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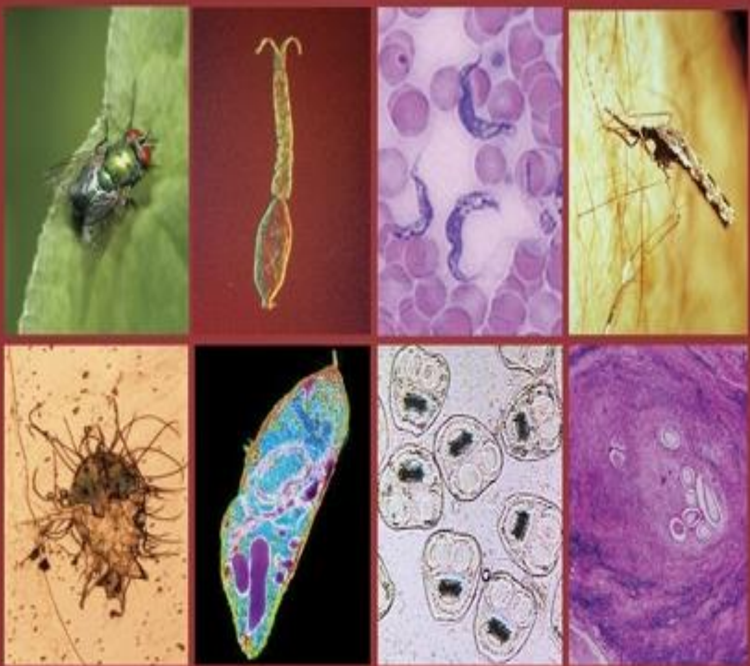
EGYPTIAN ACADEMIC JOURNAL OF

BIOLOGICAL SCIENCES

MEDICAL ENTOMOLOGY & PARASITOLOGY



ISSN
2090-0783

WWW.EAJBS.EG.NET

Vol. 12 No. 2 (2020)

Egypt. Acad. J. Biolog. Sci., 12 (2):27 – 41 (2020)

Egyptian Academic Journal of Biological Sciences
E. Medical Entom. & Parasitology

ISSN: 2090 – 0783
www.eajbse.journals.ekb.eg

Baldratia salicorniae – Salicornia fruticosa Interaction and Modeling of Their Habitat in Egypt By Using Maxent Technique.

Sanad H. Ragab[1], Mohamed Kamel[2], Ahmed S. Bream[1], and Mohamed M. Moursy[3].

1. Department of Zoology, Faculty of Science, Al-Azhar University, Cairo, Egypt.
2. Department of Environmental Basic Sciences, Institute of Environmental Studies and Research, Ain shams University, Cairo, Egypt.
3. Department of Botany and Microbiology, Faculty of Science, Al-Azhar University, Cairo, Egypt.

E-mail: Sanadragab@azhar.edu.eg

ARTICLE INFO
Article History
Received:22/5/2020
Accepted:18/8/2020

Keywords:
Galls, Interactions, Maxent, Distribution, Mediterranean coast, *Baldratia salicorniae*, *Salicornia fruticosa*.

ABSTRACT

In some regions of the Deltaic Mediterranean coastal land of Egypt, *Baldratia salicorniae* Kieffer, 1897 (Diptera: Cecidomyiidae) is a gall-forming insect that induces fleshy galls on the stem of *Salicornia fruticosa* (L.) L. (Family: Amaranthaceae). the current study tried to investigate the interaction of *B. salicorniae* with its host plant *S. fruticosa* in some regions of the Mediterranean coast and study the effect of altitude and vegetation cover on galls induction. In addition, to estimate the predicted geographic distribution habitats of *B. salicorniae* and its host plant *S. fruticosa* in Egypt by using MaxEnt technique.

INTRODUCTION

Many organisms can stimulate plant tissues to form a diversity of abnormal swellings on leaves, flowers, stems, and roots. The presence of these structures, known as galls (Barbosa and Wagner, 1989). Galls are abnormal plant growths consisting of pathologically developed cells, tissues, or plant organs, resulting mostly from overgrowth (hypertrophy) and cell proliferation (hyperplasy) (Santos *et al.*, 2018, Ascendino and Maia, 2018). These are initiated by organisms such as fungi, bacteria, nematodes, mites, viruses, and insects (Barbosa and Wagner, 1989).

Gall-Inducing insects are remarkable bioindicators of any modifications in the environment and the quality of habitat due to their abundance, host specificity, close-fitting habit, and easy localization (Julião *et al.*, 2005, Santana and Isaias, 2014). The variety of gall-inducing insects reflects the conservation status of an area (Santana and Isaias, 2014). The galls can clarify the extended phenotypes, the richness, and abundance of the gall-making insects (dos Santos Isaias *et al.*, 2014, Pan *et al.*, 2015). Galls induction is described as parasitic interaction between the gall maker and its host plant (Rocha *et al.*, 2013). Gall-inducing insects benefit from nutrition, assurance, and shelter provided by the plant galls (Ascendino and Maia, 2018).

Salicornia fruticosa (L.) L. syns. *Arthrocnemum fruticosum* (L.) Moq. (Family: Amaranthaceae) is perennial succulent glabrous subshrub which is located in several habitats such as; salt marshes, Mediterranean coastal region, and Sinai (Boulos, 1999, El-Amier *et al.*, 2014). Some of the *Salicornia* species used in folk medicine (for treatment of hepatitis, bronchitis, and diarrhea) and expressed important biological properties such as anti-inflammatory, antioxidant, hypoglycemic, and cytotoxic activities (Isca *et al.*, 2014). The different extracts and isolated compounds of *S. fruticosa* exhibited strong antioxidant activity, anticancer, anti-microbial, anti-proliferative, and anti-inflammatory activities(Gouda and Elsebaie Ahmed, 2016, Elatif *et al.*, 2019). *S. fruticosa* appears to be a promising biodiesel candidate (Abideen et al., 2015). Besides, the seed oil of *S. fruticosa* was a high-quality health oil (Elsebaie et al., 2013). *S. fruticosa* is an important candidate for future use both for processed and fresh food, due to its health and functional properties (Loconsole *et al.*, 2019).

In the Mediterranean area, *Baldratia salicorniae* Kieffer, 1897 (Diptera: Cecidomyiidae) is a gall-forming insect that induces fleshy galls on internodes of *S. fruticosa* (Dorchin and Freidberg, 2008, Skuhravá and Skuhravy, 2004, Sánchez *et al.*, 2012).

Species distribution models (SDMs) are a useful tool for assessing the potential for species to locate in regions not previously surveyed (Guisan and Thuiller, 2005). These models have been utilized for providing a baseline for predicting a species' response to landscape difference and/or climate change (Araújo *et al.*, 2006), and for determining the important regions for conservation (Wilson et al., 2005).

Recent studies showed that a statistical mechanics approach as the MaxEnt methodology performs very well even with small records (Phillips *et al.*, 2006, Hernandez *et al.*, 2006). The predicted distribution habitats of various species are determined in Egypt by using species distribution models especially MaxEnt technique (El Alqamy *et al.*, 2010, Kamel *et al.*, 2012).

Therefore, the present study tried to investigate the interaction of *B. salicorniae* with *S. fruticosa* in some regions of the Mediterranean coast and study the effect of elevation and vegetation cover on galls induction. In addition, to estimate the geographic distribution range of *B. salicorniae* and its host plant *S. fruticosa* in Egypt by using MaxEnt technique.

MATERIALS AND METHODS

Study Area:

The Mediterranean coastal region of Egypt has a narrow coastal belt that spreads from Sallum (on the Libyan borders) easting to Rafah (on the Palestinian borders) for about 970 km with an average width ranging between 15- 20 km in the north-south direction (Hadidi, 1981). The Deltaic Mediterranean coastal land of Egypt hosts a number of highly populated cities such as Alexandria, Rosetta, Damietta, and Port-Said (El-Amier *et al.*, 2014). The Nile Delta coast is differentiated into four habitats: sand formations, fertile sandy lands, salt marshes, and reed swamps (Mashaly, 2001). The Mediterranean coastal region stills floristically one of the less recognized territories of Egypt (Osman and El-Garf, 2015). The plants grown on coastal sand dunes are playing the main role in protecting the coast from flooding and erosion (El-Amier *et al.*, 2014).

A total of 1083 plant species are recorded in the Mediterranean coastal land, Of the 255 species recorded only from this region and 18 are known to be endemic (El Hadidi and Hosni, 1996). Egypt`s Mediterranean coast regions are characterized by moderate to warm temperatures in summer (20–31^{o}C) and little precipitations occurring in the winter months (Osman and El-Garf, 2015).

The current study was conducted in some regions of The Deltaic Mediterranean coastal land of Egypt, the chosen sampling sites for *S. fruticosa* were Abees, Merghem, El-tafaroa, El-amria, Abu-talat, and Burg El-arab city (Fig. 1). The study localities were visited periodically in the period from Feb. 2019 to Jun. 2020, once every two months**.**

Study Plants:

Salicornia fruticosa (L.) L. syns *Arthrocnemum fruticosum* (L.) Moq. (Family: Amaranthaceae) is perennial succulent glabrous subshrub (20-80 cm); Plant stems are decussate-branched; spikes are cylindrical; Flowers are in groups established in hollows of the spike; the plant is distributed in salt marshes, the Mediterranean region, and Sinai (Boulos, 1999, Migahid, 1988). The recorded locations of *S. fruticosa* in Egypt is shown in (Fig. 8 & Table 1).

Table 1: The recorded locations of *S. fruticosa* in Egypt

No.	Location	Coordinates		References
		Latitude	Longitude	
1	El-burullus city	32.58	31.26	(Elsebaie et al., 2013)
2	Maruit	31.03	29.9833	(Shaltout et al., 2019)
3	Edko	31.216	30.233	(Shaltout et al., 2019)
4	El-bardawil	31.055438	33.300362	(Shaltout et al., 2019)
5	El-burullus city	31.45	31.166	(Shaltout et al., 2019)
6	Wadi El-Rayan	27.46	28.58	(Zahran and Willis, 2009)
7	Bahariya Oasis	27.46	28.58	(Zahran and Willis, 2009)
8	Bahariya Oasis	28.50	29.16	(Zahran and Willis, 2009)
9	Ras El-Hikma	31.25	27.86667	(Boulos, 1995)
10	Faiyum	25.420	31.967	(Boulos, 1995)
11	Wadi Natrun.	30.7367	30.3477	(Boulos, 1995)
12	Siwa.	29.186	25.475	(Boulos, 1995)
13	Farafra	27.059	27.979	(Boulos, 1995)
14	Kharga,	25.436	30.549	(Boulos, 1995)
15	Dakhla,	25.483	30.626	(Boulos, 1995)
16	Kurkur,	23.887016	32.335358	(Boulos, 1995)
17	Dungul	23.434790	31.616681	(Boulos, 1995)
18	Uweinat.	21.894	24.952	(Boulos, 1995)
19	Omayed	30.822	29.196	(Salem, 2014)
20	The Nile Delta	29.981	31.316	(Tackholm and Drar, 1956)
21	Faiyum	29.307	30.844	(Tackholm and Drar, 1956)
22	El-Sollum	31.575	25.159	(Tackholm and Drar, 1956)
23	Rafah	31.287	34.236	(Tackholm and Drar, 1956)
24	El-Tih	29.146	33.544	(Tackholm and Drar, 1956)
26	Rosetta	31.4	30.41667	(Tackholm and Drar, 1956)
27	45 km west of Marsa Matrouh City	31.181	27.469	(El-Morsy, 2010)
28	Sidi Abd El-Rhman	30.967	28.735	(El-Morsy, 2010)
29	Alexandria-Rosetta railroad	30.25	31.25	(El-Ghareeb and Rezk, 1989)
30	Alexandria-Rosetta railroad	30.45	31.416	(El-Ghareeb and Rezk, 1989)

Samples Collection and Identification:

The width, length, and height of each plant within the sample were measured using a tape meter, besides counting the number of galls on different parts of the plant. Plant samples were identified according to (Boulos, 1999, Migahid, 1988). The immature stages of the gall inducer inside the galls were collected from the field and reared in the laboratory until emerging of the adults, which were identified by using different kinds of keys to reach the family level, genus level, and species level.

Data Analysis:

The collected data were analyzed using the IBM SPSS Statistics ver. 25, 2019). Spearman correlation test was used to determine the relationship between altitude, plant cover, and the number of galls per each plant. Also, One-way ANOVA test was used to compare the mean number of galls per plant among different localities.

Mapping and Predicting Distributions of Plant Species:

The presence records for *B. salicorniae* and its host plant *S. fruticosa* are recorded using GPS (Garmin XL 12). the geographic distribution habitats of *B. salicorniae* and *S. fruticosa* in Egypt are estimated by using MaxEnt technique. Maxent software, version (3.3.1) uses the recorded distribution together with the climatic and topographic layers for the study localities (Phillips et al., 2004, Phillips *et al.,* 2006).

Environmental Data of The Model:

Nineteen climatic predictors (Table 2), are used to estimate the eco-physiological tolerances of a species (Graham et al., 2006). These were obtained from the WorldClim dataset ((Hijmans *et al.,* 2005); http://www.worldclim.org/bioclim.htm). While Altitude provided from the Shuttle Radar Topography Mission (SRTM). furthermore, retrospective distributional records for *S. fruticosa* were obtained from published literature besides our reliable observational data.

Table 2: Definitions of the abbreviated climatic variable names

Variable Definition	
Bio1	Annual Mean Temperature.
Bio2	Mean Diurnal Range.
Bio3	Isothermality.
Bio4	Temperature Seasonality.
Bio5	Max Temperature of Warmest Month.
Bio6	Min Temperature of Coldest Month.
Bio7	Temperature Annual Range.
Bio8	Mean Temperature of Wettest Quarter.
Bio9	Mean Temperature of Driest Quarter.
Bio10	Mean Temperature of Warmest Quarter.
Bio11	Mean Temperature of Coldest Quarter.
Bio12	Annual Precipitation.
Bio13	Precipitation of Wettest Month.
Bio14	Precipitation of Driest Month.
Bio15	Precipitation Seasonality.
Bio16	Precipitation of Wettest Quarter.
Bio17	Precipitation of Driest Quarter.
Bio18	Precipitation of Warmest Quarter.
Bio19	Precipitation of Coldest Quarter.

Statistical Validation of The Model:

In order to assess the predictive performance of the model, randomly presence records partition into 75% of the points was used to predict species distribution "training data" and 25% for model testing "testing data". Statistical validation of the model was performed by calculating the area under the curve (AUC) of the receiver operating characteristic (ROC). The area under the curve (AUC) is utilized as a measure of the accuracy of the model (Phillips, 2016). The AUC ranges from 0 to 1. An AUC of 0.5 indicates a model that is no better than random, while an AUC of 1 indicates a perfect model (Phillips *et al.,* 2004, Phillips *et al.*, 2006). The percentage contribution of each predictor to the output model was provided by Maxent, the contribution values are determined by the increase in gain of the model provided by each variable (Phillips *et al.*, 2006). The MaxEnt model's internal jackknife test was used to estimate which variables contribute most to the model development.

RESULTS

Insects That Induced Galls:

The gall-midge *Baldratia salicorniae* Kieffer, 1897 (Diptera: Cecidomyiidae) (Fig. 3) induce galls on internodes of *Salicornia fruticosa* (L.) L. (Family: Amaranthaceae). The galls (Fig. 2) appear as swelling of an internodium (1 – 1.5 cm). It is most obvious, partly reddish, and fleshy. Each gall contains a gall chamber with a single orange larva. Pupation takes place inside the gall (Fig. 3), and One generation develops a year. The predominance of *Baldratia salicorniae* occurred during late winter (February) to summer (July). Adults emerge from early April to the end of July. (Fig. 3).

Factors Affecting the Distribution of The Insect Galls Induced on *Salicornia fruticose:*

1. Relationship Between the Number of Galls Per Plant, Plant Cover, And Altitude:

There was a significant negative correlation between the number of galls per plant and the altitude within the study localities ($r = -0.367$, $P < 0.01$) (Fig. 4). Meanwhile, there was no significant correlation between the number of galls per plant and the plant cover within the study localities.

2. Spatial Distribution of The Number of Galls Induced on *Salicornia Fruticosa* Among Different Localities:

There was a significant difference, in the number of galls induced on *Salicornia fruticosa* among different localities (Abees, Merghem, El-tafaroa, El- amria, Abu-talat, and Burg El-arab city) ($F (5, 48) = 8.171$ $P < 0.05$) (Fig. 5). Abees showed the greatest mean number of galls per plant 190.73; as compared to 1, 2.4, 30, 2 and 75 at Merghem, El-tafaroa, El- amria, Abu-talat, and Burg El-arab city, respectively.

The post hoc test showed that there was a significant difference between Abees and Merghem, El-tafaroa, El- amria, Abu-talat, and Burg El-arab city equal to 189.72, 188.32, 160.72, 188.72, and 115.72, respectively. ($P < 0.05$).

Spatial Prediction Model of *Salicornia fruticose*:

1. The Predicted Distribution Range of *S. fruticosa* in Egypt:

The MaxEnt model for *S. fruticosa* is shown in (Fig. 6). The predicted distribution habitat of *S. fruticosa* covers wide regions of the Mediterranean coastal lands, in addition to some localities in the Nile land region, the Red Sea coast, south of Egypt at Nasser lack, and South Sinai. 23 presence records used for training the model, 7 for testing. The AUC (Fig. 7) for the training points was 0.906 and for the test, points were 0.745, with a standard deviation of 0.098; The AUC was greater than 0.90, indicating outstanding discrimination for *S. fruticosa.* The test points were classified correctly significantly more than a random model ($p < 0.001$).

2. Effect of Predictor Variables in The Representation of The Maxent Model for *S. fruticose:*

According to the percent contribution heuristic test of the variables (Fig. 8), *S. fruticosa* showed high sensitivity to Precipitation of Wettest Month (BIO13), Temperature Annual Range (BIO7), Altitude, Precipitation of Warmest Quarter (BIO18), Isothermality (BIO3), Annual Precipitation (BIO12), and Temperature Seasonality (BIO4), with contribution percentage equal to 60%, 11%, 7%, 6%, 6%, 6%, and 4%, respectively.

The jackknife test of variable importance showed that Precipitation of Wettest Month (BIO13) and Altitude were the most important predictors of *S. fruticosa* habitat distribution. These variables showed higher gains that included the most information as compared to the other variables.

Spatial Prediction Model of *Baldratia salicorniae*:

1. The Predicted Distribution Range of *B. salicorniae* in Egypt:

The MaxEnt model for *B. salicorniae* is shown in (Fig. 9). The predicted distribution habitat of *B. salicorniae* is mainly concentrated in some areas close to the Mediterranean coastal land, in addition to some areas in the Nile delta region. 11 presence records used for training, and 3 for testing. The AUC (Fig. 10) for the training points was 0.995 and for test, points were 0.983, with a standard deviation of 0.011; The AUC was greater than 0.90, indicating outstanding discrimination for *B. salicorniae.* The Maxent model classifies the test records correctly significantly more than a random model (p <0.001).

2. Effect of Predictor Variables in The Representation of The Maxent Model for *B. salicorniae:*

According to the analysis of the variables contribution heuristic test (Fig. 11), *B. salicorniae* showed high sensitivity to Precipitation of Wettest Quarter (BIO16), Altitude, Precipitation of Wettest Month (BIO13), Precipitation of Coldest Quarter (BIO19), Mean Diurnal Range (BIO2), Precipitation of Driest Quarter (BIO17), and Mean Temperature of Warmest Quarter (BIO10), with contribution percentage equal to 43%, 24%, 10%, 7%, 6%, 5%, and 5%, respectively.

The jackknife test of variable importance showed that altitude was the most important predictor of *B. salicorniae* habitat distribution. This variable provided higher gains that contains the most information as compared to the other variables.

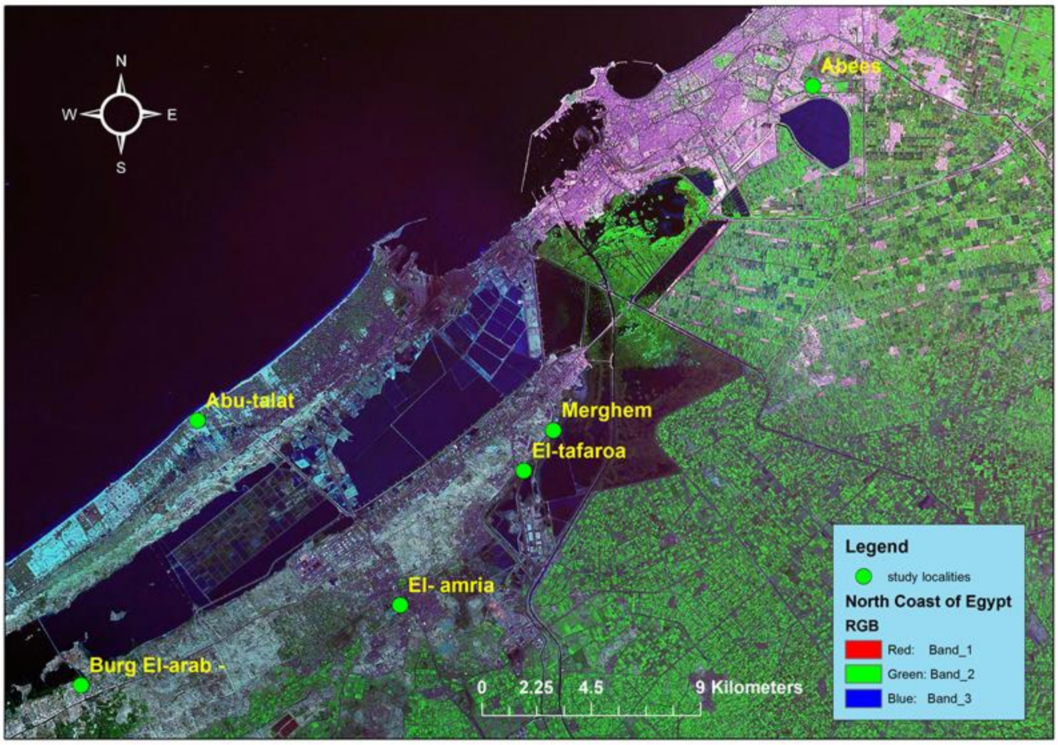


Fig. 1. Location map showing the study localities in North coast of Egypt.
(Map source: IESR, GIS unit & google map - https://www.google.com.eg/maps/@30.9582663,29.6814612,10z).

Fig. 2. The swelling galls of *Baldratia salicorniae* Kieffer, 1897 (Diptera: Cecidomyiidae).

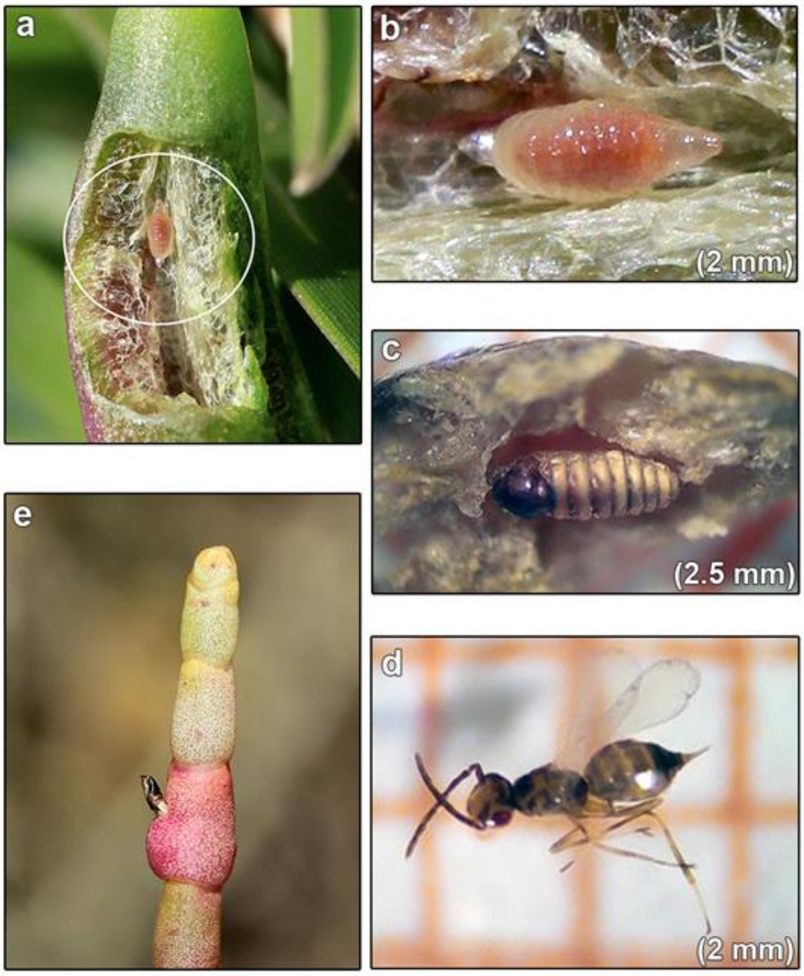


Fig. 3. The gall-midge *Baldratia salicorniae* Kieffer, 1897 (Diptera: Cecidomyiidae) ;(a & b) Larvae inside the gall (2 mm), (c) Pupa (2.5 mm), (d) Adult (2 mm) and (e) Emerging of an adult from the gall. (a & e, after (Claerbout, 2020)).

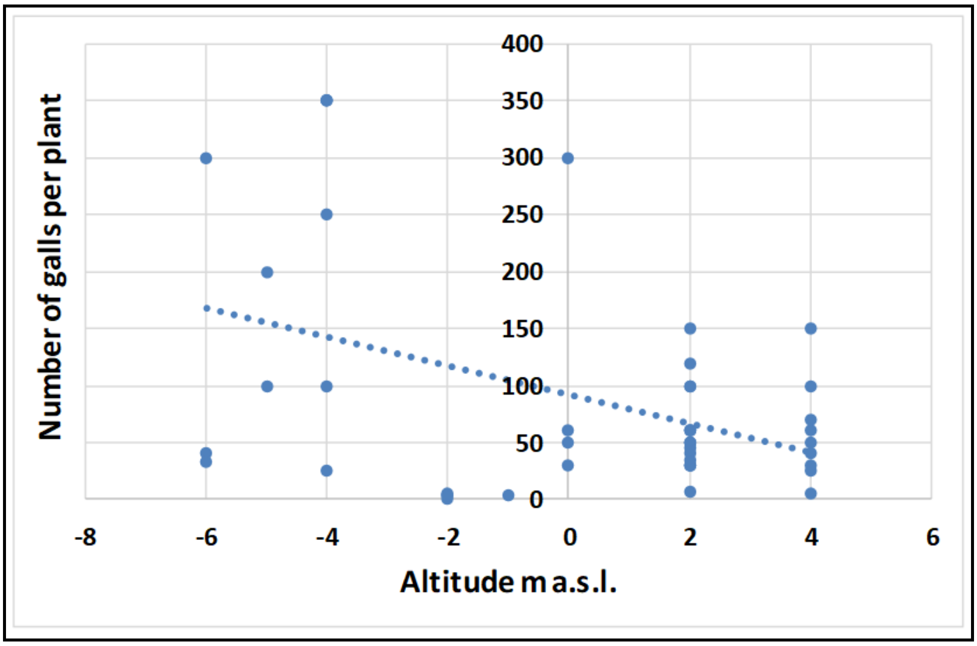


Fig. 4. The relationship between the number of galls per plant and the altitude within the study localities.

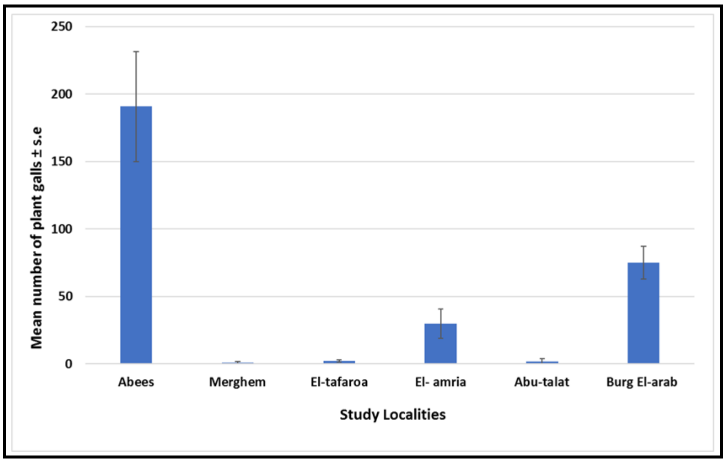


Fig. 5. The spatial pattern of gall distribution on the *Salicornia fruticosa* among different study localities.

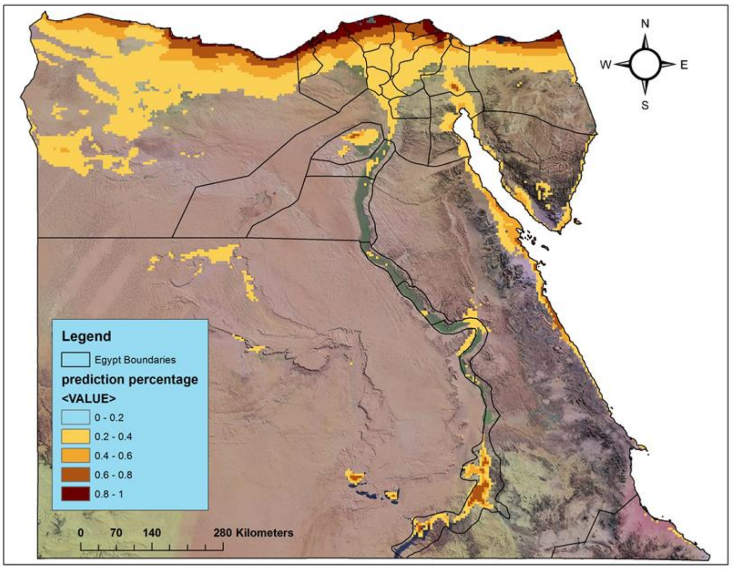


Fig. 6. The predicted distribution range of the *S. fruticosa* according to MaxEnt. (Map source: IESR, GIS unit & google map https://www.google.com.eg/maps/@27.4846067,31.3939551,6z).

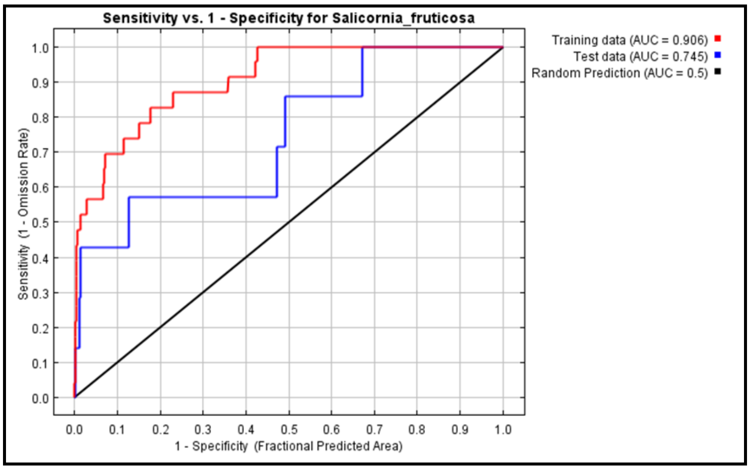


Fig. 7. Training data (AUC = 0.906) and test data (AUC = 0.745) compared to random prediction (AUC = 0.5) in the receiver operating characteristic (ROC) curve for representation of the MaxEnt distribution model for *S. fruticosa*

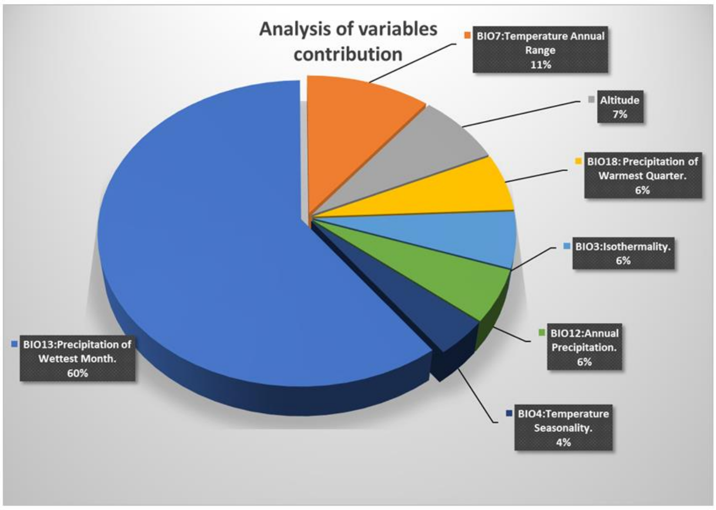


Fig. 8. Analysis of variables contributes to the prediction distribution model of *S. fruticosa.*

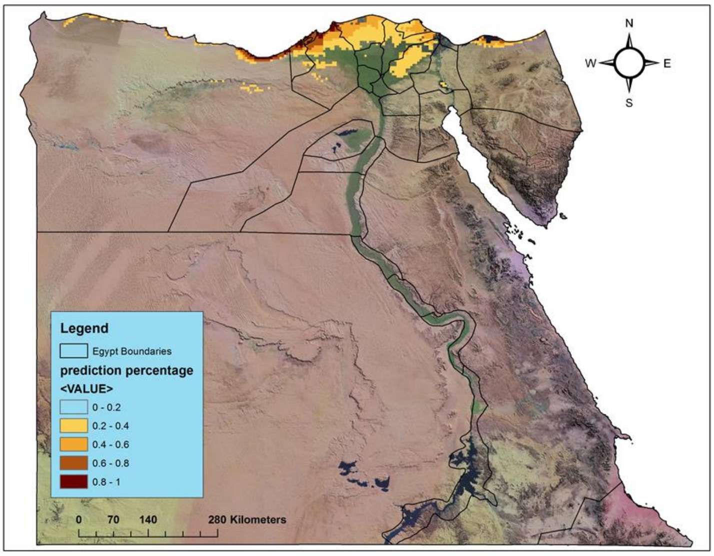


Fig. 9. The predicted distribution range of the *B. salicorniae* according to the MaxEnt model. (Map source: IESR, GIS unit & google map https://www.google.com.eg/maps//@27.4846067,31.3939551,6z).

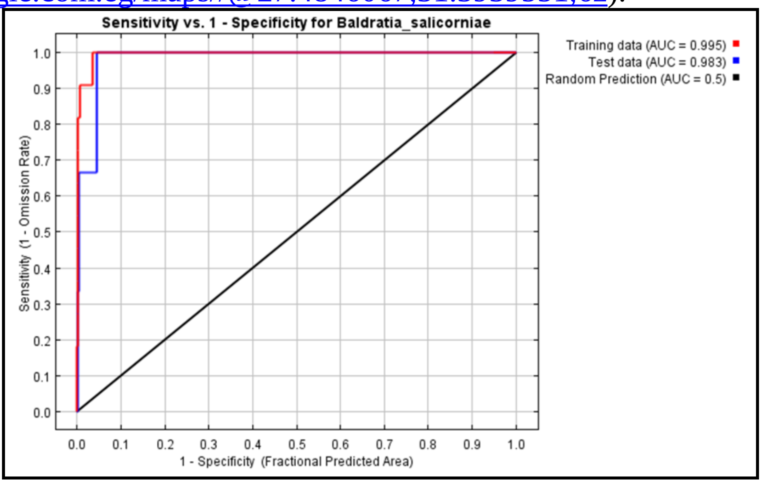


Fig. 10. Training data (AUC = 0.995) and test data (AUC = 0.983) compared to random prediction (AUC = 0.5) in ROC curve for representation of the MaxEnt model for *B. salicorniae.*

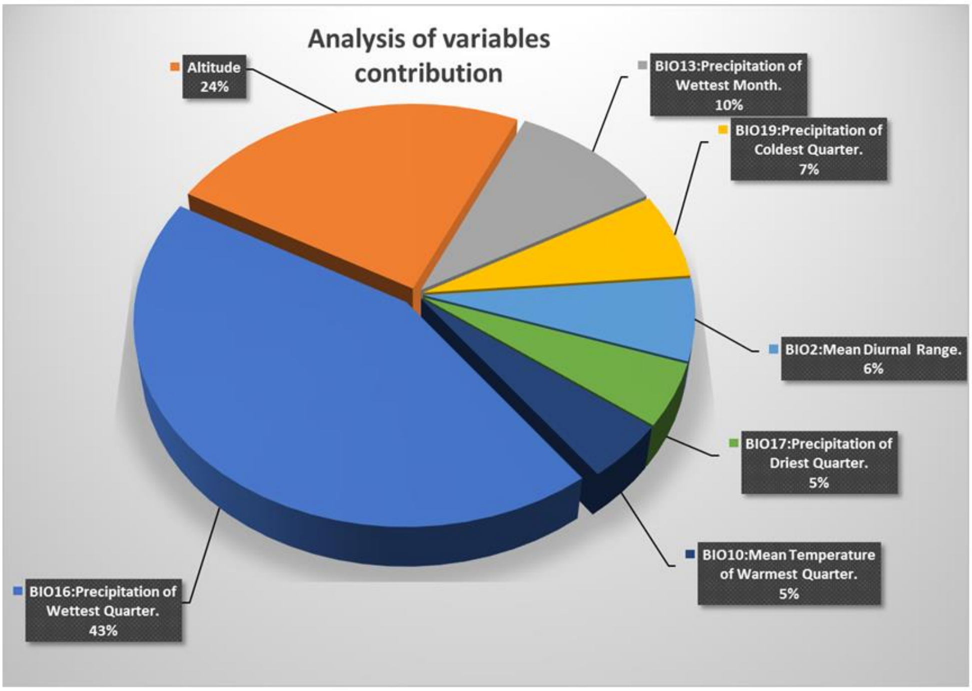


Fig. 11. Analysis of variables contribute to the prediction model of *B. salicorniae.*

DISCUSSION

According to the plant vigor hypothesis, that more energetic, potent, fast-growing plants will be prioritized by several types of herbivores that depend on high meristematic activity, where the gall inducers usually prefer fast-growing and large plant organs, such as shoots and leaves (Price, 1991). The current study showed that the stem of *S. fruticosa* is the most vital organ of the plant subjected to galls induction. It may be strongly attributed to the large diameter of the stem that may provide enough area for gall induction (De Bruyn, 1994). Also, the gall making insects prefer the more rewarding plant organs to form the gall (Whitham, 1978).

The altitude is an important variable determining the distribution of gall-inducing insects (Kamel *et al.*, 2012). The current study showed that the altitudinal gradient has a negative effect on the gall inducers. This role is clear from the negative correlation between the number of galls per plant and the altitude. It can be explained by the effect of temperature on gall inducers; as, the temperature will increase with the decrease of altitude, which is concurred with the view of (Fernandes and Price, 1988) who reported that temperate shrubs supported more galling inducers than did another plant, and the view of (Blanche and Ludwig, 1998) who suggested that gall inducers` richness increases as environments become drier and hotter because there are fewer gall insect enemies in dry, hot environments.

The current study suggests that the predicted distribution habitats of *B. salicorniae* and its host plant *S. fruticosa* in Egypt can be modeled using a small number of presence records together with environmental predictors for the study area through the maximum entropy modeling technique (MaxEnt). So the present study agrees with the view of (Hernandez et al., 2006, Kamel *et al.*, 2012) who suggested that the Maxent entropy modeling technique performed better for species with very small recorded locations that have relatively wide geographic distributions.

Also, the present study showed that the predicted distribution range size for *B. salicorniae* is less than the total predicted distribution range size for S. fruticosa. The predicted distribution habitat of *B. salicorniae* is mainly concentrated in some areas close to the Mediterranean coast, in addition to some regions in the Nile delta region. This agrees with the findings of (Skuhravá e*t al.*, 2014) who reported that the distribution of *B. salicorniae* is concentrated in Mediterranean regions. While The predicted distribution habitat of *S. fruticosa* covers wide regions of the Mediterranean coastal lands, in addition to some localities in the Nile land region, the Red Sea coast, south of Egypt at Nasser lack, and South Sinai. This has concurred with the view of (Boulos, 1995, El-Ghareeb and Rezk, 1989, Tackholm and Drar, 1956, El-Morsy, 2010, Zahran and Willis, 2009, Salem, 2014, Elsebaie *et al.*, 2013, Shaltout et al., 2019) whose recorded *S. fruticosa* in different areas of Egypt.

The MaxNet results showed that altitude was the most important predictor for the habitat distribution of *B. salicorniae* and its host plant *S. fruticosa* in Egypt This agrees with the findings of (Semida, 2006, Kamel *et al.*, 2012) whose suggested that the altitude is an important variable determining the distribution of gall-forming insects.

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ARABIC SUMMARY

دراسة العلاقة بين *بالدراتيه ساليكورنيا* وساليكورنيه*فروتيكوزا* ونمذجة موطنها في مصر باستخدام تقنية الماكسنت

سند حسين رجب [1]، محمد كامل [2]، أحمد صابربريم[1]، ومحمد متولي مرسي [3]

1- قسم علم الحيوان – كلية العلوم – جامعة الازهر- مصر.

2- قسم العلوم الأساسية البيئية – معهد الدراسات والبحوث البيئية – جامعة عين شمس- مصر.

3- قسم النبات والميكروبيولوجي - كلية العلوم – جامعة الازهر- مصر

تعتبر حشرة *بالدراتيه ساليكورنيا* (فصيلة السيسيدوميدي، رتبة ثنائيات الأجنحة) من الحشرات المسببة للأورام النباتية في بعض مناطق الدلتا الساحلية على البحر الأبيض المتوسط في مصر حيث تحدث أورام نباتية لحمية على سيقان بنات *ساليكورنيه فروتيكوزا* (الفصيلة القطيفية، رتبة القنفليات). تهدف الدراسة الحالية إلى التحقق من العلاقة بين حشرة *بالدراتيه ساليكورنيا* والنبات العائل لها*ساليكورنيه فروتيكوزا* في بعض مناطق ساحل البحر الأبيض المتوسط وهدفت هذه الدراسة أيضا إلى التعرف على تأثير العوامل البيئية المختلفة مثل الارتفاع عن سطح البحر بالإضافة لعوامل الكساء الخضري على عملية تكون الأورام النباتية. وقد حاولت الدراسة تحديد التوزيع الجغرافي المحتمل للموائل الخاصة بحشرة *بالدراتيه ساليكورنيا* والنبات العائل لها*ساليكورنيه فروتيكوزا* في مصر باستخدام تقنية الماكسنت.