



FUZZYQ: A TOOL TO MEASURE RARE SPECIES AND PRESERVE BIODIVERSITY

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YOUNG REVIEWERS



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Surprisingly, most species on Earth are rare, meaning that they exist in small numbers, and only a few are common, meaning that they are abundant and widespread. Monitoring rare species is very important because they are more vulnerable to environmental disturbances. In addition, many rare species may have unique functions in ecosystems, that we still do not understand well. Scientists need tools to tell how species rarity changes over time and across large areas. We developed an application called FuzzyQ (which stands for Fuzzy Quantification of common and rare species in ecological communities) to do that. FuzzyQ examines how individuals of each species are distributed and provides a measurement of the rarity of

each species. With FuzzyQ, we can monitor how the rarity of species changes over time or across large geographical areas. So, FuzzyQ can supply crucial information for the conservation of rare species.

BIODIVERSITY

The variety of life on Earth. Biodiversity includes the variety of genes, the variety of species, and the variety of ecosystems.

ECOLOGICAL COMMUNITY

The various populations that interact with one another in an area. For example, a pond community contains fish, plants, shrimps, frogs, insects, and many other tiny organisms.

Figure 1

Example of a fish community. A few species are common, meaning there are lots of individuals of that species present in the community, and most species are rare, meaning there are few of them present in the community. Can you tell how many species are common and how many are rare in this image? (Image credit: freepik.com).

FINDING REGULARITIES IN AN IRREGULAR WORLD

Ecology is a field that involves studying how living things interact with each other and with their environments. We need ecology to understand the way nature works. The study of ecology also helps us to produce healthy food, maintain clean air and water, and sustain **biodiversity**, which is the variety of life on Earth. Ecologists strive to find regular patterns in the data they collect from nature, so that they can understand nature better. A better understanding of nature helps scientists to make more accurate predictions about the impact of threats to biodiversity (such as climate change). Finding regular patterns is not easy because environments differ, and organisms are amazingly diverse. So patterns are like hidden treasures for ecologists. However, one of the patterns that we find over and over again in nature is that, in any **ecological community**, most species are rare, meaning that they exist in small numbers, while a few species are common, meaning that they are abundant and widespread (Figure 1) [1].

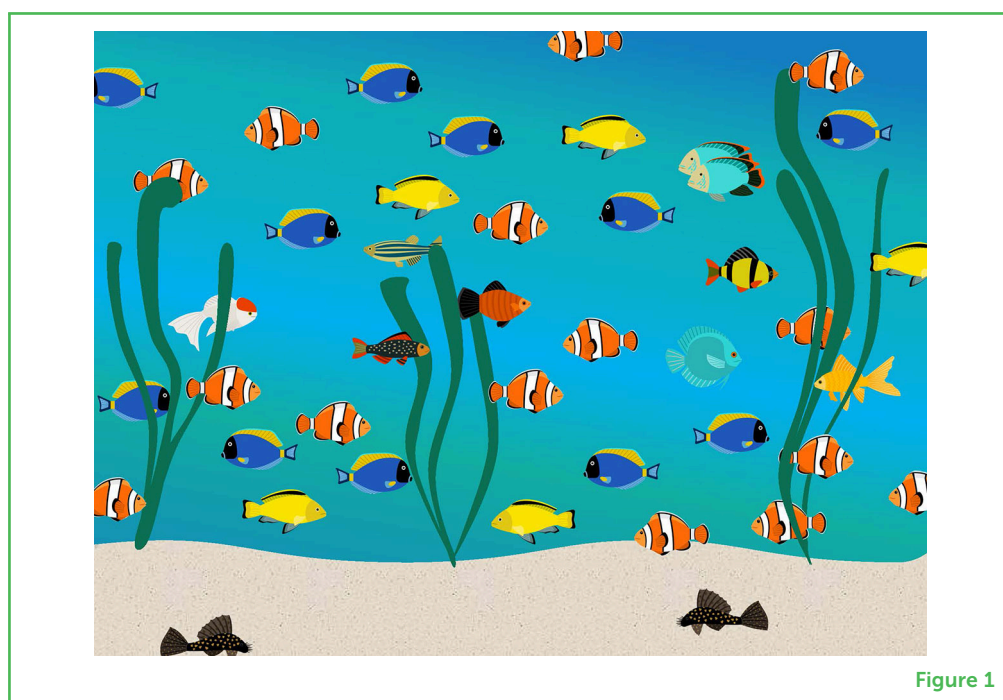


Figure 1

POPULATION

All individuals of the same species living in an area. For example, all gorillas living in the same forest form a population.

WHY ARE RARE SPECIES IMPORTANT?

So, somewhat surprisingly, it seems that most species on Earth are rare! Should we care about those rare species? The answer is yes! Small, rare **populations** are more sensitive to environmental

disturbances, like fires, flooding or pest outbreaks so rare species are at higher risk of extinction. We need to monitor rare species closely to ensure that their populations remain healthy. Keeping track of the changes in populations of rare species over time or across geographic areas is important because it will help us better evaluate the effects that environmental changes might have on ecosystems. In addition, we know that species play specific functions in ecosystems. For instance, pollinator insects make the reproduction of many plants possible. Likewise, plants growing on wetlands protect the land against floods and storms. Rare species may be responsible for unique functions. So, their extinction could have a big impact on their ecosystem.

OCCUPANCY

Number or proportion of sites where a species occurs.

ABUNDANCE

The total number of individuals of a species in an area.

HARD CLUSTERING

Statistical technique to group things that assigns each thing to one group and only one group.

FUZZY CLUSTERING

Statistical technique to group things that assigns each thing to more than one group in different proportions.

WHAT MAKES A SPECIES COMMON OR RARE?

Since rare species are so important, we need ways to tell how rare a species is. This may seem easy, but ecologists have argued about it for years. There still is not 100% agreement on the characteristics that make a species rare. However, two properties are usually involved: **occupancy** and **abundance** [2]. Imagine we survey an ecological community over several sites (called quadrats). Rare species should show both low abundance (few individuals in the entire area) and low occupancy (few sites occupied) (Figure 2). So, we attempted to classify species based on these features. However, we felt that classifying species simply as “rare” and “common” did not give us enough information to grasp how ecological communities are organized. Look, for example, at species *c* in Figure 2B. It was classified as rare, but it falls quite far from the rest of the rare species on the graph, does not it? We need to take the actual numbers into account to understand how rare a rare species is. Science works best with things that can be measured as numbers.

LOOKING AT THE NUMBERS

Mathematicians have developed methods to group things using complicated equations, which are called clustering techniques [3]. There are two types: **hard clustering** and **fuzzy clustering**. In Figure 2B, we used a hard clustering technique with the occupancy and abundance data. Hard clustering assigns each item to one—and only one—of the categories considered. So, each species is either common or rare. In Figure 2C, we applied fuzzy clustering to the same data. In fuzzy clustering, each species is common and rare at the same time, but in different proportions. For example, species *c* is 71% rare and 29% common. All the other rare species are over 95% rare. So, we can say that *c* is rare, but *d*, *e*, *f*, and *g* are rarer than *c*.

Figure 2

(A) To survey plant species (a to g), we divided the study area in 18 quadrats. Then we determined the number of quadrats occupied by each species (occupancy) and the total number of individuals of each species in the entire area (abundance). (B) Plot of occupancy and abundance of each species, based on the data from the 18 quadrats. A math technique called hard clustering was used to distinguish common from rare species. (C) Plot showing the results of another math technique called fuzzy clustering. The numbers indicate the percentage of rarity of each species (Image credit: freepik.com).

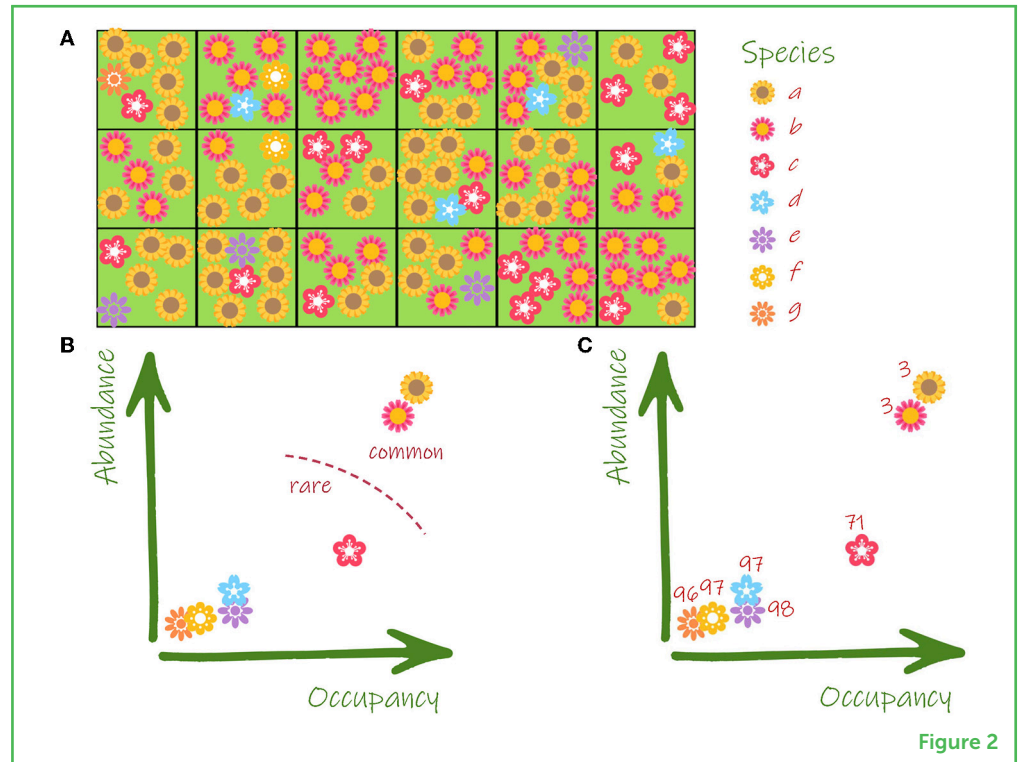


Figure 2

OUR BRAINCHILD

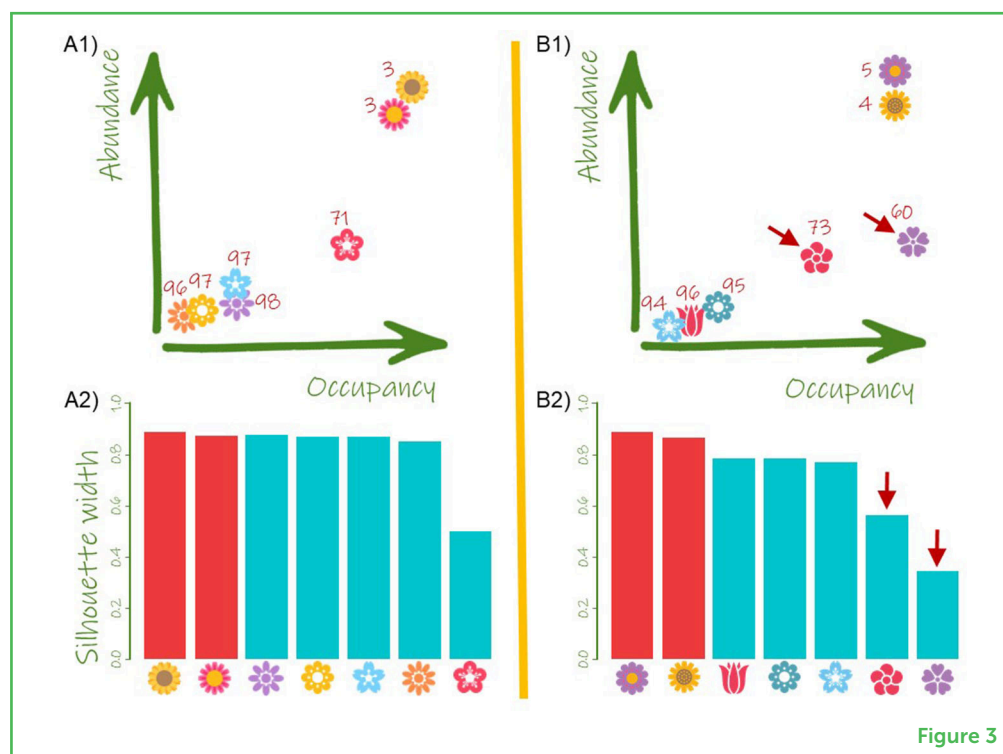
These ideas lead us to develop our own computer application to characterize ecological communities. We called it FuzzyQ, which stands for “fuzzy quantification of common and rare species in ecological communities.” We wrote it in a programming language called R. We chose R because it is a free software for statistics and graphics that anyone can use [4].

In addition to performing a fuzzy clustering of species, FuzzyQ does other cool things. For instance, it computes numbers called silhouettes (Figure 3). Silhouettes measure how well each species matches its own cluster (formed by either rare or common species). Values close to one indicate a good fit of the species to its own cluster. In Figure 3B2, two rare species (indicated with arrows) show low silhouettes because they had low abundance but fairly large occupancy (Figure 3B1). So, they are not as well-separated from the common species as the other rare species are. Overall, the silhouettes of the community in Figure 3A2 show a clearer separation between common and rare species than the community studied in Figure 3B2.

Silhouette plots allow us to easily compare communities, even if the species in each community are different. Using silhouette plots, we can compare environmental changes over very large areas. For example, birds in a savannah in Africa are quite different from birds in a meadow in Europe, but we can compare the two bird communities using

Figure 3

Silhouette plots are used to compare communities. **(A1)** Plot of abundance and occupancy of the plant community studied in Figure 2 and **(A2)** its respective silhouette bar plot. **(B1)** Plot of abundance and occupancy of a different community of plants and **(B2)** its respective silhouette plot. The numbers in **(A1,B1)** indicate the percentage (%) of rarity of each species. Silhouette plots are another way to show how common (red) or rare (blue) species are in each community. The arrows point to two rare species with high occupancy, which accounts for low silhouette values (Image credit: freepik.com).



the species silhouettes by observing how common and rare species separate in each community.

FUZZYQ CAN HELP PRESERVE RARE SPECIES

Major threats to biodiversity, such as global warming and takeover by **invasive species** [5], are important to study because they can disrupt ecological communities. Rare species are especially vulnerable to environmental changes. FuzzyQ can supply crucial information on how changes that happen within ecosystems can affect rare species. This application provides a simple way to monitor variation in species rarity over time or across large areas. In addition, it is simple to use and free. So, FuzzyQ can be a very valuable tool for scientists to help conserve rare species and protect Earth's ecosystems from the effects of environmental disturbances.

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INVASIVE SPECIES

A species that is moved from its native area, where it grew naturally, into a new area where it usually causes harm to the species of the new area.

ORIGINAL SOURCE ARTICLE

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I. C. VAL RENDENA, AGE: 14

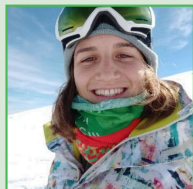
We are a small class going to a school in the middle of the Dolomites in the northern part of Italy. This is our last year at the secondary school, so we are enjoying this last year together. The most of us love skiing and snowboarding in the winter and hiking during summer time. We have a cool science teacher who loves nature and she teaches us about biodiversity, climate change so science is not a boring subjects for us, we learn a lot about our Earth and the big problem that concerns pollution and climate change. Having been reviewers for the article let us understand better how a scientist works and the impact of our actions on our Earth.

AUTHORS



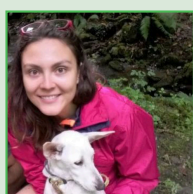
JUAN A. BALBUENA

Since I was a kid, I have been fascinated by animals and living things in general. This led me to study biology. I specialized in zoology and later got a Ph.D. in parasitology. Currently, I am an associate professor at the University of Valencia (Spain). I love my job immensely, as it lets me do exciting research and teaching. In later years, I have been very keen on applying mathematics to study various biological problems. In my opinion, maths and biology make a cool combination. Outside academia, I love swimming, music, reading, and learning foreign languages. *balbuena.ja@gmail.com



CLARA MONLLEÓ-BORRULL

Hi! I am Clara Monlleó-Borrull and I am from Reus, Catalonia. I have always enjoyed being outdoors and I love nature and animals, that is why I decided to study environmental biology in Barcelona. After that, I specialized in zoology, and I had the opportunity to work as a trainer of marine mammals in L'Oceanogràfic of Valencia. This year, I have finished my studies to teach in secondary school and I am really excited about that! I spend my free time reading fantasy novels, drawing, and practicing outdoor activities.



CRISTINA LLOPIS-BELENQUER

Since I was a child, I have had a clear vocation for the natural environment and living beings. This passion drove me to become a biologist. During my Ph.D. thesis in biodiversity, I was delighted by the hidden world of parasites and the countless processes they take part in in ecosystems when interacting with free-living species. I also enjoy teaching and outreach activities. In my leisure time, I love spending time close to the sea and taking long walks in the mountains with Foca (with me in the picture).



ISABEL BLASCO-COSTA

As a kid, my favorite toys were the little animals I could catch and observe, like snails, little fish, or frogs. I feel lucky because as a grown up I still get to learn from the big secrets they hide inside... their parasites! I am a research scientist and curator at the Natural History Museum of Geneva. I discover new parasite species and investigate their evolution (how they came to be) and ecology. I enjoy telling parasite secrets to

the museum visitors and to my students at the university. Otherwise, you can find me on the mountains.



VOLODIMIR L. SARABEEV

Since I was young, my life has revolved around research in a biological station on the Azov Sea, where I study the introduction and expansion of the so-iuy mullet. I was fascinated by parasite biodiversity and parasitic life forms that influenced my job choice. I got a Ph.D. in parasitology and a research leadership qualification in life sciences and health. I am an associate professor at the Zaporizhzhia National University (Ukraine), but currently, I have a grant from the Polish National Agency for Academic Exchange, to perform a research project on parasites of invasive amphipods in the Pomeranian region of Poland.



SERGE MORAND

When I was kid, I wanted to be explorer, veterinarian, or biologist. My dream has come true. Now, I am a disease ecologist working on biodiversity and health in tropical ecosystems. As a senior scientist at the French CNRS, I am currently based in Southeast Asia, where I conduct fieldwork on zoonotic diseases in wildlife and local communities. I also like writing popular science books.