

Rapid Communication

Invasion of alien *Prosopis* species in Israel, the West Bank and western Jordan: characteristics, distribution and control perspectives

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Abstract

The invasion history of alien *Prosopis* (mesquite) in Israel and Jordan is presented, with a detailed description of the introduction, background and the habitats now infested with *Prosopis* in these countries. While the number of escaped individuals in Israel is still limited, *Prosopis* has invaded large areas in Jordan and has become the main invasive alien tree in the Jordan valley. It is also now spreading in the canyons of south Jordan. The distinct *Prosopis* invasion patterns in Israel and Jordan are discussed. Control programs are urgently needed in order to contain the proliferation of *Prosopis*, which now poses a major threat to natural habitats as well as to fallow fields. The ongoing establishment of dense thickets of *Prosopis* along wadis with year-round water flow is likely to displace native species such as *Acacia raddiana* Savi, and to alter the function of natural ecosystems.

Key words: Mesquite, invasive species, Negev desert, Jordan valley, control

Introduction

Several *Prosopis* species are known as highly invasive taxa having severe negative impacts on natural ecosystems and agropastoral lands in Africa and Asia (Witt 2010; Muturi et al. 2013; Sankaran and Suresh 2013; El-Keblawy and Abdelfatah 2014; Shackleton et al. 2014).

The proliferation of invasive *Prosopis* species has been reported to decrease local biodiversity among plant and bird species in various arid regions (Dean et al. 2002; Berhanu and Tesfaye 2006; Schachtschneider and February 2013). The main impact of invasive *Prosopis* on natural ecosystems occurs through competition for groundwater: *Prosopis*' deep and extensive root systems lead to the depleting of groundwater reserves in water-scarce environments, which inevitably causes native trees such as *Acacia tortilis* (Forssk.) Hayne, *Hyphaena compressa* H.Wendl., or *Acacia erioloba* E.Mey. to dry out (Boy and Witt 2013; Schachtschneider and February 2013; Shackleton et al. 2015a;). A recent study carried out in the Northern Cape region (of South Africa) suggests that clearing invasive *Prosopis*

stands, or even only thinning and pruning, could save up to 70 m³/ha/month (Dzikiti et al. 2013).

Prosopis invasion is well documented in many tropical and subtropical regions but has not been investigated so far in Israel and Jordan.

Alien *Prosopis* species in Israel and Jordan

Distribution and introduction background

Israel's arid and semi-arid regions, along with the western part of Jordan, have been surveyed by the authors since 1995, with special attention to natural and semi-natural sites where the presence of alien *Prosopis* individuals was mentioned or reported by botanists (Pasiiecznik et al. 2001; Ravak and Shmida 2013). The regions investigated in Israel included: the Jordan Valley, the Dead Sea area, the Negev desert, the Arava Valley, and the Gulf of Eilat area. The regions surveyed in Jordan extended from the Irbid district in the north to the Al Aqabah area in the south, as well as the western part of the Ma'an district. The region of Azraq and eastwards was not investigated.

The alien *Prosopis* species that have been planted in Jordan and Israel were recorded as *Prosopis affinis* Spreng., *P. alba* Griseb., *P. articulata* S.Watson, *P. chilensis* (Molina) Stuntz, *P. glandulosa* Torr., *P. juliflora* (Sw.) DC., *P. nigra* Hieron., *P. pallida* (Willd.) Kurth, and *P. velutina* Wooton (Shalmon 2003; Kutiel 2004). The identification was made by the authors according to Pasiecznik et al. (2001, 2004), according to Burkart's monograph (1976), Benson (1941), and Townsend and Guest (1974). All the specimens deposited as voucher material at the herbarium of the Hebrew University of Jerusalem have been checked (Supplementary material, Table S1).

Western Jordan

Alien *Prosopis* were introduced during the 1980s to Jordan, and planted along roadsides in the Rift valley and the Rhur (Banan Al-Sheikh, pers. comm.) The Jordan Forestry Department planted mostly *P. juliflora*. *P. alba* plantations are very rare and have been observed in very few locations. We do not have direct observations about *Prosopis* prior to 1994 in Jordan since the peace treaty between Israel and Jordan was signed that year.

All escaped *Prosopis* individuals recorded in Jordan were identified as *P. juliflora*. We did not record escaped individuals of *P. alba*. In February 1996 we have observed the first naturalized individuals close to a roadside, in the Zarqa Ma'in resort area (Figure 1), next to recently planted individuals along the road. This focus included up to 30 young individuals less than 1 m tall. In the following years new individuals were recorded along the wadi bed of wadi Zarqa Ma'in, from the recreation area down to the Dead Sea, the latest record being made in 2013. Similar invasion patterns were recorded within the canyons of southern Jordan, from wadi Hizban in the north to wadi Musa in the south.

A first specimen of *P. juliflora* was recorded in the flood plain of wadi Assal, 27 km southwest of Karak, in 1997. Additional individuals of *P. juliflora* were recorded in the adjacent canyon of wadi Assal and wadi Hudeira, next to the potash plant, in 2001.

In 1998 a new road was constructed between the cities of Peifeh and Tafila. Shortly thereafter, several individuals established along the road and into nearby irrigated agricultural fields. Since then, *P. juliflora* has expanded and formed a savanna-like stand in the wadi Assal and wadi Hudeira floodplains.

The occurrence of *P. juliflora* stands in the Dead Sea region of Jordan is restricted to wadi beds with permanent water flow and irrigated fields. The permanent water flow originates from natural springs along the canyons. Out of the 31 canyons found

from the Dead Sea area to the south, 18 have permanent water flow, and half (9) of these are already infested with alien *Prosopis* (Ravak and Shmida 2013). In the Jordan Valley, from the Dead Sea to the Yarmouk river, *P. juliflora* is widespread, occurring along wadi beds, roadsides, agricultural fields, and disturbed habitats. It grows also in undisturbed, natural, dry, rocky habitats.

Israel

Since the 1960s several alien species of *Prosopis* have been introduced into Israel by the Forestry Department of the Jewish National Fund (JNF) for ornamental and environmental purposes in the semi-arid and arid regions of the country (Shalmon 2003; Kutiel 2004). The majority of trees that were planted in Israel have been named *P. nigra* (auct). However, we have identified most of the escaped and planted *Prosopis* individuals as *P. juliflora* and *P. alba* (Figure 1).

According to the identification key of Burkart's monograph (1976), all the *Prosopis* species introduced into Israel belong to Section ALGAROBIA, Series Chilenses, i.e., *P. juliflora*, *P. alba*, *P. chilensis*, *P. nigra*, *P. glandulosa*, and *P. velutina*. Most of these taxa were treated by Pasiecznik et al. (2001) as a *P. juliflora* – *P. pallida* complex and we refer to them in this note as *P. juliflora*. Already in 1941 Benson carried out a thorough survey in the southern U.S. and concluded that *P. glandulosa*, *P. velutina*, and *P. torreyana* are varieties of one species.

The *Prosopis* individuals that escaped planted plots and became naturalized in Israel were identified as *P. juliflora* characterized by long thin and almost straight pods, usually acuminate (Pasiecznik et al. 2004). It should be stressed that except for the fruit, all the other diagnosed characters, especially the leaves, are highly variable in shape among individuals within a given population.

Most of the *Prosopis* species were planted since the 1960s in the arid and the semi-arid regions of Israel, mainly in the Negev desert and in the central and southern Jordan valley. Almost all *Prosopis* individuals that established in the wild were recorded in the semiarid region: in the southern coastal plain, in the western Negev, and locally in the northern Negev region. The majority of naturalized individuals of *Prosopis* in Israel are found north and west of the city of Beer-Sheva in the northern Negev (Shalmon 2003; Blecher and Blecher 2010), where *Prosopis* established in wadi beds on limestone outcrops as well as in depressions within the loess hilly areas characteristic of this region. *Prosopis* trees rarely grow outside wadis in Israel.

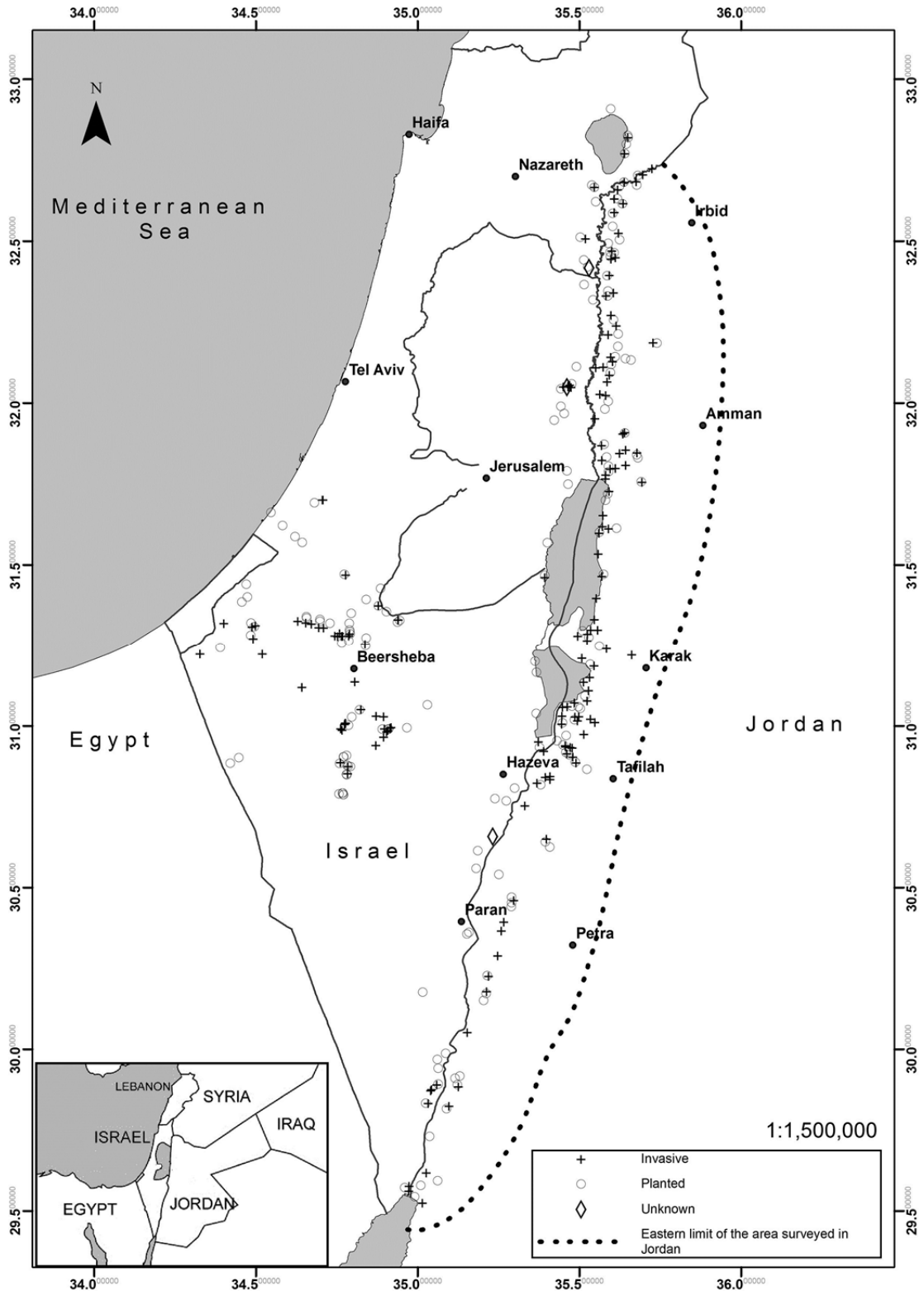


Figure 1. Distribution of *Prosopis* spp. in Israel, the West Bank and western Jordan (see details in the supplementary material Table S2 and Table S3).



Figure 2. Dense thicket of *Prosopis juliflora* in wadi Ashan in the Beer-Sheva area (Israel) (Photo: J.M. Dufour-Dror).

The densest stands are found in wadi Ashan (Figure 2), wadi Patish, and wadi Besor, 2–15 km northwest of Beer-Sheva (Figure 1). Very few individuals were recorded south of the 100 mm isohyet as only several individuals were found in the southern Arava region, next to irrigated fields and along roadsides. Compared to Jordan, relatively few naturalized individuals of alien *Proposis* were recorded in Israel.

Table 1 displays several standardized metrics related to the invasion of alien *Prosopis* in Israel and western Jordan. These metrics are based on the methodology proposed by Wilson et al. (2014).

Discussion

Dichotomy in invasion patterns between Israel and Jordan

The proliferation of alien *Prosopis* species in Israel and Jordan presents distinct invasive patterns. While *Prosopis juliflora* is widespread in western Jordan along the Jordan Valley, in the canyons of the Dead Sea area, and along the Rift, escaped individuals of alien *Prosopis* are relatively few in Israel. This difference may be rather unexpected due to Israel's and Jordan's similar environments and considering the fact that prosopis planting in Israel began in the 1960s, whereas the first *Prosopis* trees in Jordan

were planted in the late 1980s. However, two main determinants may explain the distinct invasive patterns between Jordan and Israel:

(1) The first is related to the humidity conditions of habitats sensitive to *Prosopis* establishment and invasion. In Israel, wadi beds and depressions in the *Prosopis* invasion range are almost entirely dry during the hot season, whereas in Jordan most of the wadis draining into the Jordan Valley region have year-round flowing water, due to numerous natural springs along the wadis. In addition, the traditional irrigation system found in Jordan, mainly along the Jordan Valley (= the *Rhur*), consists of an array of open water canals providing optimal conditions for *Prosopis* establishment. On the other hand, the modern irrigation systems in Israel, based on underground pipes, do not create humid conditions favorable for *Prosopis* germination and establishment in cultivated areas.

(2) The second determinant is that, unlike in Israel, grazing is still a major socioeconomic livelihood in Jordan: although goats, camels, and donkeys systematically avoid eating prosopis foliage, they particularly favor the fruits that provide valuable fodder. For this reason, many prosopis trees were planted in Jordan near Bedouin camp sites, where they also provide valuable shade conditions. As a consequence, *Prosopis* seeds

Table 1. Metrics for the assessment of alien *Prosopis* invasion in Israel and in Jordan (based on the methodology suggested by Wilson et al. 2014).

	Israel	Western Jordan
Current status ⁽¹⁾	E	E
Number of foci ⁽²⁾	18	16
Extent of occurrence (invaded area) ⁽³⁾	689.9 Km ²	1,832.3 Km ²
Threat ⁽⁴⁾	High	High

(1) According to Blackburn et al. 2011. "E: Fully invasive species, with individuals dispersing, surviving and reproducing at multiple sites across a greater or lesser spectrum of habitats and extent of occurrence".

(2) Foci are separated by at least 10 km. Foci 10 km distant one another are likely to have low levels of interaction and may be managed as distinct populations (Wilson et al. 2014).

(3) Combined total of all foci extent.

(4) Determined as a function of acknowledged transformer traits of the taxon considered and the expected invader height relative to the expected canopy height of the natural vegetation (Wilson et al. 2014). Since *Prosopis* is invading mainly in semiarid and arid environments in the region under study the difference in height is very important for the natural vegetation cover is open and made mainly of shrubs, dwarf shrubs and herbaceous species.

Note: The area of occupancy, i.e. compressed canopy area could not be calculated.

are efficiently dispersed by domestic herds in Jordan and large *Prosopis* pseudo-savannas have been establishing within the natural habitats of the native *Acacia raddiana* community, especially in the region of Tsafí, as well as in the wadi Assal and wadi Hudeira areas.

Potential impacts on natural ecosystems in Israel and Jordan

The negative impacts of *Prosopis* proliferation on natural ecosystems, as well as on pastures, have been documented and analyzed in numerous studies in many parts of the world, particularly in semi-arid regions of Africa (Maundu et al. 2009; Babiker et al. 2011; Boy and Witt 2013; Haregeweyn et al. 2013; Muturi et al. 2013; Schachtschneider and February 2013; Shackleton et al. 2014, 2015a, 2015b). Despite the distinct invasion patterns between Jordan and Israel, invasive alien *Prosopis* pose a serious threat to natural sites in both countries. In Israel, the natural ecosystems most at risk are the few streams with permanent water flow in the Dead Sea valley, notably Nahal David, Nahal Arugot, and Nahal Bokek, all located within nature reserves. The establishment of alien *Prosopis* along these streams would probably result in a displacement of the native trees such as *Acacia raddiana*, *Salvadora persica* L., or *Moringa peregrina* (Forssk.) Fiori, the latest being recorded as an extremely rare tree species in Israel (Shmida et al. 2011). These protected sites are already experiencing invasion of alien bird-dispersed *Ficus religiosa* L. and *Ficus benghalensis* L. whose numerous individuals are now well established on cliffs (Dufour-Dror 2012). Therefore the emergence of alien *Prosopis* in these nature reserves would worsen the impacts of alien species proliferation in these

valuable natural habitats. Finally, considering the ability of *Prosopis* to lower the groundwater table in dry environments (Dzikiti et al. 2013; Ntshidi et al. 2015), the formation of dense *Prosopis* thickets along these protected streams would plausibly have severe consequences on these unique riparian ecosystems on the western shores of the Dead Sea. Similar negative impacts can be expected along the wadis northwest of Beer-Sheva where stands of *Prosopis* are already established. Yet the absence of water flow during the dry season in these wadis may result in a slower proliferation rate. Finally, alien *Prosopis* may also pose a risk to disturbed sites in the Negev desert that experience relatively humid conditions during the hot season, e.g., roadside ditches.

The type of threat posed by the proliferation of alien *Prosopis* in western Jordan is similar but its magnitude is far greater than in Israel as the extent of occurrence in Jordan is 2.6 times larger (1,832 Km²) than it is in Israel (690 Km²) (see Table 1). Two reasons can explain this difference: the presence of 18 canyons with permanent water flow (out of 31) offers optimal conditions for the establishment of *Prosopis*, while alien *Prosopis* seeds are easily dispersed by the numerous herds of goats, along with donkeys and camels, known as highly effective dispersal agents of *Prosopis* seeds (Shiferaw et al. 2004). As mentioned above, half of the 18 canyons with permanent flow are already infested with alien *Prosopis*: Wadi Mukheiriris, Wadi Zarqa Ma'in, Wadi Umm Hashiba, Wadi bin Hammad, Wadi Kerak, Wadi Hudeira, Wadi Hasa, Wadi Umruk, Wadi Ghuweibe.

Control perspectives

Control options for *Prosopis* infestations in Israel, the West Bank and western Jordan are very limited

due to several different factors. As stressed by Shackleton et al. (2014), biological control of *Prosopis* is inapplicable in areas where native *Prosopis* is weedy. This is the case in Israel and Jordan where *Prosopis farcta* (Banks and Sol.) J.F. Macbr. is native (Zohary and Feinbrun-Dothan 1972). Moreover, any introduction of a biocontrol agent would inevitably affect *Prosopis* plantations. Therefore biocontrol of *Prosopis* in Israel and Jordan cannot be an option, according to current knowledge. Mechanical control of *Prosopis* may be effective but it implies the uprooting and removal of stumps and main roots, thus requiring tractors and special machinery for severing the roots below ground level (Pasicznik et al. 2001). This control technique may be relevant for the removal of a few isolated trees but is very expensive and time-consuming when it comes to controlling many mature trees. However, the manual uprooting of very young seedlings is relevant, provided the entire root system is removed. Chemical control is probably the most relevant control method at this stage and considering the restrictions mentioned above. Several individuals located along roadsides in Israel were successfully controlled by using the cut-stump control technique with triclopyr (Shalmon 2003). Yet, since the use of triclopyr in riparian habitats should be avoided (Burn 2003), it is recommended to experiment with alternative herbicides that do not pose a poisoning risk to humid habitats, e.g., Imazapyr or Amino-pyralid. These herbicides should be used only in the framework of stem treatments (cut stump, basal bark, or stem injection) with direct application onto the cambium, but not, under any circumstances, as a foliar treatment. Considering its outstanding ecotoxicological profile (Cal-IPC 2015) and its efficiency in *Fabaceae* control (DiTomasso et al. 2013), it would be very interesting to test Aminopyralid on *Prosopis*, preferably with the hack and squirt technique that enables one to control many trees within a short timeframe.

Regarding the control management strategy recommended, it is obvious that eradication is not an achievable goal in the foreseeable future in either Israel or Jordan, for the large afforested areas with *Prosopis* will maintain a high propagule pressure in both countries. However, in Israel control actions should be implemented in order to remove the main stands of *Prosopis* that have already established northwest of Beer Sheva and along roadsides in the Negev desert. Simultaneously, a prevention program based on early detection and rapid response is necessary in the nature reserves of the Dead Sea valley. Although the planting of *Prosopis* species was officially stopped in Israel by the forestry department

of the Jewish National Fund in 2004 (Avni, unpublished material), further plantings continued at least until 2012 (JNF, unpublished 2015), while *Prosopis* seedlings are still sold for planting in private plant nurseries. However, the use of *Prosopis* in Israel should be entirely prohibited, as already suggested (Dufour-Dror et al. 2013). In Jordan the control of *Prosopis* invasion definitely requires a more comprehensive control program: *Prosopis* planting was officially stopped around 2010 (Banan Al-Sheikh, pers. comm.), but *Prosopis* seedlings are still planted by individuals, apparently as a food source for herds. Hence, while the planting of *Prosopis* should be effectively stopped, it is necessary to promote the use of alternative tree species, preferably natives, or non-invasive aliens, in order to progressively replace the *Prosopis* stands in the country. Simultaneously, the removal of dense *Prosopis* thickets that recently established along the wadi canyons in the Dead Sea area should be controlled without delay.

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Supplementary material

The following supplementary material is available for this article:

Table S1. The references of the vouchers for *Prosopis juliflora* and *Prosopis alba* at the herbarium of the Hebrew University of Jerusalem.

Table S2. Records of alien *Prosopis* spp. in Israel.

Table S3. Records of alien *Prosopis* spp. in western Jordan.

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