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LOCAL, NATIONAL, REGIONAL CLIMATE CHANGE PROGRAMME

TERRESTRIAL BIODIVERSITY AND CLIMATE CHANGE

- Atmospheric Modelling
- Arabian Gulf Modelling
- Terrestrial Biodiversity & Climate Change
- Marine Ecosystems
- Transboundary Groundwater
- Water Resource Management
- Al Ain Water Resources
- Coastal Vulnerability Index
- Desalinated Water Supply
- Food Security
- Public Health Benefits of GHG Mitigation
- Sea Level Rise

Executive Summary

Climate Change Research Group

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

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Local, National and Regional Climate Change Programme 2013-2016

Socioeconomic Systems	Regional Climate Change	Environment	Coastal Zones	Water Resources
Public Health Benefits of GHG Mitigation (L)	Atmospheric Modeling (R)	Terrestrial Ecosystems (R)	Coastal Vulnerability Index (N)	Al Ain Water Resources (L)
Food Security (N)	Arabian Gulf Modeling (R)	Marine Ecosystems (R)	Sea Level Rise (R)	Water Resource Management (N)
Desalinated Water Supply (R)				Transboundary Groundwater (R)

L=Local **N=National** **R=Regional**

5 Thematic Areas 3 Spatial Regions 12 Sub-projects

12 Sub-projects
Assess the Impacts, Vulnerability & Adaptation to Climate Change in the Arabian Peninsula

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About the Terrestrial Biodiversity and Climate Change sub-Project

In October 2013, the Abu Dhabi Global Environmental Data Initiative (AGEDI) launched the Local, National, and Regional Climate Change Programme (LNRCCP) to build upon, expand, and deepen understanding of vulnerability to the impacts of climate change as well as to identify practical adaptive responses at local (Abu Dhabi), national (UAE), and regional (Arabian Peninsula) levels. The design of the Programme was stakeholder-driven, incorporating the perspectives of over 100 local, national, and regional stakeholders in shaping 12 research studies across 5 strategic themes. The "Terrestrial Biodiversity and Climate Change" study within this Programme aimed to assess the potential impacts and the vulnerability of terrestrial biodiversity in the Arabian Peninsula region to climate change.

1. Regional terrestrial biodiversity context

There is compelling evidence that climate change poses widespread adverse impacts on terrestrial biodiversity, including dramatic increases in extinction rates and changes to ecosystem structure and function (Walther et al. 2002; Root et al. 2003; Thuiller et al. 2005; Fitzpatrick et al. 2008, 2011; Urban 2015).

At regional scales, the primary impacts of climatic change are expected to be rapid geographic shifts in climatically suitable habitats (Fischlin et al. 2007). As temperatures increase and precipitation patterns change, species will be forced to either adapt to new conditions, migrate to areas that become suitable, or potentially face extinction (Rosenzweig et al. 2007; Aitken et al. 2008). The increasing isolation and fragmentation of natural habits and the rapid rates of projected climatic change are expected to make migration unfeasible for all but the most agile and widespread species (Hill et al. 1999; Malcolm et al. 2002; Travis 2003; Loarie et al. 2009).

Dryland ecosystems are expected to be particularly vulnerable to climatic change given their exposure and sensitivity to multiple drivers of global change, including habitat destruction, overgrazing, and invasive species (Talhouk 2009; El-Keblawy 2014).

Although quantitative vulnerability assessments remain relatively rare in drylands, existing modelling studies suggest that range contractions (i.e. reduction in suitable habitat) rather than range shifts may be a dominant response of dryland biota to climatic change (Midgley et al. 2003; Thuiller et al. 2006; Midgley & Thuiller 2007; Fitzpatrick et al. 2008; Loarie et al. 2008). Such impacts are likely to have significant consequences for human societies given that drylands are home to more than a third of the world's population and support many of the world's food crops and livestock. For these reasons, a critical aspect of climatic change vulnerability assessments and adaptation planning in dryland ecosystems is determining the extent to which future climatic change is expected to alter the geographic distributions of species and patterns of biodiversity.

For the UAE and other GCC countries, this suggests the need for urgent proactive action to adapt to the looming impacts of climate change.

The Arabian Peninsula houses unique ecosystems that may be particularity vulnerable to climatic change (Talhouk 2009; El-Keblawy 2014). The biodiversity of the region is heavily influenced by its setting between Africa and Eurasia and the mixing of the often distinct taxa of these two realms. Climate history is a primary influence on contemporary patterns of biodiversity as well, as increasing aridity since the last ice age has led to the isolation of Arabian species and the evolution of endemic taxa. Although deserts are the most extensive ecosystem in the hyper-arid portions of the region, other unique systems such as shrub habitats, rangelands, and woodlands occur along coastal areas and highlands (Osman-Elasha & Fisher 2008; Talhouk 2009).

Generally speaking, the vulnerability of terrestrial biodiversity on the Arabian Peninsula is expected to be highest for certain species.

Those species are those that are narrowly distributed or which exist at the margins of their environmental tolerances, such as those that thrive at high altitude or otherwise under conditions of moderate heat or moisture or in close proximity to water bodies. Desert fauna that depend on rainfall events to initiate breeding, such as resident birds, and migratory birds whose migration pathways traverse deserts, could also be severely affected (Hardy 2003). The Arabian Peninsula region's substantial range and level of biodiversity, as briefly outlined below, is the heart of this study.

Vegetation

There are estimated to be approximately 7,000 native species of plants in the Arabian Peninsula, with up to ~20% being endemic (Miller & Cope 1997).

The majority of the endemic plant taxa in Arabia are associated with mountainous areas (Miller & Cope 1997; El-Keblawy 2014), with the greatest concentrations along coastal regions, notably the western escarpments of Saudi Arabia and Yemen, the Al Hajar Mountains in Oman, and the islands of the Socotra archipelago – a global biodiversity hotspot (Cheung et al. 2007; Brown & Mies 2012). In Oman, an estimated 5% of the flora is threatened, 80% of which occurs in the southern region of the country (Ghazanfar 1998). Yemen has by far the highest overall number of threatened plant species (Talhouk 2009; IUCN 2015), though the actual threat levels for plants in the region are generally poorly known. See Al-Abbasi et al. (2010) for criteria used to define important plant conservation areas in the region. Future climatic change may hinder colonization of disturbed areas or newly suitable habitat.

Birds

As a bridge between Africa, Asia and Europe, the Arabian Peninsula lies on important bird migration routes and contains numerous stopover habitats for both migrating and overwintering birds (Shobrak 2011).

The largest concentrations of species generally occur along coasts and nearby mountainous areas, especially the southwestern portion of the peninsula near the Red Sea (Somveille et al. 2013). These areas in Saudi Arabia and Yemen, as well as marshes and wetland areas of southeastern Iraq, are considered globally important bird areas (BirdLife International & NatureServe 2014). Approximately 6% of birds in the region are considered endemic (Mallon 2011). At present, more than 150 bird species in the region are considered threatened (Talhouk 2009; IUCN 2015), and many more species are considered at high risk to climatic change (Talhouk 2009). Climatic change can adversely impact migratory birds through shifts in phenology that lead to mismatches between critical life history events and food / habitat resources (Heezik & Seddon 1999; Visser et al. 2006).

Mammals

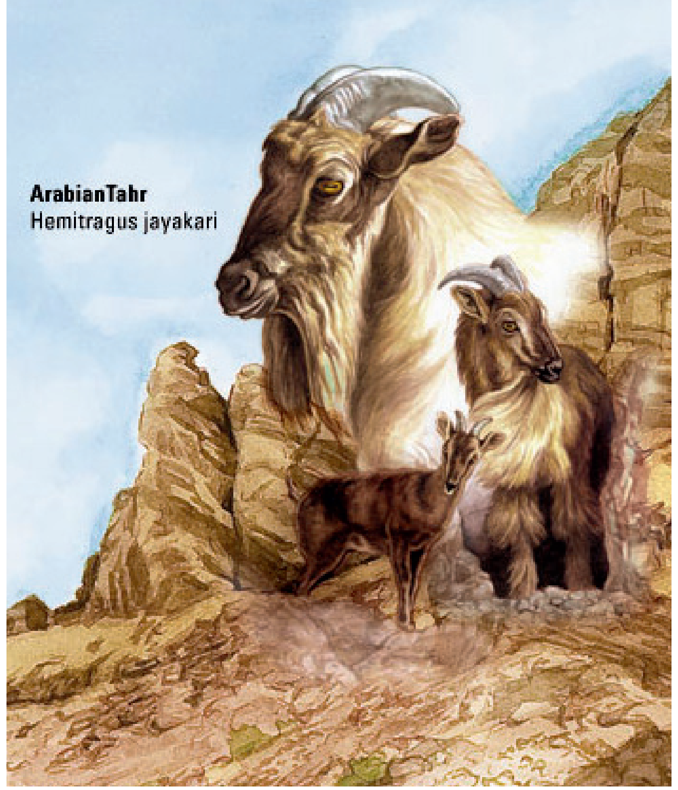
Approximately 100 species of native mammals have been recorded in the Arabian Peninsula, from small rodents and bats to large herbivores and carnivores (Kingdon 1990).

Mammal species richness is concentrated mostly in coastal mountainous regions of Saudi Arabia, Yemen, and Oman (Ceballos & Ehrlich 2006). Around 10% of the region's mammals are thought to be native or restricted to the region (Mallon 2011). Numerous mammal species in the region are already extinct (regionally), threatened with extinction, such as the Arabian oryx and tahr, leopard, wolf, hyena, cheetah, wild ass, and lion, or are declining (Mallon & Budd 2011). Many of the largest surviving species are camels, sheep, goats, and gazelles, the last of which make up about half of the mammals in the region (Kingdon 1990). Nearly all of these species have declined greatly over the last several decades (Thouless et al. 1991). As a group, carnivores are particularly threatened (Al-Johany 2007; Mallon & Budd 2011). As is the case with other dryland taxa, many desert mammals exist near the upper lethal limits of temperature and have limited access to water.

Reptiles & Amphibians

Within the Arabian Peninsula, both species richness and the proportion of endemic reptile species are relatively high, with 172 species currently recognized and 89 species (52%) considered endemic (Cox et al. 2012).

Like other groups, reptile species richness tends to be concentrated along the coastal rim of the Arabian Peninsula, and in particular the southwestern mountains and Dhofar (Farag & Banaja 1980; Mallon 2011). Richness is lowest in the Rub' al Khali (or Empty Quarter). Areas of greatest endemism follow the same general pattern, though the islands of the Socotra archipelago contain a disproportionate number of endemic species (26) (Cox et al. 2012). Most of the reptile species in the region are either lizards or snakes, with just two species of turtles and tortoises known from the Arabian Peninsula. As a group, the reptiles of the Arabian Peninsula currently are relatively well protected, with 144 of the 172 species (84%) represented in protected areas. Only six species are listed as globally threatened, and only 10 are of regional concern. The extent to which protected areas will allow for persistence under climatic change is unknown.



2. Approach

The overall aim of this study was to provide a comprehensive assessment of the potential vulnerability of terrestrial biodiversity in the Arabian Peninsula to climatic change.

There were three main objectives: (1) Describe how a group of priority species and taxonomic communities are likely to respond to changes in climate as realized across a wide range of future climate scenarios; (2) quantify the level of confidence that can be placed in the modeled responses; and (3) provide a set of visualizations pinpointing areas of species loss which can be used for future conservation planning in the region. The approach allows for an identification of species and sub-regions that are most vulnerable to climate change, while documenting the degree of uncertainty in forecasts, and offering maps depicting changes in species distributions and patterns of biodiversity. The study region is shown in Figure 1.

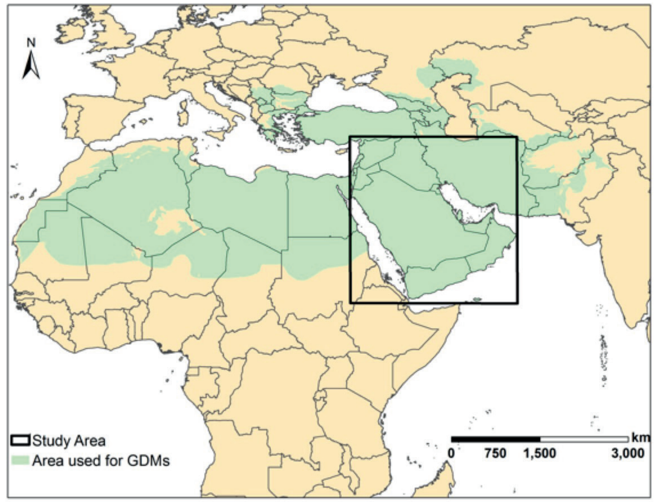


Figure 1: Map of study region (black rectangle) and general extent of areas used to fit models used

The fundamental concept underlying the vulnerability assessment is that climate-driven changes in habitat suitability will place species at risk by reducing the area that can support populations and/or by forcing individuals to shift their geographic ranges to track suitable climate regimes.

These changes in the distributions of individuals will lead to the disassembly of existing communities and the formation of new ones, which in turn will alter ecosystem structure and function. A key requirement for quantifying any shift in geographic range is a suitable amount and quality of species occurrence data. However, for the vast majority of species there is little information available in the format needed to develop quantitative predictions regarding all possible types and magnitude of changes expected. As a result, the results can be viewed as a first cut assessment of climate change impacts that should be updated as additional data become available.

Priority species

The focus of the effort was on a set of priority species, as identified by stakeholders and informed by data availability.

This involved developing a list of species for which to seek data records for subsequent modelling. A consultative approach was used whereby 1) feedback from local specialists was obtained regarding priority species; 2) existing literature and published assessments of those species were examined; and 3) the availability of all other local and internationally available occurrence records were investigated. As a result of this process, a total of 111 priority species were selected, encompassing birds, mammals, plants, reptiles, and amphibians. Table 1 provides a list of priority species considered. While all of the species in Table 1 were explored, some had to be discarded due to lack of adequate data in the resolutions needed.

Species and communities modelling

Modelling of the impact of climate change on terrestrial biodiversity was conducted at both the priority species level and the community level.

An illustration of the modelling framework is shown in Figure 2. At the priority species level, a species distribution model (SDM), Maxent, was used. At the community-level, the Generalized Dissimilarity Modelling (GDM) system was used. The rationale for selecting these models and details of their strengths and weaknesses are discussed within the Final Technical Report.

Climate change forecasts

The species-level (Maxent) and community-level (GDM) models incorporated information of current and future climate in the region.

An ensemble approach to climate change was applied to account for the range of potential future conditions. To describe current climatology, the WorldClim datasets at 10 arc-minute resolution were used. Worldclim is a database of globally-contiguous gridded representations of climate developed from interpolations of observed data for the period 1950-2000 (Hijmans et al. 2005). For future climate, a large number of future climate simulations were considered, including (1) 62 future climate simulations at 2.5 arc-minute spatial resolution and global extent for decades 2030, 2050, 2070, and 2080 and downscaled to the Arabian Peninsula and (2) output from regional high resolution climate model simulations developed as part of the Regional Atmospheric Modelling sub-project for 12 km and 36 km grid cell resolution. Representative Concentration Pathways (RCP) 4.5 and 8.5 were considered.

Figure 2: Modelling strategies used for assessing the vulnerability of terrestrial biodiversity to climatic change

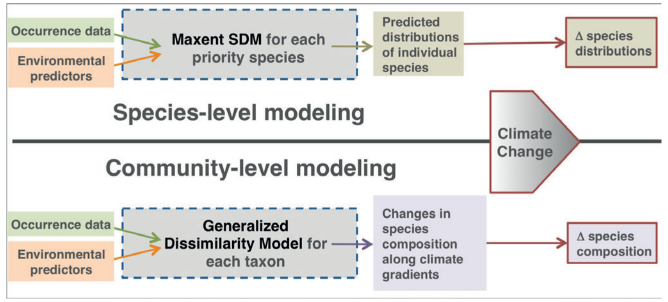


Table 1: List of priority species

	# Breeding bird	# Non breeding bird	# Resident bird
Birds (31)	1 Houbara Bustard 2 Western Reef Heron 3 European Roller 4 Griffon Vulture, Eurasian Griffon 5 Marbled Teal 6 Egyptian Vulture	7 Greater Spotted Eagle 8 Great Knot 9 Houbara Bustard 10 Western Reef Heron 11 Marbled Teal 12 Egyptian Vulture 13 Sociable Lapwing 14 Golden Eagle 15 European Roller 16 Saker Falcon 17 Griffon Vulture, Eurasian Griffon	18 Arabian Partridge 19 Sand Patridge 20 Brown-necked Raven 21 Cinereous Bunting 22 Socotra Cormorant 23 Persian Shearwater 24 Olive-rumped Serin, Arabian Canary 25 Arabian Warbler, Red Sea Warbler 26 Arabian Babbler 27 Arabian Waxbill 28 Arabian Golden Sparrow 29 Yemen Serin 30 Yemen Warbler 31 Yemen Thrush
Mammals (29)	1 Trident Leaf-nosed Bat 2 Common Jackal 3 Nubian Ibex 4 Caracal 5 Straw-colored Fruit Bat 6 Sand Cat 7 Mountain Gazelle 8 Goitered Gazelle 9 Cheesman's Gerbil 10 Dwarf Gerbil, Baluchistan Gerbil	11 Lesser Leaf-nosed Bat 12 Hyaena 13 Indian Crested Porcupine 14 Lesser Egyptian Jerboa 15 Cape Hare, Arabian Hare 16 Sundevall's Jird 17 Libyan Jird 18 Leopard 19 Rock Hyrax, Rock Dassie 20 Fat Sand Rat	21 Horseshoe Bat 22 Bushy-tailed Jird 23 Euphrates Jerboa 24 WildCat 25 Black-tufted Gerbil 26 Honey Badger 27 Arabian Oryx 28 Blanford's Fox 29 Ruppell's Fox
Plants (33)	1 Umbrella Thorn 2 Glaucous Glasswort, Soap Soda 3 Orache, Raghal 4 Grey Mangrove 5 Arta`, A`bal , Waragat Alshams 6 Spider Flower, Adheer 7 Thenda, Dune Grass, Sedge 8 Gul Mohur, Creamy Peacock Flower 9 Hopbush, Candlewood 10 Eremobium aegyptium, sleisla 11 Saxaul	12 Kary, Jery 13 African Juniper 14 Berjan 15 Wispy-needled yasar tree 16 desert grass 17 Ghaf 18 Senhwar, Sahaer, Dogbane, Harmal 19 Christ's Thorn Jujube 20 Field bindweed 21 Had, Djouri, Tahara 22 Rattlepod, Rattlebox	23 Ramram 24 Toothbrush Tree 25 Desert Campion, terba, turbah 26 Desert Grass 27 Seablite, suwaid 28 Puncture Vie 29 Bean Caper, Qatari 30 Halopyrum mucronatum 31 Indigofera argentea 32 Salsola imbricata 33 Sphaerocoma aucheri
Reptiles (13)	1 Baluch Ground Gecko 2 Horned Viper 3 Mediterranean Chameleon 4 Rough-tailed Gecko 5 Saw Scaled Viper, Carpet Viper	6 Palestine Saw-scaled Viper 7 Arabian Sand Boa 8 Persian Leaf-toed Gecko 9 Carter's Rock Gecko 10 Middle Eastern Rock Gecko	11 Dwarf Rock Gecko 12 Middle Eastern Short-fingered Gecko 13 Arnold's Rock Gecko
Amphibians	1 Arabian Toad	3 Dhofar Toad	5 Lemon-yellow Tree Frog

3. Priority species level vulnerability to climate change

A total of 95 priority species were considered

This included 3 amphibians, 26 birds, 25 mammals, 29 plants, and 12 reptiles. When combined across all priority species, areas of greatest habitat suitability is concentrated in the southern half of the Arabian Peninsula and along coasts. For nonbreeding birds, high habitat suitability is concentrated mainly along coastlines. For amphibians, habitat suitability is highest mainly in mountainous regions near the southwestern and southeastern coasts, and in particular in the Al Hajar, Hadhramaut, and Asir Mountain ranges. Mammals and breeding birds followed similar patterns to amphibians, but high habitat suitability for these groups being somewhat less restricted to mountainous regions. The highest habitat suitability for plants is currently restricted mainly to areas along coasts and the southeastern third of the study region.

The impacts of climate change were analyzed and reported for only 75 of the 95 priority species due to data limitations.

Mapped results for each modeled priority species are provided online in the Terrestrial Biodiversity Inspector (www.ccr-group.org/terrestrial). These outputs include 3 amphibians, 18 birds, 22 mammals, 20 plants, and 12 reptiles. In this Executive Briefing, this large amount of outputs are synthesized to show projections of future habitat suitability across all global or regional scenarios and across all priority species collectively and each taxon individually.

The most pronounced difference in projected change in habitat suitability between 2030 and 2070 was an increase in the magnitude of projected change (either increases or decreases in habitat suitability) rather than changes in the spatial pattern of change per se.

For the global climate forecasts, this is illustrated in Figure 3 by comparing the second and third row of panels. Breeding birds, mammals, and amphibians were projected to have the most extensive reductions in suitable habitat (red shading), which covered nearly all of the study region for these taxa. In contrast, nonbreeding birds, plants, and reptiles were projected to gain suitable habitat across much of the study region (blue shading), with the exception of coastal regions of extreme southwestern Saudi Arabia and western Yemen. Plants and reptiles were projected to lose suitable habitat across the UAE and easternmost Oman, with the exception of the Al Hajar mountains, where these taxa were projected to gain suitable habitat. For the regional climate scenarios (Figure 3; bottom row of panels showing 2070 results for the 12 km domain), the projected changes in habitat suitability were largely consistent with those based on the global climate scenarios. Notable exceptions to this pattern include projected increases in habitat suitability for amphibians in northern Saudi Arabia and Iraq and more extensive declines in habitat suitability in the Rub Al Kali for most taxa.

4. Community level vulnerability to climate change

The GDM model incorporated over 200,000 occurrence records for thousands of species

Community level modelling proved to be effective in explaining the difference between the outputs projected by the model and the nature and distribution of terrestrial biodiversity revealed by the species occurrence data. The higher the amount of difference, or "deviance" explained, the better the modeled projection. This is illustrated in Table 2 which shows that community-level modelling was able to explain between a low 41% for amphibians, indicating poor explanation and about 57% for plants, indicating much better explanatory power of the model.

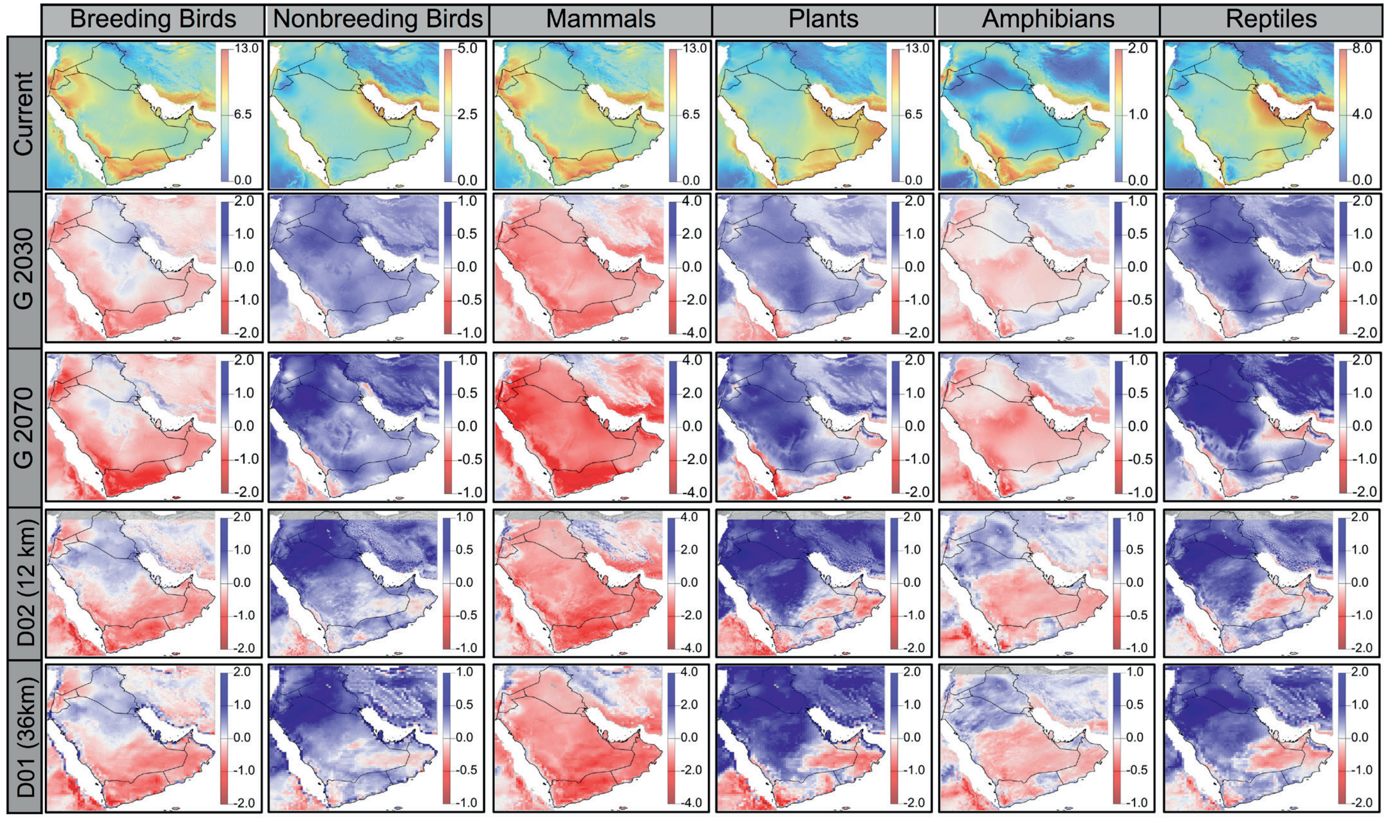


Figure 3: Mean current habitat suitability and all-scenario ensemble projections of projected change in habitat suitability across all priority species by taxonomic group for global (2030 and 2070) and regional (2070 only) future climate scenarios.

Of the five taxonomic groups modeled using GDM, plants exhibit the least predicted spatial variation in species composition in the present day.

This is shown in Figure 4 in the top row of panels, where areas of similar color are expected to harbor similar composition of species. For mammals, much of the study region is predicted to have similar species composition, with the exception of extreme western Yemen (see Figure 4; yellow versus red shading in the current prediction panel for mammals) and to a lesser extent northern Iraq (see Figure 4; blue vs. red shading), which were predicted to be host to mammal species that differed from the rest of the region. In contrast, the composition of bird, amphibian, and reptile species assemblages, was predicted to vary across the study region, with reptiles in particular showing fine scale compositional variation as a function of environmental and topographic gradients.

When projected to future climate scenarios, GDM estimates the expected percent change in species composition at each location as a function of how much climate is expected to change in that location, weighted by the importance of different climate gradients in determining current biodiversity patterns.

A value of zero indicates no expected change in composition and a value of one indicates an expected 100% turnover in species composition (i.e. current and future assemblages share no species in common). Given lags in species responses to changes in climate, these estimates are best interpreted as an index of climatic stress on each taxonomic group at each location, with higher values indicating greater climatic stress. Reptiles have some of the most widespread and highest forecasted adverse impacts of any of the taxonomic groups. Projected impacts were also widespread for birds and amphibians by 2070, but were of a lower magnitude than for all other taxonomic groups. Mammals were projected to experience the least widespread climatic stress, for which the severest of projected impacts largely were limited to the northernmost portion of the region. For all taxonomic groups except mammals, mountainous regions in the southwestern corner of the study region were identified as potential climate change refugia as this area was projected to have comparatively low climatic stress.

Table 2: Percent deviance explained is a metric of model fit for GDM modelling

Taxon	Number of Species	Number of Occurrence Records	Number of Sites	Weighting Threshold	Percent Deviance Explained
Birds	657	75,754	348	60	42.9%
Mammals	123	5,440	115	10	51.2%
Plants	3,700	121,564	288	75	56.7%
Amphibians	87	2,120	85	5	41.0%
Reptiles	122	2,727	142	5	48.4%

GDM projections for the regional climate scenario at the 12 km resolution (Figure 4; bottom two rows of panels) largely mirrored those to the global scenarios, including the southwestern corner of the study region being projected to serve as a climate refugia in the future.

In contrast, the Al Hajar Mountains were predicted to experience high climatic stress for all taxonomic groups but birds. However, the projections to the regional scenarios tended to be more severe in terms of both spatial extent and magnitude of projected climatic stress than those to the global scenarios. This pattern was especially evident for plants. For this group, the regional scenarios suggest nearly 100% change in plant species composition across nearly all of the study region.

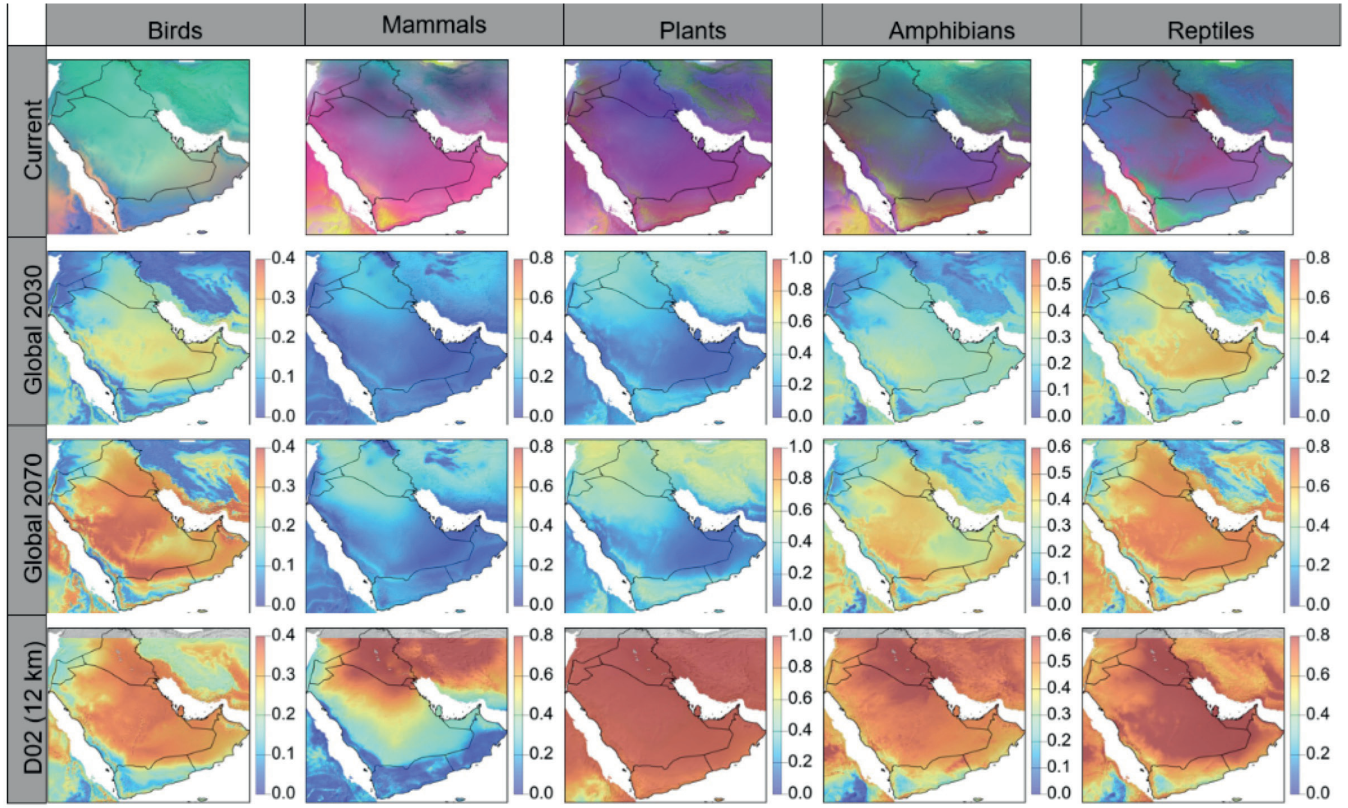


Figure 4: Current predicted patterns of species composition by taxonomic group (top row of panels, locations with similar colors are expected to be host to similar species composition) and all-scenario ensemble projections of expected change in species composition between current and future climate for global (2030 and 2070) and regional future climate scenarios (2070).

5. Conclusions and recommendations

Ensemble projections from Maxent and GDM to numerous climate scenarios provide a comprehensive overview of the potential future of terrestrial biodiversity in the Arabian Gulf countries from the perspective of both individual species and from biodiversity as a whole.

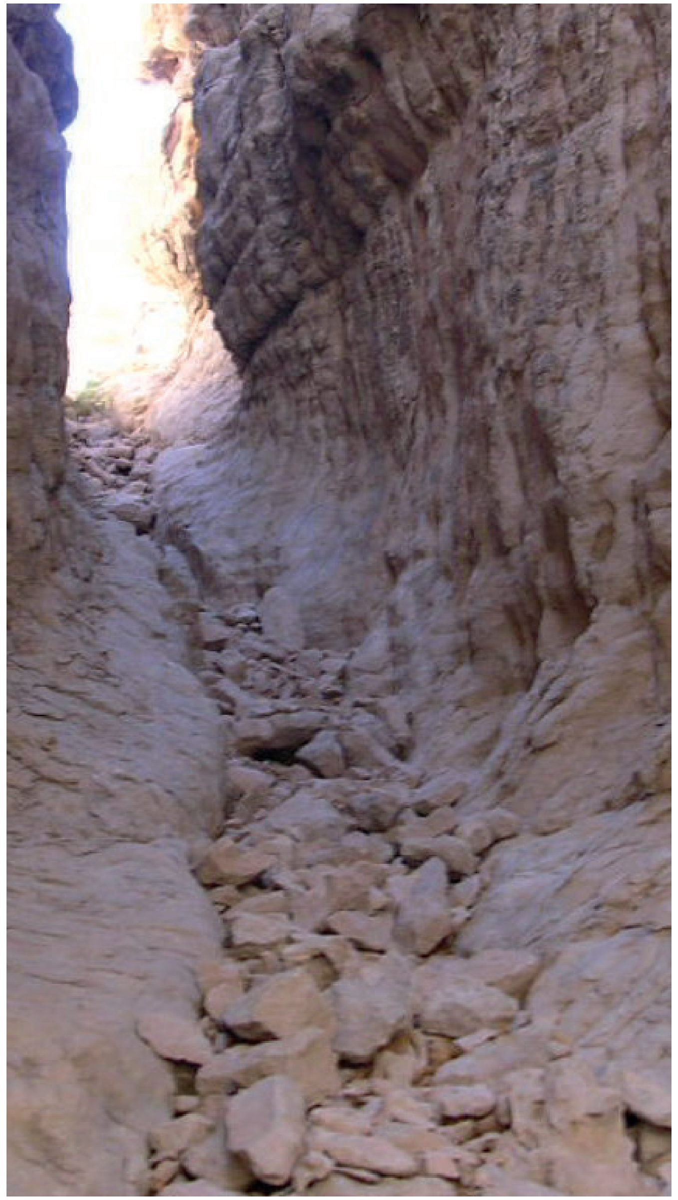
When considered collectively in terms of species, taxonomic groups, climate scenarios, and modelling methods, similarities in projected outcomes reveal impacts that are largely insensitive to particular characteristics of species or assumptions regarding models. With this in mind, findings from this study suggest climate change has the potential to cause widespread changes in species distributions and patterns of biodiversity across the Arabian Peninsula and that the magnitude and spatial extent of impacts will increase through time.

For the 75 priority species for which Maxent models were projected, loss of suitable habitat is expected to be most pronounced in the southern half of the region. This includes Qatar, the UAE, Yemen (including the island of Socotra), and Oman, and along the western coast of Saudi Arabia. However, these losses may be offset to some extent by gains in suitable habitat in north central Saudi Arabia and Iraq. The extent to which such gains in habitat may be exploited by species in the future depends on the ability of species to successfully disperse to new habitats and how well these areas provide other aspects of habitat not included in the models, such as shelter, food resources, etc., among other factors. It is also important to note that projections to later decades (i.e. 2080) suggest increases in suitable habitat may be temporary.

For biodiversity as a whole, findings from GDM suggest that both northern and southern areas may undergo substantial changes in species composition (high climatic stress). Only a fraction of the southern portion of the region – and the southwestern corner in particular – was projected to experience low climatic stresses and therefore comparatively little changes in species composition. However, these generalities do not necessarily apply across all taxonomic groups or climate scenarios. For example, plants were projected to experience low climatic stress across nearly all of the study region based on the global climate scenarios and very high climatic stress across the entire study region under the regional projections over 50% available for discretionary purchases.

The climates of the Arabian Gulf region are some of the most extreme globally in terms of high temperatures and low precipitation. While species in the region are adapted to such extreme environments, many species also exist near the limits of their climatic tolerances and survive by opportunistically exploiting microrefugia[1] in space and/or time. Such factors are difficult to represent using the empirical models and broad scale climatic gradients. However, community-level modelling was able to adequately account for the impact of climatic factors on terrestrial biodiversity patterns in the region under current conditions. This means that community-level modelling provides a good basis by which to explain/project the future nature and distribution of terrestrial biodiversity in the region under climate change. A core conclusion of the modelling suggest that climate change will result in widespread alteration of existing biodiversity composition, including local extinction of species.

[1]Microrefugia are locations that are able support populations of species when their ranges contract during unfavorable climate episodes such as those that are projected to occur in the region under climate change.



When viewed together, the species-level and community-level modelling provide complimentary and contrasting inferences regarding areas where changes in biodiversity may be greatest/least.

On the surface, it may appear that Maxent and GDM largely disagreed given that GDM projected extensive impacts across the entire study region except the southernmost portion, while the projected impacts from Maxent tended to be less extensive and mainly limited to the southern portion of the study region. However, that these models produced contrasting results is not necessary a correct interpretation.

Maxent emphasizes individual priority species and produces estimates of changes in habitat suitability (both gains and losses) for each species.

When combined across species, Maxent highlights where multiple species may gain or lose habitat. However, both increases and decreases in habitat suitability would be expected to result in changes in species composition, with some areas gaining new species and others experiencing local extinction. In contrast, GDM considers biodiversity collectively and provides inference regarding the expected magnitude of change in species composition, but not the nature of this change (i.e. whether the projected changes in species composition arise due to losses / gains of species in a location). When considered together and in this light, both modelling methods agree that climate change may cause widespread changes in species composition across terrestrial environments of the Arabian Gulf countries. Maxent provides the additional insight that these changes may be driven largely by local extinction in the south and increases in species richness to the north, while GDM suggests that the lowest changes overall mainly may be limited to the southwestern portion of the Arabian Peninsula.

Several important caveats must be considered when interpreting model projections.

Foremost, it must be kept in mind that the models used in the report are modelling the effects of climate only on biodiversity patterns and ignore all other factors determining habitat suitability. Other abiotic and biotic factors, such as soils, access to groundwater, species interactions, dispersal, etc., can all influence species distributions, but were not included in this study. For higher taxa such as mammals and birds, vegetation is an important component of habitat that provides food resources and shelter. Therefore models fit with climate variables alone may not fully reflect habitat requirements. In addition, climate-driven changes to vegetation will also affect higher taxa. For example, GDM predicts the greatest magnitude and most widespread changes for plant assemblages. Therefore, in addition to climate change itself, dramatic changes to vegetation structure will also impact species that depend on certain vegetation types.

The models also ignore dispersal constraints, both in constraining current patterns and in the colonization of habitat that becomes suitable in the future.

In essence, the model projections assume "unlimited" dispersal in that species are assumed to immediately colonize any and all habitats that become suitable, no matter how distant those location are from current populations. For these reasons, reductions in habitat suitability are likely more reliable indicators of vulnerability, whereas increases in habitat suitability should be considered as future opportunities for range expansion.

Finally, the modelling effort suffered from a lack of comprehensive, unbiased species occurrence records, and especially so for priority species.

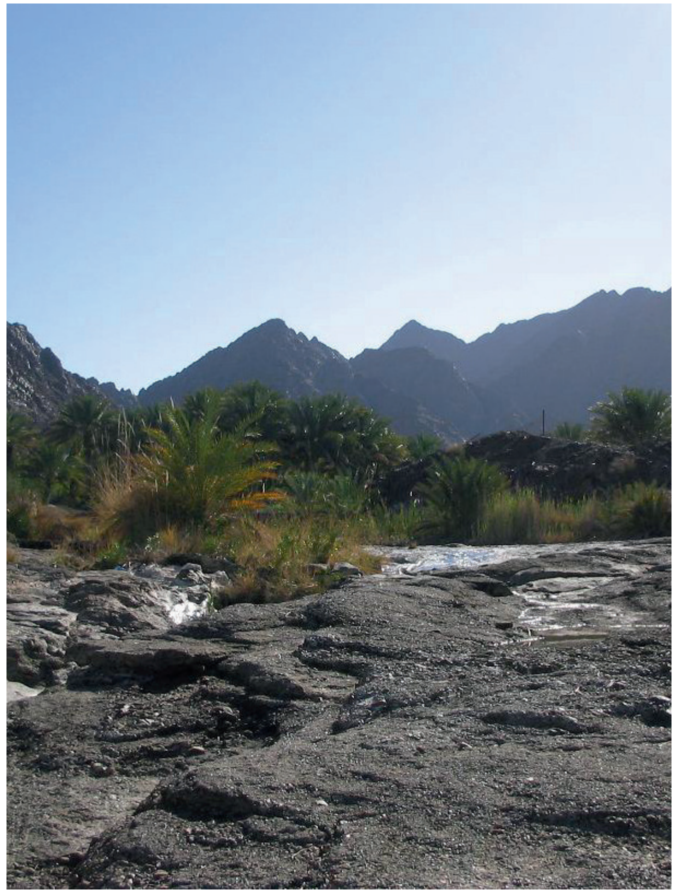
Much of the available occurrence data used for fitting biodiversity models in this study were highly biased to a few geographic areas. As a result, not only were species distributions poorly represented and Maxent models data limited, some environments were overrepresented while others were not represented at all. For many of the priority species, the fitted relationships between species distributions and climate may not fully represent the climatic tolerances of the study organisms. For these reasons, results for individual priority species should be interpreted with caution. Because GDMs were fitted with thousands of records for thousands of species, these results should exhibit less influence of bias and therefore may be considered more robust than the individual species results. Nonetheless, data uncertainties likely represent the single largest source of uncertainty in this study and exceeds that arising from different assumptions regarding future climate, etc. For this reason, it is recommended that future efforts focus on improving the availability species occurrence data in the region, both thorough the digitization of existing records as well as through targeted field studies designed to sample poorly represented environments throughout the study region.

Targeted management efforts may help reduce the impacts of climate change in coming decades.

This is particularly true for efforts that are designed to increase the resilience natural systems and enable species to migrate between suitable habitats. Because climate change is just one among many threats to terrestrial ecosystems in the region, reducing other human perturbations such as overgrazing, invasive species, and land use change, will be critical to ensure resilience in the face of climate change. In addition, it is important to note that the impact of climatic change will be felt by biodiversity collectively, not just by priority species, and will be ongoing for many decades if not centuries. A systematic management response rather than a short-term focus individual species is likely to be most successful, yet most challenging. The magnitude of uncertainty regarding the impacts of future climatic change on terrestrial biodiversity are exceedingly high and there is little time left to reduce uncertainty by observing early impacts given that climate-driven changes will be difficult to detect against the backdrop of other threats and environmental variation and because impacts will be felt everywhere. This uncertainty makes prediction very difficult, even when high quality data is available.

For these reasons, conservation and management actions should emphasize the preservation of ecological processes, while allowing or facilitating changes in biodiversity states.

These goals might most effectively be met through the design and implementation of a network of protected areas that facilitate movement to and from regions of projected high / low changes in species composition. Efforts should focus on areas where different models and future climate scenarios agree that projected changes in biodiversity could be most pronounced and regions that models suggest could serve as climate refugia in the future. Results from the present study suggest that the mountainous regions in the southwestern corner of the Arabian Peninsula may serve as refugia and therefore may be candidates for protection and/or restoration in the context of the protected area network that facilities migration to the northern portion of the Arabian Peninsula.



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