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Perspective

Dragging into the open: the polythetic nature of areas of endemism

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Areas of endemism represent territories (no matter the size) of non-random overlap in the geographic distribution of two or more taxa, reflecting a common spatial history of these taxa. The common spatial history is a result of different processes that connect areas of endemism to evolutionary theory. Numerous and diverse definitions of areas of endemism have been proposed. All of them have used as the conceptual foundation of the definition a certain degree of non-random congruence of geographic distribution amongst at least two taxa. 'Certain degree' means that geographic congruence does not demand complete agreement on the boundaries of those taxa's distributions at all possible scales of mapping. The words 'certain degree' mask the polythetic nature of areas of endemism. The polythetic characterization of areas of endemism implies that each locality of the study area has a large number of a set of species. Each species of this set is present in many of those localities and, generally, none of those species is present in every locality of the area. The converse will be a monothetic nature of areas of endemism where a taxon or group of taxa is present in all the localities of the study area. We propose here that the expansion of the definition of areas of endemism, including their polythetic characterization, will improve understanding of large biogeographic areas such as realms, regions, provinces, and districts, and will increase the scientific content (e.g., predictive capability and explanatory power) of areas of endemism.

Keywords: areas of endemism, evolutionary theory, geographic distribution congruence, historical biogeography, monothetic grouping, polythetic grouping, spatial history

It is hazardous to think that a coordination of words … can have much resemblance to the universe. It is also hazardous to think that of those … coordinations, one – albeit in an infinitesimal way – might resemble it a little more than the others.
J. L. Borges. Avatars of the tortoise. 1983.

Introduction

Areas of endemism are widely recognized as a main concept in biogeography (Crisci, Katinas, & Posadas, 2003; Lomolino, Riddle, Whittaker, & Brown, 2010). They represent territories (no matter the size) of non-random overlap in the geographic distribution of two or more taxa, reflecting a common spatial history of the taxa. The hypothesis of 'a common spatial history' generating a distributional pattern connects the concept of areas of endemism with evolutionary theory. The definition (and as a consequence of it, its delimitation) of areas of endemism is central to biogeographic historical regionalization (Crisci, Katinas, & Posadas, 2000), historical biogeographic studies (Linder, 2001), and biodiversity conservation (Riddle, Ladle, Lourie, & Whittaker, 2011).

The botanist Augustin P. de Candolle (1820) presented the first definition of areas of endemism (1820, translated by Nelson, 1978):

From all these facts, one may deduce that there are botanical regions; and by this term I denote whatever areas that, with the exception of introduced species, have a certain number of plants that to them are a peculiar, and that can be called truly aboriginal.

In 1858 the zoologist, Philip Sclater (1858, p. 131) made some interesting remarks about what we currently call areas of endemism: '*two or more of these [bio]*

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geographical divisions may have much closer relations to each other than to any third.'

Implicit in Sclater's assertion is that areas of endemism are interrelated in a specifiable way. The specifiable, he suggests is currently the foundation of the hierarchical structure of areas of endemism, reflected in the regionalization using a hierarchic organization such as: realms, regions, provinces, districts.

Numerous and diverse definitions of areas of endemism have been proposed using sympatry as the main criterion (e.g., Anderson, 1994; Axelius, 1991; Giokas & Sfenthourakis, 2008; Humphries & Parenti, 1999; Linder, 2001; Morrone, 1994; Müller, 1973; Noguera-Urbano, 2017; Platnick, 1991; Platnick & Nelson, 1984; Riddle, 1998; Riddle & Hafner, 2006; Szumik & Goloboff, 2004). Other criteria have been proposed as complements to sympatry, for example:

1) The existence of barriers delimiting the area of endemism (Hausdorf, 2002).
2) The use of phylogenetic information, where an area of endemism is a geographic region comprising the distribution of two or more monophyletic taxa that exhibit a phylogenetic and distributional congruence and whose respective relatives occur in another defined region (Harold & Mooi, 1994). Recent attempts at regionalization using, besides the geographic distribution, the phylogenetic information of the taxa involved (e.g., Holt et al., 2013), reflect the implicit application of this complementary criterion to the definition of area of endemism.

One can assert, however, that all of the definitions use as the conceptual foundation a certain degree of non-random congruence of geographic distribution amongst at least two taxa. The words 'certain degree' imply that geographic congruence does not demand complete agreement on the boundaries of those taxa distributions at all possible scales of mapping (Morrone, 1994). More importantly, these two words implicitly convey the polythetic nature of areas of endemism.

A polythetic group shares a great number of features where no single feature or set of features is sufficient or necessary for membership in the group. The converse, a monothetic group, is defined by the possession of a unique feature or a unique set of features that is both sufficient and necessary for membership in the group. If we apply the concepts of polythetic and monothetic grouping in biogeography, 'feature' means species (or any other taxa of different Linnaean category) inhabiting localities of a given area.

It could be most useful to recognize the polythetic nature of areas of endemism in their definition. This recognition will provide:

– a better understanding of the nature of areas of endemism,
– a tool for operational methods of areas of endemism discovery,
– a way to frame scientific questions regarding areas of endemism, and
– a tool for researchers to structure and articulate more thoroughly historical biogeographic problems.

It is not our intention to discuss the different definitions of areas of endemism (see Noguera-Urbano, 2016 for such a discussion). Instead, we will take the common basis of all definitions, spatial congruence, to make visible the polythetic nature of most areas of endemism recognized so far, without ignoring the possibility that there are quite small areas that may be of monothetic nature. Our objective is to discuss briefly the monothetic and polythetic grouping and the application of those concepts to the definition of areas of endemism.

Monothetic and polythetic grouping

Monothetic grouping is the oldest idea in classificatory theory and is rooted in Aristotelian logic, where a group is defined by a unique feature or a set of features (Winsor, 2003).

The starting point of the recognition of the polythetic grouping is the work of the botanist Michel Adanson (1763), who proposed that a given member of a class of plants did not need to possess all the defining feature of the class. Later, the economist and logician William Jevons (1877) suggested, in the context of classification theory, that a group is not necessarily defined by the invariable presence of common attributes.

In 1934, polythetic grouping was elaborated independently and almost simultaneously in psychology by Lev Vygotsky in Russia and in philosophy and social anthropology by Ludwig Wittgenstein in England. One can find the history of this intriguing convergence of ideas in Toulmin (1969) and Needham (1972). Vygotsky (1962, translation from Russian) called polythetic grouping 'complex thinking': where no feature forms a 'nucleus' of the group, meaning that not all the members of the group share a feature or a set of features. Wittgenstein, in a set of notes from 1934 called The Blue Book (taken during lectures and later formally published, Wittgenstein, 1958), resorted to the image of a long rope to convey the same constitution of a polythetic concept: although the rope consists of fibres, it does not derive its strength from any fibre that runs through it from one end to another, but from the vast number of shorter, overlapping fibres. Amongst the members of such a class there is a complex network of similarities overlapping and criss-crossing. Wittgenstein (1953) termed this polythetic nature (in a

famous phrase in philosophical investigations and social anthropology) 'family resemblances' (Needham, 1975).

Biological implications

The philosopher of biology, Morton Beckner (1959) elucidated the concepts of monothetic and polythetic at greater length and in modern terms. He enunciated the existence of the 'polytypic' natural taxa. Since this term and its converse, 'monotypic', already had well-established meaning in systematics, the substitute terms 'polythetic' (Greek, *poly*, many; *thetos*, arrangements) and 'monothetic' (Greek, *mono*, one; *thetos*, arrangements) suggested by Sneath (1962) have come into general use. The implications of monothetic and polythetic grouping in systematics have been discussed by Mayr (1969), Simpson (1961), and recently and extensively by Williams and Ebach (2017).

The controlling idea for monothetic groups is that they are formed by rigid and successive logical divisions so that the possession of a unique set of features is both sufficient and necessary for membership in the group thus defined. They are called monothetic because the defining set of features is unique. That is, all the members of any group possess all of the features that are used to define that group.

In a polythetic group, by contrast, the members are placed together by the greatest number of features, and no single feature is essential to group membership or is sufficient for membership of the group (Sneath & Sokal, 1973). It is interesting to point out the use of polythetic diagnostic classification in medicine (e.g., in psychiatric classifications, Parnas, 2015; and in the nosology of cancer, Vineis, 1993).

Biogeographic implications

Beckner (1959) presented a definition of a polythetic group using three enunciates. We adapt here Beckner's enunciates to biogeography, where the term 'property' used by Beckner has been replaced by the presence of a species (or any other taxon of different Linnaean category) in a locality of a candidate to became an area of endemism. Therefore his enunciates adapted to biogeography are as follows:

An area of endemism is polythetic if,

1. Each locality has a large number of a set of species occurring in the area as a whole.
2. Each of those species is present in a large number of those localities.
3. None of those species is present in every locality of the area.

The notion of 'large' should be considered in the context of the application of these requirements to a specific study area, taking into consideration the number of species and the number of localities of that area.

Let us illustrate monothetic and polythetic groups, with the aid of a presence-absence matrix of species by localities (modified from Sneath & Sokal, 1973):

	Localities					
Species	a	b	c	d	e	f
1	1	0	1	1	0	0
2	1	1	1	0	0	0
3	1	1	0	1	0	0
4	0	1	1	1	0	0
5	0	0	0	0	1	1
6	0	0	0	0	1	1

Locality 'a' possesses species 1, 2, 3; locality 'b' possesses species 2, 3, 4; locality 'c' possesses species 1, 2, 4 and locality 'd' possesses species 1, 3, 4; then the group 'a', 'b', 'c' and 'd' is polythetic. Localities 'e' and 'f' possess species 5, 6; then 'e' and 'f' form a monothetic group.

A real example of the application of the polythetic enunciates is the Parana biogeographic province (Neotropical region) established by the botanist, Ángel L. Cabrera (1971), and defined by the presence of the following taxa (Morrone, 2014):

MAGNOLIOPHYTA. Asteraceae: *Chionolaena arbuscula*, *C. lychnophorioides*, *Holocheilus illustris*, *Jungia floribunda*, *J. sellowii*, and *Panphalea missionum*; Onagraceae: *Fuchsia bracelinae*, *F. coccinea*, and *F. regia* subsp. *regia*. ARTHROPODA. Acrididae: *Borellia saezi* and *Neopedies megacercis*; Apidae: *Geotrigona subterranea*; Cicadellidae: *Balacha caparao*, *B. distincta*, *B. lepida*, and *B. rubripennis*; Curculionidae: *Achia hustachei*, *Aramigus globoculus*, and *A. intermedius*; Schendylidae: *Schendylops demartini*, *S. demelloi*, *S. gounellei*, *S. longitarsis*, *S. paulistus*, and *S. sublaevis*; Staphylinidae: *Neobisnius brasilianus*; Nemesiidae: *Rachias timbo*, *Stenoterommata iguazu*, and *S. uruguai*; Reduviidae: *Melanolestes lugens*; Sciaridae: *Rhynchosciara hollaenderi*.

Each of these taxa is present in a large number of the localities of the Parana province, but none of these taxa is present in every locality. Even when we employ the Parana province as an example, most biogeographic units of historical regionalizations are polythetic.

Conclusions

The numerous and diverse definitions of areas of endemism have in common the fact that they are based on a certain degree of non-random geographic distribution

congruence reflecting a common spatial history of the taxa involved. This foundation does not demand complete agreement on the boundaries of those taxa's distribution at all possible scales of mapping. As a consequence of this foundation, areas of endemism are in most cases polythetic.

Although a fairly small area could be of monothetic nature (e.g., a small lake), it would be unrealistic to define extended areas such as districts, provinces, regions, or realms as monothetic. The requirement that a species or group of species inhabit all the localities of an area is always difficult to meet.

We therefore propose here to expand the definition of areas of endemism to include their polythetic nature:

An area of endemism is in most cases polythetic, meaning that each locality of the area has a large number of a set of taxa. Each taxon of this set is present in many of those localities. Not one of those taxa is present in all localities.

A definition is intended to achieve a purpose, and its value rests entirely on its utility. The expansion of the definition of areas of endemism, including a polythetic characterization, will help to facilitate research and promote understanding of extended areas such as realms, regions or provinces and enhance the scientific content (e.g., predictive capability and explanatory power) of the areas of endemism.

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