Rainfall distribution and population dynamics of desert annuals

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Abstract

Precipitation patterns of Mediterranean and desert regions in Israel have become more similar since the 1930s. We used a computer model to simulate the effect of rainfall variation on three common desert annuals.

We manipulated daily rainfall intensity to create data sets with skewed or normal distributions in combination with higher (≈100 mm), average (≈88 mm), and lower (≈70 mm) rainfall compared to a reference site.

In general, population persistence was in line with the species' minimum requirement of rainfall to initate germination. The lowest persistence of all three species was when annual precipitation was normally distributed and its mean across years lower than the reference site.

Apparently, the replenishment of the seedbank depends on high seed production in years with very high rainfalls. Thus, the model suggests that the species' range will shrink if the rain distribution continues to become more normal.

Methods

We used a computer model to simulate rainfall, water infiltration, and plant growth. The model is based on published values and known or presumed functional relations.

We compared the effects of rainfall patterns on the persistence of populations of three annual plant species (*Reboudia pinnata*, *Filago desertorum*, *Schismus arabicus*) that differ in the amount of rain required to initiate germination.

In addition, we tested whether persistence is higher in moister habitats like runnels. In runnels, germination of seeds has been observed after half the volume of rainfall required for germination on flat ground (Loria & Noy–Meir 1980).

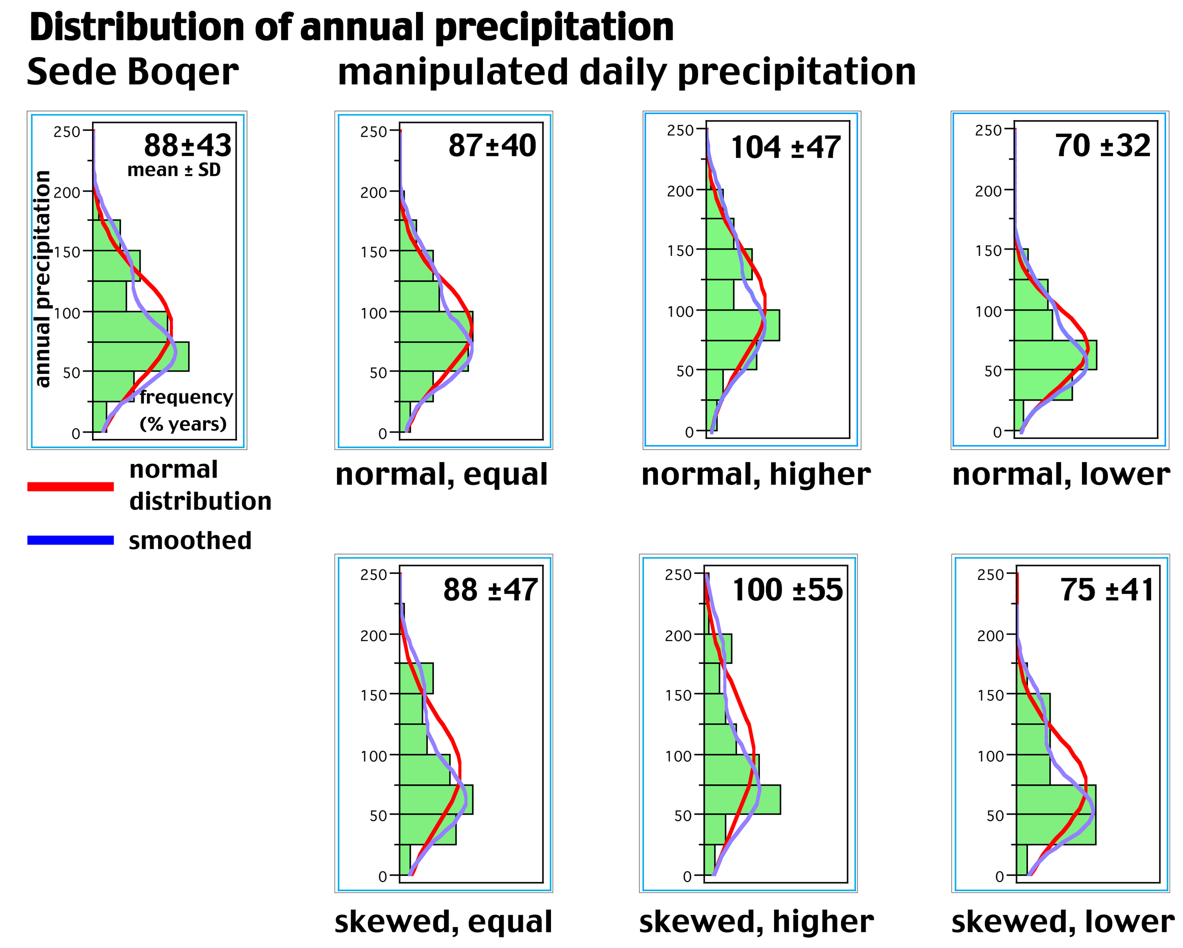
We manipulated daily rain data of the Sede Boqer station (nothern Negev desert) to produce data sets with the same daily rainfall pattern but more normal or more extreme (skewed) distributions and lower, similar or higher annual sums.

Important parameters used in the model

		Reboudia pinnata	*Filago desertorum*	*Schismus arabicus*
net weight of seed (mg)	1,2	0.22	0.037	0.07
biomass (mg)/plant, dry year	1	15.87	7.01	5.20
biomass (mg)/plant, wet year	1	710.80	21.96	18.83
reproductive effort	1	0.6	0.6	0.6
minimum rain (mm) for germination	1	30	20	10
shoot RGR max ($mg \cdot mg^{-1} \cdot d^{-1}$)	2	0.166	0.166	0.166
max germination rate	3	0.5	0.3	0.3
seeds/reprod. tissue (mg), dry year	1	40	104	41
seeds/reprod. tissue (mg), wet year	1	1777	326	148

[1] Loria & Noy-Meir 1980
[2] Dyer et al. 2001
[3] Meidan 1990

Distribution of annual precipitation



Introduction

The rainfall patterns of Mediterranean and desert regions in Israel have become more similar since the 1930s (Ben–Gai et al. 1998). In the Mediterr–anean region, years with high rainfall (compared to the local mean) occur more often, whereas in the desert region, years with high rainfall (again compared to the local mean) have become rarer. How will this change affect the population dynamics of desert annuals?


Reboudia pinnata (Brassicaceae)


Filago desertorum (Asteraceae)


Schismus arabicus (Poaceae)

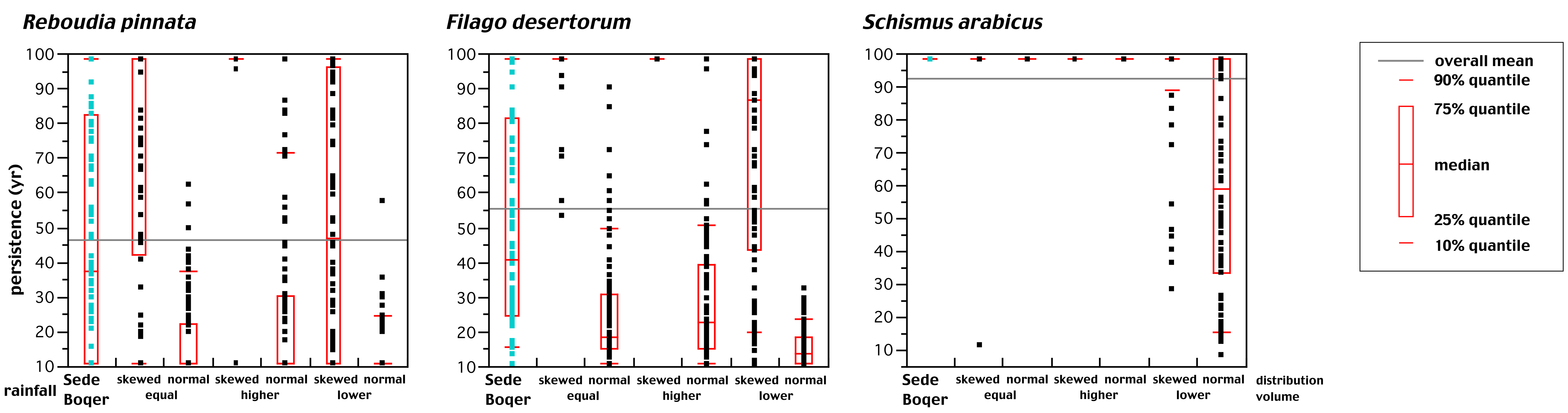
Photo credits: Claus Holzapfel, Katja Tielbörger

Results

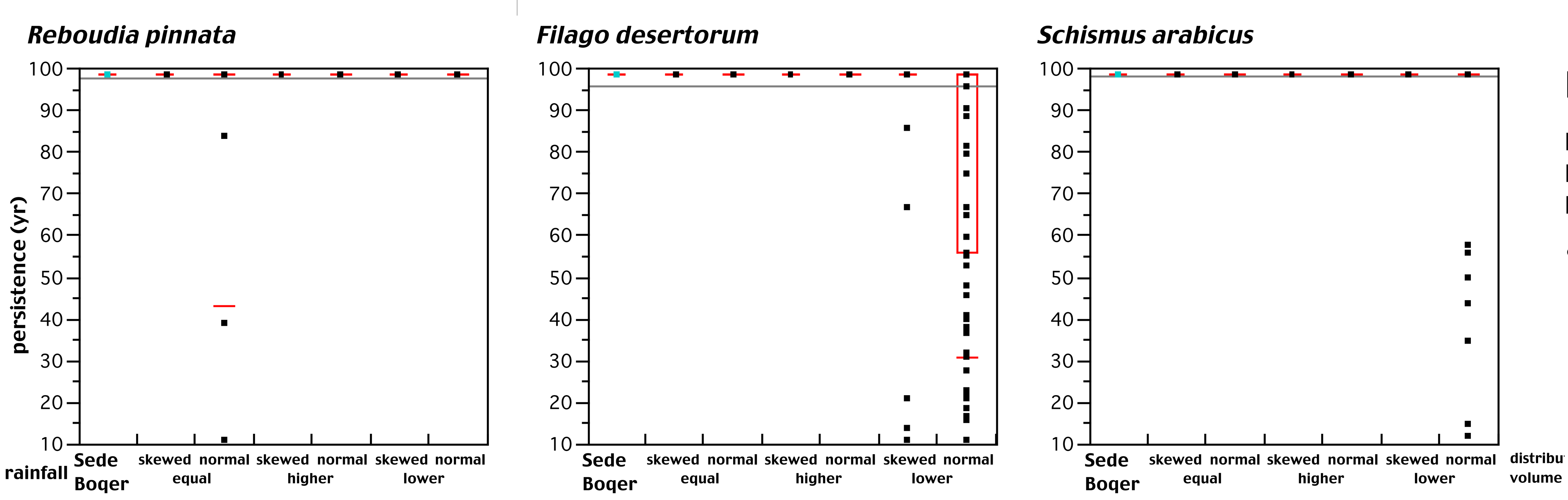
Distribution and relatively small changes of the annual rain volume had significant effects on the persistence of *Reboudia* and *Filago* on flat ground.

Persistence decreased with volume and when the distribution was more normal.

Schismus persistence, in contrast, was reduced only when rain volume was lower. Nonetheless, normal rain dis–tribution further reduced persistence.



In runnels, the treatment effects were small. Only *Filago* and *Schismus* under lower volume, normal distribution conditions had reduced persistence.



Research needs

Despite the importance of the seed bank for species persistence, seed bank dynamics are not well known.

- The model assumes that 40% of seeds in the seed bank are lost between years. This is much less than the 60 – 98 % found in experi–ments for other annual species in hot deserts (Tielbörger 1997, Cabin et al. 2000). It was, however, neces–sary to assume a high value to achieve at least temporary persist–ence in the model; all other impor–tant model parameters are backed by published studies.
- The rain requirements for germi–nation (Loria & Noy–Meir 1980) are probably valid only for a fine sandy–silty loam and, in our experience, are lower for sandy soils.

Discussion

The resilience to changes in rain pattern is in line with the species' demand for rain to initiate germination. *Reboudia*, germinating after ≥30 mm rainfall and *Filago*, germinating after ≥20 mm rainfall responded more strongly to treatments than *Schismus* (≥10 mm).

Populations persisted longer when the distribution of rainfall was more skewed, because the species produced many seeds during the rare years with extremely high rainfall. This replenished the seed bank and allowed the species to persist during drought years.

The results emphasize that even a small change (compared to the SD) of the average annual rainfall can have pro–nounced effects on the persistence of populations in the desert. Based on our results we predict that the species' range will shrink if the change of the rainfall pattern continues.

Program description

The area is simulated as a periodical grid subdivided in 10 × 10 hexagonal cells.

Program flow

The program starts with a seedbank set to mean seed production.

For each simulated year

- the program selects a year from the rain database,
- calculates the loss of viable seeds from the seed bank.
- For each five-day-period ("week") within a year
  - the program records the sum of rainfall and the maximum rainfall event of the current week,
  - calculates the rain infiltration,
  - and follows the plant life cycle:
    - germination
    - plant growth
    - seed production.

Seeds are dispersed at the end of the year.

Seed loss

Forty percent of the seeds are lost due to mortality in–cluding predation. This is an underestimation because seed loss in the Negev ranges from 50 to 98% depend–ing on species, habitat, and year (Tielbörger 1997, see *Research needs*).

Rain infiltration

"Infiltration" here is a net process including water losses (evaporation, drainage, and plant water use) of 20%.

Germination

Seeds germinate when rainfall is above a certain thre–shold (Meidan 1990, Loria & Noy–Meir 1980) and when their dormancy is low (Meidan 1990). The germination rate increases with the soil water potential near the soil surface (Meidan 1990) and the germinability (inverse of dormancy). The probability that one seed germinates is proportional to the number of seeds in the seed bank. The rainfall threshold refers to a fine sandy–silty loam.

Plant growth

Plant growth is basically logistic (m_{max} = final mass in wet years). In addition, growth rate increases with the soil water potential and decreases with the average mass of neighbours. After the plant has reached maturity (defined by 70 % of final mass in dry years), 60 % of new biomass is used for seed production (Loria & Noy–Meir 1980).

Seed production

Seed production is proportional to the mass of the reproductive tissue, including inflorescences and fruit tissue. In wet years the plants produce more seeds per unit biomass than in dry years.

Seed dispersal

Seeds are dispersed in packages of 1/3 of the produced number into the same cell or adjacent neighbour cells.

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For more information see http://www.glowa.org

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