Mapping and Monitoring an Invasive Alien Plant in Tunisia: Silverleaf Nightshade (*Solanum elaeagnifolium*) a Noxious Weed of Agricultural Areas

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ABSTRACT

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The study was conducted during the period of June-July 2014 to update *Solanum elaeagnifolium* mapping in the irrigated land of Chott-Mariem (Tunisia). *S. elaeagnifolium* distribution was mapped with a handheld GPS. GPS point positioning took place in the centroid of each infestation. Surveys were made following roads and tracks using the full covering method. We recorded, for each plot, observation date, plot size, *S. elaeagnifolium* ground cover and distribution pattern within each plot and along its borders. The weed distribution maps were drawn using Quantum GIS software. Of the 105 surveyed plots 36% were infested by *S. elaeagnifolium*, covering 196 ha. The patchy pattern was the most common distribution type for the weed which was moderately abundant (10-50% ground cover) in 70% of the infested plots and highly abundant (> 50%) in 22% of them. On the other hand, 25 linear infestations were recorded along plot borders. They were spread over 4.8 km with an estimated continuous length of 0.5 km. Compared to 2008 survey data, the number of infested plots increased by 50% and the infested area increased by 60%. Furthermore, *S. elaeagnifolium* presence along plot borders increased by 3.5 times. This updated *S. elaeagnifolium* mapping in the irrigated land of Chott-Mariem reveals an ongoing invasion process in the absence of an effective control program.

Keywords: Invasive alien plants, mapping,monitoring, *Solanum elaeagnifolium*, Tunisia

Invasive non-native weeds are a serious threat to native species, communities, and ecosystems in many areas around the world (9, 16). They can compete with and displace native plants, animals, and other organisms that depend on them, alter ecosystem functions and cycles significantly, hybridize with native species, and promote other invaders (19). Accordingly, early detection, mapping and active management of invasive weeds are extremely important, particularly with the swift increase in global travel and trade, which accelerates weed invasion (6). Mapping of invasive weeds is considered the foundation for the development of a strategic long-term management plan to protect agro-

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biodiversity and prevent invasion of other noxious weed species (14, 18). It allows characterizing the pattern of distribution of these plants, predicting their rate of spread and evaluating the relationship between their spatial extent and abundance (8).

One of the most widespread invasive weeds in the world is Silverleaf nightshade (*Solanum elaeagnifolium*, *Solanaceae*). Native to Northeast Mexico and Southwest USA (2, 11), *S. elaeagnifolium* is recorded as an alien plant species in many regions of the world (3). It is listed as a noxious weed in 21 USA states (13) and figures on the EPPO A2 list of species recommended for regulation to EPPO member countries (5). Introduced into Morocco in contaminated cotton seeds in 1950, it is now considered the nation's most noxious weed (15) in irrigated fields (1).

In Tunisia, *S. elaeagnifolium* was first detected around 1985 at Sbikha in the Kairouan district (4). Since then, the invaded area is increasing and this alien plant is becoming a potential threat to thousands of hectares of irrigated fields in arid and semi-arid regions (10). The most infested habitats and land-uses are roadsides, waste lands and summer crops (4). These infestations generate considerable crop yield losses. Therefore, the implementation of a management strategy for this invasive weed is fundamental. *S. elaeagnifolium* mapping in the irrigated land of Chott-Mariem (Tunisia) was first conducted in May 2008, with a comprehensive survey of the entire region. In each infested area, *S.elaeagnifolium* ground cover and distribution pattern were recorded (17). *S. elaeagnifolium* distribution maps were drawn manually based on the site map.

We describe in the present paper the mapping survey of 2014 to compare the actual situation with the previous survey and to highlight the importance of monitoring weed population dynamics for future management plans.

MATERIALS AND METHODS

Study area and survey methodology.

The region of Chott-Mariem is located in the Centre-East of Tunisia, between 35°90'-35°99' N and 10°50'-10°60' E. The climate is semi-arid with mild rainy winters and hot, dry summers. Annual rainfall ranges from 300 to 400 mm. The irrigated land of Chott-Mariem (IL-CM) covers 576 ha, extending 9 km along the coast, divided into three main sectors with similar ecological characteristics (Fig. 1): ZI: 173 ha, ZII: 154 ha, and ZIII: 249 ha. The choice of the study site was based on land accessibility, which plays a crucial role in mapping alien plants, and makes mapping easier and geometrically correct. The study area is also representative of the main irrigated crops (vegetable crops) that are usually affected by *S. elaeagnifolium* in Tunisia.

Field surveys were conducted during June-July 2014, based on the site map and taking into account the imagery available in "Google Earth". The study site was divided into 105 large plots (Fig. 2). For each plot, a descriptive fact sheet was completed to document: (1) Observation date: day/month/year; (2) Plot size: length (m), width (m) and surface (ha); (3) *S. elaeagnifolium* distribution patterns within each plot (Fig. 3) and along its borders (Table 1), and (4) *S. elaeagnifolium* ground covering using the scale: low (1-10%), moderate (10-50%) and high (> 50%).

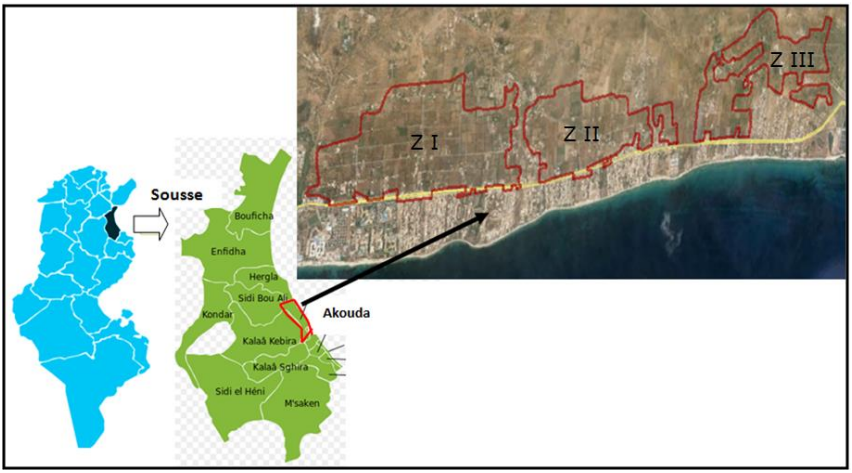

Fig. 1. Geographical position of irrigated land in the region of Chott-Mariem, Sousse (Tunisia)

Fig. 2. Study site and plots in the region of Chott-Mariem, Sousse (Tunisia)

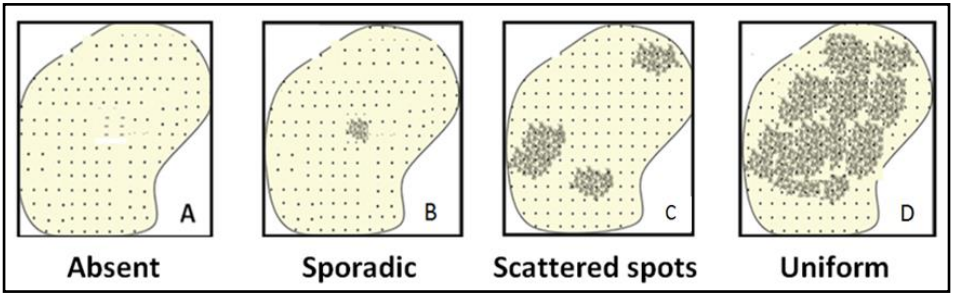

Fig. 3. Scheme used in the field to evaluate the distribution patterns of *Solanum elaeagnifolium* in the invaded plots.

Table1. *Solanum elaeagnifolium* distribution patterns along plot borders

Parameter	Data collected
Infestation continuity	1: isolated plants (< 10%) 2: discontinued (11-50%) 3:continued (> 51%)
Density	Low: <10 plants/m^2 Moderate: 10-20 plants/m^2 High: > 20 plants/m^2

Mapping methodology.

S. elaeagnifolium patches were located using a handheld GPS (Garmin eTrex Vista, 12 channels) and the coordinates of the centroid of each invaded area were recorded. GPS accuracy was about 5 m. Prospection was made following primary and secondary road networks, surveying the whole surface of the study area. Additional surveys were located in adjacent fields, to evaluate the situation at the borders of the investigated area (IL-CM). GPS data were imported into a geographic information system (GIS) (WGS84 Geographic - EPSG 4326) to produce *S. elaeagnifolium* distribution maps, using Quantum GIS software (version 1.8, "Lisboa 2012"). A topographical map of the studied site, provided by the Regional Department of Agriculture and Water Resources, was used as a base map for the GIS analysis.

RESULTS

S. elaeagnifolium was found in 36 plots (over the 105 considered), covering a total area of 196 ha, corresponding to 34% of the total investigated area of IL-CM (Table 2). The patchy pattern was the most common distribution type. In fact, scattered spots were present in above 64% of the infested plots and uniform distribution was the second dominant pattern in over 22% of the infested plots. However, sporadic infestations were only recorded in 5% of the infested plots.

S. elaeagnifolium abundance in the infested plots was moderate (10-50% ground cover) in 70% of these plots and high (> 50% ground cover) in 22% of them (Fig. 4).

Table 2. *Solanum elaeagnifolium* distribution patterns in the irrigated land of Chott-Mariem-Sousse (Tunisia) in 2014

Distribution pattern	Infested plots	
	Number	Surface (ha)
Absent	69	380
Sporadic	2	12.5
Scattered plants	3	16.5
Scattered spots	23	128
Uniform	8	39
Total	36	196

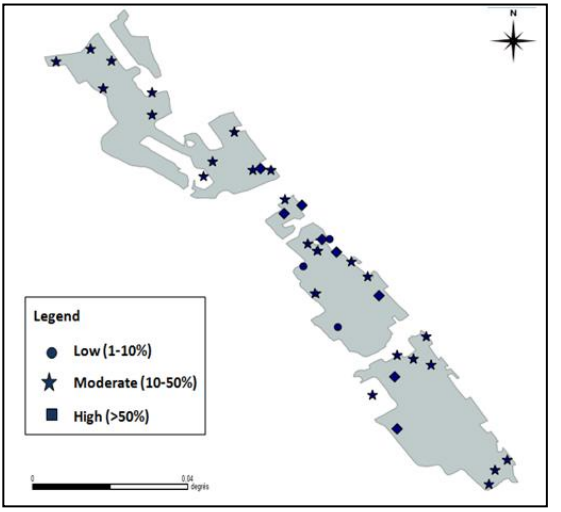

Fig. 4. *Solanum elaeagnifolium* abundance in the irrigated land of Chott-Mariem, Sousse (Tunisia) in 2014.

Along plots borders, 25 linear infestations were recorded along 4.8 km, having an estimated continuous length of 0.5 km (Table 3). These infestations were most frequently discontinued (56%) and less frequently continued (20%). Therefore, *S. elaeagnifolium* density in plot borders was moderate (10-20 plants/m^2) to high (> 20 plants/m^2) and low densities (< 10 plants/m^2) were only occasional.

Table 3. *Solanum elaeagnifolium* distribution patterns along plot borders of the irrigated land of Chott-Mariem, Sousse (Tunisia) in 2014

Distribution patterns	Frequency	Infestation length (km)	Plot border length (km)
Sporadic	6	-	-
Discontinued	14	0.429	3.434
Continued	5	0.080	1.376
Total	25	0.509	4.810

Compared to 2008, *S. elaeagnifolium* occurence increased by 50%. In fact, the number of infested plots evolved from 24 in 2008 (Fig. 5A) to 36 in 2014 (Fig. 5B). Consequently, the total surface of infested plots increased by 60%, it evolved from 123.5 ha in 2008 to 196 ha in 2014. In addition, the weed abundance in infested plots varied from low (1-10%) to moderate (10-50%) in 2008 and from moderate to high (> 50%) in 2014. Furthermore, along plot borders *S. elaeagnifolium* occurrence increased 3.5 times. Indeed, 7 linear infestations were recorded along 1.5 km in 2008 (Fig. 5A) and 25 linear infestations were recorded along 4.8 km in 2014 (Fig. 5B).

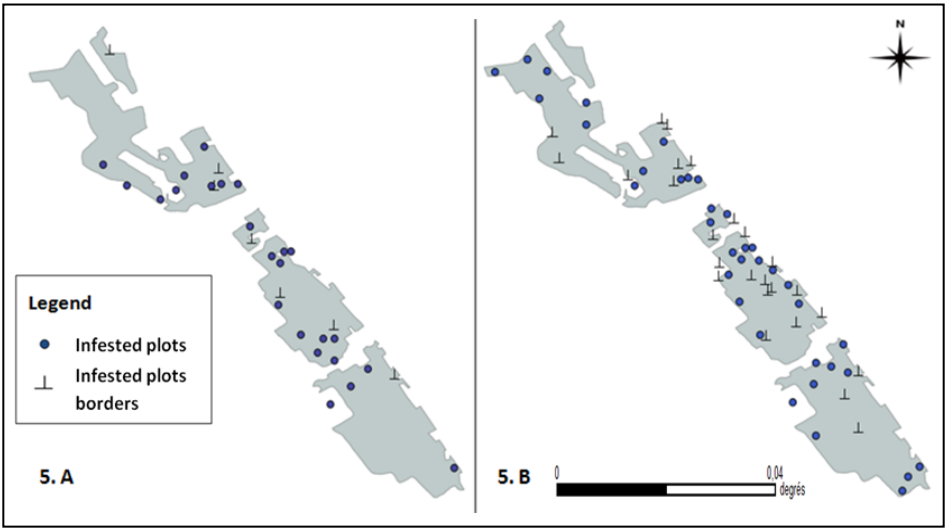

Fig. 5. *Solanum elaeagnifolium* infestation progress in the irrigated land of Chott-Mariem, Sousse (Tunisia) from 2008 to 2014 (5.A: 2008; 5.B: 2014).

The ongoing colonization process of *S. elaeagnifolium* has been expanded to adjacent fields of the IL-CM. An additional number of 18 infested fields were recorded (Fig. 6) where this weed abundance varied from moderate to high. Along plots borders, six linear infestations were recorded and their densities were mainly moderate (10-20 plants/m^2).

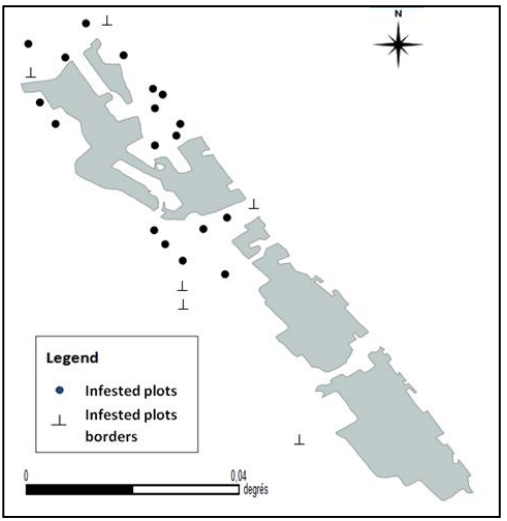

Fig. 6. *Solanum elaeagnifolium* infestations in the adjacent fields to the irrigated land of Chott-Mariem, Sousse (Tunisia) in 2014.

DISCUSSION

Mapping of invasive weeds allows characterizing the pattern of distribution of these plants, predicting their rate of spread and evaluating the relationship between their spatial extent and abundance (8). In our case, *S. elaeagnifolium* occurrence in IL-CM was about 34% and the patchy pattern was the most common distribution type for the weed which reflects a wide expansion of this species in IL-CM and gives us an idea about its residence time in the study area. Furthermore, moderate and high abundance may be explained by a long and continuing colonisation process without any effective control program.

Along plot borders, *S. elaeagnifolium* density varied from moderate to high which indicate that plot borders do act as reservoirs for further spread. Therefore, any management strategy should consider *S. elaeagnifolium* as an agricultural, ruderal and environmental weed. On the other hand, according to Sabra and Haidar (14), surveying the spread of invasive weeds in arable and non-arable lands is essential for identifying their sources and preventing their distribution.

From 2008 to 2014, *S. elaeagnifolium* occurence in IL-CM increased by 50% and the total surface of infested plots augmented by 60%. Moreover, infestations have been expanded to adjacent fields of the IL-CM. These results confirm the ongoing colonization process of *S. elaeagnifolium* and show that its control as a conventional weed is inappropriate and that a specific strategy should be adopted. In fact, according to Mekki (12), weed control and invasive alien plants management are two distinct approaches. In intensive agriculture, weed control is mainly a reactive approach based on herbicide technology and aims to preserve crop yields. However, invasive alien plants management based on a risk assessment scheme is mainly a proactive approach which aims to prevent invasive alien plants introduction and establishment.

These findings highlight the importance of mapping of invasive alien plants using the GPS/GIS technologies which offers many advantages, including increased speed and accuracy, enhanced data sharing capabilities, comaparison with other thematic layes, multitemporal analysis and easy updates. *S. elaeagnifolium* mapping in IL-CM in 2008 and its update in 2014 draw attention to the ongoing invasion process of this alien weed. We can expect that this trend may be similar in the following years without any management strategy or specific action plan. In fact, management action tackling EPPO A2 invasive alien plants (i.e., pests recommended for regulation as quarantine pests) seems to be generally neglected, in comparison with other quarantine organisms. Invasive alien plants mapping and monitoring are very useful tools to address management priorities and provide a baseline for future monitoring efforts (7).

Agricultural land infested with *S. elaeagnifolium* loses considerable rental and resale value, there is an increase in crop production costs due to the need of using management methods (mechanical and chemical control + hand weeding) and the species can also invade adjoining natural or semi-natural areas. Therefore a national action plan to tackel *S. elaeagnifolium* is urgently required.

RESUME

Sayari N., Brundu G. et Mekki M. 2016. Cartographie et monitoring d'une plante exotique envahissante en Tunisie: la morelle jaune (*Solanum elaeagnifolium*), une mauvaise herbe redoutable dans les zones agricoles. Tunisian Journal of Plant Protection 11: 219-227.

L'étude a été menée durant la période juin-juillet 2014 dans le but d'actualiser la cartographie de *Solanum elaeagnifolium* dans le périmètre irrigué de Chott-Mariem (Tunisie). La localisation des infestations a été faite à l'aide d'un GPS portatif. Les coordonnées géographiques des infestations ont été déterminées à l'aide d'un point au centre de chaque infestation. Tout le périmètre a été parcouru, lot par lot, en suivant les routes et les pistes. Pour chaque lot, nous avons enregistré la date d'observation, les dimensions du lot, la couverture du sol par *S. elaeagnifolium* et son mode de distribution à l'intérieur et au niveau des bordures des lots. Les cartes de distribution de la mauvaise herbe ont été établies en utilisant le logiciel *Quantum GIS.* Parmi les 105 lots explorés, 36% étaient infestés par *S. elaeagnifolium* couvrant une superficie totale de 196 ha. Les infestations en taches dispersées étaient les plus fréquentes. Les infestations ayant une couverture moyenne (10-50%) ont été enregistrées dans environ 70% des lots infestés; celles ayant une couverture élevée (> 50%) ont été enregistrées dans 22% des lots infestés. Les infestations linéaires au niveau des bordures des lots étaient au nombre de 25, réparties sur environ 4.8 km et ayant une longueur totale de 0.5 km. Depuis 2008, le nombre de lots infestés a augmenté de 50% et ainsi la surface totale infestée a augmenté de 60%. De même, le nombre d'infestations linéaires a augmenté de 3,5 fois. Cette actualisation de la cartographie de *S. elaeagnifolium* dans le périmètre irrigué de Chott-Mariem montre que, en l'absence de tout programme de gestion, le degré d'infestation ne cesse d'accroitre au fil du temps.

Mots clés: Cartographie, monitoring, plantes exotiques envahissantes, *Solanum elaeagnifolium*, Tunisie

ملخص

السياري،نجلاء وجوزيبيروندوومنير المكي.2016. التوزيع الجغرافي والمراقبة لنبتة غريبة غازية بتونس: الشويكة الصفراء (*Solanum elaeagnifolium*) نبتة ضارة خطيرة في المناطق الفلاحية.

Tunisian Journalof Plant Protection 11: 219-227.

تمت هذه الدراسة في غضون الفترة ما بين جوان وجويلية2014 بهدف تحيين خريطة التوزيع الجغرافي للشويكة الصفراء (*Solanum elaeagnifolium*) بالمنطقة السقوية بشط مريم (تونس). تم تحديد الإحداثيات الجغرافية للمناطق الموبوءة باستعمال GPSو تم إعداد الخرائط باستعمال البرنامج الالكترونيGIS *Quantum*. تبين من خلال مسح كامل المنطقة السقوية أن 36% من مجموع 150 قطعة فلاحية كانت موبوءة وهو ما يمثل 196 هك. كان انتشار الشويكة الصفراء بشكل غير منتظم في معظم القطع الموبوءة. احتوت 70% من هذه الأخيرة على تغطية متوسطة (10-50%) لهذه النبتة و22% منها احتوت على تغطية عالية (>50%).من جهة أخرى قدرانتشارالشويكة الصفراء بالطرقات والمسالك الفلاحية بحوالي 0.5 كم ممتدة على 4.5 كم. مقارنة بما تضمنته الدراسة المنجزة في 2008، يمكن أن نستنتج أن عدد القطع الموبوءة تزايد بنسبة 50% و بالتالي ارتفعت المساحة الجملية لانتشار الشويكة الصفراء بنسبة 60%. أما في ما يخص انتشارها بالطرقات والمسالك الفلاحية فقد كان 3.5 مرات اكثر من 2008. يبين هذا التحيين للتوزيع الجغرافي للشويكة الصفراء أنه، في غياب أي برنامج لمقاومة النباتات الغريبة الغازية بتونس، لا ينفك مستوى الإصابةيرتفع مع مضي الزمن.

كلمات مفتاحية: تونس، توزيع جغرافي، نباتات غريبة غازية، مراقبة، *Solanum elaeagnifolium*

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