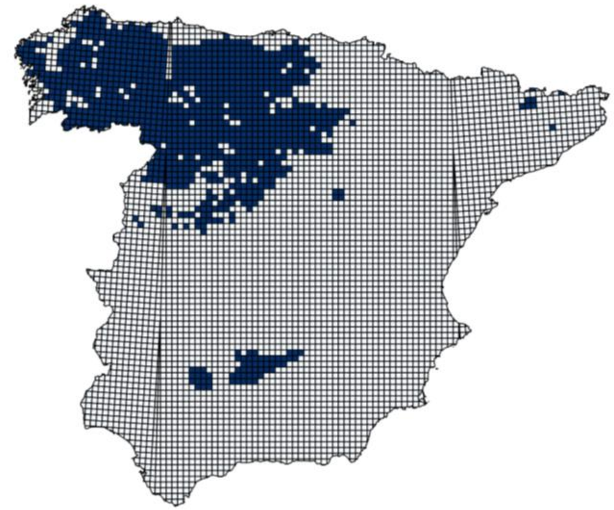
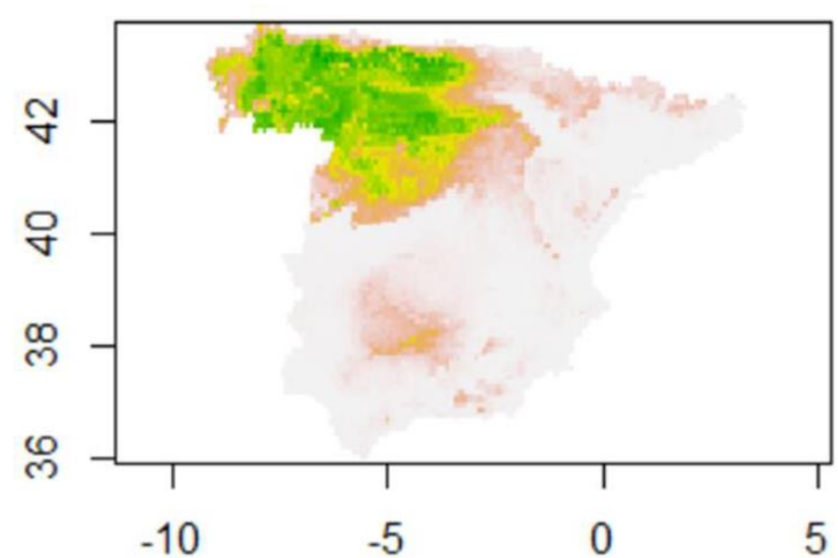
Fuzzy conservation metrics: richness, rarity, vulnerability, endemicity

Occupancy and entropy

Area of occupancy: sum of localities with presence for one species



Fuzzy area of occupancy: sum of favourabilities for all localities for a single species



Occupancy and entropy

Entropy reflects the **uncertainty** associated with a probability distribution, and represents the degree of **disorganization** of a system.

Entropy is **intrinsic** to the **geographical distribution of a species**.

With maximum entropy, the distribution of the species is completely disordered, i.e., the probability of occurrence is equally distributed in the entire territory. The smaller the entropy, the more orderly the distribution of the species is, i.e., more clearly suitable and unsuitable areas are distinguished.

Occupancy and entropy

Fuzzy entropy -> Fuzzy sets (favourability)

$$R = \frac{\sum_{i=1}^{n}\left(F_i \cap F_i^c\right)}{\sum_{i=1}^{n}\left(F_i \cup F_i^c\right)}$$

Fuzzy entropy has values between zero and one. If fuzzy entropy is one, the distribution of the species is completely disordered, i.e., favourability is equally distributed in the entire territory with F_i = 0.5. The smaller the entropy, the more orderly the distribution of the species is, i.e., the model more clearly distinguished between presences and absences.

Results are commensurable between species even if the entropy is calculated in different study areas.

Occupancy and entropy

Fuzzy entropy -> Fuzzy sets (favourability)

$$R = \frac{\sum_{i=1}^{n} \left(F_i \cap F_i^c \right)}{\sum_{i=1}^{n} \left(F_i \cup F_i^c \right)}$$

INFORMATION SCIENCES **40**, 165–174 (1986)

Fuzzy Entropy and Conditioning

BART KOSKO

VERAC, Incorporated, 9605 Scranton Road, San Diego, California 92121

Communicated by Lotfi Zadeh

entropy MDPI

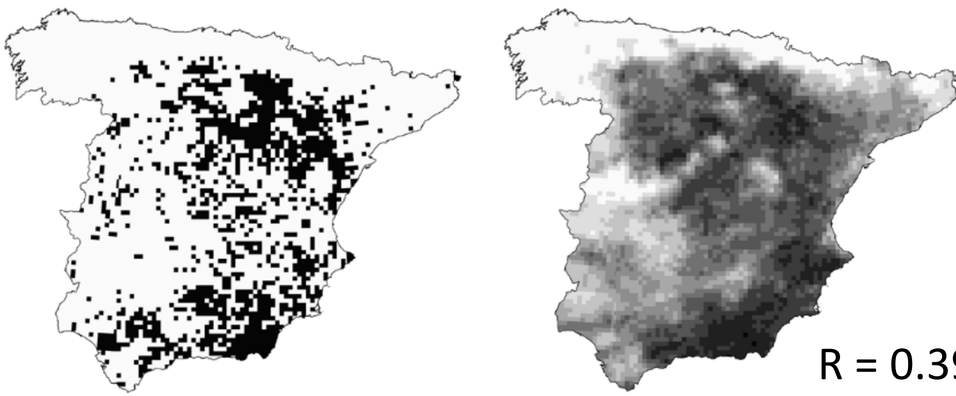
Article

A Stepwise Assessment of Parsimony and Fuzzy Entropy in Species Distribution Modelling

Alba Estrada * and Raimundo Real *

Occupancy and entropy

Fuzzy entropy -> Fuzzy sets (favourability)

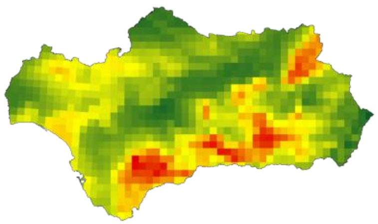


R = 0.394

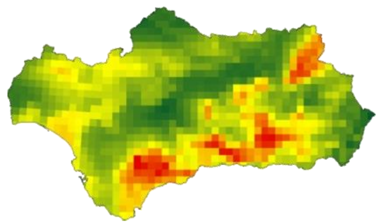
R = 0.00848

Combination of models

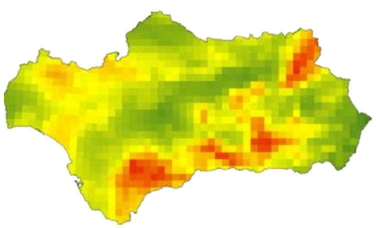
Important areas for mammals after aplying different conservation criteria and fuzzy logic



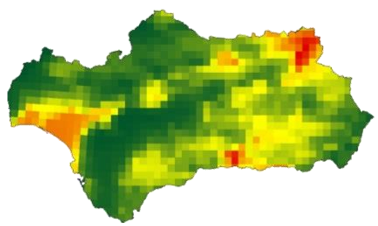
Richness



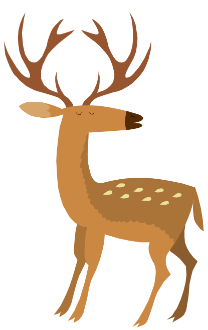
Rarity



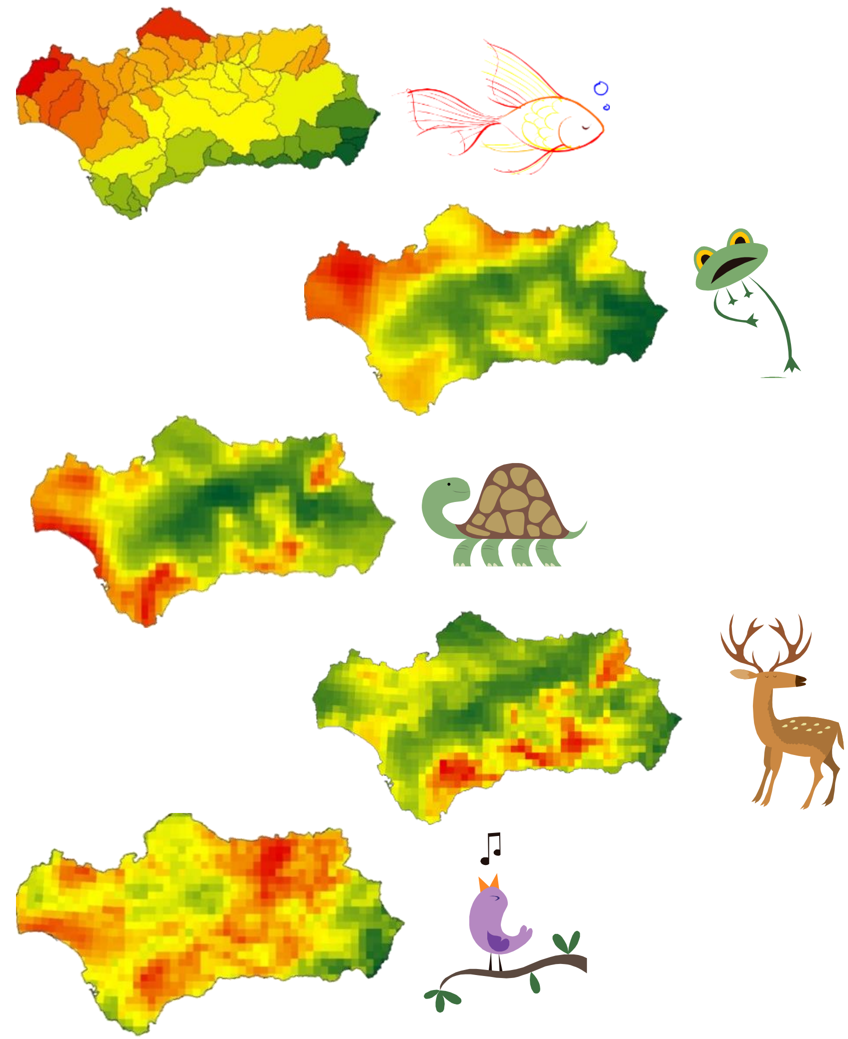
Vulnerability



Endemicity



Important areas for vertebrate groups



Estrada *et al.* 2011. *Biological Conservation*, 144: 1120-1129.

Combination of models

species richness: sum of species present

fuzzy species richness: sum of favourabilities for all species

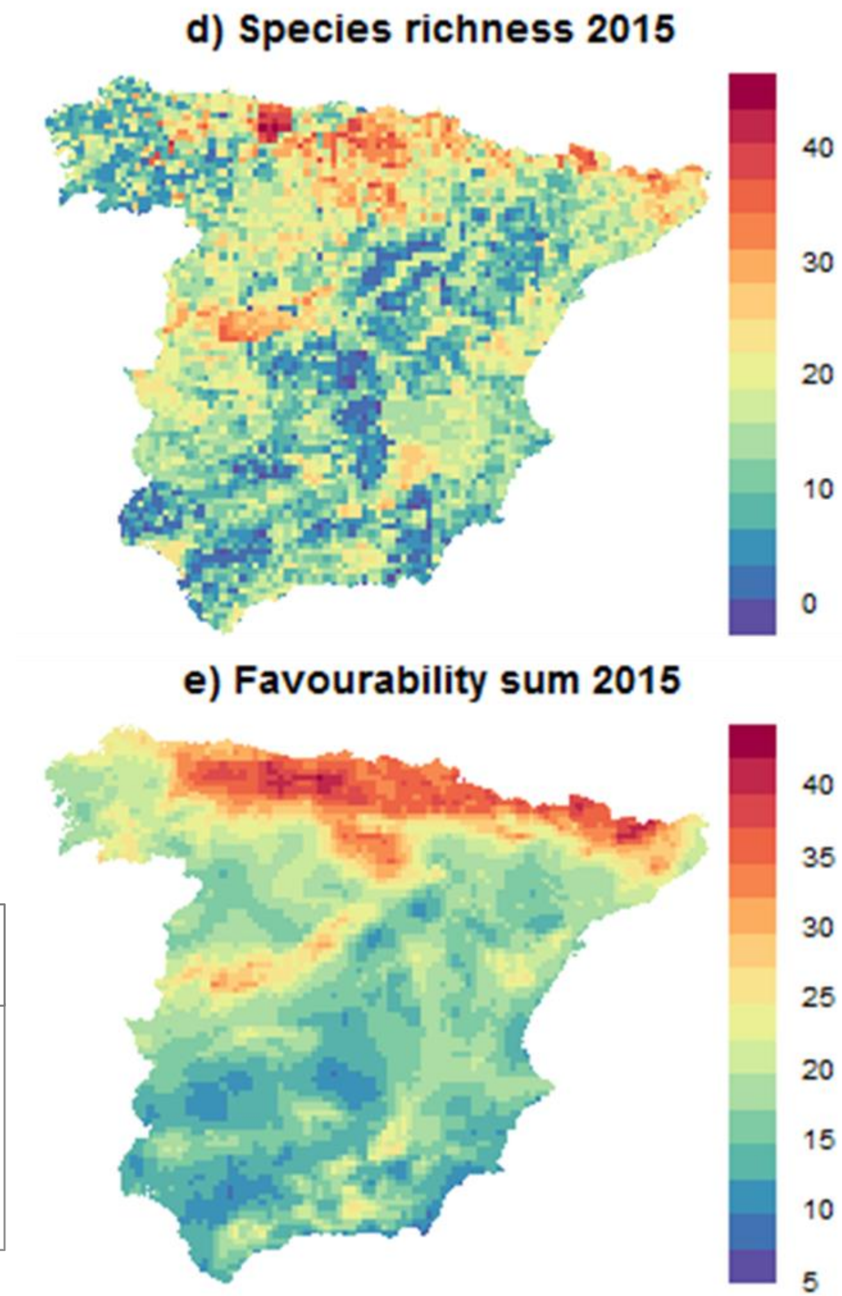
- varies more smoothly (more realistic)
- reduces survey bias (lower correlation with survey effort)

Points of View

Species Distributions, Quantum Theory, and the Enhancement of Biodiversity Measures FREE

Raimundo Real, A. Márcia Barbosa, Joseph W. Bull

Systematic Biology, Volume 66, Issue 3, May 2017, Pages 453–462, https://doi.org/10.1093/sysbio/syw072



Combination of models

F_{ij} is the favourability value for a species **i** in a cell **j**

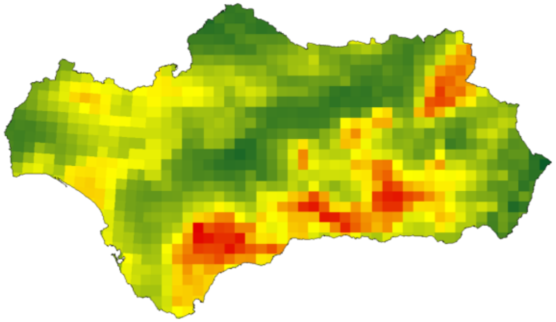
Total number of species is **n**

Total number of cells is **m**

Fuzzy richness

$$FRi = \sum_{i=1}^{n} \left(F_{ij} \right)$$

 +  +  + …

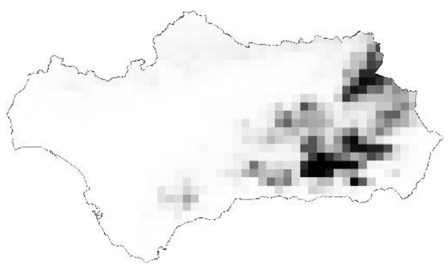
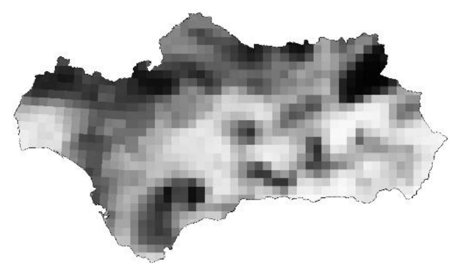


Combination of models

Fuzzy rarity

Rare species (those with narrower distributions) will have more weight

Rarity value for each species: $$Ra_i = \frac{1}{\sum_{j=1}^{m}(F_{ij})}$$


Rarity index for all the species:

$$FRa = \sum_{i=1}^{n}\left(F_{ij} \times Ra_i\right)$$

Combination of models

Fuzzy vulnerability

Threatened species will have more weight

Score of vulnerability according to IUCN criteria:

16 for critically endangered species (CR)
8 for endangered species (EN)
4 for vulnerable species (VU)
2 for near threatened species (NT)
1 for least concern (LC) and data-deficient species (DD)
0 for not evaluated species (NE)

$$\mathrm{V}_i$$

16

$$FV = \sum_{i=1}^{n} \left(V_i \times F_{ij} \right)$$

Combination of models

Fuzzy endemicity

It is a fuzzy richness only applied to endemic species of a region

$$FE = \sum_{i=1}^{n} \left(F_{ij} \right)$$

Total number of endemic species

E.g. some species endemic to the Iberian Peninsula:

 +  + 

Combination of models

Combination of indexes

Richness + Rarity + Vulnerability + Endemicity

But... using fuzzy logic operations: Intersection and Union

Re-scaled indexes between 0 and 1 by dividing the values of each index by the maximum value

Intersection represents the areas that are simultaneously favourable for a set of criteria, and is computed in each locality as the minimum value

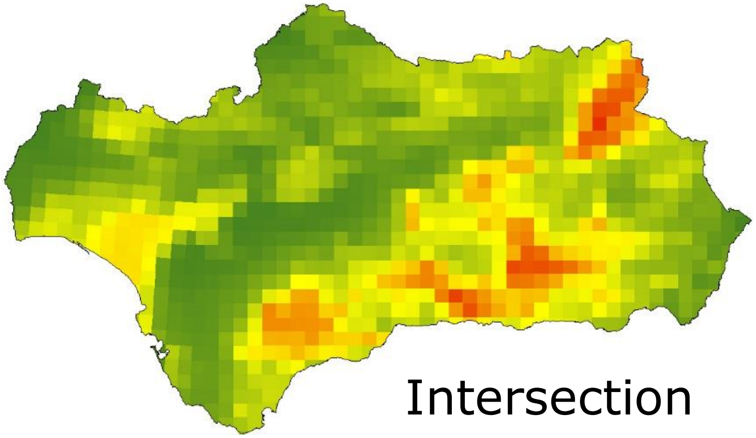
$$I = FRi \cap FRa \cap FV \cap FE = \min(FRi, FRa, FV, FE)$$

Union represents areas favourable for at least one criterion and is computed as the maximum value

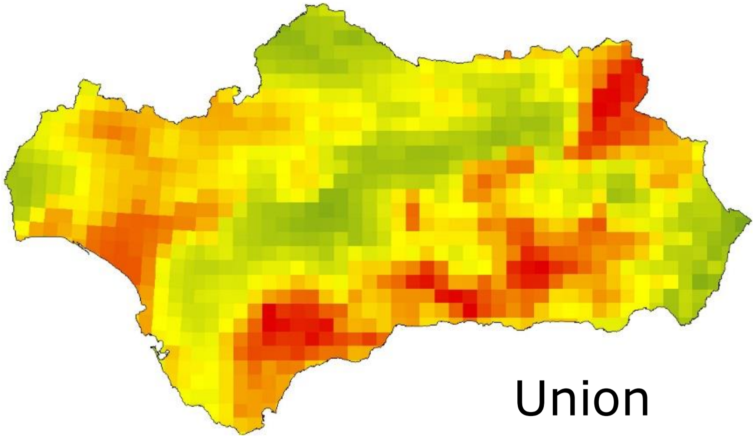
$$U = FRi \cup FRa \cup FV \cup FE = \max(FRi, FRa, FV, FE)$$

Combination of models

Combination of indexes



Intersection



Union

PRACTICAL

```
# crisp and fuzzy area of occupancy:

sum(dat[ , "Muslut"], na.rm = TRUE)

sum(dat[ , "Muslut_F"], na.rm = TRUE)


# crisp and fuzzy species richness:

dat$SR <- rowSums(dat[ , spc_cols])

dat$SR_fuzzy <- rowSums(dat[ , fav_cols])


# fuzzy entropy:

entropy(dat, fav_cols) # the fuzzier the values (i.e.,
the farther from 0 or 1), the higher the entropy
```

PRACTICAL

```
# crisp and fuzzy rarity:

# you can get individual rarity for each species:

ra <- sapply(dat[ , spc_cols], rarity)

ra_fuzzy <- sapply(dat[ , fav_cols], rarity)



# and you can compute rarity across the data to map it:

dat$rarity <- rarity(dat, sp.cols = spc_cols)

dat$rarity_fuzzy <- rarity(dat, sp.cols = fav_cols)
```

PRACTICAL

```
# crisp and fuzzy vulnerability:

# first, get the IUCN Red List category for each species:
Muslut_cat <- 16  # CR (https://www.iucnredlist.org)
Lutlut_cat <- 2  # NT (https://www.iucnredlist.org)

# then, compute vulnerability across the dataset:
dat$vulnerability <- vulnerability(dat, c("Muslut",
"Lutlut"), categories = c(Muslut_cat, Lutlut_cat))

dat$vulnerability_fuzzy <- vulnerability(dat,
c("Muslut_F", "Lutlut_F"), categories = c(Muslut_cat,
Lutlut_cat))
```