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A Model to Predict Dispersion of the Alien Nutria, *Myocastor coypus* Molina, 1782 (Rodentia), in Northern Iran

Azita Farashi[1] & Mitra Shariati Najafabadi[2]

[1]Department of Environmental Sciences, Faculty of Natural Resource and Environment, Ferdowsi University of Mashhad, Iran; E-mail: farashi@um.ac.ir
[2]Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, the Netherlands

Abstract: Nutria (*Myocastor coypus* Molina, 1782) is a semi-aquatic rodent with a native geographical range in South America. It was introduced to Iran at the beginning of the 20th century. The Ecological Niche Factor Analysis (ENFA) was used to describe the realised niche of this invasive species and to predict the area under risk of invasion in Northern Iran using three categories of environmental variables, i.e. topography, land use/land cover and climate. Our results indicated that the spatial distribution of the nutria was highly affected by vegetation density and water resource. Furthermore, about 48.7% of the land area in Northern Iran can be considered as potentially suitable habitat for nutria. The results of ENFA showed that areas with a higher probability of invasion risk were mostly located near the Caspian Sea. The results also demonstrated that 62% of the distribution range of this species was inside the protected areas that could be a threat for the biodiversity of Northern Iran. We sought to identify the areas under risk of nutria invasion that need more attention by conservationists.

Key words: ENFA, invasion, distribution, nutria, *Myocastor coypus*

Introduction

Non-native species can be a big threat for native biodiversity (Wilcove *et al.* 1998; Mooney & Hobbs 2000; Sax & Gaines 2008). Furthermore, it is known that the ecosystems functioning could be changed by non-native species and that they could carry infectious diseases thus endangering native species and human health (Daszak *et al.* 2000; Ehrenfeld 2003). Non-native species are responsible for annual economic losses of billions of dollars per year, since they damage commercial crops and interfere with industrial activities (Pimentel *et al.* 2005). However, lack of knowledge about the expected distribution and the impacts of the species makes the management decisions against a certain invasive species difficult (Strubbe & Matthysen 2009).

Ecological understanding of species distribution has long been sought by ecologist. Species distribution models (SDMs) use correlative statistics to relate geolocated observations of occurrence to environmental variables that contribute to species survival and propagation (Franklin 1995; Guisan & Zimmermann 2000). This relation is based on a wide range of statistical models associating environmental conditions with the ecological niche of a given organism (Austin 2007).

Nutria (*Myocastor coypus* Molina, 1782) is a semi-aquatic rodent, which is native in South America and introduced to Europe, Asia, Africa and North America for fur farming (Carter & Leonard 2002; Bertolino & Genovesi 2007). However, after a while they were established throughout the river banks and in wetlands because many of them escaped and/or were released to the wild. The South American nutria is now considered a pest in the area of introduction, since it had a negative impact on biodiversity, ecological relationships, crop and irrigation systems (Llewellyn & Shaffer 1993; Kaplan *et al.* 1998; Carter *et al.* 1999; Cabral *et al.* 2004; Randall & Foote 2005). At the beginning of the 20th century, the nutria was introduced into the

Middle East (Carter & Leonard 2002) and in 1995 it was recorded for the first time near the border between Iran and Azerbaijan. It was assumed that the nutria entered Iran through this border. Considering the location of Iran in Eurasia and Western Asia, the nutria population in Iran can be a source population to neighbouring countries. This highlights the importance of studies about distribution, invasion trend, habitat selection, and effects of *M. coypus* in Iran. However, our current knowledge about this species still remains extremely poor, although it has been a long time since the nutria has been recorded in Iran.

In this study, we aim to determine the relationship between landscape features with the species ecological requirements and to develop a robust statistical framework for the prediction of the distribution of the nutria in Northern Iran.

Materials and Methods

Study area

We limited our study area to Hyrcanian forests in Northern Iran because previous reports of the nutria presence were limited to Northern Iran. Hyrcanian forests are areas with unique richness of biodiversity due to its endemic and endangered species and their unique environment. North of Iran has diverse natural, economic and social conditions. It is characterised by various ecological conditions with precipitation ranging 550-2200 mm/year, 0-5671 m elevation and various vegetation landscapes ranging from conifers to broadleaved or to Mediterranean plants. These conditions favour great species diversity. Due to its diverse ecological conditions, this area is rich in relict species, with some of them from the Tertiary. The Hyrcanian forests contain some of the most important and significant natural habitats for *in situ* conservation of biodiversity, including those containing threatened species of high value from the point of view of science or conservation. It also contains natural phenomena or areas of exceptional natural beauty and aesthetic importance. It is an outstanding example in the record of significant ongoing geological processes in the development of landforms and significant geomorphic or physiographic features. It is also a valuable example representing significant ongoing ecological and biological processes in the development of terrestrial ecosystems and plant communities (Ramezani *et al.* 2008).

Sample collection

Occurrence data for nutria covering several time periods were collected from two main data sources: (1) collated databases originating from previous field samplings, from regional inventories covering the period 2005–2014 and (2) our own field sampling data recorded in 2013 - 2014. A number of 60 waterways were sampled randomly, each 500 m long and 20 m wide perpendicular from the water to the land. This length corresponds to the optimal size of surveys for muskrat, nutria and beaver territories along waterways (Jouventin *et al.* 1996; Willner *et al.* 1980; Müller-Schwarze & Sun 2003). The minimum distance between the two sites was 3 km, although most sites were separated by at least 5 km.

The variables (Table 1) were subdivided into three categories, i.e. topography, land use/land cover and climate. Topography variables were obtained from a Digital Elevation Model (DEM) generated by the National Cartographic Center of Iran (NCC), scale 1:25000. Vegetation variables were extracted from the Normalized Difference Vegetation Index (NDVI) based on Landsat TM imagery existed at a 28.5 × 28.5 m. Land cover data were obtained from the Iranian Forests, Range and Watershed Management Organization (IFRWO) and Iran Department of Environment. The data were derived from 30 m Landsat Enhanced Thematic Mapper Plus (ETM+) imagery for the conterminous Iran in 2010 (7% forests, 4.7% woodlands, 6.3% irrigated farms, 9.1% dry farms, 42.3% ranges, 5% scrublands, 4.2% rocky land, 18.9% bare land, 2.5% lakes) (Fig. 1). Values of the human density were interpolated from data derived from the Statistical Center of Iran collected in 2011.

Data analysis

We used the Ecological Niche Factor Analysis (ENFA) to predict the expansion range of nutria in Northern Iran. ENFA (Biomapper v4.0) transforms a number of correlated environmental variables into the niche factors (Hutchinson 1957). The first of the extracted ENFA factors maximises the absolute value of the marginality of the species, defined as the ecological distance between the species optimum and the mean available habitat. The higher the coefficient absolute value is, the farther the species distribution departs from the mean available habitat for that particular variable. The positive coefficients indicate a higher preference with high values and the negative coefficients indicate a higher preference for the mean values. The remaining factors (i.e. the species specialisation) were defined as the ratio of the ecological variance of the available habitat to that observed for the species. The higher positive or negative specialisation values indicate the species distribution is more narrowly focused with regard to the corresponding variable (Hirzel *et al.* 2002). The ENFA factors are also used to compute global mar-

Table 1. Scores of the habitat variables on the first three factors of the ENFA for the nutria in Northern Iran

Variable	**Factor 1**	**Factor 2**	**Factor 3**
	82.400 % Specialisation	4.600 % Speciali-sation	4.000 % Speciali-sation
Topography variables			
Altitude	0.224	0.439	- 0.221
Slope	0.125	0.437	0.265
Climatic variables			
Annual mean temperature (°C)	0.094	0.032	0.653
Mean temperature of coldest quarter (°C)	0.579	0.374	0.342
Annual precipitation (mm)	0.182	0.051	0.113
Land use/land cover variables			
Distance of settlements in urban area	- 0.144	0.820	0.031
Distance of settlements in rural area	- 0.051	0.041	0.371
Human population density in urban area	- 0.094	0.089	0.051
Human population density in rural area	- 0.179	0.262	0.089
Distance from road	0.182	- 0.147	0.142
Distance from stream	**0.826**	0.147	- 0.127
Distance from river	**0.714**	0.055	0.092
Distance from lake	**0.619**	- 0.077	0.141
Distance from dry farm	0.095	0.578	0.679
Distance from irrigated farm	0.003	0.181	0.020
Distance from forest	0.216	0.346	0.615
Distance from woodland	0.216	0.042	0.221
Distance from scrubland	0.226	- 0.074	0.034
Distance from range	0.057	0.014	-0.023
Distance from bare	0.092	0.215	- 0.074
Distance from rocky area	0.079	- 0.386	0.013
Distance from protected area	0.082	0.361	0.342
NDVI	**0.913**	0.241	0.375
	Marginality: 1.50, Tolerance: 0.25		

ginality (M, indicating some degree of marginality when greater than 1), specialisation (S, varying generally from 0 to ∞), and global tolerance that is the inverse of specialisation (T, varying generally from 0 to 1; Hirzel *et al.* 2002, 2004). In the present study, a certain number of factors were retained to produce the nutria distribution map based on a comparison with MacArthur's broken stick distribution (Hirzel *et al.* 2002). The median, harmonic mean, and geometric mean algorithms were applied to estimate the nutria distribution map.

To assess the robustness and the predictive power of a HS model, ENFA uses the novel continuous Boyce index, ExS and ExI (Hirzel *et al.* 2006, 2002) with their value ranging between 0 and 1 (the closer to 1, the better the model). The novel continuous Boyce index is an independent threshold modification of the Boyce index (Boyce *et al.* 2002) measuring the relation between the observed and expected number of validation points for different HS values. The continuous Boyce index yields a smooth curve. By applying a k-fold cross validation, k estimates of the continuous Boyce index are produced allowing the assessment of its central tendency and variance (Hirzel *et al.* 2006). The advantage of the continuous Boyce index is that it provides guidelines for choosing the number of HS classes and their boundaries that give the most consistent prediction of HS (see Strubbe & Matthysen 2009).

Results

In total, 141 presence points of the nutria were recognised. The collated databases contained around 800 sites which were reduced to 100 sites after a detailed quality check for the reliability of the biological and spatial information, and 41 presence points were scanned by field sampling.

The results of model evaluation showed that the harmonic mean algorithm had a higher accuracy (median: 72±0.09, harmonic mean: 82±0.03 and geometric mean: 74±0.12). The results of ENFA trans-

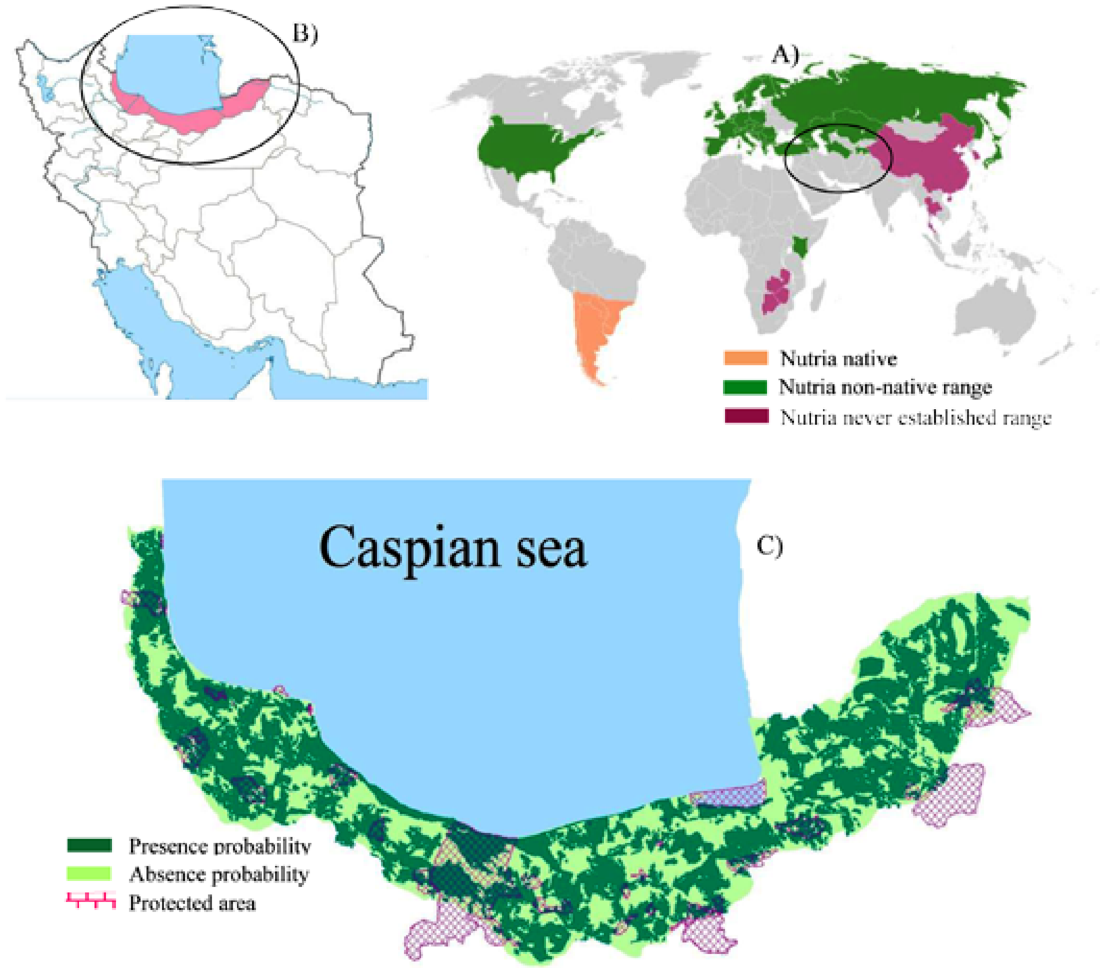

Fig. 1. Distribution of *Myocastor coypus* in its native and invasive geographical range (A), the studied region in Northern Iran (B) and a model predicting its distribution in Hyrcanian Forests (C)

formation are presented in Table 1. The first three factors were retained based on a comparison with the broken-stick distribution of the invasion prediction accounting for 91% specialisation variance of nutria distribution in Northern Iran. Moreover, the first factor explained 100% marginality of nutria distribution. The first factor also showed the importance of each environmental variable for the nutria distribution (Table 1). The probability of nutria occurrence is shown in Fig 1. We demonstrated that a large part of Northern Iran is a suitable habitat for the nutria.

Discussion

Our results show that vegetation density (through vegetation proxy NDVI) is the most important environmental variable for distribution of nutria. The vegetation cover provides shelter and food to nutria. The predictive power of NDVI increases when we combine it with water resources (e.g. rivers and streams), since the latter is also one of the most important environmental variables in the distribution of the species. Our results show that the suitable habitats overlapped with rivers. Many researchers pointed out the importance of vegetation cover (Hong *et al.* 2014; Farashi & Shariati Najafabadi 2015) and water resources (Doncaster & Micol 1990; Reggiani *et al.* 1995; Carter & Leonard 2002; Hong *et al.* 2014; Farashi & Shariati Najafabadi 2015) for the distribution of this species.

The potential distribution map of the nutria shows that 48.7% of Northern Iran can be considered as suitable habitats. Also, it reveals that the lowland plains are preferred by this species as compared to the mountainous regions. Further, we identify new areas as suitable habitats for this species in Northern Iran. According to this model, some areas are at the risk of invasion, although no incidence was recorded. Thus, these areas need further attention.

Protected areas are the foundation for most national conservation policies. Accordingly, governments around the world have made commitments to establish systems of protected areas that conserve viable representations of terrestrial, freshwater, and marine ecosystems (Jenkins & Joppa 2009). We found that 62% of the distribution range of *M. coypus* was inside the protected areas. This might be a serious threat for biodiversity. The areas which are at invasion risk in the future need more attention to be paid by conservationist and wildlife managers.

The high values of the continuous Boyce index (82 ± 0.03) indicate a reliable map with a high predictive power. Global marginality and specialisation indicated that nutria was more inclined to inhabit marginal landscapes. Moreover, it can be considered as a specialised species in the area, since it occupied a narrow niche.

Although ENFA is a very powerful method, it has some limitations. ENFA as presence-only models, it might result in weaker predictions in comparison with the presence/absence models. In fact, the prediction results of ENFA cannot be compared with the characteristics of sites where the species is absent. Although assessing the predictive power of a model is of paramount importance both for theoretical and applied issues, evaluation of presence-only models is lagging behind. However, it is not the case for presence/absence models, since they have received a lot of attention from many evaluators (Hirzel *et al.* 2006).

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