and started to provide recapture information.

Additional data analysis and a minimum of one year of field data collection are required to compare the reliability of different methods of monitoring population trends and to assess the minimum sampling effort required to obtain statistically robust indicators with the most cost-effective and reliable measures of change in the ecosystem.

2.2.5 Reptiles

Half of the species of reptiles present in Wadi Wurayah are endemic to the Hajar Mountains (eight species out of 16). As WWNP is the only protected mountain area of the UAE, it is the only place where these species' habitats are officially protected. By ratifying the CBD convention, the UAE made the commitment to ensure the survival and conservation of its biodiversity. This conservation responsibility is even higher when it comes to ensuring the survival of endemic species, which, by definition, have a distribution range restricted to a small geographical region. The species endemic to Wadi Wurayah have a distribution range limited to the Hajar Mountains of the UAE and Oman.

2.2.5.1 Objectives

Mina Zaki studied the reptile community of Wadi Wurayah National Park from October 2014 to June 2015 in the framework of a volunteer internship. The main objective was to assess the reliability of different methodological approaches to monitoring reptile populations. Field surveys explored several methods of monitoring population trends, including distance sampling on line transects, quadrat sampling, pitfall trapping, and site occupancy modelling from presence/absence records.

2.2.5.2 Methodology

Area sampling consisted of recording all reptiles encountered on a predefined surface area. Only one trial was done on an area of 350 m by 350 m; four persons covered this area.

The use of line transects involved recording the presence of reptiles and their distance to line transects in order to assess densities of all individual reptiles encountered on a walk. Thirty-seven line transects, totaling a distance of 49.5 km (mean: 1.3 ± 0.9 km, min–max: 0.2–3.4 km) were conducted.

Elvin Miller deployed two lines of nine pitfall traps each for a week in February 2015. The first line was on a gravel terrace close to Said's water tank, and the second one was in the wadi bed behind the waterfall.

In addition, all reptiles encountered in the park in the absence of a specific methodology were recorded as random observations.

2.2.5.3 Diversity and abundance

From November 2014 to January 2015, 100 individuals from 10 species of reptiles were recorded (Table 12; 63% of the total number of species known in WWNP). The most abundant species were the rock semaphore gecko (Pristurus rupestris), followed by the Hajar agama (Pseudotrapelus cf. jensvendumi) and the Blue-tailed Oman lizard (Omanosaura cyanura, Picture 3).

Table 12: Reptile species encountered in Wadi Wurayah National Park between November 2014 and January 2015, ranked according to abundance.

Species	Methods				Total
	Area	Line transect	Random	Pitfalls	
Pristurus rupestris Rock semaphore gecko		26	6		32
Pseudotrapelus cf. jensvendumi Sinai (Hajar) agama		12	8		20
Omanosaura cyanura Blue-tailed Oman lizard		13			13
Pristurus celerrimus Bar-tailed semaphore gecko		4	3		7
Ptyodactylus hasselquistii Fan-footed gecko		7			7
Echis omanensis Omani carpet viper	2	3	1		6
Platyceps rhodorachis Wadi racer	1	3	2		6
Omanosaura jayakari Jayakar's Oman lizard	2	2			4
Trachylepis tessellate Tesselated skink		2			2
Bunopus spatalurus hajarensis Spacious rock gecko			1	1	2
Lacertidae sp. Lizard unidentified	1				1
Total	**6**	**72**	**21**	**1**	**100**

2.2.5.4 Densities per habitat

Reptile densities were assessed based on species records on line transects (Table 13). All individuals encountered on a 3-m-wide band were recorded without taking into account the detection probability analysed by distance sampling.

Table 13: Densities of reptiles in WWNP (in number of individuals per ha) assessed through strip line transects per habitat

Species	Gorge	Mountain slope	Wadi bed with water	Dry wadi bed	All habitats
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Echis omanensis	0.1 ± 0.4	0	4.3 ± 7.3	0	0.7 ± 3.2
Omanosaura cyanura	1.2 ± 1.3	3.3 ± 2.9	0	0.2 ± 0. 8	1.2 ± 2.15
Omanosaura jayakari	0	0	0	0.4 ± 1.0	0.1 ± 0.6
Platyceps rhodorachis	0.4 ± 0.9	0	2.8 ± 4.4	0	0.5 ± 2.0
Pristurus celerrimus	0.4 ± 0.9	0	0	0.3 ± 0.8	0.2 ± 0.6
Pristurus rupestris	0.4 ± 2.5	3.7 ± 3.7	2.1 ± 5.0	1.6 ± 2.1	2.1 ± 3.3
Pseudotrapelus cf. jensvendumi	0	3.2 ± 6.2	0	1.1 ± 2.6	1.2 ± 3.7
Ptyodactylus hasselquistii	0.2 ± 0.6	0.2 ± 0.6	0	0.5 ± 1.3	0.3 ± 0.9
Trachylepis tessellate	0.2 ± 0.4	0	0	0.1 ± 0.4	0.1 ± 0.3

Not surprisingly, species densities were higher in wadi beds with water, where the availability of food was higher. The highest measured densities were for the Omani carpet viper (*Echis omanensis*), with a mean density of 4.3 individuals per ha. Dry wadi beds and gorges were the habitats with the highest species diversity. Only the rock semaphore gecko was encountered in all habitats; other species seemed to be more selective habitat choice.

2.2.5.5 Choice of methods for long term monitoring

The use of pitfall traps is presumably an interesting method to consider for detecting and/or capturing species, either those that are nocturnal or difficult to detect visually. However, this method is heavier to deploy and more difficult to implement in the long term. The area sampling count method can provide accurate results of densities and appears to be more efficient than other methods when several observers conduct it, but it also requires a more significant effort to sample different habitats. This method would not be recommended for long-term monitoring. Taking into account the staff and time requirements, the most efficient method for covering larger areas in different habitats is presumably the census by distance sampling on line transects. However, the presence/absence method has not been sufficiently investigated and may receive more attention in the future as an alternative to line transects.

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Picture 3: *Omanosaura cyanura* (blue-tailed Oman lizard), endemic to the Hajar Mountains, present in WWNP

2.2.6 Birds

All bird species observed in the park during field surveys from November 2012 to December 2015 have been recorded. However, these records result more from opportunistic observations than from a regular systematic method. They provide interesting information on the periods of the presence of the different species and on their statuses, but they are difficult to analyse for long-term population monitoring. A table of presence in the park has been created based on these observations (Table 14).

Table 14: The presence per month of all bird species recorded in Wadi Wurayah National Park by the alphabetic order of their scientific names. The number in each cell indicates the number of records per month, cumulated over 3 years. Confirmed presence is highlighted in dark blue, while light blue indicates the suspicion or possibility of presence.

Scientific name	English name	J	F	M	A	M	J	J	A	S	O	N	D
Accipiter nisus	European sparrowhawk	1		3	2							1	1
Acridotheres tristis	Common mynah	1	1	2	2	2	1	1	1	2	1	2	4
Acrocephalus palustris	Marsh warbler				1	1							
Actitis hypoleucos	Common sandpiper												
Alcedo atthis	European kingfisher	1	1		1					2			1
Ammomanes deserti	Desert lark	3	4	2	3	2	2	3	1	3	2	4	3
Ammoperdix heyi	Sand partridge	3	1		2	1	1			2	1	1	1
Anas crecca	Teal	1											
Anas platyrhynchos	Mallard	2											
Anthus similis	Long-billed pipit	1	1										
Apus apus	Black swift												
Apus pallidus	Pallid swift				1								
Aquila fasciata	Bonelli›s eagle		3	4	2	1	1			2	1	1	2
Aquila heliacal	Imperial eagle	1											
Ardea cinerea	Grey heron												
Athene noctua	Little owl	2	7	12	2				1	1	1		
Bucanetes githagineus	Trumpeter finch		1			1	1	1		1		2	
Butorides striatus	Striated heron	1											
Caprimulgus aegyptius	Egyptian nightjar			1									
Caprimulgus europaeus	European nightjar				2								
Carpospiza brachydactyla	Pale Rock sparrow			1			1						
Cercotrichas galactotes	Rufous-tailed scrub-robin				3	1							
Charadrius dubius	Little ringed plover	1											
Chlamydotis macqueeni	Houbara bustard												
Cinnyris asiaticus	Purple sunbird	2	1	3	3	3	1	1		1	1		2
Circaetus gallicus	Short-toed eagle										2		

Scientific name	English name	J	F	M	A	M	J	J	A	S	O	N	D
Columba livia	Rock dove	2	1	1	1	2	1	2		1		2	1
Coracias benghalensis	Indian roller	1	1	1	1	1						4	
Coracias garrulous	European roller					1							
Corvus ruficollis	Brown-necked raven	1		2	2							2	
Corvus splendens	House crow		1	1	2	1					1	2	
Cuculus canorus	Common cuckoo					1							
Emberiza cineracea	Cinereous bunting				1								
Emberiza striolata	House bunting	3	2	3	2	1	1	3		1	1	3	2
Euodice malabarica	Indian silverbill	1	1	2	2	1	1	2	1	2	1	3	2
Falco naumanni	Lesser kestrel				2								
Falco pelegrinoides	Barbary falcon												1
Falco tinnunculus	Kestrel												2
Francolinus pondicerianus	Grey francolin					1							
Galerida cristata	Crested lark												
Gallinago gallinago	Common snipe	1											
Himantopus himantopus	Black-winged stilt	2			1		1					1	1
Hippolais languida	Upcher›s warbler				3					1			
Hirundo rustica	Barn swallow											1	
Iduna pallida	Eastern olivaceous warbler			1	1								
Irania gutturalis	White-throated robin				2								
Ixobrychus minutus	Little bittern					1							
Jynx torquilla	Eurasian wryneck											2	
Lanius isabellinus	Daurian shrike			2									
Lanius meridionalis	Southern grey shrike	3			1		2	1		2	1	2	3
Lanius minor	Lesser grey shrike				1								
Lanius phoenicuroides	Turkestan shrike				3								
Lanius senator	Woodchat shrike												
Lonchura punctulata	Scaley-breasted munia						1						
Lymnocryptes minimus	Jack snipe	1											
Merops apiaster	European bee eater				3	1							
Merops orientalis	Little green bee eater	2	2	1	1	1	1	1			1	3	1
Merops persicus	Blue-cheeked bee eater					1		1		1			
Monticola saxatilis	Rock thrush			1	1								
Monticola solitarius	Blue rock thrush		1	2									1
Motacilla alba	White wagtail	1											
Motacilla cinerea	Grey wagtail	2	1	1						1		2	1
Motacilla citreola	Citrine wagtail									1			

Scientific name	English name	J	F	M	A	M	J	J	A	S	O	N	D
Motacilla flava	Yellow wagtail												
Muscicapa striata	Spotted flycatcher				1	1							
Oenanthe albonigra	Hume›s wheatear	5	3	2	2	1	2	3		3	1	5	4
Oenanthe deserti	Desert wheatear				1								
Oenanthe isabellina	Isabelline wheatear				1								
Oenanthe lugens	Mourning wheatear												
Oenanthe monacha	Hooded wheatear	1	1				1	1		1	1	1	
Oenanthe oenanthe	Northern wheatear				2								
Oenanthe picata	Variable wheatear												
Oenanthe pleschanka	Pied wheatear			1	1							1	
Oenanthe xanthoprymna	Red-tailed wheatear	2	1									2	3
Oriolus oriolus	Golden oriole												
Otus brucei	Pallid scops owl	1	8	2							2	2	
Passer domesticus	House sparrow	2	1	2	2	2				1	1	3	3
Phoenicurus ochruros	Black redstart	3	1	2							1	4	3
Phylloscopus collybita	Chiffchaff	1			1							1	4
Phylloscopus neglectus	Plain leaf warbler	2	1									4	2
Phylloscopus trochilus	Willow warbler				1								
Prinia gracilis	Graceful warbler												
Pterocles lichtensteinii	Lichtenstein›s sandgrouse	3	1			1	1			2	1	3	1
Ptyonoprogne obsoleta	Pale crag martin	3	1	2	1	2	2	1		2		2	2
Pycnonotus leucotis	White-cheeked bulbul	3	2	2	2	1				1	1	3	4
Pycnonotus xanthopygos	Yellow-vented bulbul	3	4	2	3	1	1	3	1	3	1	2	3
Scotocerca inquieta	Scrub warbler	1							1			1	3
Streptopelia decaocto	Collared dove							1			1	1	
Streptopelia senegalensis	Laughing dove	3	3	2	2	2	2	3	1	3	1	3	4
Strix butleri	Omani owl			3									
Sylvia communis	Common whitethroat				1					1			
Sylvia curruca	Lesser whitethroat			1	2					1			
Sylvia minula	Desert lesser whitethroat	2	1								1	2	3
Sylvia mystacea	Menetries›s warbler			2	2								
Sylvia nisoria	Barred warbler				1								
Tringa ochropus	Green sandpiper	2							1	1			
Turdoides squamiceps	Arabian babbler				1								
Turdus atrogularis	Black-throated thrush											2	
Upupa epops	Hoopoe	1		2				1	1				
Vanellus indicus	Red-wattled lapwing	2					1						

2.2.6.1 Monthly variations in bird diversity

From November 2012 to December 2015, 91 bird species were recorded in WWNP, out of the 109 species known to have been recorded at least once (see § 3.2.5 , p. 79).

The number of species per month varied on average from six species (in August) to 39 in April (Figure 16). The low number of species recorded in August is, however, mainly due to the lack of records since there are at least 21 resident species and possibly up to 35 if we include 10 visitors from nearby habitats and four species for which the status of "resident" could not yet be ascertained (the long-billed pipit (*Anthus similis*), the trumpeter finch (*Bucanetes githagineus*), the pallid scops owl (*Otus brucei*) and the Omani owl (*Strix butleri*)).

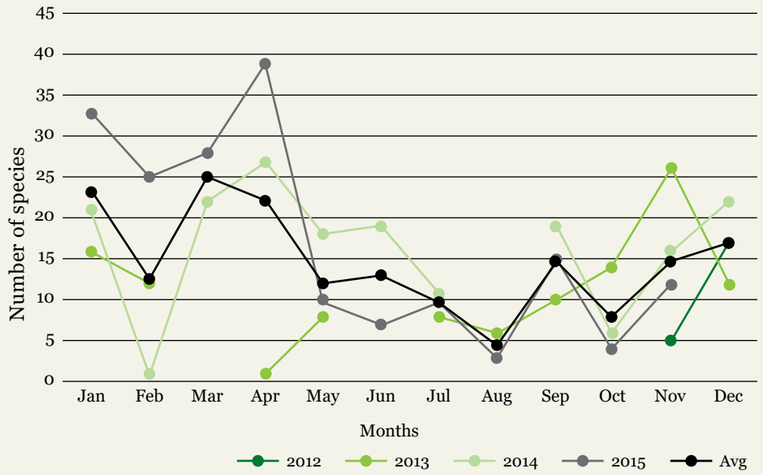

Figure 16: Monthly variations in the number of bird species present in WWNP from November 2012 to December 2015.

2.2.6.2 Owl survey

Elvin Miller conducted an owl survey from December 2014 to March 2015 in the ecotourism zone of the park, focusing on detecting which species were present and assessing their density or relative abundance (Miller et al., 2015). He conducted the survey using the playback method, which consisted of playing records of owls' songs with an amplified speaker and waiting for owls' responses. Three owl species were contacted: the pallid scops owl (*Otus brucei*), the little owl (*Athene noctua*) and the Omani owl (*Strix butleri*, Figure 17). No eagle-owls were reported during the survey. The densities of the Pallid Scops Owl and the Little Owl were assessed and found to be 0.75 and 1.6 singing males per km², respectively. By extrapolation, these gave estimates of 90–165 pallid scops owl territories and 275–350 little owl territories for the whole national park. Only one individual Omani owl was contacted twice over a week at the beginning of March 2015, and its hooting was recorded (Judas et al., 2015). This was the first authenticated record of the species in UAE. The most recent genetic analyses showed that the discovery of the Omani owl in Oman in 2013 (Robb et al., 2013; Picture 4) was a rediscovery of *Strix butleri* and that the *Strix* populations of Western Arabia belong to another species, the newly named *Strix hadorami* (Kirwan et al., 2015; Robb et al., 2015).

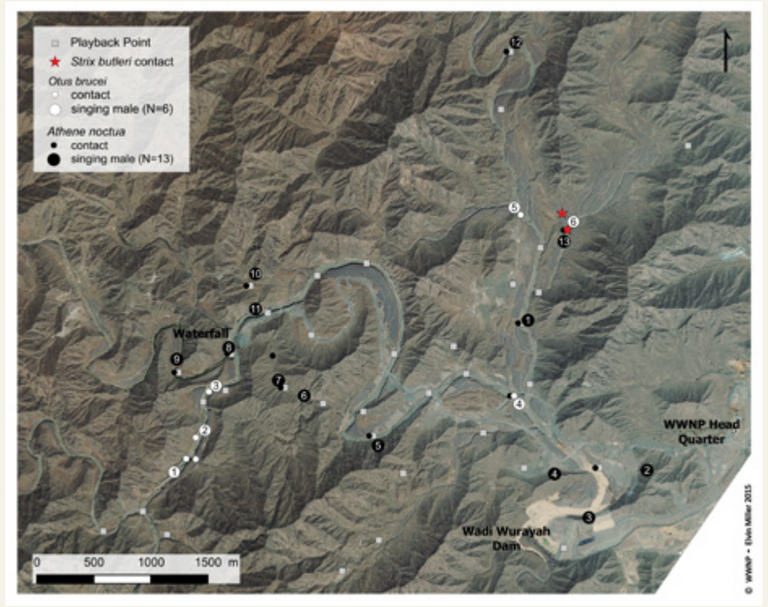

Figure 17: Map of playback locations and contact with three species of owls during an owl survey conducted in the ecotourism zone of WWNP from December 2014 to March 2015.

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Picture 4: Omani owl (*Strix butleri*) photographed in Jebel Akhdar, Oman.

2.2.6.3 Bird ringing:

A ringing programme was initiated in WWNP together with a resident bird population monitoring programme. A few trapping sessions with mist nets were conducted in April 2013 and between February and April 2014, resulting in the ringing of 15 birds of nine species.

Table 15: Number of birds caught and ringed (n) in WWNP per species

Scientific name of species	English name	n
Acridotheres tristis	Common mynah	1
Alcedo athis	European kingfisher	1
Cercotrichas galactotes	Rufous-tailed scrub robin	1
Lonchura malabarica	Indian silverbill	2
Passer domesticus	House sparrow	6
Pycnonotus xanthopygos	White-spectacled bulbul	1
Streptopelia senegalensis	Laughing dove	1
Sylvia mystacea	Menetries's warbler	1
Otus brucei	Pallid scops-owl	1

Bird ringing, which required specific handling and identification skills and is a time-consuming method, has not been developed enough to provide sufficient data for monitoring bird populations. Birds have mainly been captured using mist nets. This method has resulted in rather low capture success and may not be the most suitable method in open areas with very low bird density. Other trapping methods, such as clap nets or cage traps coupled with playback to target specific individuals may provide better results. However, capturing and ringing a sufficient number of birds to provide reliable data for monitoring bird population trends will always take a long time and require significant staff involvement. Bird ringing with both metal and coloured rings would be an efficient method for monitoring population size and dynamics within the park, given the ability of trained and dedicated staff.

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Picture 5: Ringing an European Kingfisher (*Alcedo atthis*) in WWNP in April 2013

2.2.6.4 Options for long term monitoring

In addition to bird tagging, which targets shortlisted species (resident passerines), territory mapping and site occupancy model should be investigated for the long-term monitoring of the bird population in the park.

2.2.7 Mammals

2.2.7.1 Camera trapping

A camera trapping programme was initiated in 2013 (Judas, 2013a). The objectives of this programme were to assess, with the greatest degree of reliability and precision, the abundance and distribution of the Arabian tahr population in Wadi Wurayah National Park, to determine the need for population reinforcement or reintroduction, and to assess potential competition for resources with feral goats. The camera trapping method was selected as the best option for obtaining information on the status of the Arabian tahr population, either by assessing relative or absolute density through the capture-recapture model (Karanth et al., 2004), or by assessing occupancy rates.

In 2013, the Arabian tahr population was thought to be small and localised to the most inaccessible parts of the park (steep cliffs, remote areas), which poachers could not easily access to kill the last individuals.

Following the recommendations of Jackson et al. (2005), the population survey was designed based on a 2 by 2 km sampling grid that covered the whole national park. Two camera traps would have to be deployed per sampling grid cell. The size of the grid cell was determined from estimates of the Arabian Tahr home range size (2 to 5 km² with daily movements of 0.5 to 4.5 km), which Steve Ross, who had studied the species in Wadi Sareen, Oman, for several years, provided. Since physical, logistical and human constraints (site access, costs, and staff availability) limited the completion of an exhaustive survey covering the whole area with equal intensity, 25 sampling grid cells were selected for their remoteness and high elevations and the presence of water for the deployment of 50 camera traps (Figure 18).

Additionally, the setting up of a survey plan to assess the status of the Arabian tahr in Wadi Wurayah National Park was associated with the intention to provide relevant information on the wildlife community and the relative abundance of other large mammal species (carnivores and the feral goat population in particular).

In August 2013, 32 camera traps were deployed in the most remote parts of the wadi, thanks to the UAE National Air Force, which sent a Blackhawk helicopter to drop field-survey teams at locations that were difficult to access during a one-week period (Judas, 2013b). Additional cameras were deployed in the following months (Figure 19) and checked twice a year to maintain, replace, or relocate them and to recover pictures.

2.2.7.2 The status of the Arabian tahr

The Arabian Tahr, an artiodactyl of the Bovidae family (*Caprinae* sub-family), is an endemic species of the Hajar Mountains of the UAE and Northern Oman. It is listed as “Endangered” in the IUCN Red List of Endangered Species (Insall, 2008), and as “Critically Endangered” at the UAE national level (Hornby, 1996). Thus, it is considered to be facing a very high risk of extinction in the wild. Surveys and ecological studies have been conducted in the Omani part of the range, mainly in the Wadi Sareen Protected Area (Munton, 1985; S. Ross, 2013, personal communication), which is thought to be the stronghold of the global population. The current status of the population in the UAE has been poorly investigated and is therefore not well known. The scarcity of records strongly suggests that the Emirati population is very low, has suffered important decreases due to uncontrolled poaching in recent decades, and is possibly at risk of imminent local extinction.

Wildlife surveys, which different organisations and individuals have coordinated, have been conducted in Wadi Wurayah National Park over the last 30 years. The Arabian Leopard Trust conducted preliminary surveys, and, more recently, from 2005 to 2008, the EWS-WWF team conducted baseline surveys which sought to create a Protected Area (Tourenq et al., 2009).

During these surveys, few observations of tahrs have been recorded. These have mainly involved camera trapping:

- In 1995, a camera trap photographer a female with a two-to-three-month-old calf during the Arabian Leopard Trust survey (Stuart & Stuart, 1995).
- During a camera trapping session conducted in summer 2000, nine females, at the most, were identified (CAMP, 2003). It was then thought that the Arabian tahr population of UAE could number less than 50 individuals.
- During the most recent camera trapping surveys (2006–2008), camera traps were deployed in different parts of the park. The objectives were mainly qualitative and focused on obtaining pictures that were representative of the wildlife diversity of the wadi so as to draw attention to the major role of the area in wildlife conservation. The deployment of the camera traps was not undertaken for any quantitative population assessment (C. Tourenq, 2013, personal communication), but pictures of Tahrs were recorded irregularly at two sites.

These previous records were mainly obtained through camera trapping. In addition, droppings were recorded at a few locations, while direct observations were rarely reported. Altogether, the distribution of these records in space and time hardly provides reliable figures on the population status, but it indicates that the species has been present in low numbers. Since the deployment of a large number of camera traps all over WWNP in August 2013, no pictures and no signs attesting the presence of the Arabian tahr have been obtained.

From three cameras traps deployed between August 2010 and March 2013 in an area where tahr occurences were still noted (Galeel al Haban), totaling 117 sampling occasions of 10 days' duration, the capture rate was estimated to be 0.094 ± 0.293 per occasion (i.e. the probability of a tahr being photographed during a 10-day period), with an average time to recapture of 25 ± 21.1 days (n=6). To reach a probability of non-detection of 0.05 ((1-p)n, where p is the probability of detection per occasion and n is the number of occasions), or, by contrast, a probability of detection of 0.95, we assessed that camera traps should be operated for a total of 30 occasions per sampling unit. If two cameras are operated in one sampling unit, they should stay active simultaneously for 15 consecutive occasions of 10 days, i.e. 150 days. In other words, if two cameras are operated for five months and do not provide any evidence of the presence of tahr, there is only a probability of 5% that the species is present but undetected.

The last picture of a live Arabian tahr in WWNP was recorded in October 2012 (Picture 6). After three years without any indication of the tahr's presence, the probability that it continues to survive in the park in the surveyed sampling grid cells is <0.001.

These results stress the need to reintroduce the species to the park after ensuring that all causes of extinction (poaching, overgrazing, and competition with goats) have been removed. As the only Mountain Protected Area of the UAE, Wadi Wurayah National Park is, for the time being, the country's most suitable area for the implementation of a conservation programme for this species.

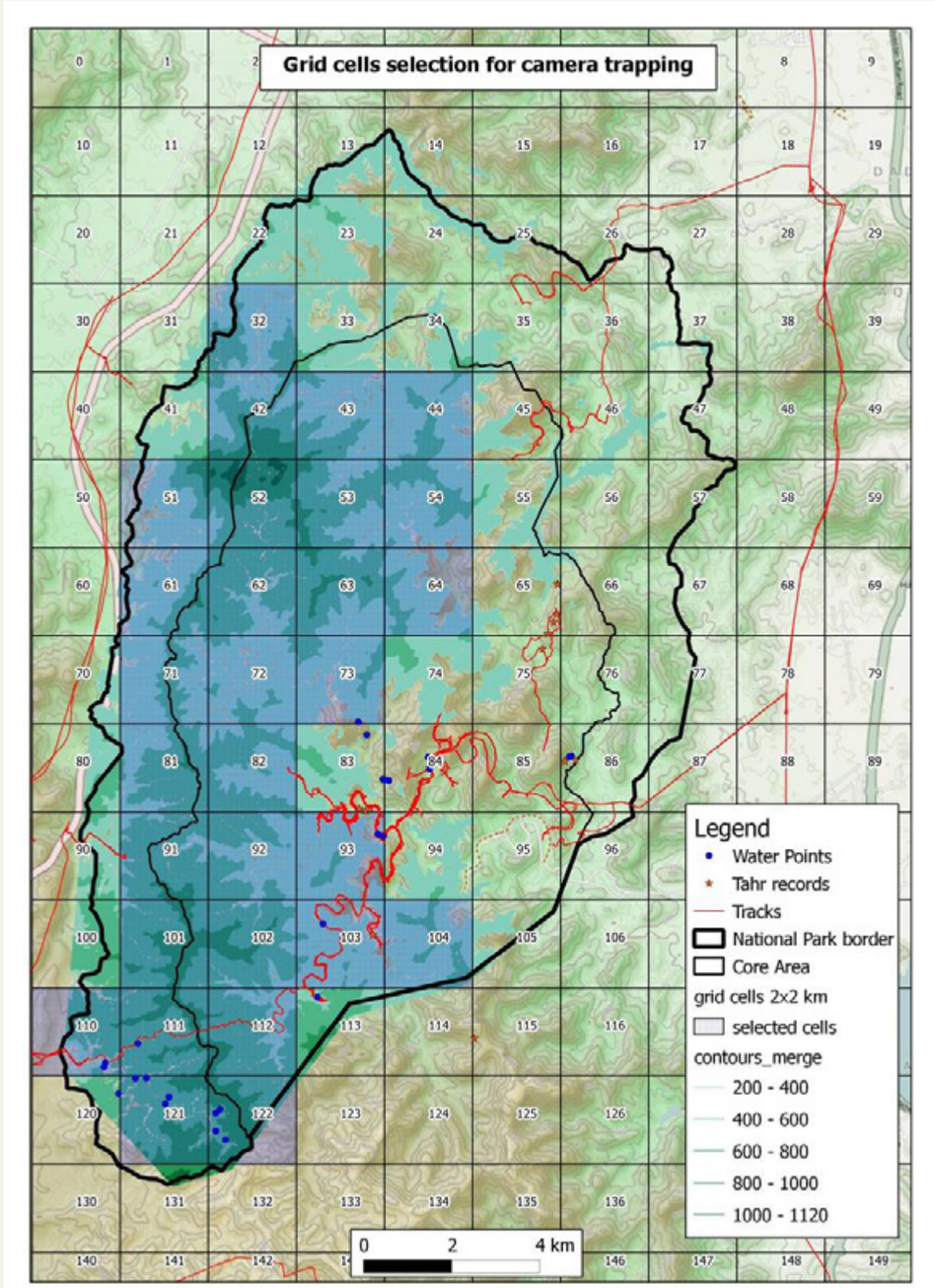

Figure 18: Map of the 25 selected 2 km by 2 km sampling grid cells for camera trap deployment in Wadi Wurayah National Park

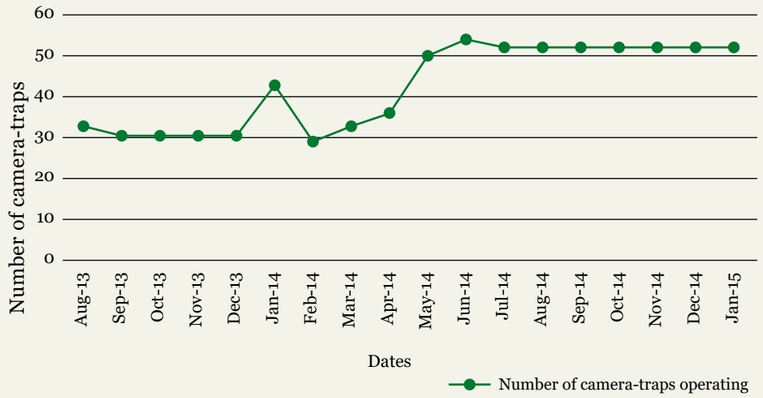

Figure 19: The number of camera traps operating from August 2013 to January 2015. Data were not available to EWS-WWF after these dates.

Picture 6: The last picture of a live Arabian tahr obtained by camera trap in WWNP in October 2012.

2.2.7.3 Carnivores

The network of camera traps, initially deployed to assess the Arabian tahr populations, has also accomplished the monitoring of other large mammals such as the carnivore population of the park (the red fox, Blanford's fox, the caracal, and the wild cat). The red fox, Blanford's fox, and the caracal appear to be well represented in the park, but no definitive confirmation of the presence of the wild cat has been obtained yet.

Picture data are yet to be analysed at length, and the whole data set and the management of the camera trapping monitoring programme were handed over to Fujairah Municipality in early 2015. No figures can be presented on the assessment of the population size.

From January to March 2015, Elvin Miller (2015) conducted carnivore trapping in the WWNP ecotourism zone. The objectives were to assess the effort and effectiveness of trapping and tagging carnivores and Brandt's hedgehogs to monitor their populations and to deploy several radio-transmitters for the study of the ecology of these species (their home ranges, activity patterns, population structures, and densities) in the park.

Up to 20 Tomahawk traps were deployed for a total of 332 trap-nights. Different baits (apples, chicken, sardines, live pigeons) were tested, and the behaviour of animals approaching the cages was punctually captured by camera traps. Nine individuals of three species were caught (Table 16): Blanford's fox (Picture 7), Brandt's hedgehog, and one feral goat incidentally entered one trap. No red fox was caught although they came close to the traps several times. They appeared much more cautious and reluctant to enter traps than Blanford's fox.

Table 16: The number of captures and recaptures per species with Tomahawk traps between January and March 2015

Species	English name	Number of captures	Number of individuals	Number of recaptures	Number of individuals recaptured
Vulpes cana	Blanford's fox	15	6	9	3
Paraechinus hypomelas	Brandt's hedgehog	4	2	2	
Capra aegagrus hircus	Feral goat	1	1	0	
Total		**19**	**9**	**11**	

One of the Blanford's foxes was a recaptured an individual who had been tagged two years previously in the same area during the WRLP pilot. Two Blanford's fox and two Brandt's hedgehogs were equipped with VHF transmitters (Microsensory, UHF-GPS - 40g) or GPS bugs (Biotrack). The acquisition of GPS locations by the electronic devices provided poor results mainly due to the harsh relief, which increased the time necessary to get a GPS fix. Moreover, the difficult terrain made radio-tracking by foot a very challenging task, either where the retrieval of the signal or the reliable location of the origin of the signal (there were many echoes when the signals were received) was concerned.

The few locations obtained for both species did not authorize any home range size estimates but allowed the location of a few burrows and the assessment of some amplitudes of movements.

Studying large mammals or meso-carnivores is time-intensive work, which requires the involvement of trained and dedicated staff. More fieldwork efforts would be required to pursue these objectives. The capture-recapture method with ear tagging would presumably be the most cost-effective and staff-effective method of monitoring the population dynamics and health status of the Brandt's hedgehog and Blanford's fox populations. However, more investigations that study their home ranges in the park are required to obtain reliable estimates of their population sizes, crossing home range data with camera trap results.

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Picture 7: A Blanford's fox caught in a Tomahawk trap

2.2.7.4 Rodent trapping

Rodents occupy an important position in the food chain. As they are the prey of a number of predators (snakes, raptors, owls, small carnivores), the monitoring of their population dynamics is important. It facilitates the conservation of all their predators. As primary consumers, rodents contribute to the dissemination of plant species.

EWS-WWF consultant, Elvin Miller carried out rodent trapping, aimed at testing methods and quantifying sampling efforts for population monitoring, for three months between December 2014 and March 2015. Lines of 10 Sherman traps, baited with peanut butter on bread were deployed at seven different locations, which were representative of five different habitats (the wadi bed, reeds, slopes, gulleys, and terraces).

Two species were caught (Table 17): the Egyptian spiny mouse (*Acomys cahirinus*) and Wagner's gerbil (*Dipodillus dasyurus*). The Egyptian spiny mouse was the most abundant species. It was encountered in all habitats, while Wagner's gerbil seems to prefer terraces and drier areas. Habitats near water, such as the reeds of the waterfall, had the highest density of rodents, mainly spiny mice. Ninety-two percent of the individuals caught were tagged using an individual code with permanent ink applied on different parts of their bodies. The trapping was conducted over two sessions of nine and 12 days in three and four lines respectively. Averaging the seven lines indicated that it took eight days to reach a recapture rate of 50%. This meant that eight days were not sufficient for capturing the overall populations frequenting the areas since new individuals were still being caught.

Table 17: The number of captures and recaptures of rodents by Sherman trapping from January to March 2015 at seven different locations

Habitats	Capture Session duration	Number of captures			Number tagged	Number of recaptures	Recapture rate
	(In days)	*Acomys cahirinus*	*Gerbillus dasyurus*	Total			
L1- Wadi Ghayl - lateral canyon	12	5	1	6	5	3	60%
L2- Wadi Ghayl - wadi bed	12	5	8	13	12	3	25%
L3- Wadi Ghayl - plateau	12	7	13	20	19	11	58%
L4- Waterfall - reeds down	12	40	3	43	39	27	69%
L5- Waterfall - reeds up	9	27	0	27	24	17	71%
L6- Wadi Wurayah - slopes on plateau	9	7	0	7	7	4	57%
L7- Wadi Wurayah - plateau	9	0	6	6	6	2	33%
Total		**91**	**31**	**122**	**112**	**67**	**60%**

More trapping sessions and tagging would need to be conducted to get a better understanding of the population dynamics and the reliability of the method for assessing population trends.

An individual PIT tagging programme was initiated in October 2015 with WRLP volunteers. It should also shed light on population sizes and dynamics. However, presumably in relation to very low rainfall in 2015 and the low availability of food, capture success in autumn 2015 was much lower than that in spring.

2.3 THREATS

A threat analysis conducted during the elaboration of the WWNP management plan resulted in the listing and broad description of perceived active pressures and a selection of persistent critical threats. However, none of these has been quantified to date, and no indicators to monitor their trends and evaluate the effectiveness of management actions have been defined. In order to eradicate or mitigate the threats that compromise the restoration and conservation of WWNP ecosystems and to evaluate the impact of the measures taken, the quantification and monitoring of the threats are essential. But they still require further development. Some orientations and a summary of the situation per threat is provided below.

2.3.1 Overgrazing

Overgrazing is one of the major threats, if not the largest threat, to WWNP habitats. The state of the vegetation as it should be without grazing is largely unknown. However, reference to the vegetation recovery of fenced areas in similar arid climates where grazing has been excluded suggests that the overall vegetation cover and species richness (relative abundance per species) should be much higher than they are now. The problem of overgrazing is nearly entirely linked to feral goats, to grazing by domestic herds of sheep and goats, and to feral donkeys to a lesser extent.

Feral goats were counted during a helicopter survey in January 2014 in order to estimate their population size. During a 1-hour-40-minute flight, covering a distance of 179 km, three observers counted a total of 143 goats distributed in 28 groups of one to 15 goats (Mean ± SD: 5.1 ± 3.9, n=28). With an average estimated distance of 129.8 ± 68m (min–max: 0–270 m) between the observers and the groups of goats, the survey allowed the coverage of between 12% and 22% of the park area. Assuming the homogeneous distribution of goats throughout the park, the goat population was assessed to range between 663 and 1,193 individuals, that is, to have a density of three to five goats per km^2.

The method of counting goats from a helicopter gave encouraging results, but it would need to be repeated in order to standardise it and evaluate its reliability in estimating the goats' population size and its variations. Surveys may have to be conducted at least twice a year, but it is only by investigating the monitoring methodology and analysing the results that the appropriate frequency of surveys can be determined reliably. The accurate assessment of the goat population size is critical to the development and evaluation of control measures. Controlling feral goats may include the regular slaughter of a number of animals, with quotas based on the population demography (age and sex structure, mortality, and reproductive success). The second factor worth considering to address the problem of overgrazing is the quantification of the effects of goats on the vegetation. Which plant species are the most affected? How do they affect plant diversity, abundance, and productivity? These questions may be answered partially through the implementation of experimental exclosures.

2.3.2 Poaching

Poaching has presumably contributed largely to the local extinction of several species (the Arabian leopard, the Arabian tahr, the mountain gazelle, the chukar partridge) and to the suspected reduction in population size of other species (the Barbary falcon, Bonelli's eagle).

Poaching has been monitored by camera trapping since the deployment of a network of cameras in August 2013, but the current deployment has been designed to monitor large to medium-size mammals. This framework is currently not optimised to provide fully reliable control of most access points to the park (which mainly involve access by foot). Moreover, the time taken to recover the information depends on the frequency of the control of the cameras (once every four to six months), which is ineffective for immediate intervention. Poaching control should be reinforced by the deployment of camera traps in all areas of access to the park, automating the transmission of data in real time. This would entail the deployment of a wireless network and the increase in the number of rangers and their patrolling operations.

2.3.3 Physical damage

Before the closure of the park in December 2013, litter, garbage, and rock graffiti marred all areas that were easily accessible to visitors. The waterfall area was the most affected. Following the closure of the park, EWS-WWF organised several cleaning operations and coordinated graffiti removal and litter cleaning in collaboration with Fujairah Municipality.

While an important amount of litter has been removed, there are still many areas where litter can be found, even in remote places. Graffiti removal has progressed substantially, but graffiti is still largely visible in the waterfall area. More distant areas remain uncleaned.

An exhaustive inventory of all remaining graffiti would need to be conducted to constructively plan their cleaning, monitor their status, quantify the efforts made, and, eventually, monitor the appearance of new graffiti following the reopening.

2.3.4 Alien species

In 2008, EWS-WWF successfully coordinated the removal of tilapia (*Oreochromis sp.*) that had been introduced to the Wadi Wurayah waterfall. However between 2012 and 2013, tilapia reappeared at the waterfall, most presumably following voluntary introduction. Plans were made for a second removal operation, but a violent flash flood did the job naturally.

In the framework of the biodiversity inventory, all exotic species observed in the park were recorded. With the exception of the feral goat, which can be considered to be the main invasive species, other exotic or introduced species recorded so far in the park are present in small numbers or appear occasionally. They do not seem to represent a serious threat at this stage. However, monitoring their presence and abundance is important for the detection of any population increase. Invasive species are more likely to be exotic introduced species, but they can also be native species which benefit from environmental disturbances such as climate change or the disappearance of predators or competitors that create disequilibrium in the ecosystem.

Specific monitoring protocols or watchfulness mechanisms based on regional or national information may be developed for the timely detection of their occurrence in the park, along with threshold indices requiring intervention/management. Exotic species that present a risk of becoming invasive should be listed and monitored.

In his plant survey of the park, Feulner (2015, p.27) provided a list of introduced species but indicated that "none of these species have become or are likely to become established in WWNP":

- *Citrullus lanatus* (Cucurbitaceae, the cultivated watermelon),
- *Ficus religiosa* (Moraceae, the peepul tree),
- *Solanum lycopersicum* (Solanaceae, the cultivated tomato), and
- *Mangifera indica* (Anacardiaceae, the cultivated mango).

He also stated the following (p. 54):

> *No exotic species, invasive or otherwise, were encountered at wild sites within WWNP, notwithstanding the large scale introduction of dry-adapted exotic plants for landscaping in the UAE as a whole over the past 40 years, including the East Coast. This may be an oblique tribute to the rigors of the local environment. In particular, the introduced mesquite tree, Prosopis juliflora, the only UAE plant species generally regarded as invasive in natural environments, was not recorded within WWNP, although it has spread extensively on the sand and gravel plains and waste ground of the East Coast, bordering the mountains. With respect to its status in the UAE, the view has been expressed that, at this point, P. juliflora has already spread to all places where it can thrive (A. El-Keblawy, pers. comm.). If so, then only significant disturbance of the environment within WWNP would pose a threat from this invader. (Feulner, 2015)*

Few introduced species of birds, now well-established in UAE, have been recorded in WWNP. These include *Acridotheres tristis* (common myna), *Columba livia* (feral rock pigeon), *Corvus splendens* (house crow), *Lonchura punctulata* (nutmeg mannikin) and *Pycnonotus leucotis* (white-cheeked bulbul). All these species, with the exception of the feral pigeon, are encountered in small groups, irregularly, and mainly in the buffer zone. This is because they are all attracted to urbanised or inhabited areas. The feral rock pigeon may be a species that is worthy of more detailed examination. Although some individuals present the typical plumage of wild rock pigeons, most of them have the mixed plumage of interbred races. It is unlikely that there are pure-bred rock pigeons in Wadi Wurayah; this may have to be investigated through genetic analysis. Feral rock pigeons breed in small colonies in the overhanging rocks of gorges and cliffs. Their defecation could pollute the water under their nests. However, they could constitute prey for the now rare Barbary falcons. The place and impact of feral rock pigeons in WWNP may need to be investigated.

Where mammals are concerned (with the exception of goats and sheep, whose role in overgrazing we already discussed in a previous paragraph), the presence of feral cats and dogs, even in peripheral areas of the park, can have a damaging impact on wildlife. Feral cats have been observed on several occasions, even quite deep in the park and far away from the closer, inhabited areas. The black rat (*Rattus rattus*) is also present in the park. Its presence was mainly recorded in the vicinity of the waterfall in the past. This species was presumably benefiting from the food leftovers of picnickers when the park was still freely accessible. The closure of the park in December 2013 may have seriously impacted their food resources and populations. Except for a young individual found dead downstream of the Wadi Wurayah gorge, the species has not been recorded in the surroundings of the waterfall since December 2013. The status, movements, and impact of feral donkeys (*Equus asinus*) should also be investigated. They seem to be present in low numbers (only two groups totaling six individuals were counted during the helicopter survey in January 2014), and their movements are limited by the harshness of the relief. Unlike goats, they are unable to climb in abrupt rocky areas, which limits their distribution in the park to the most easily accessible areas. However, where they are present, damage on trees has been observed; the *Moringa peregrina* bark has being scratched and peeled.

Several introduced and potentially invasive arthropod species have been recorded: *Brephidium exilis* (the western pygmy blue) was identified once in Wadi Zikt. This species, originating from North America, is known to have colonised many habitats in Arabia in recent decades. The invasive red palm weevil (*Rhynchophorus ferrugineus*), a pest on palm plantations, has also been recorded once. However, this species is unlikely to be a serious threat to WWNP habitats.

2.3.5 Pollution

The occurrence of organic pollution has been monitored since October 2013 through the regular measurement of phosphate, nitrate, and coliforms in the fresh water. Other sources of pollution may also need to be monitored:

- The heavy metal concentration may be measured on a regular basis (once a year);
- Air pollution;
- Noise pollution: WWNP is generally a very quiet and peaceful place, but several sources of strong noise can potentially disturb the wildlife and the quietness of the area. They include tourist planes or helicopters flying at low altitudes or noisy motorised engines circulating in urbanised areas close to the buffer zone. The associated noise can be heard from the park. Specific regulations may be considered to address these issues. Electromagnetic fields that high-voltage power lines generate have been largely ignored, but the permanent hissing sound that can be heard a few hundred metres from the lines could have an impact on wildlife. This might require investigation. Some power lines cross the park close to the borders, and some line extension projects, which involve crossing part of the park, are ongoing. The effects of power lines on wildlife may be part of the research work developed to quantify threats.

The presence of E. coli and other coliform bacteria is monitored on a regular basis. The concentration of coliforms has decreased noticeably at the waterfall following the closure of the park, while E. coli, which are more specifically linked to human faeces and were still present in early 2014, disappeared from the main pool of the waterfall in 2015.

2.3.6 The loss of spatial connectivity

The economic growth of the UAE has accompanied the development of a growing network of roads, facilitating the transit of people and goods. But this often occurs at the expense of natural ecosystem integrity. New roads increase land penetration and human frequentation, resulting in a higher level of disturbance and the development of new urban and industrial areas that are barriers to wildlife. The minimisation of the environmental impacts should occur through cautious environmental impact assessment, environmentally friendly land management, and the implementation of compensation or mitigation measures such as the creation or maintenance of green corridors. Ecological data on population distribution and movements should inform the management efforts.

Important GIS work is requested to map and quantify the extent of connectivity loss and to identify areas where conservation efforts should be focused or connectivity should be maintained or re-established. EWS-WWF should develop this work in the coming years in the framework of the broader terrestrial habitat conservation strategy for the development of a Protected Areas Network and the implementation of a nationwide biodiversity database.

2.3.7 Interbreeding between feral and domestic animals

The presence of the wild cat in WWNP, which is evidentfrom past records on camera traps (possibly not more than two to three pictures) has not been confirmed in the last three years, but feral cats are present and have been recorded quite deep in the wadi. The threat of interbreeding, which is recognised as possibly occurring in WWNP based on its occurrence in other parts of the wild cat distribution range, requires further investigations. The first step is obviously the confirmation of the presence of wild cats in the park. If any are found, the next steps involve quantifying the animals abundance and distribution and considering catching some for blood sampling and genetic analysis.

2.3.8 Infectious diseases

Chytridiomycosis, an infectious disease of amphibians resulting from the chytrid, *Batrachochytrium dendrobatidis*, has been spreading worldwide in the last 20 years, affecting 30% of amphibian species. The disease can induce a high mortality rate, eventually leading to the extinction of a population or species. This disease has not been recorded in the UAE, but monitoring its possible emergence by conducting regular tests is important to address the situation in a timely fashion should it occur. This is in keeping with the adage, “Prevention is better than cure.”

Other infectious diseases of concern are those that goats may transmit to reintroduced ungulates. One farm with more than 100 goats is still active in WWNP, and several shepherds regularly bring their goats to the ecotourism zone of the park for grazing. This unregulated situation could put the reintroduction programme of the Arabian tahr or other ungulates at risk. The persistence of threats that may have contributed to the disappearance of the Arabian tahr does not favour the initiation of Tahr reintroduction at this stage. The elimination or substantial decrease of the threats that caused species extinction or population reduction are among the main recommendations of the IUCN species reintroduction guidelines’ best practises.

The diseases that carnivores may carry are also of concern and need to be monitored on a regular basis by trapping carnivores and blood sample analysis.

2.3.9 Climate change

The problem of climate change is global and obviously cannot be addressed directly at the scale of WWNP. However, it is generally recognised that it is possible to mitigate the future potential effects of climate change on the habitats by increasing the ecosystems' capacity for resilience. This level of resilience can be maintained or improved by ensuring that ecosystems remain healthy and ecologically well-balanced.

The effect of climate change can be measured by monitoring a series of environmental parameters in the long term. The monitoring programmes initiated for different taxonomic groups that may be more sensitive to climate change (for instance, Odonata, toads) will provide valuable information if they run for the long term. Data on population trends, water parameters, and meteorology that WRLP volunteers record will contribute to the building of a data set that can be analysed to interpret the effects of climate change. Years may pass before the detection of any significant trend that can be correlated with climate change at a single site. However, the data collected in WWNP can be shared with other research projects for the performance of meta-data analysis on data sets from a multiplicity of sites or regions.

Climate change is affecting environmental variables (air temperature, water temperature, wind speed, atmospheric pressure) for which species have their own tolerance limits. Modelling the effects of climate change on the ecosystems requires an understanding of how species will be affected. This points to the need for better knowledge of their ecological requirements. For instance, what would be the effect of an increase in the mean water temperature by 2° C on the larval development of aquatic invertebrates? Some species may be able to cope with it, but those which cannot have no other choice but to move into more suitable areas or disappear. This has the capacity to disrupt the balance of the ecosystem, depending on the roles of the species in the ecosystem. On the other hand, the new environmental conditions may become more optimal for other species and favour their development. Some data exist on the ecological requirements of freshwater species in Europe or North America. However, they are incomplete. In the Middle East, such data is largely deficient. It is important to develop the experimental research approach to elucidate the mechanisms by which climate change may affect species.

3. BIODIVERSITY INVENTORY

Biodiversity is decreasing at an unprecedented rate worldwide. In 1992, at the Earth Summit in Rio de Janeiro, 150 countries signed the first biodiversity convention that defined six reasons for protecting biodiversity:

- **Moral reasons:** a culture that protects biodiversity is preferable to one that does not;
- **Aesthetic reasons:** wildlife and landscape are beautiful and enrich human lives;
- **Fulfilling important natural functions:** ecosystems serve humans because they fulfill natural functions, and every single species plays a role in the ecosystems' functioning;
- **Biodiversity provides actual and potential material and economic benefits to people;**
- **The continuance of evolutionary processes;**
- **Insurance: every species may prove to be beneficial to humans; if they become extinct, humans can never benefit from them.**

As we can only efficiently protect that which we know and understand, describing biodiversity is one of the first steps towards better protection. Biodiversity has not been identified as a conservation priority or target per se in the management plan, but it should, nevertheless, be the focus of the park management efforts. Between 2013 and 2015, efforts were made to maintain and regularly update a checklist of all species recorded in WWNP. As of December 31, 2015, the 1,146 currently existent or historically recorded species were included in the biodiversity inventory of the park (Appendix 1, Table 18). Eighty-four of those have not been identified at the species level yet or their identification requires confirmation. Thirteen species of vertebrates are endemic (one fish, two amphibians, one mammal, and nine reptiles) as are eight species of plants. The number of endemic invertebrates is more difficult to assess given that little is known about the distribution of many of them. However, there are at least three endemic Odonates and two scorpions.

Table 18: The number of species recorded in WWNP per phylum and class as of December 31, 2015

Phylum	Class	Comments	n Species
Arthropods	**Arachnida**	Including 29 spiders, one pseudo-scorpion, seven scorpions, one camel spider, and one whip spider	39
	Collembola	Springtails	8
	Insecta	Including 182 families of 15 orders	729
	Malacostraca	Crustacean woodlice	1
	Chilopoda	Myriapod centipede	1
	Maxillopoda	Crustacean copepode	1
Arthropoda sub-total			***779***
Vertebrates	**Fish**	Two native and one introduced	3
	Amphibia		2
	Aves	Thirty-six resident, 42 migrant, 23 wintering, three vagrant, and five of unclear status	109
	Mammalia	Four extinct, four introduced, one domestic	21
	Reptilia	Twelve lizards and geckos, three snakes	15
Vertebrates sub-total			***146***
Molluscs		Gastropods	6
Platyhelminthes	**Turbellaria**	Flatworm	1
Plants		including 54 families	208
Fungi			2
Grand Total			***1146***

3.1 FLORA

Gary Feulner, who conducted field surveys irregularly over a period of 20 years but more regularly between December 2012 and November 2014, has studied and described the flora of the park in detail. During the latter period, Gary Feulner carried out a baseline survey of the flora, which HSBC sponsored, for EWS-WWF. All the information presented in this paragraph is extracted from his report (Feulner, 2015). This original work highlights the following (p.7):

> *The northern Hajar Mountains is an important area from the perspective of regional plant biogeography ...and moderates the prevailing view that the flora of the ultrabasic rocks of the Hajar Mountains is limited in diversity relative to more geologically conventional environments.*

Moreover, Feulner (2015) states the following (p.7):

> *A number of plant species common in other areas of the Hajar Mountains of the UAE and northernmost Oman appear to be absent within WWNP, indicating that more focused study of WWNP in comparison to neighbouring mountain areas has the potential to reveal previously unrecognized biogeographical patterns and/or ecological relationships.*

3.1.1 The purpose of the survey

The main purpose of the baseline survey was to produce an annotated checklist, including all species of vascular plants recorded within the area of WWNP:

> *The checklist can be expanded by adding, at a later stage, additional categories of data, including e.g. global range, regional range, UAE Red Data List status, geographic coordinates of important sites, and traditional uses. Valuable indications of the nature and significance of the results are provided, highlighting a number of specific facts and generalizations relevant to a better appreciation of the flora of WWNP.* (Feulner, 2015, p.19)

3.1.2 Methodology

The methodology follows:

> *The survey consisted of botanical excursions by foot within WWNP, totalizing 33 field days between 15 December 2012 and 4 November 2014. In addition to the survey data, the report and the accompanying checklist incorporate the botanical results of historical natural history investigations by the author, amounting to 22 field days between March 1992 and January 2012. The overall coverage is extensive but investigation of summit ridges, passes and uppermost slopes and wadis was more limited. At least eighteen excursions explored terrain lying at ca. 400 meters or more, but only ten excursions reached elevations exceeding ca. 550 meters and only five of those reached or exceeded ca. 700 meters. The checklist also relies on information contained in selected literature sources as well as unpublished documents available to the author. Almost all taxonomic determinations were made by the author, based on field experience in the UAE and Oman. On the basis of survey data and historical records, an annotated checklist has been prepared in digital format using Microsoft Office Excel 2003.* (Feulner, 2015, p.17)

All these species of vascular plants recorded within WWNP are included in the biodiversity inventory (Appendix 1).

3.1.3 Results and discussion

The baseline survey allowed the recognition of the presence of 206 plant species within WWNP, including one new to the UAE and all eight mountain endemics of the UAE:

WWNP, including its buffer zone, is home to at least 53 families, 163 genera, 202 species of native higher terrestrial plants, and four introduced exotics (see §2.3.4 p.65 and Feulner 2015 for the full detailed report).

The list includes:

- *178 species (86%) recorded from within the core zone, either by the current survey or historically.*
- *28 species (14%) recorded only from within the buffer zone, either by the current survey or historically.*
- *19 species (9%) represented by historical records only, i.e., species previously recorded from within the area of WWNP (core zone or buffer zone) but not recorded during the current survey.*
- *17 species (8%) represented by records of single plants only, whether current or historical. An additional 8 species are represented by historical records from which it cannot be determined whether more than a single plant was observed. This amounts to more than one-quarter of the ca. 720+ species of higher terrestrial plants recorded to date for the UAE and adjacent areas of Northern Oman.* (Feulner, 2015, p.20)

3.1.4 Family level diversity and regional comparisons

The following characterizes the park's family level diversity as well as regional comparisons:

> *The families best represented in WWNP, in terms of numbers of species, are Poaceae (30 spp.), Asteraceae (20 spp.) and Fabaceae (13 spp.). A small majority of the families present are represented by more than one species (29 of 53 families, or 55%); 24 of the 53 known families (45%) are represented by only a single species. The top three families (Poaceae, Asteraceae, and Fabaceae) also hold the top three positions within the flora of the neighbouring Ru'us al-Jibal range (Feulner 2011) and the nearby Wadi Helo Protected Area (El-Keblawy 2011), as well as the florae of the UAE (Jongbloed 2003) and Oman (Ghazanfar 1992b) as a whole. Six additional families (Boraginaceae, Brassicaceae, Caryophyllaceae, Euphorbiaceae, Lamiaceae and Scrophulariaceae) appear in the top dozen in each list.* (Feulner, 2015, p.28)

3.1.5 Qualitative assessment of species abundance

Feulner goes on to state the following:

> *The checklist includes a qualitative assessment of the abundance of each species, on a scale of Hyperabundant (H), Common (C), Locally Common (L), Occasional (O), Rare (R) and Exceptional (E). Only four species have been designated as Hyper-abundant: the tall perennial reed Arundo donax and three annuals – the lily Asphodelus tenuifolius, the blue pimpernel Anagallis arvensis, and the dock Rumex vesicarius. Otherwise, the numerical results follow a "normal" distribution curve from Common (27 species) through Locally Common and Occasional (combined 87 species) to Rare (65 species) and Exceptional (23 species). Exceptional species include the rare UAE-Oman endemic Scrophularia imbricata, Tephrosia cf. uniflora, the tiny herbaceous Asterolinon linum-stellatum, otherwise known only from the high Musandam, and "indigenous exotics" such as the large, errant desert shrub Leptadenia pyrotechnica. Eight species considered endemic to the mountains of the UAE and Northern Oman have been recorded within the UAE (picture 8). All of those species are found in WWNP. One was recorded in the UAE for the first time during the course of the baseline survey: Desmidorchis arabicus (formerly Caralluma arabica) (Asclepiadaceae), Echinops erinaceus (Asteraceae), Lindenbergia arabica (Scrophulariaceae), Pteropyrum scoparium (Polygonaceae), Pulicaria edmondsonii (Asteraceae), Rumex limoniastrum (Polygonaceae), Schweinfurthia imbricata (Scrophulariaceae), and Launaea omanensis (Asteraceae): The baseline survey produced the first record of this plant from the UAE. Single specimens have been found at four widespread and varied sites within WWNP.* (Feulner, 2015, p.29)

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a) Pteropyrum scoparium

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b) Pulicaria edmonsoni

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d) Desmidorchis arabicus

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c) Schweinfurthia imbricata

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e) Echinops erinaceus

Picture 8: Five of the eight endemic plants present in WWNP

WWNP is an important site, and in some cases one of the only known UAE sites, for a number of rare or otherwise noteworthy UAE plant species. A few of those are associated with the mesic environment of the permanent waterfall. The following list is indicative, not exhaustive:

- *Asterolinon linum-stellatum (Primulaceae): The Wadi Ghayl branch of Wadi Wurayah is the only known UAE site outside the Ru'us al-Jibal for this delicate annual herb.*
- *Bromus danthoniae (Poaceae): This coarse-headed grass, apparently limited to high elevations, has previously been recorded in the UAE only from the Ru'us al-Jibal. It was found on a ridgetop in the southwest of WWNP.*
- *Castellia tuberculosa (Poaceae): The survey produced a photo record of this species from Wadi Ghayl. It was previously known in the UAE only from a single collection in upper Wadi Siji, within the WWNP buffer zone. A number of specimens have subsequently been recorded from the bed of a major ravine on the slopes of Jebel Qitab, southwest of Fujairah city.*

14% of the recorded species (n = 28) were found only in the buffer zones of WWNP, signaling the importance of these marginal mountain and foothills areas for biodiversity. There is no single explanation for the presence of the buffer zone species. The majority (16) are species found in mountain habitats elsewhere in the UAE that could reasonably be expected within the core zone. Four native species (2% of the total) were only found within the newly fenced area of the WWNP headquarters compound. Eight (8) species, or 4% of the total, were found only within the watershed of Wadi Zikt, including one species found only within the buffer zone in Wadi Zikt. Only seven tree species (3.5% of the total naturally occurring species) are found within WWNP: Acacia ehrenbergiana, Acacia tortilis, Ficus cordata salicifolia, Ficus johannis, Moringa peregrina, Prosopis cineraria, and Ziziphus spina-christi. This situation is typical of the Hajar Mountains of the UAE and northernmost Oman.

A number of species generally considered to be common in the Hajar Mountains of the UAE were recorded only extremely rarely or not at all during the baseline survey, nor is their presence in WWNP reflected in historical data. The species "absent" from WWNP are: Erucaria hispanica (Brassicaceae), Fagonia indica (Zygophyllaceae), Juncus rigidus (Juncaceae), Lycium shawii (Solanaceae), Rhazya stricta (Apocynaceae), Sclerocephalus arabicus (Caryophyllaceae), and Teucrium stocksianum (Lamiaceae).

Most of the absent or rare species were absent unexpectedly. In some cases, upon closer consideration, those absences can be explained in terms of many of the same factors accounting to differences between WWNP with the Ru'us al-Jibal, including: (i) regional biogeographical gradients; (ii) edaphic differences, i.e., differences in the development and character of the soil or substrate; and (iii) geochemical differences – now, within the ophiolite – and specifically the difference between ultrabasic (harzburgite) and basic (gabbro) bedrock). In other cases an explanation remains speculative.

The survey emphasizes the ephemeral nature of even some very common annual species, with implications for floral assessments. One obvious example is the dock Rumex vesicarius (Polygonaceae) was hyperabundant in January through March 2012. In many places it dominated the overall impression of the wadis and wadi slopes, in terms of color and vegetative cover. But by June, only occasional dried plants were seen, and it was possible to overlook it. (Feulner, 2015, p.53)

3.1.6 Conclusion and remarks

The flora baseline survey of WWNP recorded 206 species of plants, including one species new to the UAE:

This total exceeds earlier informed estimates by one-third or more, moderating although not negating the prevailing view that the flora of the ultrabasic rocks of the Hajar Mountains is limited in diversity relative to more geologically conventional environments. Comparison of the baseline survey results with published studies of nearby mountain areas indicates that WWNP has more than 70% of the number of plant species found at comparable elevations in the carbonate environment of the Ru'us al-Jibal range (the mountains of the Musandam peninsula), and may have ca. 8-12% more plant species than Wadi Hiluw, which drains a watershed composed almost wholly of basic rock (gabbro). The latter finding casts doubt on the conventional wisdom that the ultrabasic environment alone is responsible for reduced floral diversity. All eight Hajar Mountain endemic plant species found in the UAE were recorded within WWNP. WWNP is also an important site, and in some cases the only UAE site, for more than a dozen other rare or noteworthy plant species. At the same time, a number of plant species common in other areas of the Hajar Mountains of the UAE and northernmost Oman appear to be absent within WWNP, indicating that more focused study of WWNP in comparison to neighboring mountain areas has the potential to reveal previously unrecognized biogeographical patterns and/or ecological relationships. (Feulner, 2015, p.7)

3.2 FAUNA

3.2.1 Arthropods

The inventory that Tony Van Harten took and published in his impressive five volumes of the *Arthropods fauna of the United Arab Emirates* (Van Harten, 2008, 2009, 2010, 2011, 2014) is responsible for a significant proportion of current knowledge regarding arthropods in WWNP (Table 19). The collection of arthropods in the park has resulted in the description of 85 species new to science so far.

Since August 2014, Roland Breithaupt, a German resident of Abu Dhabi and a wise, amateur moth-specialist, has been investigating the moths of the park through light trapping conducted in the ecotourism area on a monthly basis. His work has allowed the addition of 110 species of Lepidoptera, six Coleoptera, and one Hymenoptera to the WWNP biodiversity inventory. Some of the specimens collected have been or will be sent to different taxonomic specialists for taxonomic research and accurate identification. Administrative procedures have been undertaken at the Ministry of Climate Change and Environment to comply with international regulations and, more specifically, with the Nagoya protocol of the Convention for Biological Diversity, which the UAE ratified on September 12, 2014.

Lionel Monod, a scorpion specialist from the Natural History Museum of Geneva, and Hubert Siegfried, an independent German spider specialist, investigated the scorpions and spiders of WWNP during a three-week visit to WWNP in May 2015. Their work contributed to the revision of the list of arachnids and to the addition of several new species. Several specimens were collected and taken to the Natural History Museum of Geneva for further taxonomic studies.

In the past three years, important investigations have been conducted on the Odonata (damselflies and dragonflies) of the park, resulting in the addition of seven species to its odonate list. The highlight was the discovery, in June 2013, of *Urothemis thomasi* (Feulner & Judas, 2013), a rare Libellulidae, previously only known from a few locations in Oman with no published records since the 1990s (Waterson & Pittaway, 1991; Schneider & Dumont, 1997). This new species record for the UAE stimulated the organisation of a survey to clarify the status of the species in UAE and in Oman, which the Mohammed bin Zayed Species Conservation Fund provided funds for (Lambret et al., 2015).

Table 19: The number of arthropod species recorded in WWNP per order and family, listed alphabetically, as of December 31, 2015

Class	Order	n Family	n Species
Arachnida	Araneae	19	29
	Pseudoscorpiones	1	1
	Scorpiones	3	7
	Solifugae	1	1
	Amblypygi	1	1
Collembola	Entomobryomorpha	1	2
	Symphypleona	4	6
Insecta	Blattodea	1	1
	Coleoptera	32	143
	Diptera	27	123
	Ephemeroptera	2	5
	Hemiptera	30	62
	Hymenoptera	31	189
	Lepidoptera	35	149
	Mantodea	3	4
	Neuroptera	4	6
	Odonata	6	25
	Psocoptera	2	2
	Thysanoptera	2	5
	Orthoptera	5	12
	Phasmatodea	1	1
	Trichoptera	1	2
Malacostraca	Isopoda	1	1
Chilopoda	Scolopendromorpha	1	1
Maxillopoda	Cyclopoida	1	1
Total			**779**

Gary Feulner, assisted by Binish Robas, also made significant contributions to the biodiversity inventory of arthropods during several visits they made to the park between 2013 and 2015, investigating a wide range of arthropod families and, noticeably, spiders, a taxonomic group which has received little attention in the UAE so far (Feulner and Robas, 2015).


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Picture 9: A selection of diurnal Lepidoptera recorded in Wadi Wurayah National Park. On left page, from top left to bottom*: Papilio demoleus* (Lime Swallowtail), *Pontia glauconome* (Desert White), *Brephidium exilis* (Western Pygmy Blue - introduced), *Tarucus rosaceus* (Mediterranean Pierrot), and *Colotis fausta* (Salmon Arab), and right page, from top left to bottom right: *Papilio machaon* (Common Swallowtail), *Junonia orythia* (Blue Pansy), *Euchrysops osiris* (African Cupid), *Danaus chrysippus* (Plain Tiger).

Regular field surveys conducted in WWNP in the period 2012-2015 allowed the revision and completion of the park's vertebrate species list, which was established during surveys conducted between 2006 and 2008 (Tourenq et al., 2009).

3.2.2 Fish

The main species of fish present in most permanent and temporary pools is the endemic Garra fish (*Garra barreimiae,* Picture 10). A second species, the Arabian killifish (*Aphanius dispar*) was found in a pool on the western side of the park in October 2014. This species is widespread in the Hajar Mountains of the UAE (Feulner, 1998). Tilapia (*Oreochromis spp.*) were present at the waterfall pool in early 2013 as a result of an earlier illegal introduction, but they disappeared naturally, swept away by a significant flash flood in March 2013.

Picture 10: *Garra barreimiae*, endemic fish of Wadi Wurayah National Park

3.2.3 Amphibians

The presence of the Arabian Toad (*Scleratophrys arabicus*) and the Dhofar Toad (*Duttaphrynus dhofarensis*) has been confirmed regularly (Picture 11) although the second species is rarely spotted, and much less abundant in the park. It must be noted that the taxonomic position and nomenclature of these species have been revised lately. Initially classified as being of the genus Bubo, both were later linked to the *Duttaphrynus* genus (Van Bocxlaer et al., 2009). A new genetic study concluded that the Arabian toad was more likely to be of an African lineage, and it was renamed *Amietophrynus*, while the Dhofar toad was confirmed to be of Asian origin and it was retained in the genus *Duttaphrynus* (Portik and Papenfuss, 2015). However, a more recent study invalidated the genus nomen *Amietophrynus*, replacing it with the genus nomen *Scleratophrys*, in accordance with anteriority principle in the nomenclature code (Ohler and Dubois, 2016).

Picture 11: The two species of toads present in Wadi Wurayah National Park. On the top: *Scleratophrys arabicus* (Arabian toad), and on the bottom: *Duttaphrynus dhofarensis* (Dhofar toad)

3.2.4 Reptiles

Fourteen native species were listed in Wadi Wurayah National Park following the surveys and literature review which EWS conducted between 2006 and 2008 (Tourenq et al., 2009). Two species were added: the Hadramawt sand lizard (*Mesalina adramitana*) and the endemic Gallagher's leaf-toed gecko (*Asaccus gallagheri*). Inversely, in the absence of confirmation or supporting evidence for this record, the Sind saw-scaled viper (*Echis carinatus sochureki*), which Stuart and Stuart (1996) recorded, as cited in Tourenq (2009), has been removed from the list. This species prevails in sandy areas, a habitat that is absent from the park. The Sinai agama, initially listed as *Pseudotrapelus sinaitus*, has been split into different species following a genetic revision of the genus in Arabia (Melnikov et al., 2013). The whole Hajar Mountain population is now believed to be of the species *Pseudotrapelus jensvindumi*, described in Nizwa, Oman, although this would need to be confirmed by the thorough examination of diagnostic criteria. The number of wild reptile species currently known to live in Wadi Wurayah National Park is 15 (Table 20); nine of them are endemic to the Hajar Mountains.

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Picture 12: Pictures of reptiles of Wadi Wurayah National Park. On the top, *Pseudotrapelus cf. jensvindumi* (Hajar agama), and on the bottom: *Echis omanensis* (Omani carpet viper)

Table 20: List of reptile species in Wadi Wurayah National Park.

Species	English name	Note
Agamidae		
Pseudotrapelus jensvindumi	Sinai agama	Populations in the Hajar Mountains split from Pseudotraelus sinaitus—Endemic
Gekkonidae		
Bunopus spatalarus hajarensis	Banded ground gecko	Endemic
Hemidactylus flaviventris	House gecko	
Lacertidae		
Mesalina adramitana	Hadramawt sand lizard	
Omanosaura cyanura	Blue-tailed Oman lizard	Endemic
Omanosaura jayakari	Jayakar›s Oman lizard	Endemic
Phyllodactylidae		
Asaccus gallagheri	Gallagher›s leaf-toed gecko	Endemic
Ptyodactylus hasselquistii	Fan-footed gecko	
Scincidae		
Chalcides ocellatus ocellatus	Ocellated skink	
Trachylepis tesselata	Tesselated skink	Endemic. Formerly Mabuya tesselata
Sphaerodactylidae		
Pristurus celerrimus	Bar-tailed semaphore gecko	Endemic
Pristurus rupestris	Rock semaphore gecko	Endemic
Colubridae		
Platyceps rhodorachis	Wadi racer	
Psammophis schokari	Schokari sand racer	
Viperidae		
Echis omanensis	Oman carpet viper	Endemic

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3.2.5 Birds

The previously published statement on the avifauna of Wadi Wurayah listed 74 species (Tourenq et al., 2009). This list has been substantially modified with the addition of 38 species, mainly migrant species that use the park temporarily during stopovers along their migration routes or for wintering. Three species have been removed from the list in the absence of confirmed records: the coot (*Fulica atra*), the Arabian spotted eagle-owl (*Bubo africanus milesi*), and the African rock martin (*Ptyonoprogne fuligula*). The record of the coot was from Wadi Shi. The record of the African rock martin (*Ptyonoprogne fuligula*) is presumably the result of taxonomic confusion. The population present in Arabia is sometimes considered a subspecies in the [fuligula] group (Clements et al., 2015) or as a distinct species that some authors name *Ptyonoprogne obsoleta* (Aspinall and Porter, 2011). The presence of the Arabian spotted eagle-owl was assumed due to a single record of a chick presumably collected in the mountains of Dibba and brought to Dubai zoo in 2003. The presence of this species in UAE has never been confirmed. At the end of December 2014, 109 species were included in the park's bird list (see Appendix 1 for details). They included the following:

- Twenty-three wintering species;
- Forty-one migrants making a stopover;
- Ten confirmed breeding residents;
- Seventeen other residents, suspected to be breeding but not confirmed;
- Three vagrants (vulture species);
- Ten visitors from nearby habitats (mainly farms);
- One locally extinct species (chukar); and
- Four of unclear status (long-legged buzzard, striated heron, scaly-breasted munia, and hoopoe).

Of the 74 species recorded before 2008, 12 have not been recorded again except for a single record in 2013. The chukar (*Alectoris chukar*) should now presumably be considered locally extinct, the desert eagle-owl (*Bubo ascalaphus*), the long-legged buzzard (*Buteo rufinus*), the griffon vulture (*Gyps fulvus*), the Egyptian vulture (*Neophron percnopterus*), the lappet-faced vulture (*Torgos tracheliotus*), the black swift (*Apus apus*), the houbara bustard (*Chlamydotis macqueenii*), the mourning wheatear (*Oenanthe lugens*), the yellow-throated sparrow (*Petronia xanthocollis*), the turtle dove (*Streptopelia turtur*), and the little grebe (*Tachybaptus ruficollis*). The failure to observe three vulture species in recent years may be related to a degradation in habitat quality and the availability of food, as well as a general decrease in the vulture population size. This could also be the case for the long-legged buzzard. The little grebe is a common species in the UAE. It is dependent on water, with sufficient depth for diving. The only habitat available for this species in Wadi Wurayah is at the dam after a flash flood.

Picture 13: A selection of resident birds typical of WWNP. From top left to bottom right: *Ammomanes deserti* (Desert lark), *Emberiza striolata* (striolated bunting), *Bucanethes githagineus* (trumpeter finch), *Otus brucei* (pallid scops owl)

3.2.6 Mammals

Tourenq et al. (2009) listed 20 mammal species, out of which 12 were observed during the 2006–2008 survey. From November 2012 to December 2015, 15 species were recorded, but four that were considered present during the previous survey have presumably gone extinct locally in the last few years or have reached critically low numbers. They are described below:

- The Arabian leopard (*Panthera pardus nimr*): the last confirmed record dates back to May 1999, but suspicious loud roaring was heard in March 2006 (EWS-WWF, 2006).
- Gordon's wildcat (*Felis sylvestris gordoni*): despite intensive camera trapping throughout the park, the presence of this species could not be confirmed recently.
- The mountain gazelle (*Gazella gazella cora*): the last record dates back to 2006. However, apparent gazelle droppings were found in the upper part of Wadi Ghayl in 2014.
- The Arabian tahr (*Arabitragus jayakari*): despite an intensive camera trapping survey, the last individual was photographed in October 2012 (Figure 16). All successive attempts to relocate the species failed, increasing the probability that it is now locally extinct.

Eight species of mammals that were previously included in the list of species due to their presence in the region were removed in the absence of any confirmed records in the park. Only one species, previously listed as possible, was confirmed: the Sind serotine bat (*Rhyneptesicus nasutus*, Picture 14). A third species of bats was recorded: the Egyptian fruit bat (*Rousettus aegyptiacus*). Four other mammal species were added to the list: the feral goat (*Capra aegagrus hircus*), the domestic sheep (*Ovis aries*), the feral cat (*Felis catus*), and the feral donkey (*Equus asinus*). Although these species are either feral or domestic, their presence cannot be ignored. In fact, they should receive special attention in the context of park management.

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Picture 14: *Rhyneptesicus nasutus* (Sind serotine Bat), found in WWNP in October 2015.

Table 21: List of mammal species recorded in WWNP from 2012 to 2015 and previously assumed to be present (Tourenq et al., 2009)

Order	Family	Species	English name		EWS-WWF survey 2006	Other surveys	2012–2015	WWNP status
Artiodactyla	Bovidae	*Arabitragus jayakari*	Arabian tahr		x	x	x	Presumed extinct in 2013
		Capra aegagrus hircus	Feral goat		(x)		x	Introduced
		Gazella gazella cora	Mountain gazelle		x	x		Extinct locally
		Ovis aries	Domestic sheep				x	Domestic
Carnivora	Canidae	*Canis lupus arabis*	Arabian wolf					Extinct locally
		Vulpes cana	Blanford›s fox		x	x	x	Common
		Vulpes vulpes arabica	Red Fox		x	x	x	Locally common
	Felidae	*Caracal caracal schmitzi*	Caracal		x	x	x	Few individuals
		Felis catus	Feral cat				x	Introduced
		Felis sylvestris gordoni	Gordon›s wildcat		x	x		Not confirmed
		Panthera pardus nimr	Arabian leopard		x	x		Extinct locally
	Hyenidae	*Hyena hyena*	Striped hyena					Extinct locally
	Herpestidae	*Ichneumia albicauda*	White-tailed mongoose		Listed			Never recorded
Chiroptera	Pteropodidae	*Rousettus aegyptiacus*	Egyptian fruit bat				X	Two records
	Rhinopomatidae	*Rhinopoma muscatellum*	Muscat mouse-tailed bat		x	x	X	All year long in small numbers
	Emballonuridae	*Taphozous nudiventris*	Naked-rumped tomb bat		Listed			Never recorded
	Hipposideridae	*Asellia tridens*	Trident bat		Listed			Never recorded
	Hipposideridae	*Triaenops persicus*	Rufous trident bat		Listed			Never recorded
	Vespertilionidae	*Pipistrellus kuhlii*	Kuhl's pipistrelle		Listed			Never recorded
		Otonycteris hemprichii	Desert long-eared bat		Listed			Never recorded
		Rhyneptesicus nasutus	Sind serotine bat		Listed		X	One record
Insectivora	Erinaceidae	*Paraechinus hypomelas*	Brandt›s hedgehog		x	x	X	Common
Perissodactyla	Equidae	*Equus asinus*	Feral donkey		(x)		X	Introduced
Rodentia	Muridae	*Acomys [cahirinus] dimidiatus*	Arabian spiny mouse		x	x	X	Common
		Dipodillus dasyurus	Wagner›s gerbil		x		X	Common
		Gerbillus nanus			Listed			Never recorded
		Rattus rattus	Black rat		x		x	Introduced

3.3 SPECIMEN REFERENCE COLLECTION

Reference collections are important resources for use as educational tools and in taxonomic research. Small-scale reference collections of plants and arthropods have been initiated, mainly for the purpose of education in the framework of the Water Research and Learning Programme: A herbarium contains a dozen specimens of common species. Several arthropods have been sampled and are preserved in insect boxes (Table 22), and a reference collection of Odonata exuviae is under development with the assistance of David Chelmick, President of the British Odonatological Society.

Another important resource for taxonomic reference is the development of a species picture database, which is regularly updated as new specimens are photographed. The picture database is managed with Picasa 3-Google Inc.

Further development of the reference collection for Wadi Wurayah National Park would be an important educational and research tool as means would be allocated to ensure the proper storage and maintenance of the collections (store, database, and curator).

Table 22: List of specimens included in the reference arthropod collection maintained in WRLP

Order	Family	Species	Sample ref
Coleoptera	Carabidae	*Chlaenius (Nectochlaenius) canariensis*	2015020401PC
		Pheropsophus africanus	2014011401PC
		Unidentified	2015020402PC
	Coccinellidae	*Menochilus sexmaculatus*	2015030308PC
	Dryophthoridae	*Rhynchophorus ferrugineus*	2015021101PC
	Dytiscidae	*Cybister (Melanectes) vulneratus*	2014111102PC
		Hydaticus (Prodaticus) histrio	2015030304PC
	Elateridae	*Cardiophorus safadensis*	2014111106PC
	Gyrinidae	*Dineutus aereus*	2014111101PC
	Hydrophilidae	*Coelostoma (Holocoelostoma) stultum*	2014111105PC
	Unknown	*Unidentified*	2015030305PC
		Unidentified	2015030309PC
Hemiptera	Gerridae	*Unidentified*	2014111104PC
	Naucoridae	*Heleocoris minusculus*	2015030307PC
Heteroptera	Notonectidae	*Enithares lineatipes*	2014111103PC
Hymenoptera	Vespidae	*Unidentified*	2015021103PC
		Vespa orientalis	2015021102PC
	Unknown	*Unidentified*	2015030313PC
Lepidoptera	Psychidae	*Amicta mauretanicus arabica*	2014121001PC
Orthoptera	Unknown	*Unidentified*	2014101101PL
		Unidentified	2014101102PL
Unknown		*Unidentified*	2015030310PC
		Unidentified	2015030311PC
		Unidentified	2015030312PC

4. PERSPECTIVES

We have made important progress in our knowledge of park biodiversity in the last three years (2013-2015). Good progress has also been made in the development and implementation of monitoring programmes for different taxonomic groups. This work would not have been possible without HSBC funding to run the Water Research and Learning Programme, the contributions of hundreds of volunteers involved in this programme, and the support of Fujairah Municipality.

Despite all this progress, there is still much to do. Work on the biodiversity inventory is an ongoing task; several taxonomic groups have not been properly investigated yet. Only among arthropods could it be expected that the pursuit of sampling could result in the addition of hundreds of new species, with some presumably still unknown to science.

The water quality parameter monitoring programme is now running well, but it requires improvements in the sensitivity and accuracy of the measurement of some parameters to evaluate the causes of slight natural variations (phosphate, nitrate, nitrite, and ammonium, for instance). The population monitoring of several taxonomic groups linked to freshwater habitats (Odonata and toads in particular, but also freshwater invertebrates and zooplankton) has been developed and the methodology improved, providing reliable indicators for the assessment of population trends. For other groups, monitoring methodologies have been tested, but they still need improvements and investigations to be implemented (rodents, carnivores). Camera trap picture analysis still needs to be performed to measure the reliability of the results for the effective monitoring of population changes and to evaluate the pertinence of the deployment scheme. Methodologies and protocols for monitoring threats also need to be developed. In order to detect any significant trends, monitoring programmes need to be run in the long term. For success here, dedicated staff should be trained and funding secured to run the programme in the long term.

Some factors of variation in population parameters still need to be investigated. Specific research programmes should be continued (carnivore trapping, tagging, and radio-tracking) or developed (bird population studies to assess densities, distributions, and population sizes), emphasizing interspecific relations (predation, competition) at different trophic levels to enhance understanding of ecosystem functioning.

Research programmes are meant to evolve in accordance with the new questions that ongoing research raises. The securing of these programmes may result in the establishment of a permanent research and education centre within the ecotourism zone of WWNP in continuity with the WRLP. This vision has been integrated as a medium-term objective of the WWNP management plan and is part of the blueprint.

The scientific component of the Water Research and Learning Programme was voluntarily designed with ambitious goals to broadly frame the development in the coming years. It might require several more years and additional means to answer the main questions.

A new scientific programme should be prepared on the firm foundation of the results accumulated in the past few years. It should include a detailed statement of the objectives and methodologies, integrating how data will be collected, analysed and interpreted, as well as an assessment of budget and staff requirements and a scheduled workplan.

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6. APPENDICES

Appendix 1: Biodiversity inventory - Checklist of species recorded in Wadi Wurayah National Park up to December 31, 2015. Species are listed by class, order, family, and species and sorted in alphabetic order.

Class	Order	Family	Species	Notes
Phylum: Arthropoda				
Sub-phylum: Chelicerata				
Arachnida	Amblypygi	Phrynicicae	*Phrynicus jayakari*	
	Araneae	Araneidae	*Aculepeira ceropegia*	
			Argiope lobata	
			Argiope sp.	
		Ctenidae	*sp.*	
		Eresidae	*Stegodyphus cf. dufouri*	
		Licosidae	*sp.*	
		Linyphiidae	*Nesioneta arabica*	
		Lycosidae	*Pardosa sp.*	
		Lycosidae	*Xerolycosa miniata / nemoralis*	
		Palpimanidae	*sp.*	
		Philodromidae	*Philodromus hierosolymitanus*	
			Thanatus lesserti	
		Pholcidae	*Artema atlanta*	
		Pisauridae	*cf. Dolomedes*	
		Salticidae	*Bianor albobimaculatus*	
			Evarcha dotata	
			Evarcha seyun	
			Heliophanillus fulgens	
			Pellenes geniculatus	
			Rafalus arabicus	NS
			Thyene imperialis	
		Scytodidae	*Scytodes cf. thoracica*	
		Sparassidae	*Eusparassus laevatus*	
			Eusparassus xerxes	
		Tetragnathidae	*Tetragnatha sp.*	
		Theraphosidae	*Ischnocolus sp. (under description)*	NS
		Theridiidae	*Latrodectus cf. hasselti*	
		Thomisidae	*sp. (pale green crab spider)*	
		Zodariidae	*Parazodarion raddei*	
	Pseudoscorpiones	Chernetidae	*Lamprochernes savignyi*	
	Scorpiones	Buthidae	*Compsobuthus maindroni*	
			Hottentotta jayakari	
			Orthochirus glabrifrons	End.
			sp.	
		Diplocentridae	*Nebo cf. hierichonticus*	
		Hemiscorpiidae	*cf. Hemiscorpius falcifer (?)*	End.
			Hemiscorpius maindroni	
	Solifugae	Galeodidae	*Galeodidae sp.*	
Sub-phylum: Crustacea				
Malacostraca	Isopoda	Eubelidae	*Periscyphis fuscocaudatus*	NS
Maxillopoda	Cyclopoida	Cyclopidae	*Cyclops sp.*	
Sub-phylum: Hexapoda				
Collembola	Entomobryomorpha	Entomobryidae	*Seira ferrarii*	
			Seira infrequens	NS
	Symphypleona	Bourletiellida	*Bourletiella cf. luteovernalis*	
			Bourletiella coeruleovernalis	
			Bourletiella cf. luteovernalis	
			Bourletiella coeruleovernalis	
		Katiannida	*Stenognathellus cassagnaui*	
		Sminthuridida	*Denisiella serroseta*	
Insecta	Blattodea	Blattellidae	*Supellina buxtoni*	
	Coleoptera	Anthicidae	*Anthelephila multiformis*	
			Leptaleus klugii	
			Stricticollis desolatius	
			Stricticollis ophthalmicus	
			Stricticollis peyerimhoffi	
		Bostrichidae	*sp.*	
		Bothrideridae	*Triboderus andrewesi*	
		Buprestidae	*Acmaeodera vanharteni*	NS
			Agrilus desertus	
			Anthaxia pinda	
			Anthaxia semiramis	
			Chrysobothris parvipunctata	
			Julodis cf. Fimbriata	
			Julodis euphratica euphratica	
			Sphenoptera batelkai	NS
			Sphenoptera cf. artemisiae	
			Sphenoptera vanharteni	NS
			Sterospis sp.	
			Trachys cf. bodenheimeri	
		Carabidae	*Bembidion atlanticum*	
			Calosoma sp.	
			Chlaenius (Nectochlaenius) canariensis	
			Elaphropus hoemorroidalis	
			Merizomena sp.	
			Metadromius ephippiatus	
			Perigona nigriceps	
			Pheropsophus africanus	
			Phloeozeteus persicus	
			Tachys brevicornis	
		Cerambycidae	*Derolus iranensis*	
			Idactus iranicus	
Insecta	Coleoptera	Chrysomelidae	*Acolastus arabicus*	
			Acolastus latifrons	
			Aphthona signatifrons	
			Bruchidius buettikeri	
			Bruchidius medaniensis	
			Calomicrus emir	NS
			Epitrix dieckmanni	
			Eryxia coracina	
			Hermaeophaga ruficollis	

Class	Order	Family	Species	Notes
			Hypocassida cornea	
			Longitarsus sp.	
			Phyllotreta peyerimhoffi	
			Phyllotreta tenuimarginata	
			Phyllotreta tenuimarginata	
			Psylliodes hospes	
			Psylliodes maculatipes	
			Psylliodes peyerimhoffi	
			Spermophagus humilis	
			Spermophagus pubiventris	
			Stator limbatus	
		Cleridae	*Tillodenops bimaculatus*	
			Tillodenops plagiatus	
		Coccinellidae	*Coccinella undecimpunctata*	
			Hyperaspis vinciguerrae	
			Menochilus sexmaculatus	
			Nephus hieckei	
			Pharoscymnus flexibilis	
		Curculionidae	*Hypolixus pica*	
			Pseudobarirrhinus conicus	NS
			Rhamphus micros	NS
			sp.	
		Dermestidae	*Attagenus papei*	NS
		Dryophthoridae	*Rhynchophorus ferrugineus*	
		Dryopidae	*Dryops lutulentus*	
		Dytiscidae	*Copelatus antoniorum*	NS
			Cybister tripunctatus lateralis	
			Cybister vulneratus	
			Eretes cf. sticticus	VU
			Glareadessus stocki	
			Herophydrus musicus	
			Hydaticus (Prodaticus) histrio	
			Hydaticus (Prodaticus) pictus	
			Hydroglyphus angularis	
			Hydroglyphus signatellus	
Insecta	Coleoptera	Dytiscidae	*Hygrotus inscriptus*	
			Laccophilus maindroni	
			Nebrioporus mascatensis	
		Elateridae	*Cardiophorus safadensis*	
		Elmidae	*Potamodytes subrotundatus*	
			Stenelmis sp.	
		Georissidae	*Georissus chameleo*	
		Gyrinidae	*Dineutus aereus*	
		Histeridae	*Acritus komai*	
			Platylomalus digitatus	
			Teretrius pulex	
		Hydraenidae	*Coleoptera Leiodidae*	NS
			Hydraena gattolliati	NS
			Hydraena putearius	
			Leiodes antoniusi	NS
			Ochthebius wurayah	NS

Class	Order	Family	Species	Notes
			Sogda hirta	NS
		Hydrophilidae	*Agraphydrus minutissimus*	
			Arabhydrus gallagheri	
			Berosus nigriceps	
			Cercyon deserticola	NS
			Cercyon quisquilius	
			Coelostoma (Holocoelostoma) stultum	
			Coelostoma transcaspicum	
			Enochrus politus	
			Enochrus segmentinotatus	
			Enochrus sinuatus	
			Laccobius harteni	NS
			Laccobius praecipuus	
			Paracymus relaxus	
			Sternolophus decens	
		Limnichidae	*Pelochares sinbad*	NS
		Meloidae	*Epicauta sharpi*	
			cf. Euzonitis sp.(?)	
			cf. Hycleus bipunctatus (?)	
			Hycleus gratiosus	
			Lydomorphus angusticollis	
			Lydomorphus brittoni	
			Nemognatha chrysomelina	
		Mordellidae	*Paratomoxioda harteni*	NS
		Nitidulidae	*Carpophilus hemipterus*	
			Carpophilus mutilatus	
			Carpophilus nepos	
			Epuraea luteola	
Insecta	Coleoptera	Nitidulidae	*Meligethinus gedrosiacus*	
		Oedemeridae	*Alloxantha flava*	
		Phalacridae	*Olibrosoma testacea*	
		Ptinidae	*Xyletinus bucephalus*	
		Scarabaeidae	*Oryctes agamemnon arabicus*	
			Pentodon algerinus	
			sp.	
		Staphylinidae	*Bibloplectus eximius*	NS
			Ctenisomorphus fortipalpis	NS
			Ctenisomorphus major	
			Enoptostomus arabicus	NS
			Epicaris ventralis	
			Trissemus maroccanus	
			Trissemus vanharteni	NS
		Tenebrionidae	*Adesmia arabica wittmeri*	
			Adesmia cancellata clathrata	
			Arabcynaeus bremeri	NS
			Capnisiceps maindroni	
			Cheirodes asperulus	
			Leichenum pulchellum	
			Mesostena blairi	
			Phtora subclavata	
			Sclerum evansi	

Class	Order	Family	Species	Notes
			Thraustocolus arabicus	
	Diptera	Anthomyiidae	*Anthomyia tempestatum*	
		Asilidae	*Leptogaster arabica*	NS
			Neolophonotus papei	NS
			Promachus sp.	
			Stichopogon deserti	
			Stiphrolamyra albibarbis	
			Wadipogon szpilai	NS
		Asteiidae	*Asteia afghanica*	
		Bombyliidae	*sp. 1*	
			sp. 2	
			sp. 3	
		Calliphoridae	*Bengalia peuhi*	
			Chrysomia sp.	
			Rhyncomya bullata	
			Rhyncomya jordanensis	
		Cecidomyiidae	*Allarete vernalis*	
			Anarete conaretoides	
			Buschingomyia harteni	NS
			Micromya cf. transispina	
			Monardia toxicodendri	
Insecta	Diptera	Ceratopogonidae	*Allohelea vespertilio*	NS
			Atrichopogon arabicus	NS
			Culicoides imicola	
			Dasyhelea deemingi	
			Dasyhelea fasciigera	
			Dasyhelea tibestiensis	
			Forcipomyia eremita	NS
			Forcipomyia pulcherrima	
		Chamaemyiidae	*Leucopis formosana*	
		Chironomidae	*Cladotanytarsus pseudomancus*	
			Dicrotendipes pallidicornis	
			Paratendipes nudisquama	
			Polypedilum alticola	
			Polypedilum malickianum	
			Tanytarsus mcmillani	
			Tanytarsus trifidus	
		Chloropidae	*Hapleginella arabica*	NS
			Lagaroceras albolineatum	NS
			Melanochaeta flavofrontata	
			Pselaphia flava	
			Sabroskyina aharonii	
			Tricimba humeralis	
		Conopidae	*Physocephala schmideggeri*	NS
		Corethrellidae	*Corethrella buettikeri*	
		Culicidae	*Culex pipiens*	
		Limoniidae	*Geranomyia annandalei*	
		Lonchaeidae	*Lamprolonchaea metatarsata*	
		Muscidae	*Atherigona hyalinipennis*	
			Atherigona lineata	
			Atherigona reversura	

Class	Order	Family	Species	Notes
			Limnophora bipunctata	
			Limnophora cf. simulans	
			Lispe bivittata	
			Lispe cf. pygmaea	
			Lispe nivalis	
			Lispe pectinipes	
			Lispe persica	
			Musca conducens	
			Musca sorbens	
			Pygophora immaculipennis	
		Nemestrinidae	*Nemestrinus rufipes*	
		Phoridae	*Dohrniphora cornuta*	
			Megaselia curtineura	
			Megaselia dilatimana	
Insecta	Diptera	Phoridae	*Megaselia gallagheri*	NS
			Megaselia gouteuxi	
			Megaselia microcurtineura	
			Megaselia nudihalterata	NS
			Megaselia papei	NS
			Megaselia parvula	
			Megaselia xanthozona	
		Psychodidae	*Falsologima savaiiensis*	
			Iranotelmatoscopus hajiabadi	
			Limomormia wadi	NS
			Tinearia acanthostyla	
			Tinearia alternata	
		Rhinophoridae	*Mimodexia cf. setiventris*	
		Scenopinidae	*Scenopinus megapodemus*	NS
		Sphaeroceridae	*Opacifrons sp.*	
		Stratiomyidae	*Adoxomyia heminopla*	
		Syrphidae	*Eristalinus aeneus*	
			Eristalinus tabanoides	
			Eristalinus taeniops	
			Eumerus cistanchei	
			Eumerus lacertosus	NS
			Eumerus vestitus	
			Eupeodes corollae	
			Paragus pusillus	
			Scaeva albomaculata	
			Simosyrphus aegyptius	
			Sphaerophoria bengalensis	
		Tabanidae	*Tabanus unifaciatus*	
		Tachinidae	*Cadurciella sp.*	
			Cestonia cf. harteni	
			Clausicella xanthomera	
			Cyrtophleba eremophila	
			Drino ciliata	
			Drino latigena	
			Exorista xanthaspis	
			Leucostoma engeddense	
			Macquartia cf. nitidicollis	

Class	Order	Family	Species	Notes
			Peleteria ruficornis	
			Peribaea palaestina	
			Thecocarcelia cf. latifrons	
		Tephritidae	*Acanthiophilus helianthi*	
			Bactrocera zonata	
			Dacus semisphaereus	
			Euarestella korneyevi	NS
Insecta	Diptera	Tephritidae	*Euarestella vanharteni*	
			Goniurellia octoradiata	
			Goniurellia octoradiata	
			Goniurellia tridens	
			Goniurellia tridens	
			Katonaia aida	
			Katonaia aida	
			Metasphenisca cf. tetrachaeta	
			Metasphenisca negeviana	
			Oxyaciura nigra	NS
			Sphaeniscus trifasciatus	
			Trupanea amoena	
			Trupanea amoena	
			Trupanea pulcherrima	
			Trupanea pulcherrima	
			Trupanea stellata	
			Trupanea stellata	
			Trupanea stellata	
	Ephemeroptera	Baetidae	*Caenis malzacheri*	NS
			Cheleocloeon soldani	NS
			Cloeon arenorum	NS
			Nigrobaetis arabiensis	NS
		Leptophlebiidae	*Choroterpes pacis*	
	Hemiptera	Alydidae	*cf. Mirperus jaculus*	
		Anthocoridae	*Buchananiella crassicornis*	
			Buchananiella pseudococci pseudococci	
			Orius albidipennis	
			Orius laevigatus laevigatus	
			Xylocoris flavipes	
		Cicadidae	*Platypleura arabica*	
		Cixiidae	*Cixiidae sp.*	
		Coreidae	*Coreidae sp. or Reduviidae sp.*	
		Corixidae	*Heliocorisa vermiculata*	
		Corixidae	*Sigara lateralis*	
		Dictyopharidae	*Raivuna iranica*	
		Dinioridae / Pentatomidae	*sp.*	
		Fulgoridae	*Dorysarthrus mobilicornis*	
			Raivuna iranica	
		Geocoridae	*Geocoris pallidipennis pallidipennis*	
			Geocoris titan	
		Gerridae	*Metrocoris communis*	
			Neogerris parvulus	
		Hebridae	*Hebrus pusillus*	
		Kinnaridae	*Perloma brunnescens*	

Class	Order	Family	Species	Notes
		Leptopodidae	*Valleriola assouanensis*	
Insecta	Hemiptera	Lygaeidae	*Compleurus cf. fulvipes*	
			Nysius cymoides	
			Nysius ericae ericae	
			Paranysius fallaciosus fallaciosus	
			Spilostethus cf. pandurus	
		Meenoplidae	*Nisia nervosa*	
		Micronectidae	*Micronecta desertana*	
			Micronecta quadristrigata	
		Miridae	*Badezorus tomentosus*	
			Creontiades pallidus	
			Eurystylus bellevoyei	
			Hallodapus costae	
			Lygidolon eurystylioides	
			Phytocoris strigilifer	
			Reuterista demeter	
			Trigonotylus tenuis	
			Tytthus parviceps	
		Nabidae	*Nabis capsiformis*	
		Naucoridae	*Heleocoris minusculus*	
		Nepidae	*Laccotrephes fabricii*	
		Notonectidae	*Anisops sardeus*	
		Notonectidae	*Enithares lineatipes*	
		Ochteridae	*Ochterus marginatus*	
		Oycarenidae	*Leptodemus minutus*	
		Psyllidae	*Caillardia dilatata*	
		Reduviidae	*Oncocephalus nebulosus*	NS
			Oncocephalus pilicornis	
		Rhyparochromidae	*Anepsiocoris encaustus*	
			Emblethis gracilicornis	
			Lethaeus fulvovarius	
			Remaudiereana annulipes	
		Saldidae	*Micracanthia ornatula*	
		Tingidae	*Cochlochila bullita*	
			Dictyla nassata nassata	
			Galeatus scrophicus	
			Kalama pusana	
			Magmara alfierii	
			Phaenotropis cleopatra	
			Urentius euonymus	
		Veliidae	*Microvelia macani*	
	Hymenoptera	Agaonidae	*Platyscapa awekei*	
		Ampulicidae	*Dolichurus arabicus*	NS
		Andrenidae	*Andrena arabica*	NS
		Apidae	*Apis florea*	
Insecta	Hymenoptera	Apidae	*Apis mellifera*	
			cf. Paramegilla semirufa (?)	
			Xylocopa sp.	
		Bethylidae	*Clytrovorus exaggeratus*	NS
			Disepyris abacinus	
			Disepyris guigliae	

Class	Order	Family	Species	Notes
			Epyris afer	
			Glenosema paulae	NS
			Glenosema satiae	NS
			Laelius pedatus	
			Mesitius absentis	NS
			Metrionotus minutissimus	
			Metrionotus yarrowi	
		Braconidae	*Coccygidium melleum*	
			Ephedrus persicae	
			Homolobus truncatoides	
		Chrysididae	*Chrysis adenica*	
			Chrysis alternans	
			Chrysis cf. jousseaumei	
			Chrysis cupriminuta	
			Chrysis dawahi	
			Chrysis elegantula	
			Chrysis harteni	NS
			Chrysis palliditarsis	
			Chrysis procuprata	
			Chrysis viridissima fasciolata	
			Chrysis viridissima viridissima	
			Elampus albipennis	
			Hedychridium monochroum	
			Hedychridium sericatum	
			Holophris imbecillus	
			Holopyga beaumonti	
			Spintharina dubai	
		Colletidae	*Colletes maroccanus*	
			Colletes nanus	
		Crabronidae	*Ammoplanus rhodesianus*	
			Ammoplanus simplex	
			Astata cleopatra	
			Bembecinus bytinskii	
			Bembecinus iranicus	
			Bembix oculata	
			Bembix rufiventris	
			Cerceris tricolorata	
			Crossocerus emirorum	
Insecta	Hymenoptera	Crabronidae	*Dasyproctus arabs*	
			Dryudella nephertiti	
			Dryudella pulawskii	NS
			Dryudella vanharteni	NS
			Gastrosericus electus	
			Gastrosericus moricei	
			Gastrosericus waltlii	
			Hoplisoides ferrugineus	
			Liris agilis	
			Liris braueri	
			Mimesa scheuchli	NS
			Miscophus helveticus	
			Miscophus pharaonis	

Class	Order	Family	Species	Notes
			Miscophus sericeus	
			Nitela arabica	NS
			Nitela feltoni	NS
			Oxybelus arabicus	
			Oxybelus lamellatus	
			Oxybelus tinklyi	
			Philanthus coarctatus	
			Philanthus triangulum	
			Prosopigastra creon	
			Prosopigastra handlirschi	
			Pseudoscolia camela	NS
			Solierella insidiosa	
			Solierella jacobsi	NS
			Solierella longicornis	
			Solierella nigridorsum	
			Synnevrus barrei	
			Tachysphex albocinctus	
			Tachysphex argentatus	
			Tachysphex atris	NS
			Tachysphex consocius	
			Tachysphex difficilis	NS
			Tachysphex palopterus	
			Tachysphex persa catharinae	
			Tachysphex vanharteni	NS
			Tachytes pygmaeus	
		Dryinidae	*Anteon abdulnouri*	
			Bocchus hyalinus	
			Echthrodelphax tauricus	
		Eulophidae	*Closterocerus formosus*	
			Closterocerus pulcherrimus	
			Elasmus viridiceps	
Insecta	Hymenoptera	Eulophidae	*Minotetrastichus frontalis*	
			Pediobius pyrgo	
			Sympiesis notata	
		Eupelmidae	*Reikosiella vanharteni*	NS
		Figitidae	*Nordlanderia pallida*	
			Nordlanderia phaedrae	NS
			Nordlanderia plowa	
		Formicidae	*Camponotus alii*	
			Lepisiota elegantissima	
			Leptothorax megalops	
			Monomorium fayfaense	
			Monomorium nitidiventre	
			Monomorium sp.	
			sp.	
		Gasteruptiidae	*Gasteruption vanharteni*	NS
		Halictidae	*Lasioglossum ablenum*	
			Lasioglossum articulare	
			Lasioglossum cribrum	NS
			Lasioglossum dathei	NS
			Lasioglossum leptorhynchum	

Class	Order	Family	Species	Notes
			Lasioglossum mos	
			Nomia forbesi	
			Nomioides arabicus	
			Systropha diacantha	
		Heterogynaidae	*Heterogyna nocticola*	
		Megachilidae	*Megachile cf. walkeri*	
		Megaspilidae	*Dendrocerus aphidum*	
			Dendrocerus perlucidus	
			Dendrocerus propodealis	
			Dendrocerus vivianae	NS
		Melittidae	*Anthidium amabile*	
			Eremaphanta iranica	
		Mutillidae	*Dentilla rasnitsyni*	NS
			Nanomutilla wurayahensis	NS
			Physetopoda vanharteni	NS
		Ormyridae	*Ormyrus novus*	NS
			Ormyrus rufimanus	
		Platygastridae	*Amblyaspis cf. scelionoides*	
			Amblyaspis harteni	NS
			Piestopleura cf. nievesi	
			Platygaster arabica	
			Platygaster papei	NS
			Synopeas laurae	
			Synopeas osaces	
Insecta	Hymenoptera	Platygastridae	*Synopeas scutoscutellaris*	NS
			Synopeas ubiquitosus	NS
		Pompilidae	*Agenioideus spiniprivus*	
			Anoplius wurayahensis	NS
			Auplopus pumilio	
			Ctenagenia vespiformis	
			Evagetes argenteodecoratus	
			Evagetes palmatus	
			Gonaporus omanicus	
			Hemipepsis semenovi	
			Microphadnus brevicornis	
			Microphadnus pumilus	
			Mygnimia flava	
			Tachyagetes arabicus	
			Tachypompilus analis	
			Telostegus masrensis	
		Pteromalidae	*Sycorcytes sp.*	
		Sapygidae	*Asmisapyga guichardi*	
		Sclerogibbidae	*Sclerogibba berlandi*	
		Scoliidae	*Scolia flaviceps*	
		Sphecidae	*Ammophila dubia*	
			Ammophila erminea	
			Ammophila insignis	
			Ammophila poecilocnemis	
			Chalybion flebile	
			Parapsammophila dolichostoma	
			Parapsammophila turanica	

Class	Order	Family	Species	Notes
			Podalonia tydei	
			Prionyx kirbii	
			Sceliphron madraspatanum	
			Stizus cf. marnonis(?)	
		Thynnidae	*Lamprowara leucothorax*	
		Vespidae	*Alastor dalyi*	
			Antepipona arabica	
			Celonites yemenensis	
			Cyrtolabulus gracilis	
			Delta dimidiatipenne	
			Eumenes mediterraneus	
			Eumenes pomiformis	
			Euodynerus rufinus	
			Euodynerus salzi	
			Ischnogasteroides leptogaster	
			Jugurtia jemenensis	
			Katamenes sichelii biblicus	
Insecta	Hymenoptera	Vespidae	*Knemodynerus excellens*	
			Polistes [Hemipepsis] semenowi	
			Polistes wattii	
			Psiliglossa algeriensis	
			Quartinia arabica	NS
			Quartinia gusenleitneri	NS
			Quartinia nubiana	
			Syneuodynerus fouadi	
			Vespa orientalis	
	Lepidoptera	Alucitidae	*Alucita inflativora*	
		Arctiidae	*Utetheisa pulchella*	
		Brachodidae	*Nigilgia superbella*	
		Bucculatricidae	*sp.*	
		Choreutidae	*Choreutis aegyptiaca*	
		Coleophoridae	*sp.*	
		Cosmopterigidae	*Alloclita delozona*	
		Cossidae	*cf. Holcocerus gloriosus*	
			Meharia semilactea	
		Crambidae	*Aeschremon ochrealis*	
			Ecpyrrhorrhoe diffusalis	
			Ephelis [Emprepes] flavomarginalis	
		Erebidae	*Acantholipes circumdata*	
			Casama innotata	
			Spilosoma [Creatonotos] arabica	
		Ethmiidae	*Ethmia lecmima*	
			Ethmia lepidella	
			Ethmia quadrinotella quinquenotella	
		Gelechiidae	*Dichomeris sp.*	
			sp.	
			Syncopacma polychromella	
		Geometridae	*cf. Hyperythra swinhoei*	
			Eupithecia mekrana amiralis	
			Hemidromodes sabulifera	
			Idaea eremica	

Class	Order	Family	Species	Notes
			Idaea sanctaria crassisquama	
			Neromina integrata	
			Palaeaspilates sublutearia	
			Pasiphila palearctica	
			Pseudosterrha rufistrigata	
			Rhodometra sacraria	
			Scopula harteni	
			Xanthorhoe wiltshirei	
			Xanthorhoe wiltshirei	
		Hesperiidae	*Gegenes sp.*	
Insecta	Lepidoptera	Hesperiidae	*Pelopidas thrax*	
		Lasiocampidae	*Chilena laristana*	
		Lycaenidae	*Anthene amarah*	
			Azanus jesous	
			Brephidium exilis	
			Chilades parrhasius	
			Chilades trochylus	
			Euchrysops osiris	
			Lampides boeticus	
			Myrina silenus	
			Tarucus rosaceus	
		Lymantridae	*Lymantridae sp.*	
		Lyonetiidae	*sp.*	
		Nepticulidae	*sp.*	
		Noctuidae	*Acontia trimaculata*	
			Africalpe intrusa	
			Agrotis haifae	
			Agrotis sardzeana	
			Caradrina flava	
			Caradrina soudanensis	
			Condica viscosa	
			Creataloum arabicum	
			Drasteria yerburyi	
			Drasteriodes ellisoni	
			Dysmilichia phaulopsis	
			Elocastra diaphora	
			Epharmottomena tenera	
			Eublemma buettikeri	
			Eublemma parva	
			Heliothis nubigera	
			Heliothis peltigera	
			Heteropalpia vetusta	
			Iranada turcorum atrior	
			Ozarba sancta	
			Pandesma robusta	
			Pseudozorba mesosona	
			Raparna conicephala	
			Rhynchodontodes orientalis	
			Rhynchodontodes sagittalis	
			Spodoptera exigua	
			Thalerastria diaphora	

Class	Order	Family	Species	Notes
			Thalerastria ochrizona	
			Thalerastria tamsina	
			Tytroca dispar	
Insecta	Lepidoptera	Nymphalidae	*Danaus chrysippus*	
			Hypolimnas misippus	
			Precis orythia	
			Vanessa cardui	
			Ypthima asterope	
		Oecophoridae	*Stathmopoda bicolorella*	
			Stathmopoda cf ficivora	
		Papilionidae	*Papilio demoleus*	
			Papilio machaon	
		Phycitinae	*sp.*	
			Valva pseudodiscomaculella	
		Pieridae	*Belenois aurota*	
			Catopsillia florella	
			Colotis fausta	
			Colotis phisadia	
			Pontia glauconome	
		Plutellidae	*Plutella xylostella*	LC
		Psychidae	*Amicta mauretanica arabica*	
			Oiketicoides sp.	
			Placodoma haettenschwileri	
			Urobarba longicauda	
		Pterophoridae	*Agdistis sp.*	
			Stenodacma wahlbergi	
		Pyralidae	*Ancylolomia micropalpella*	
			Ancylosis nubeculella	
			Asalebria adiudicata	
			Bazaria lixiviella	
			Belutschistania squamalis	
			Cherchera abatesella	
			Cornifrons ulceratalis	
			Diaphania indica	
			Eoophyla sp. indesc.	
			Etiella zinckenella	
			Euchromius ocellea	
			Euchromius vinculellus	
			Euclasta mirabilis	
			Evergestis laristanalis	
			Faveria tchourouma	
			Metasia sp.	
			Neorastia albicostella	
			Nomophila noctuella	
			Noorda blitealis	
			Pempelia arida	
			Pempelia tchahbaharella	
Insecta	Lepidoptera	Pyralidae	*Phycitinae sp.*	
			Pseudosyria malacella	
			Scotomera sp.	
			Sitochroa umbrosalis	

Class	Order	Family	Species	Notes
			sp.	
			Susia uberalis	
		Scythrididae	*Apostibes dharahni*	
			sp.	
		Sphingidae	*Acherontia styx / atropos*	
			Daphnis nerii	
			Hippotion celerio	
			Hyles livornica	
			Macroglossum stellatarum	
		Tineidae	*Ceratobia irakiella*	
			Hapsiferona arabica	
			Pachyarthra grisea	
			Pachyarthra iranica	
			Perissomastix cf wadimaidaq	NS
			Trichophaga bipartitella	
		Tortricidae	*Ancylis sederana*	
			Dasodis cladographa	
			Fulcrifera refrigescens	
			Ophiorrhabda cellifera	
			Selania resedana	
		Ypsolophidae	*Ypsolopha desertella*	
			sp.	
	Mantodea	Empusidae	*Blepharopsis mendica*	
		Eremiaphilidae	*Eremiaphila braueri*	
		Mantidae	*Mantis religiosa*	
			sp.	
	Neuroptera	Ascalaphidae	*Ptyngidricerus venustus*	
		Chrysopidae	*Chrysoperia carnea*	
		Myrmeleonidae	*Palpares dispar*	
			Myrmeleon hyalinus hyalinus	
			Neuroleon leptaleus	
			Neuroleon tenellus	
	Odonata	Aeshnidae	*Anax imperator*	LC
			Anax parthenope	LC
			Hemianax ephippiger	LC
		Coenagrionidae	*Ishneura evansi*	NE
			Ishneura senegalensis	NE
			Pseudagrion decorum	LC
		Gomphidae	*Paragomphus genei*	LC
			Paragomphus sinaiticus	NT
Insecta	Odonata	Libellulidae	*Crocothemis erythraea*	LC
			Crocothemis sanguinolenta	LC
			Diplacodes lefebvrii	LC
			Orthetrum abbotti	LC
			Orthetrum chrysostigma	LC
			Orthetrum ransonneti	NE
			Orthetrum sabina	LC
			Pantala flavescens	LC
			Sympetrum fonscolombii	LC
			Tramea basilaris	LC
			Trithemis annulata	LC

Class	Order	Family	Species	Notes
			Trithemis arteriosa	LC
			Trithemis kirbyi	LC
			Urothemis thomasi	EN End.
			Zygonyx torridus	LC
		Platycnemidae	*Arabicnemis caerulea*	LC End.
		Protoneuridae	*Arabineura khalidi*	EN End.
	Orthoptera	Acrididae	*Dorianella parallela*	
			Sphingonotus cf. lavandulus (?)	
			Sphingonotus rubescens	
			Sphingonotus cf. octofasciatus (?)	
			Sphingonotus sp. 1.	
			Sphingonotus sp. 2	
			Truxalis fitzgeraldi	
		Gryllidae	*Acheta sp.*	
		Pyrgomorphidae	*Chrotogonus homalodenus*	
			Pyrgomorpha conica tereticornis	
		Tetrigidae	*sp.*	
		Tettigoniidae	*Conocephalus maculatus*	LC
	Phasmatodea	Diapheromeridae	*Clonaria sp.*	
	Psocoptera	Mesopsocidae	*Rhinopsocus cincinnatus*	
		Psocidae	*Arabopsocus spiniproctus*	NS
	Thysanoptera	Phlaeothripidae	*Dolicholepta micrura*	
		Thripidae	*Bregmatothrips dimorphus*	
			Frankliniella schultzei	
			Megalurothrips sjostedti	
			Scirtothrips oligochaetus	
	Trichoptera		*sp. 1*	
			sp. 2	
Sub-phylum: Myriapoda				
Chilopoda	Scolopendromorpha	Scolopendridae	*cf. Scolopendra valida (?)*	
Phylum: Chordata				
Sub-phylum: Vertebrata				
Actinopterygii	Cypriniformes	Cyprinidae	*Cyprinius carpio*	
Actinopterygii	Cypriniformes	Cyprinidae	*Garra barreimiae*	VU End.
	Cyprinodontiformes	Aphaniidae	*Aphanius dispar*	LC
		Poeciliidae	*Poecilia sphenops*	Int.
	Perciformes	Cichlidae	*Oreochromis sp.*	Int.
Amphibia	Anura	Bufonidae	*Amietophrynus arabicus*	End.
			Duttaphrynus dhufarensis	End.
Aves	Accipitriformes	Accipitridae	*Accipiter nisus*	LC
			Aquila heliaca	VU
			Buteo rufinus	LC
			Circaetus gallicus	LC
			Gyps fulvus	LC
			Hieraaetus fasciatus	LC
			Neophron percnopterus	EN
			Torgos tracheliotus	VU
	Anseriformes	Anatidae	*Anas crecca*	LC
			Anas platyrhynchos	LC
	Apodiformes	Apodidae	*Apus apus*	LC
			Apus pallidus	LC

Class	Order	Family	Species	Notes
	Caprimulgiformes	Caprimulgidae	*Caprimulgus europaeus*	LC
	Charadriiformes	Charadriidae	*Charadrius dubius*	LC
			Vanellus indicus	LC
		Recurvirostridae	*Himantopus himantopus*	LC
		Scolopacidae	*Actitis hypoleucos*	LC
			Gallinago gallinago	LC
			Tringa ochropus	LC
	Columbiformes	Columbidae	*Columba livia*	LC
			Streptopelia decaocto	LC
			Streptopelia senegalensis	LC
			Streptopelia turtur	LC
	Coraciiformes	Alcedinidae	*Alcedo athis*	LC
		Coraciidae	*Coracias benghalensis*	LC
			Coracias garrulus	NT
		Meropidae	*Merops apiaster*	LC
			Merops orientalis	LC
			Merops persicus	LC
		Upupidae	*Upupa epops*	LC
	Cuculiformes	Cuculidae	*Cuculus canorus*	LC
	Falconiformes	Falconidae	*Falco naumanni*	VU
			Falco peregrinoides	LC
			Falco tinnunculus	LC
	Galliformes	Phasianidae	*Alectoris chukar*	LC
			Ammoperdix heyii	LC
			Francolinus pondicerianus	LC
	Gruiformes	Rallidae	*Fulica atra*	LC
Aves	Otidiformes	Otididae	*Chlamydotis macqueeni*	VU
	Passeriformes	Acrocephalidae	*Acrocephalus palustris*	LC
			Hippolais languida	LC
		Alaudidae	*Ammomanes deserti*	LC
			Galerida cristata	LC
		Cettiidae	*Scotocerca inquieta*	LC
		Cisticolidae	*Prinia gracilis*	LC
		Corvidae	*Corvus ruficollis*	LC
			Corvus splendens	LC
		Emberizidae	*Emberiza cineracea*	NT
			Emberiza striolata	LC
		Estrildidae	*Lonchura malabarica*	LC
			Lonchura punctulata	LC
		Fringillidae	*Bucanetes githagineus*	LC
		Hirundinidae	*Hirundo rustica*	LC
			Ptyonoprogne obsoleta	LC
		Laniidae	*Lanius isabellinus*	LC
			Lanius meridionalis	LC
			Lanius minor	LC
			Lanius pallidirostris	LC
			Lanius phoenicuroides	LC
			Lanius senator	LC
		Leiotrichidae	*Turdoides squamiceps*	LC
		Motacillidae	*Anthus similis*	LC
			Motacilla cinerea	LC

Class	Order	Family	Species	Notes
			Motacilla citreola	LC
			Motacilla flava	LC
		Muscicapidae	*Cercotrichas galactotes*	LC
			Monticola solitarius	LC
			Muscicapa striata	LC
			Oenanthe albonigra	LC
			Oenanthe lugens	LC
			Oenanthe monacha	LC
			Oenanthe oenanthe	LC
			Oenanthe picata	LC
			Oenanthe pleschanka	LC
			Oenanthe xanthoprymna	LC
			Phoenicurus ochruros	LC
		Nectariniidae	*Cinnyris asiaticus*	LC
		Oriolidae	*Oriolus oriolus*	LC
		Passeridae	*Carpospiza brachydactyla*	LC
			Passer domesticus	LC
			Petronia xanthocollis	LC
		Phylloscopidae	*Phylloscopus collybita*	LC
Phylloscopidae	Passeriformes	Phylloscopidae	*Phylloscopus neglectus*	LC
			Phylloscopus trochilus	LC
		Pycnonotidae	*Pycnonotus leucotis*	LC
			Pycnonotus xanthopygos	LC
		Sturnidae	*Acridotheres tristis*	LC
		Sylviidae	*Sylvia curruca*	LC
			Sylvia minula	LC
			Sylvia mystacea	LC
			Sylvia nisoria	LC
		Turdidae	*Irania gutturalis*	LC
			Turdus atrogularis	LC
	Pelecaniformes	Ardeidae	*Ardea cinerea*	LC
			Butorides striatus	LC
			Ixobrychus minutus	LC
	Piciformes	Picidae	*Jynx torquilla*	LC
	Podicipediformes	Podicipedidae	*Tachybaptus ruficollis*	LC
	Pterocliformes	Pteroclidae	*Pterocles lichtensteinii*	LC
	Strigiformes	Strigidae	*Athene noctua*	LC
			Bubo ascalaphus	LC
			Otus brucei	LC
			Strix butleri	DD
Mammalia	Artiodactyla	Bovidae	*Arabitragus jayakari*	EN End.
			Capra aegagrus hirta	N/A
			Gazella gazella cora	VU
			Ovis aries	Dom.
	Carnivora	Canidae	*Canis lupus arabis*	LC
			Vulpes cana	LC
			Vulpes vulpes arabica	LC
		Felidae	*Caracal caracal schmitzi*	LC
			Felis catus	Int.
			Felis sylvestris gordoni	LC
			Panthera pardus nimr	CR, L.Ext.

Class	Order	Family	Species	Notes
		Hyenidae	*Hyena hyena*	NT, L. Ext.
	Chiroptera	Pteropodidae	*Rousettus aegyptiacus*	LC
		Rhinopomatidae	*Rhinopoma muscatellum*	LC
		Vespertilionidae	*Rhyneptesicus nasutus*	LC
	Insectivora	Erinaceidae	*Paraechinus hypomelas*	LC
	Perissodactyla	Equidae	*Equus asinus*	Int.
	Primates	Hominidae	*Homo sapiens*	N/A
	Rodentia	Muridae	*Acomys [cahirinus] dimidiatus*	LC
			Gerbillus dasyurus	LC
			Rattus rattus	LC
Reptilia	Squamata	Agamidae	*Pseudotrapelus jensvindumi*	NE
		Colubridae	*Platyceps rhodorachis*	NE
Reptilia	Squamata	Colubridae	*Psammophis schokari*	NE
		Gekkonidae	*Bunopus spatalarus hajarensis*	LC End.
			Hemidactylus flaviventris	LC
		Lacertidae	*Mesalina adramitana*	LC
			Omanosaura cyanura	LC End.
			Omanosaura jayakari	LC End.
		Phyllodactylidae	*Asaccus gallagheri*	LC End.
			Ptyodactylus hasselquistii	NE
		Scincidae	*Chalcides ocellatus ocellatus*	NE
			Trachylepis tesselata	LC End.
		Sphaerodactylidae	*Pristurus celerrimus*	LC End.
			Pristurus rupestris	LC End.
		Viperidae	*Echis omanensis*	LC End.
Phylum: Fungi				
Agaricomycetes	Agaricales	Psathyrellaceae	*Coprinopsis cf. lagopus*	
	Polyporales	Ganodermataceae	*cf. Ganoderma (?)*	
Phylum: Mollusca				
Gastropoda	Caenogastropoda	Thiaridae	*Melanoides tuberculata*	
		Lymnaeidae	*Lymnaea (Radix) natalensis*	
		Planorbidae	*Gyraulus convexiusculus*	
		Pupilidae	*Pupoides coenopictus*	
		Subulunidae	*Allopeas gracilis*	
			Zootecus insularis	
Phylum: Platyhelminthes				
Turbellaria	Tricladida	Planariidae	*sp.*	
Phylum: Plantae				
Filicopsida	Ophioglossales	Ophioglossaceae	*Ophioglossum polyphyllum*	
	Polypodiales	Pteridaceae	*Adiantum capillus-veneris*	
			Cheilanthes acrostica	
			Onychium divaricatum	
Gnetopsida	Ephedrales	Ephedraceae	*Ephedra foliata*	
Liliopsida	Arecales	Arecaceae	*Phoenix dactylifera*	
	Asparagales	Xanthorrhoeaceae	*Asphodelus tenuifolius*	
	Cyperales	Cyperaceae	*Bolboschoenus maritimus*	
			Cladium mariscus	
			Cyperus cf. conglomeratus	
			Cyperus rotundus	
			Schoenus nigricans	
		Poaceae	*Aristida abnormis*	

Class	Order	Family	Species	Notes
			Aristida adscensionis	
			Arundo donax	
			Brachypodium distachyum	
Liliopsida	Cyperales	Poaceae	*Bromus danthoniae*	
			Bromus madritensis	
			Castellia tuberculosa	
			Cenchrus ciliaris	
			Cymbopogon schoenanthus	
			Cynodon dactylon	
			Dicanthium foveolatum	
			Digitaria nodosa	
			Echinochloa crusgalli	
			Enneapogon desvauxii	
			Enneapogon persicus	
			Eragrostis barrelieri	
			Eragrostis cilianensis	
			Eragrostis ciliaris	
			Gastridium phleoides	
			Hyparrhenia hirta	
			Pennisetum divisum	
			Pennisetum orientale	
			Rostraria pumila	
			Saccharum griffithii	
			Saccharum kajkaiense	
			Sporobolus spicatus	
			Stipa capensis	
			Stipagrostis hirtigluma	
			Tetrapogon villosus	
			Tricholaena teneriffae	
			Typha domingensis	
	Orchidales	Orchidaceae	*Epipactis veratrifolia*	LC
	Scrophulariales	Acanthaceae	*Blepharis ciliaris*	
Magnioliopsida	Asterales	Asteraceae	*Echinops erinaceus*	End.
			Filago desertorum	
			Filago pyramidatum	
			Helichrysum glumaceum	
			Ifloga spicata	
			Iphiona scabra	
			Launaea bornmuelleri	
			Launaea capitata	
			Launaea massauensis	
			Launaea nudicaulis	
			Launaea omanensis	End.
			Launaea procumbens	
			Pentanema divaricatum	
			Phagnalon schweinfurthii	
			Pulicaria edmondsonii	End.
Magnioliopsida	Asterales	Asteraceae	*Pulicaria glutinosa*	
			Reichardia tingitana	
			Senecio breviflorus	
			Sonchus oleraceus	

Class	Order	Family	Species	Notes
			Vernonia arabica	
			Zoegea purpurea	
		Campanulaceae	*Campanula erinus*	
	Brassicales	Brassicaceae	*Diplotaxis harra*	
			Morettia parviflora	
			Notoceras bicorne	
			Physorrhynchus chamaerapistrum	
			Sinapis arvensis	
			Sisymbrium erysimoides	
	Capparales	Capparaceae	*Capparis spinosa*	
			Cleome austroarabica	
			Cleome noeana	
			Cleome rupicola	
			Cleome scaposa	
		Moringaceae	*Moringa peregrina*	
		Resedaceae	*Ochradenus arabicus*	
			Ochradenus aucheri	
			Oligomeris linifolia	
			Reseda cf. muricata	
	Caryophylales	Aizoaceae	*Aizoon canariense*	
			Zaleya pentandra	
		Amaranthaceae	*Aerva javanica*	
		Caryophyllaceae	*Cometes surattensis*	
			Dianthus crinitus	
			Gymnocarpos decandrus	
			Gypsophila bellidifolia	
			Paronychia arabica	
			Polycarpaea robbairea	
			Sclerocephalus arabicus	
			Silene austro-iranica	
			Spergula fallax	
			Spergularia diandra	
		Chenopodaceae	*Chenopodium murale*	
			Haloxylon salicornicum	
			Sueda aegyptiaca	
		Nyctaginaceae	*Boerhavia elegans*	
	Euphorbiales	Euphorbiaceae	*Andrachne aspera*	
			Chrozophora oblongifolia	
			Euphorbia arabica	
			Euphorbia granulata	
Magnioliopsida	Euphorbiales	Euphorbiaceae	*Euphorbia larica*	
	Fabales	Fabaceae	*Argyrolobeum roseum*	
			Astragalus fasciculifolius	
			Crotalaria aegyptiaca	
			Hippocrepis constricta	
			Indigofera caerulea	
			Lotononis platycarpa	
			Lotus schmperi	
			Medicago laciniata	
			Pseudolotus makranicus	
			Rhynchosia minima	

Class	Order	Family	Species	Notes
			Senna italica	
			Taverniera cuneifolia	
			Tephrosia apollinea	
			Tephrosia sp. 1	
		Mimosaceae	*Acacia ehrenbergiana*	
			Acacia tortilis	
			Prosopis cineraria	
	Gentianales	Apocynaceae	*Nerium oleander*	
		Asclepiadaceae	*Calotropis procera*	
			Desmidorchis [Caralluma] arabicus	End.
			Glossonema varians	
			Leptadenia pyrotechnica	
			Pentatropis nivalis	
			Pergularia tomentosa	
			Periploca aphylla	
		Gentianaceae	*Centaurium pulchellum*	
	Geraniales	Geraniaceae	*Erodium neuradifolium*	
			Geranium biuncinatum	
			Geranium trilophum	
			Monsonia cf. heliotropioides	
	Lamiales	Boraginaceae	*Anchusa aegyptiaca*	
			Arnebia hispidissima	
			Echiochilon persicum	
			Heliotropium brevilimbe	
			Lappula spinocarpos	
			Paracaryum intermedium	
			Trichodesma enetotrichum	
		Lamiaceae	*Lavandula subnuda*	
			Leucas inflata	
			Salvia aegyptiaca	
			Salvia macilenta	
			Salvia macrosiphon	
			Satureja imbricata	
Magnioliopsida	Lamiales	Lamiaceae	*Teucrium stocksianum*	
	Linales	Linaceae	*Linum corymbulosum*	
	Malvales	Cistaceae	*Helianthemum lippii*	
		Malvaceae	*Hibiscus micranthus*	
			Malva parviflora	
		Tiliaceae	*Corchorus depressus*	
			Grewia erythraea	
	Plantaginales	Plantaginaceae	*Plantago afra*	
			Plantago amplexicaulis	
			Plantago ciliaris	
			Plantago ovata	
	Plumbaginales	Plumbaginaceae	*Dyerophytum indicum*	
	Polygalales	Polygalaceae	*Polygala erioptera*	
	Polygonales	Polygonaceae	*Pteropyrum scoparium*	End.
			Rumex limoniastrum	End.
			Rumex vesicarius	
	Primulales	Primulaceae	*Anagallis arvensis*	
			Asterolinon linum-stellatum	

Class	Order	Family	Species	Notes
	Ranunculales	Menispermaceae	*Cocculus pendulus*	
		Papaveraceae	*Papaver decaisnei*	
	Rhamnales	Rhamnaceae	*Ziziphus spina-christi*	
	Rosales	Moraceae	*Ficus cordata salicifolia*	
			Ficus johannis	
			Ficus religiosa	
	Rubiales	Rubiaceae	*Callipeltis cucullaris*	
			cf. Galium sp. 1	
			Galium decaisnei	
			Plocama aucheri	
			Plocama hymenostephana	
	Sapindales	Anacardiaceae	*Mangifera indica*	
		Rutaceae	*Haplophyllum tuberculatum*	
		Sapindaceae	*Dodonaea viscosa*	
		Zygophyllaceae	*Fagonia brugueri*	
			Fagonia indica	
			Tribulus terrestris	
	Scrophulariales	Orobanchaceae	*Orobanche cernua*	
		Scrophulariaceae	*Anticharis glandulosa*	
			Chaenorrhinum rubrifolium	
			Lindenbergia arabica	End.
			Lindenbergia indica	
			Misopates orontium	
			Nanorrhinum acerbianum	
			Nanorrhinum hastatum	
			Schweinfurthia imbricata	End.
Magnioliopsida	Scrophulariales	Scrophulariaceae	*Schweinfurthia papilionacea*	
			Scrophularia deserti	
	Solanales	Convolvulaceae	*Convolvulus glomeratus*	
			Convolvulus virgatus	
			Cuscuta planifora	
			Ipomoea pes-caprae	
		Solanaceae	*Hyoscyamus muticus*	
			Lycium shawii	
			Lycopersicum esculentum	
			Physalis minima	
	Urticales	Urticaceae	*Forsskaolea tenacissima*	
			Parietaria alsinifolia	
	Violales	Cucurbitaceae	*Citrullus colocynthis*	
			Citrullus lanatus	
			Cucumis prophetarum	
		Violaceae	*Viola cinerea*	

Abbreviations used in the notes per species:

CR: Critically Endangered, DD: Data Defficient, Dom.: domestic,
EN: Endangered, End.: Endemic, Int. : Introduced, L. Ext.: Locally Extinct,
LC : Least Concern, N/A : Not Applicable, NE : Not Evaluated,
NS: New to Science, NT: Near Threatened, VU: Vulnerable

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