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

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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 extension 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 that 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:

\[
\text{colset Isozyme:= LAp|ADHa|PGMa|I6P Gda|IDHa|GOTa|PGIa|ESTa;}
\]

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 isozyme was considered. The \( b \) allele frequency associated to each isozyme 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 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.

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 1. Island sites in Tunisia.

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>I15</td>
<td>Galite</td>
</tr>
<tr>
<td>I16</td>
<td>Zembra</td>
</tr>
<tr>
<td>I17</td>
<td>Kuriat</td>
</tr>
<tr>
<td>I18</td>
<td>Karkennah</td>
</tr>
<tr>
<td>I19</td>
<td>Djerba</td>
</tr>
</tbody>
</table>

Table 2. Mainland sites in Tunisia.

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

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.

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].

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.

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