CPN Modeling of Seed Dispersal by the Modified Atlantic Water among the Tunisian Islands

Adnen Sanaa
Laboratory of Plant Biotechnology.
INSAT, University of Carthage.
North Urban Center, BP 676,
1080 Tunis Cedex, Tunisia

Samir Ben Abid
6'Com Laboratory,
ENIT, El Manar University.
BP 37, Le Belvedere 1002 Tunis,
Tunisia

ABSTRACT
Environmental and meteorological phenomena play a major role in the transport and diversification of plant populations. According to a wide range of parameters, including the seed size and density, winds and water currents are instrumental in the dispersal of the said populations.

In this paper, a colored Petri Nets (CPN) based behavioral model of the transport and dispersal of populations through the Tunisian coats islands is presented. A special attention to the Isozyme transport mechanism and frequencies, and the simulation results did show a uni-directional flow of the genetic material that matches with the observed populations.

General Terms
Modeling using Colored Petri Nets.

Keywords
Colored Petri Nets, Isozyme, MAW, Island, Hydrocory, Modeling.

1. INTRODUCTION
Hydrochory, the seed dispersal by water, is a strategy used by many aquatic plants, and some terrestrial plants to move into areas appropriate for establishment [1]. The buoyant seeds produced by the plants belonging to the Nymphaea genus, for example, float for a set time, and then sink to the water floor of a pond to take roots [2]. Moreover, the seeds of the plants of the Arecaceae family, growing near on the shore of oceans, are transported by the oceanic currents over tremendous distances which allow for the propagation of their populations even inter-continents [3].

In this paper, the aim is to model the impact of the Modified Atlantic Water (MAW) in the Tunisian island population of plants. Due to cyclic nature of the MAW phenomena, we did opt for a discrete model based on stochastic colored Petri Nets. We did model the isozyme diversity as to abstract the movement of individual seeds within the populations.

Isozymes have been studied for a long time as the most widely used genetic markers in the study of population genetics [4].

By the end of this paper, the complete model, which included a selection of the most prominent mainland sites as sources of the genetic material, is presented. The obtain results, which are discussed in the last section, should exhibit a high correlation between the MAW course and the population grouping, taking into account the initial mainland populations.

2. MODIFIED ATLANTIC WATER
The Modified Atlantic Water (MAW) is transported by the Algerian Current (AC) which, approaching the Straits of Sicily, splits in two branches (Fig. 1). The branch passing the region of the Straits of Sicily constitutes an energetic and meandering stream [5] known as the Atlantic Ionian Stream (AIS), while the southern branch is called the Atlantic Tunisian Current (ATC) flowing along the Tunisian shelf break. Both branches are characterized by a strong seasonal variability, in terms of path and hydrological features. The ATC signature is weaker in summer, while in winter it is well developed [6]

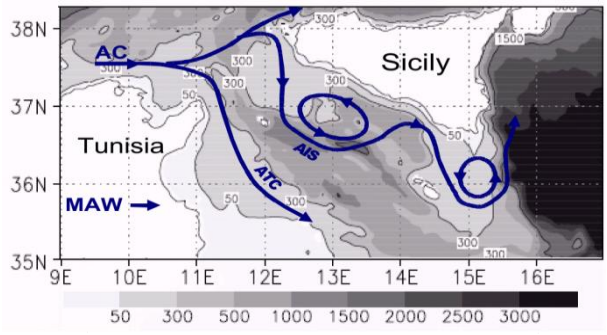


Fig 1: Scheme of the MAW [7]

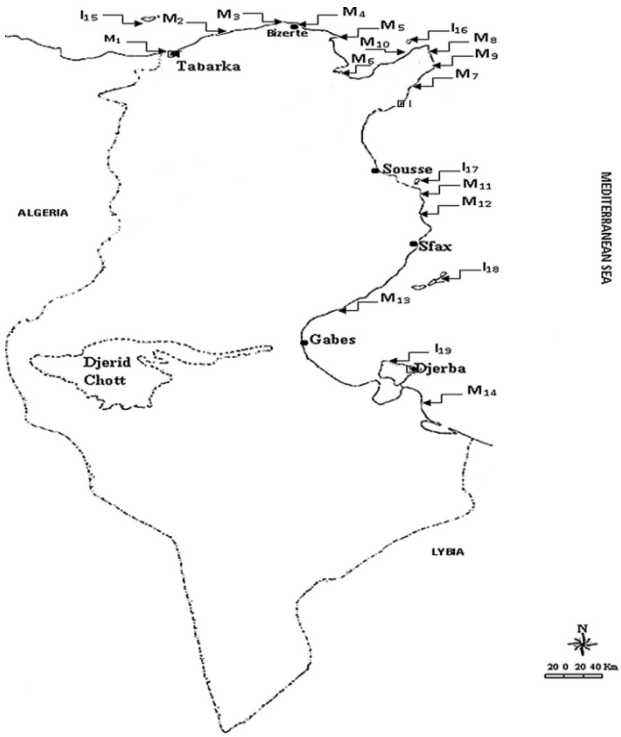


Fig 2: Map of the considered mainland and island sites in Tunisia.

3. COLORED PETRI NETS

3.1 General Description

Colored Petri Nets (CPNs) are an extention of the classical Petri Nets where only one type of tokens is defined. As a graphical language, CPNs have shown their suitability to model a plethora of discrete event systems, and to represent Sequential and parallel systems with clarity and without distraction due to anachronisms of the representation [8].

A CPN is a compound set of transitions, places and inscriptions. Each inscription is a set containing a number of tokens than may have no less than one color. A color can be compared to the instance of a complex type (record or structure) in a standard programming language.

In order to model using CPNs, the colors must be defined first. Classical scalar types, in addition to compound types, could be used for the representation. Each field of the color must be explicitly defined (type and name), and for each token the value of the field must be stated. At each transition firing, the inscription on the arc could be used to move the input token without modification or a new token, or tokens, can be created according to the inscription [8].

In this work, we use CPNTools [9] for the implementation of the model.

4. MAW SEED DISPERSAL MODEL

In order to model the individual isozymes, an enumerated color is defined for the particular plant population:

```
colset Isozyme:= with
LAPa|ADHa|PGMa|I6PGDa|IDHa|GOTa|PGIa|ESTa
;
```

The color, in itself, doesn't give information about the prevalence of the particular isozyme. The frequency of the isozymes within a given place is what defines its mean frequency within the considered population. We did consider that all the isozymes are diallelic. In order to speed the simulation, only the *a* allele for each isozymes were considered. The *b* allele frequency associated to each isozymes is inferred from the latter's frequency.

The initial mainland populations are considered to be static and isolated through the simulation. The dispersal occurs to and through islands exclusively. We suppose that the seedling season of the studied plant population occurs during the ATC season (autumn and winter), and that the transport of seeds is limited to a certain distance. We did consider that the seeds would survive for no more than 25 days when transported by the current.

Table 1 and Table 2 contain the list of the considered mainland and island sites.

The flow motion between the sites is as follows. I15 is isolated from the other island sites due to the high distance between it and its nearest neighboring island (I16). For the rest of the island sites, a one way dispersal path is considered. Seed transport between the mainland sites and the island sites is determined according to the geographical distance except for the gulf of Tunis where the Eddy phenomena leads to seeds being transported back and forth I16.

The Eddy and tide phenomena are present in the gulfs of Hammamet and Gabes. The tide phenomena are modeled by a higher transport probability, whereas the effect of the Eddy phenomena is limited compared to the gulf of Tunis due to the divergent nature of the ATC current [7].

Table 1. Island sites in Tunisia.

Identifier	Site
I15	Galite
I16	Zembra
I17	Kuriat
I18	Karkennah
I19	Djerba

In figure 3, the proposed CPN model is illustrated. Every mainland site is represented by a subnet bearing its identifier. A mainland could be considered as a random generator, where each output token is an isozyme token. The value of the token is randomly chosen according to its prevalence within the initial population.

Table 2. Mainland sites in Tunisia.

Identifier	Site	Identifier	Site
M1	Tabarka	M8	Sidi Daoued
M2	Cap Serrat	M9	Dar Allouch
M3	Bizerte	M10	Oued Laabid
M4	Jarzouna	M11	Monastir
M5	Sidi Ali el Mekki	M12	Mahdia
M6	Borj Sedria	M13	Chaffar
M7	Chott Ezzouhour	M14	Zarzis

The insular places hold the isozyme tokens, and their frequencies are computed directly according to the total place count. Extinction was also taken into account. A "black hole" place is used to randomly eliminate tokens from the insular places.

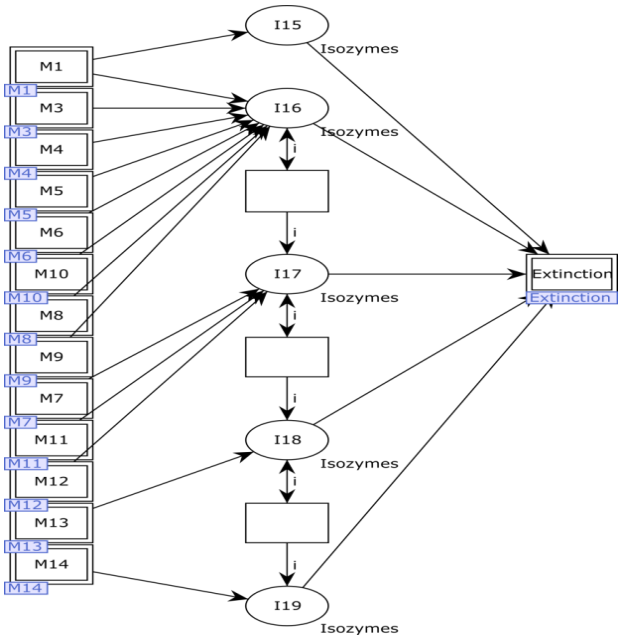
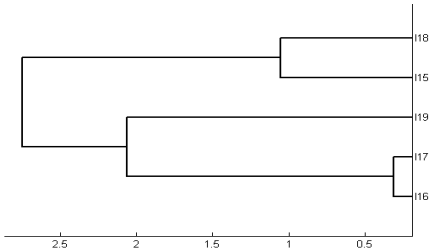


Fig 3: CPN model of the MAW seed dispersal model.

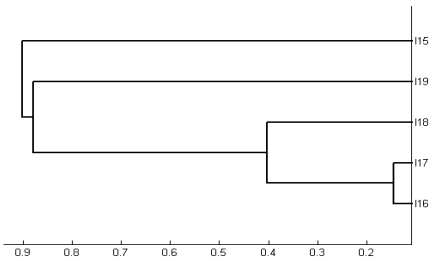
5. SIMULATION RESULTS

The proposed model was simulated for 50 000 years, 100 000 years and 200 000 years. The obtained respective dendrograms are given in Fig 4.a, Fig 4.b and Fig 4.c.

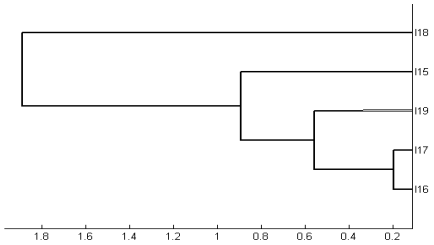
The dendrograms constructed using the genetic distances grouped populations into two aggregates. The populations I16, I17 and I19 are grouped together in the three dendrograms. However, the populations I15 and I18 formed the second group together or they are presented as single and separate populations or clustered with the populations of I16, I17 and I19. This result could give an evidence of hydrochory. Adding to that, tide phenomena and wind could also participate significantly in seed dispersal.



(a) 50,000 MAW Cycles



(b) 100,000 MAW Cycles



(c) 200,000 MAW Cycles

Fig 4: Dendrograms of the island populations for 50,000, 100,000 and 200,000 MAW cycles.

6. CONCLUSION

A Colored Petri Nets model is the contribution of the Modified Atlantic Water on the island plant populations among the Tunisian coast. The model was based on the seed dispersal by hydrocory, which was abstracted by isozyme transfer.The simulation results for 50,000, 100,000 and 200,000 MAW cycles, and the obtained dendrograms did conform to our initial hypothesis. This idea is a predictive approach to study the change of the biodiversity among the

7. REFERENCES

[1] Van Den Broek, T., R. Van Diggelen and R. Bobbink. 2005, "Variation in seed buoyancy of species in wetland ecosystems with different flooding dynamics." Journal of vegetation science. 16: 597-586

[2] Nilsson, C., R.L. Brown, R. Jansson, and D.M. Merritt. 2010, "The role of hydrochory in structuring riparian and wetland vegetation.", Biological Reviews 85:837–858

[3] Pearson RG, Dawson TP, 2003, "Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful?" Global Ecology and Biogeography 12:361-371.

[4] Frankham R., 1997, "Do island populations have less genetic variation than mainland populations?" Heredity. 78, 311-327.

[5] Robinson, A.R., Arango, H.G., Varnas, A.W., Leslie, W.G., Miller, A.J., Haley, P.J., Lozano,C.J, 1996, "Modern approaches to Data Assimilation in Ocean Modelling." P. Melanotte-Rizzoli ed., Elsevier Science B.V.

[6] Manzella, G.M.R., Hopkins, T.S., Minnett, P.J., Nacini, E. 1990, "Atlantic Water in the Strait of Sicily". J. Geophys. Res., 95, C2, 1569-1575.

[7] MedSudMed, 2010, "Sea temperature, salinity and total velocity climatological fields for the south–central Mediterranean Sea." FAO.

[8] Jensen, K. 1987, "Coloured petri nets." Springer Berlin Heidelberg. pp. 248-299

[9] Jensen, K., Kristensen, L. M., & Wells, L., 2007, "Coloured Petri Nets and CPN Tools for modelling and validation of concurrent systems". International Journal on Software Tools for Technology Transfer, 9(3-4), 213-254.