THE MID DOMAIN EFFECT IN THE MEDITERRANEAN SEA: DO GEOMETRIC CONSTRAINTS SHAPE FISH DIVERSITY PATTERNS?

David Mouillot [1]* and Frida Ben Rais Lasram [1]
[1] Université Montpellier 2 UMR 5119 - david.mouillot@univ-montp2.fr

Abstract
We challenged the hypothesis that fish richness gradients are simply artefacts of the bounded nature of the Mediterranean Sea (Mid Domain Effect theory). To this aim, we built a new database on the distribution of the 619 Mediterranean fishes and we implemented one dimensional as well as two dimensional MDE null models to predict fish diversity patterns. Our results revealed that a strong MDE is displayed in 1D and that in 2D, the MDE accounted for a non negligible proportion of species richness variation but is not sufficient to explain the diversity pattern in the Mediterranean Sea.
Keywords: Biodiversity, Fishes

Introduction
The foundations underlying fish diversity patterns in the Mediterranean Sea have been overlooked despite the conservation importance of this biodiversity hotspot. One of the most intriguing theories that have been proposed to explain the spatial distribution of species richness is the Mid Domain Effect (MDE). This theory posits that geometric constraints on species range distributions may create patterns in richness without any environmental gradient. The Mediterranean is an "archetypal situation" where we would expect a MDE, so we tested the predictions of the MDE for fish richness spatial patterns in one (longitude and latitude) and two dimensions.

Material and Methods
We created a database on the geographical distribution areas of all known fish species in the Mediterranean Sea using a Geographical Information System software (ArcView3.3). Data on exotic species were compiled by updating the list of the CIESM Atlas [1] and the list of Quignard and Tomasini [2]. For all other species, data were compiled from the primary literature and particularly from the FNAM atlas [3]. The database was used to map the geographical distribution of fish diversity by overlaying range maps of the 619 species to a 0.1° bin grid for one-dimensional analysis and to a 0.1° cell grid for two-dimensional analysis. Species were also classified according to their range extent into small, intermediate and large ranges [4]. Empirical patterns of species richness in one dimension (longitudinal then latitudinal gradient) were compared to the predictions using two null models: the Colwell's model [5] and the Willig & Lyon's model [6]. We also explored the Mediterranean fish species distribution patterns using the null model of Willig & Lyon extended by Bokma et al. [7] in two dimensions. The relative predictive power of the MDE was assessed by a coefficient of determination (R^2) of the regression between the empirical values of species richness and the predicted values of the models.

Results and Discussion
Longitudinally, fish richness patterns are highly asymmetric for the entire species pool and for the "without exotics" pool, and thus differ markedly from mid-domain predictions. At the opposite, the longitudinal gradient of endemic fish richness appears much closer to MDE predictions (R^2=0.69, $p < 0.001$): endemic species richness (especially large ranged species) exhibits a pronounced mid longitude peak consistent with predictions of a simple 1D MDE model between 13.45° and 15.55° of longitude, which corresponds to the middle of the Mediterranean longitude. Latitudinally, agreement between observed and predicted fish richness gradients was weak for the endemic pool while the agreement was very strong for both the entire species and the "without exotics" pools. When all species were considered together, the explanatory power of MDE on latitudinal fish species richness is strongly significant (R^2=0.63, $p < 0.001$). The highest species richness occurs at about 37.85° to 38.15° of latitude, which corresponds to the middle of the Mediterranean latitude. In two dimensions, R^2 were low except for the large range species. Indeed, the MDE explained 38% (p= 0.001) of variation in fish richness for both the entire and "without exotics" pools and 26% ($p < 0.001$) of variations in fish richness for the endemic pool when considering large range species. For large range species, the highest richness values were found around Sicily, northern Tunisia and Sardinia which is consistent with predictions of the 2D MDE model.   Conclusion The Mediterranean Sea can be defined as an archetypical domain where we expect a MDE because this biome is a big domain, is an enclosed area with well defined boundaries, has a high rate of endemic species and has a non negligible proportion of large range species. While a strong MDE is displayed in 1D (both latitudinally and longitudinally), our data on fish species are less consistent with the 2D patterns predicted by the null model: in2D, the MDE accounted for a non negligible proportion of species richness variation but is not sufficient to explain the diversity pattern in the Mediterranean Sea, which corroborates other bi-dimensional studies testing the MDE [8]: other processes such as biological and environmental factors should be considered. However our results suggest that geometric constraints on the locations of large range coastal fish species imply a marked mid-domain peak in species richness, even in the absence of any environmental gradient.

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