

# Topological properties in the spatial distribution of amphibians in Alabama USA for the use of large scale conservation

X. Chen

Chen, X., 2008. Topological properties in the spatial distribution of amphibians in Alabama USA for the use of large scale conservation. *Animal Biodiversity and Conservation*, 31.1: 1–13.

## Abstract

*Topological properties in the spatial distribution of amphibians in Alabama USA for the use of large scale conservation.*— Large-scale biodiversity conservation is urgently needed due to increasing habitat loss and fragmentation. Understanding topological perspectives of species' distribution patterns can provide useful information for linking conservation studies at larger scales. We studied topological properties of localities in Alabama where 60 species of 12 families of amphibians were present. Analysis included a clustering coefficient which measures the strength of a population group, the relationship between occurrence localities and species number, the fractal dimension of occurrence localities (which emphasizes spatial irregularity), and distance to nearest-neighbor. The results indicate that the clustering coefficients of most amphibian species were low, but were higher for species with few occurrence localities, such as *Rana sylvatica* and *Limnaoedus ocularis*. The general relationship between species number and occurrence localities was that the majority of species held few localities in their distribution, while the remaining species occupied a greater number of localities. The fractal dimension (FD) for all amphibian localities was about 1.58, although FD was low for most individual species. We identified four relationships in the distribution of distance to nearest-neighbor: linear, logarithmic, power and polynomial. These topological properties may indicate intrinsic features about amphibians in Alabama and provide useful information for regional planning. Enhancing landscape linkages across a large area using undisturbed areas, such as 300–500 km in diameter may be a good approach to conservation practice in this region. Steps needed for biodiversity conservation planning in Alabama include creating or conserving small habitats across agricultural and urban land, and maintaining suitable spatial complexity and distance to nearest neighbors.

Key words: Amphibians, Clustering coefficient, Distance to nearest-neighbor, Fractal dimension, Topology.

## Resumen

*Características topológicas de la distribución de anfibios en Alabama, EUA, para su conservación a gran escala.*— La conservación a gran escala de la biodiversidad es una necesidad urgente debido a la pérdida y fragmentación de los hábitats. La comprensión de las perspectivas topológicas de los patrones de distribución de una especie, puede proporcionarnos una información de gran utilidad para vincular los estudios conservacionistas a escalas mayores. Se han estudiado las propiedades topológicas de ciertas localidades de Alabama en las que estaban presentes 60 especies de 12 familias de anfibios. Los análisis incluyen un coeficiente de agrupamiento, que mide el número de individuos de un grupo de población, la relación entre las localidades en que se encuentran los anfibios y el número de especies, la dimensión fractal de dichas localidades (que pone su énfasis en la irregularidad espacial), y la distancia a la vecina más próxima. Los resultados indican que los coeficientes de agrupamiento de la mayoría de especies de anfibios son bajos, pero eran mayores en las especies que se hallaban en pocas localidades, tales como *Rana sylvatica* y *Limnaoedus ocularis*. La relación general entre el número de especies y las localidades en que se hallaban indicó que la mayoría de las especies contaban con unas pocas localidades en su distribución, mientras que el resto ocupaban un número mayor de localidades. La dimensión fractal (FD) de todas las localidades con anfibios fue aproximadamente de 1,85, aunque la FD era baja para la mayoría de las especies individuales. Se identificaron cuatro relaciones en la distribución de la distancia a la vecina más

cercana: lineal, logarítmica, potencial y polinómica. Estas propiedades topológicas pueden indicar características intrínsecas de los anfibios que habitan en Alabama, y proporcionar una información útil para la planificación regional. Un buen enfoque para la práctica conservacionista en esta región sería estimular la vinculación geográfica para formar una gran área, utilizando zonas no perturbadas, de p. ej. de 300–500 km de diámetro. Los pasos necesarios para la planificación de la conservación de la biodiversidad en Alabama incluyen la creación o conservación de pequeños hábitats a lo largo de los terrenos urbanos y dedicados a la agricultura, así como mantener la complejidad espacial adecuada y la distancia a las localidades vecinas más cercanas.

Palabras clave: Anfibios, Coeficiente de agrupamiento, Distancia al vecino más cercano, Dimensión fractal, Topología.

*(Received: 24 IV 07; Conditional acceptance: 17 VII 07; Final acceptance: 28 VIII 07)*

*Xiongwen Chen, Center for Forestry, Ecology & Wildlife, P. O. Box 1927, Alabama A. & M. University, Normal, AL 35762, U.S.A.*

E-mail: [xiongwen.chen@aamu.edu](mailto:xiongwen.chen@aamu.edu)

## Introduction

Biodiversity conservation is experiencing a paradigm shift (Boersma, 1997) from the original consideration of single species at small scales to multiple species at larger scales (Chen et al., 2005) in response to increased species loss under the increasing pressure of urbanization, land use change, and invasive species. Noss (2002) indicated that management actions undertaken at a local scale to increase biodiversity might have an opposite effect on a large scale. Every local area is only a piece of a bigger ecological puzzle, and its importance can be understood only in relation to a larger whole, such as population or species' source–sink dynamics' role in species conservation within a landscape context. It is important for conservationists to expand their thinking to larger scales as a whole in which these species are embedded (Noss & Harris, 1986). Also, some properties of complexity can only emerge at a large scale (Green et al., 2006). The survival of complex systems depends largely on their topological structure (Albert et al., 2000; Newman, 2003), that is, the configuration of these species and locality in terms of the layout (such as ring and tree topology). For example, there are some general rules governing circulatory systems or the drainage networks of watersheds. Understanding the topological perspective of ecological patterns and possible underlying processes could provide a formal structure for linking studies at local scales to larger ones (Thompson et al., 2001). A change in an ecologist's typical thinking about ecosystems and landscapes is required in order to focus on the topological perspective.

There has recently been much renewed interest in topological analysis of food webs in ecological research (Williams & Martinez, 2000; Solé & Montoya, 2001; Camacho et al., 2002). Major issues concern how individuals (or species) are connected to others through the network or which individuals exert the most influence. Many natural systems can be represented by networks, and topological analysis can illustrate system properties using the number and distribution of nodes, or connections in an integrated network. Ricotta et al. (2001) aggregated cells of numerical surface variables into hierarchically–related topological entities to characterize the spatial structure of plant species richness across the city of Rome in Italy. Network analysis has shown that the sensitivity of a network to node loss depends on the frequency distribution of connections among nodes (Albert et al., 2000). Rhodes et al. (2006) applied network analysis to the conservation of habitat trees in the urban environment of Brisbane, Australia. Chen et al. (2006c) studied tolerance of potential habitat loss within a reserve network system in southern California and found that the current network of habitats for species group (plants, reptiles, mammals, birds, and overall species) had low tolerance for further habitat loss. Therefore, a topological approach, modified to incorporate basic biological realism, may

provide a framework for understanding ecological properties resulting from patterns of species distributions.

The amphibians of Alabama are used here to characterize topological properties as they are highly diverse in this state due to its particular geography and climate (Mount, 1975). In recent decades, however, a global decline in amphibian species and populations has been reported (e.g., Gibbons et al., 2000; Gardner, 2001). Amphibians play an important role in both aquatic and terrestrial ecosystems, such as an energetic link between trophic levels (Pough, 1980; Whiles et al., 2006). Holomuzki et al. (1994) and Wissinger et al. (1999) indicated that amphibians may have a strong impact on ecosystem structure because they are keystone species in some habitats. Many causal factors have been considered in the world–wide decline of amphibians. These include physical habitat modification and habitat loss (Sjogren, 1991; Alford & Richards, 1999; Chen et al., 2006a), ultraviolet radiation (e.g., Blaustein et al., 1994), chemical pollutions (e.g., Beebee et al., 1990), diseases (Laurance et al., 1996), and climate change (Pounds & Crump, 1994; Chen et al., 2006b). With the global decline of biodiversity and possible complexity of underlying mechanisms, the previous reductionist approach, which concerns detailed information on a single species at a small scale, may not be sufficient to provide a general picture about all amphibians and regional conservation strategies (Smallwood et al., 1998; Chase et al., 2000; Chen et al., 2005). New ideas and approaches are needed to further our understanding of biodiversity patterns and structure and also to effectively conduct conservation programs on a large scale so that Alabama can maintain its high diversity of amphibians during its economical development. This approach could also be used for large–scale animal conservation in other regions. The goal of this study was to analyze topological properties in the spatial distribution of amphibians in Alabama, USA to obtain inference for large scale conservation efforts. Metrics were applied to describe amphibians' topological structure, and topological characteristics were compared for each species and family. The implications for large scale conservation based on topological characteristics are discussed.

## Material and methods

### Study area

The study area covers the entire state of Alabama (fig. 1), which is located between the southern foothills of the Appalachian Mountain Range and the Gulf of Mexico (between 31° and 35° N latitude) and includes a total of 67 counties. Alabama has a warm, humid, subtropical climate. Summers are hot and humid with temperatures around 33°C. Late summer and fall are usually the driest time of the year. Winters are typified by a series of cold fronts. Regional rainfall varies from 1,500 mm to

1,620 mm in the north and from 1,800 mm to 1,950 mm along the coast (Carter & Carter, 1984). Due to a combination of all these factors, especially the mild and humid climate, remarkable surface drainage and diverse physiographic subdivisions, the amphibians of Alabama have reached a high level of diversity (Mount, 1975). They are therefore an important consideration for conservation in the USA.

#### Amphibian dataset

The dataset for amphibians in Alabama is from the book "The Reptiles and Amphibians of Alabama" (Mount, 1975), which included thousands of locality records (hereafter referred to as localities) of 60 species in 12 families examined by its author and from the literature. All these records were digitized using ArcGIS 9 (ESRI, Redland, California). This dataset may not represent all species within the state or the current distribution of species, but it represents data from all records that were available in the 1970s. The data reflect the period prior to the most recent major growth in suburban development, and therefore provide a bench mark for topological properties of amphibians in Alabama. The names of all species are listed in table 1.

#### Metrics of topological properties

Many metrics are available to characterize topological properties in physics. However, to efficiently monitor status and trends of biodiversity, it is necessary to identify indicators that can be applied to various landscape types but with reasonable costs. Indices selected for this study took biological meaning, available data and possible applications for large scale conservation into account.

#### Clustering coefficient

The clustering coefficient is important to quantify the hierarchical structure of a network (Ravasz & Barabasi, 2003). Some methods for estimating cluster (e.g.,  $K$  function), emphasize local scales and ignore properties at large scales. Watts & Strogatz (1998) introduced the clustering coefficient graph measure. The clustering coefficient  $c_i$  for each vertex  $i$  of the network (here referring to distribution of species occurred locations) as

$$c_i = \frac{e_i}{d_i(d_i - 1)}$$

where  $d_i$  is the number of the different nearest neighbors of vertex  $i$  (with  $d_i \neq 0,1$ ) and  $e_i$  is the number of directed edges that connect those nearest neighbors. This formula is a generalization for undirected network. The clustering coefficient for the whole system is the average of the clustering coefficients for all vertexes (Watts & Strogatz, 1998). However as  $e_i$  is the number of directed edges that connect those nearest neighbors, the length of

directed edge is not distinguished. Besides, the different lengths of direct edges could change the clustering even with the same structure. Albert et al. (1999) used the diameter to characterize the whole network, but networks with the same diameter may also display different structures. Here we used the following equation to estimate clustering coefficient (CC) for each species and family

$$CC_i = \frac{1}{D_i}$$

where  $D_i$  is the minimum diameter (km) of a circle to cover all localities of a species or family. This index can describe (i) the extent of the species' clustering; and (ii) the coefficient which can be used to compare clustering with other species.

#### Statistical distribution of occurrence localities of species

Based on the distribution for each species, the occurrence localities were classified as 0–10, 10–20, 20–30, and so on, up to 130–140. The number of species in each group of localities was counted. The midpoint in each group of localities was used for the subsequent calculation and plotting, i.e. 5 was used to represent the group 0–10 and 15 for the group 10–20. Networks with power-law degree distribution, sometimes also referred to as scale-free networks, have been the focus of much attention in the literature (e.g., Strogatz, 2001).

Power-laws can be generated from the study of a species' exponential growth, exponential decay and highly optimized tolerance (Brookings et al., 2005). In scale-free networks, some nodes act as highly connected hubs (high degree), while most nodes are of low degree. Scale-free network structure and dynamics are independent of the system's size ( $N$ ) and the number of nodes the system has. In other words, a network that is scale-free will have the same properties no matter how many nodes it has (e.g., Albert & Barabási, 2000).

#### Fractal dimension of occurrence localities

The notion of dimension is also called topological dimension. The fractal dimension of localities can be used for measuring spatial complexity of biodiversity distributions or the degree of occupation of the physical space by a contorted or fragmented surface (Mandelbrot, 1977; Frontier, 1987). Here, the fractal dimension of localities for species in each family was determined by the box-counting method, using box lengths of 50, 25 and 10 km, respectively. The fractal dimension ( $D$ ) was determined by the formula:

$$D = \lim \frac{N(\varepsilon)}{\log_{10} (1/\varepsilon)}$$

where  $\varepsilon$  is the box length, and  $N(\varepsilon)$  is the number of

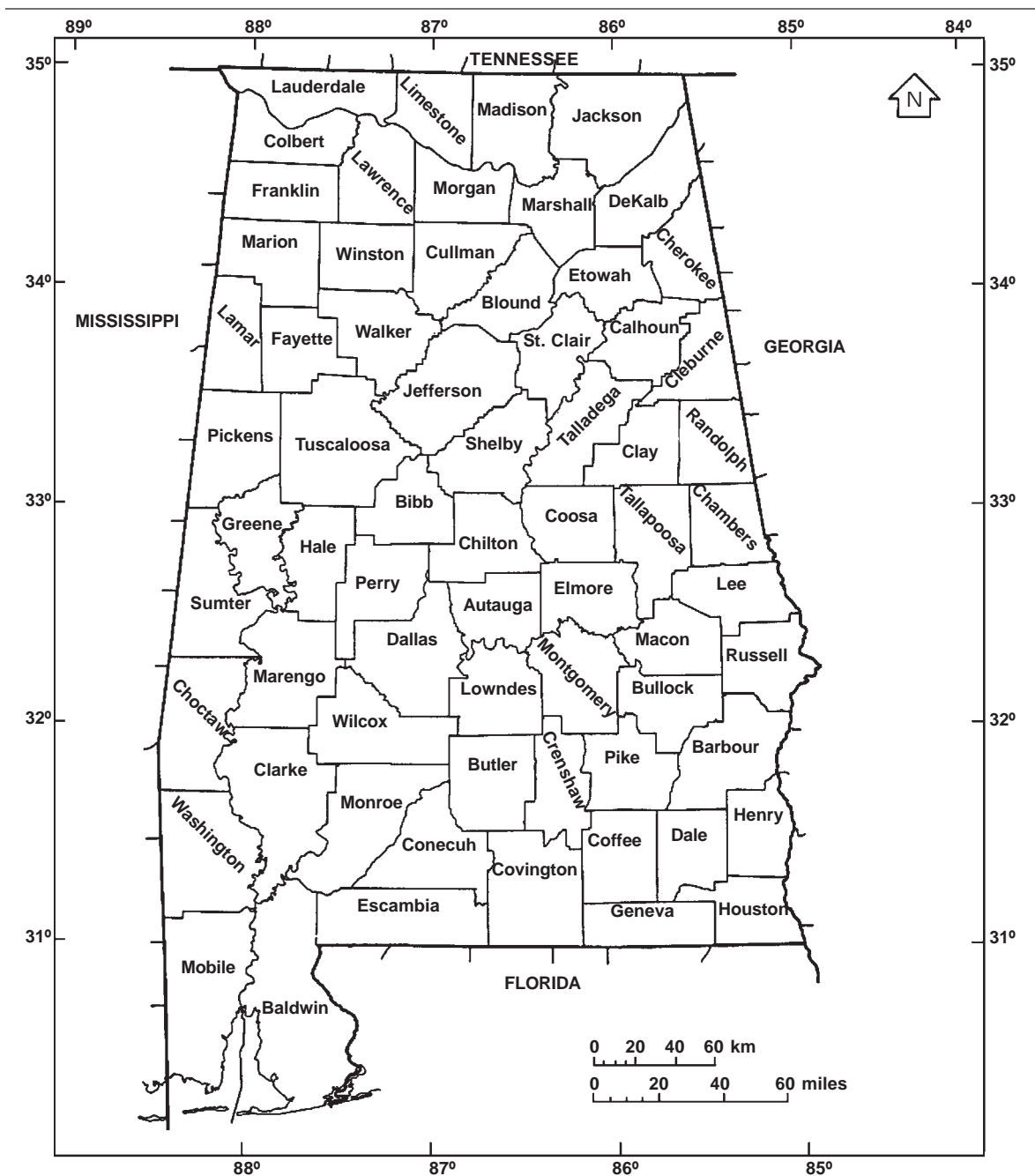


Fig. 1. The location of study area (the map of Alabama is from U.S. Department of Commerce).

Fig. 1. Localización del área de estudio (el mapa de Alabama proviene del Departamento de Comercio de EUA).

boxes with the length of  $\epsilon$  that covered the occurrence localities (e.g., Jumarie, 2000; Li, 2000). Amphiumidae and Cryptobranchidae are not included in this analysis as they were found in few localities. A species (or family) with a high fractal dimension has high complexity in its spatial distribution.

Distance to nearest-neighbor

The distance to nearest-neighbor is important for species interpopulation migrations, such as for "rescue effect", because immigrants have a higher probability of entering a cluster with a high connectivity and therefore preventing a population from

Table 1. Amphibian species, families and their identification numbers included in this study (source from Mount, 1975): FN. Family number; SN. Species number.

Tabla 1. Especies y familias de anfibios, y los números de identificación que se usaron en este estudio (procedencia: Mount, 1975): FN. Número de la familia; SN: Número de la especie.

Family			Family		
FN	SN	Species name	FN	SN	Species name
<b>Bufonidae</b>			<b>Amphiumidae</b>		
1	1	<i>Bufo americanus americanus</i>	7	35	<i>Amphiuma means</i>
	2	<i>Bufo quercicus</i>		36	<i>Amphiuma tridactylum</i>
	3	<i>Bufo terrestris</i>	<b>Cryptobranchidae</b>		
	4	<i>Bufo woodhousei fowleri</i>	8	37	<i>Cryptobranchus alleganiensis</i>
<b>Hylidae</b>			<b>Plethodontidae</b>		
2	5	<i>Acris crepitans crepitans</i>	9	38	<i>Aneides aeneus</i>
	6	<i>Acris gryllus</i>		39	<i>Desmognathus aeneus</i>
	7	<i>Hyla avivoca</i>		40	<i>Desmognathus fuscus</i>
	8	<i>Hyla cinerea</i>		41	<i>Desmognathus monticola</i>
	9	<i>Hyla crucifer</i>		42	<i>Desmognathus ochrophaeus</i>
	10	<i>Hyla femoralis</i>		43	<i>Eurycea bislineata</i>
	11	<i>Hyla gratiosa</i>		44	<i>Eurycea longicauda</i>
	12	<i>Hyla squirella</i>		45	<i>Eurycea lucifuga</i>
	13	<i>Hyla versicolor</i>		46	<i>Gyrinophilus palleucus</i>
	14	<i>Limnaeodius ocellaris</i>		47	<i>Gyrinophilus porphyriticus</i>
	15	<i>Pseudacris brachyphona</i>		48	<i>Hemidactylium scutatum</i>
	16	<i>Pseudacris nigrita nigrita</i>		49	<i>Manculus quadridigitatus</i>
	17	<i>Pseudacris ornate</i>		50	<i>Phaeognathus hubrichti</i>
	18	<i>Pseudacris triseriata</i>		51	<i>Plethodon cinereus polycentratus</i>
<b>Microhylidae</b>				52	<i>Plethodon dorsalis dorsalis</i>
3	19	<i>Gastrophryne carolinensis</i>		53	<i>Plethodon glutinosus</i>
<b>Pelobatidae</b>				54	<i>Pseudotriton montanus flavissimus</i>
4	20	<i>Scaphiopus holbrooki holbrooki</i>		55	<i>Pseudotriton ruber</i>
<b>Ranidae</b>			<b>Proteidae</b>		
5	21	<i>Rana areolata sevosa</i>	10	56	<i>Necturus maculosus</i>
	22	<i>Rana catesbeiana</i>		57	<i>Necturus beyeri</i>
	23	<i>Rana clamitans</i>	<b>Salamandridae</b>		
	24	<i>Rana grylio</i>	11	58	<i>Notophthalmus viridescens</i>
	25	<i>Rana heckscheri</i>	<b>Sirenidae</b>		
	26	<i>Rana palustris</i>	12	59	<i>Siren intermedia</i>
	27	<i>Rana pipiens sphenoccephala</i>		60	<i>Siren lacertian</i>
	28	<i>Rana sylvatica</i>	<b>Ambystomatidae</b>		
6	29	<i>Ambystoma cingulatum</i>			
	30	<i>Ambystoma maculatum</i>			
	31	<i>Ambystoma opacum</i>			
	32	<i>Ambystoma talpoideum</i>			
	33	<i>Ambystoma texanum</i>			
	34	<i>Ambystoma tigrinum tigrinum</i>			

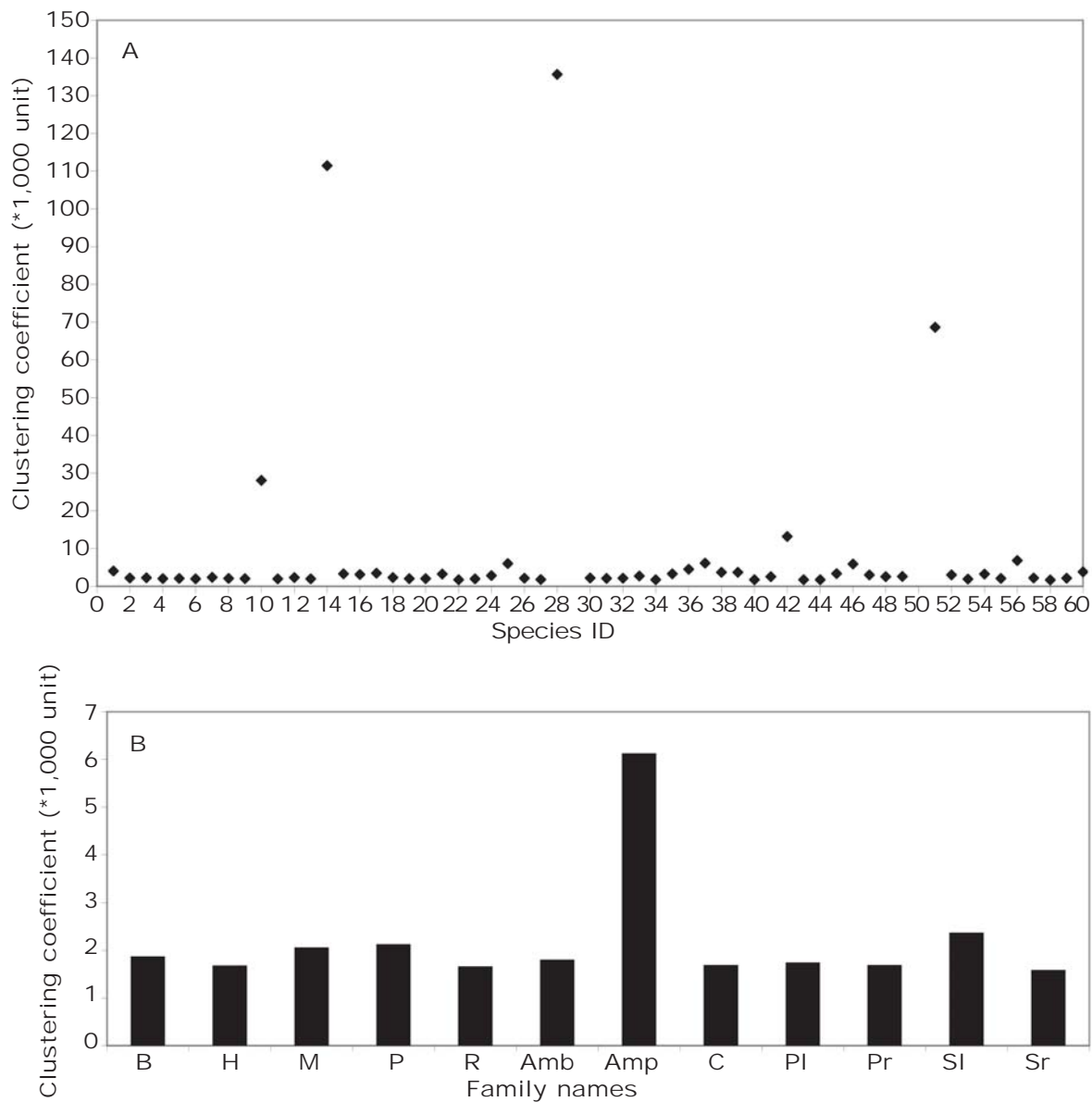


Fig. 2. The clustering coefficients of amphibian species (A) and families (B). Species and family names are listed in table 1. Most species and families have low clustering coefficients. Abbreviations: B. Bufonidae; H. Hylidae; M. Microhylidae; P. Pelobatidae; R. Randiae; Amb. Ambystomatidae; Amp. Amphiumidae; C. Cryptobranchidae; Pl. Plethodontidae; Pr. Proteidae; Sl. Salamandridae; Sr. Sirens.

Fig. 2. Coeficientes de agrupamiento de las especies de anfibios (A) y de las familias (B). Los nombres de dichas especies y familias se hallan en la tabla 1. La mayoría de las especies y las familias tienen coeficientes de agrupamiento bajos. (Para las abreviaturas de las familias, ver arriba.)

extinction (Brown & Kodric–Brown, 1977). We used two methods to evaluate the distance to nearest-neighbor. The first approach was to estimate the average distance to nearest-neighbor for each family by measuring the nearest distance between the species' localities. The second way was to examine the distribution of distances to nearest-neighbors

for each species. The distances were classified into 25 classes (< 10, < 15, < 20,..., < 125, and < 130 km), and the total distance to nearest-neighbor in each class was calculated for each species. Due to their limited localities, 10 species (No. 14, 25, 28, 29, 35, 36, 39, 50, 51 and 60 listed in table 1) were not included in this analysis. Differ-

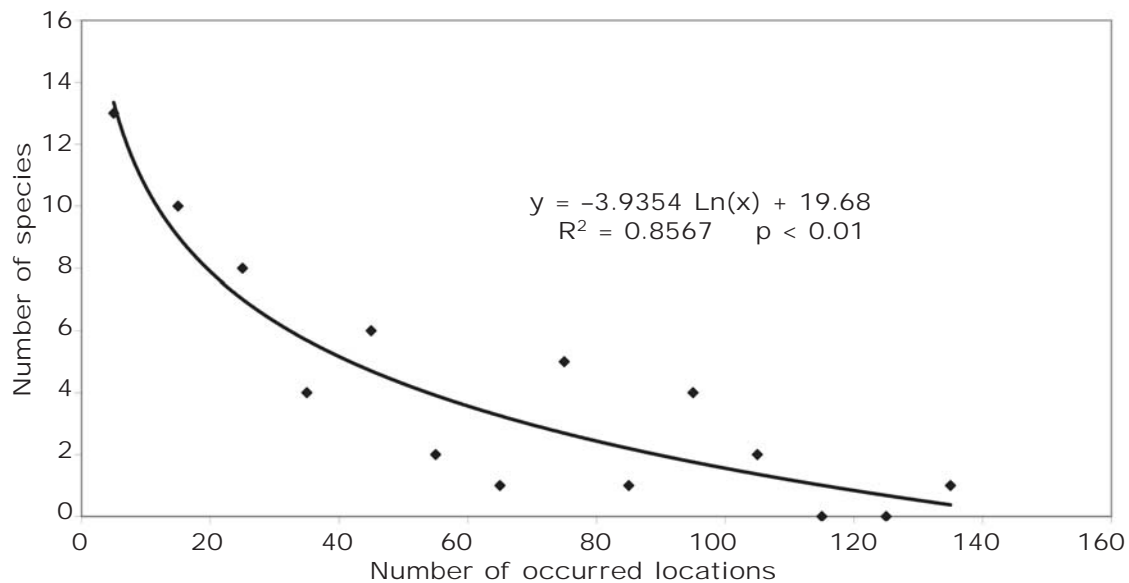


Fig. 3. The logarithmic relationship between the locality records and species number.

Fig. 3. Relación logarítmica entre la presencia y el número de especies en las distintas localidades.

ent species may have different distributions of distance to nearest-neighbor. For example, a linear relationship could mean there is even distribution of the distance to nearest-neighbor. A logarithmic relationship would mean that there are more long distances to nearest-neighbor than short ones, or oppositely, a power relationship would indicate that there are more short distances to nearest-neighbor than long ones. Polynomial relationships include a mixture of all the above types as they may occur in a combination across a different scale of distances.

## Results

### Clustering coefficient

The clustering coefficients for most amphibian species were below 10 (fig. 2A), but both *Rana sylvatica* (No. 28) and *Limnaeodius ocularis* (No. 14) had clustering coefficients of more than 100, because they had only two localities. At the family level, the clustering coefficients were below 3 for most families (fig. 2B), but the clustering coefficient of the family of Cryptobranchidae (giant salamanders) was above 6.

### Statistical distribution of occurrence localities

A relationship was found between the number of localities and species' richness (fig. 3). Only a limited number of species (three) had more than 100 locality records, while most species had less than 20 occurrence localities.

### Fractal dimension of locality records

Families Hylidae, Plethodontidae, and overall amphibian families had a fractal dimension of over 1.0 (fig. 4). Families Pelobatidae, Proteidae, Salamandridae and Sirens had fractal dimensions less than 0.4. The fractal dimension (FD) for all amphibian localities was about 1.58, while for most species FD values were lower than this.

### Distances to nearest-neighbor

The average distance to nearest-neighbor was more than 50 km for families Ambystomatidae and Sirens (fig. 5), but was less than 30 km for families Bufonidae, Microhylidae, Cryptobranchidae and Plethodontidae. Based on the distribution of distances to nearest-neighbor, there were four types of relationships: linear, logarithmic, power and polynomial (fig. 6; table 2). Species from the families Microhylidae, Salamandridae, and Sirens showed linear relationships, while single species from the family Cryptobranchidae showed a polynomial relationship.

## Discussion

Spatial clustering is often observed in nature due to a combination of ecological processes including limits to dispersal imposed by landscape structure, disturbance, and heterogeneity of the abiotic environment (Coomes et al., 1999). There are several ways to characterize spatial clustering. Chen et al.



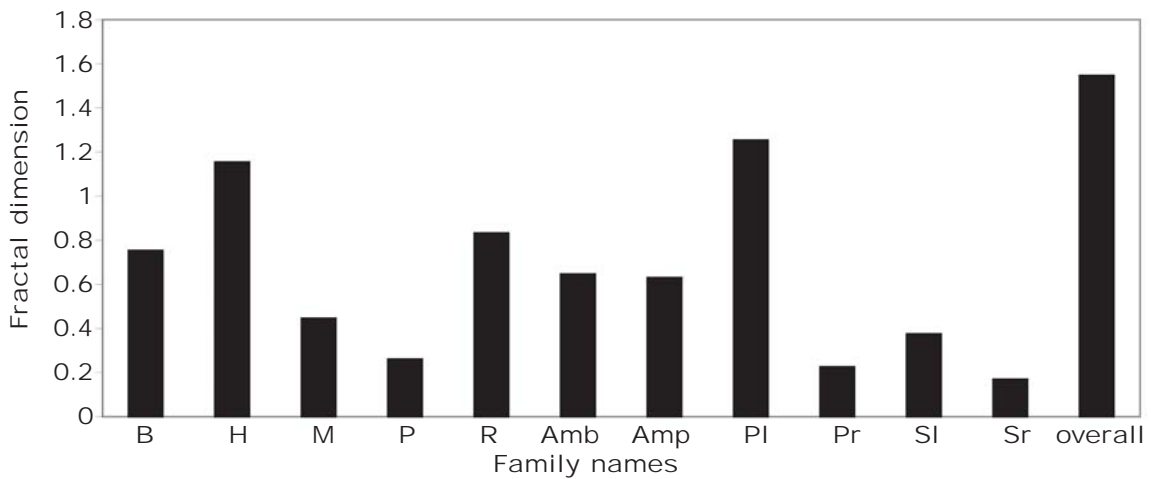


Fig. 4. Fractal dimensions of locality records for 12 amphibian families based on box accounting method. (For the abbreviations of families, see fig. 2.)

*Fig. 4. Dimensiones fractales de la presencia en las localidades para 12 familias de anfibios, basadas en el método de contabilización de cajas. (Para las abreviaturas de las familias, ver fig. 2.)*

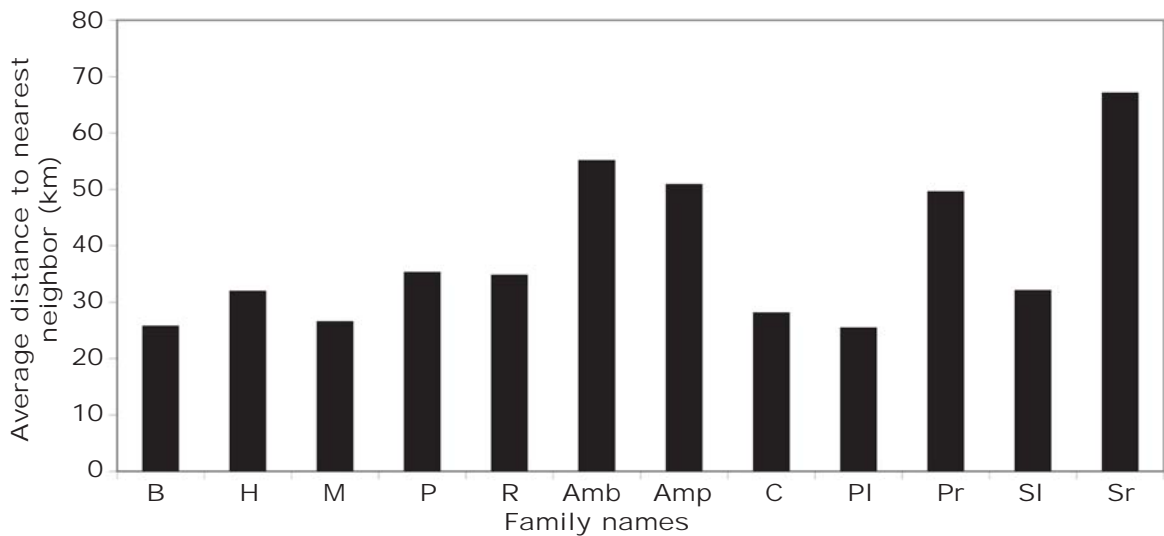


Fig. 5. The average distance of nearest–neighbor for each family based on locality records. (For the abbreviations of families, see fig. 2.)

*Fig. 5. Distancia promedio al vecino más próximo para cada familia, basándose en la presencia en las localidades. (Para las abreviaturas de las familias, ver fig. 2.)*

(2005) applied an aggregation index to measure the spatial scale of localities for different species groups. However, the scale identified by an aggregation index is a local scale and may be misleading under increasing habitat loss and fragmentation.

From the perspective of large-scale conservation, more attention should be focused on the extent of clustering, such as size of cluster area for a given species including all its sub-populations. Clustering coefficients should also be included so that patterns

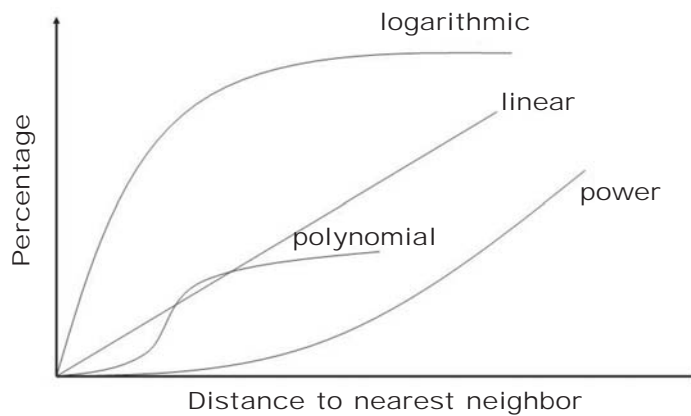


Fig. 6. The possible four conceptual models for Alabama amphibians in the distribution of distance to nearest-neighbor.

*Fig. 6. Los cuatro posibles modelos conceptuales para los anfibios de Alabama, en la distribución de la distancia al vecino más cercano.*

can be compared. For further clarification, the magnitude of clustering coefficients (high, medium, or low) for species is generally distinguished as having a narrow, flexible or broad distribution, respectively. In the present study, three species (*Limnaoedus ocularis*, *Rana sylvatica*, and *Phaeognathus hubrichti*) and one family (Cryptobranchidae) of amphibians showed relatively high clustering coefficients due to their limited distribution. This also indicates that they were rare from a spatial perspective, even though their population might not be low (currently all three species are protected in Alabama). Condit et al. (2000) indicated that the rare tree species tend to be more aggregated than abundant species. Most amphibian species had low clustering coefficients in this study, meaning they were broadly distributed. Although the distribution centers may differ between species, the average diameter of their distribution was around 380 km. When a sub-population decreases dramatically at one location, the "rescue effect" depends on the immigration from neighboring sub-populations. If all recorded locations of a species are considered to work as nodes (Bunn et al., 2000), it is important to maintain the integrity of these networks for amphibian conservation at a large scale in view of current rates of habitat loss and fragmentation.

Most species in the study had a low number of occurrence localities, consistent with the pattern reported by Chen et al. (2006c) in a previous study. However, in the present study, the relationship between locality number and species number can be described using a logarithm. Although a weak power-law relationship also fits the data, it may underestimate the relationship in this study. This

means that the relationships of locality number and species number may be derived from the available data set and results may differ from a theoretical approach. This pattern indicates that in order to preserve a greater number of species, some key locations shared by most species need to be preserved with priority if the entire area can not be preserved. By using this algorithm it is also possible to estimate the number of rare amphibian species based on their occurrence localities.

There is self-similarity in the distribution of amphibians in Alabama. Generally, the high fractal dimension indicates the high spatial complexity in the species distribution pattern. The overall fractal dimension of localities of all families was about 1.58, and the minimum fractal dimension was only 0.17 for the family of Sirenidae. The self-similarity of amphibian families may be due to the self-similarity in natural resources, such as vegetation and wetland landscapes. Burrough (1981) reported that many landscape features, such as vegetation, have fractal structure. Ostling et al. (2000) indicated that clustering distribution is consistent with self-similar distribution. We found that families with relatively lower fractal dimensions, such as Pelobatidae and Sirens, usually have relatively higher clustering coefficients, (figs. 2B, 4). Mandelbrot (1977) indicated that as fractal dimension decreases, clusters of visited points (here localities) become increasingly packed. Maintaining proper spatial complexity (part of spatial integrity), such as for habitats, vegetation and other environmental factors, is considered to be beneficial for species survival. This should be taken into account in strategy-making concerning land-use changes, preservation, construction and urban development.

Table 2. The species ID and family names in the four distribution types of distance to nearest-neighbor (source from Mount, 1975): \*Family only listed in this type of distribution.

*Tabla 2. Número de identificación de las especies y familia a la que pertenecen, distribuidas en los cuatro tipos de distancia al vecino más cercano (procedencia: Mount, 1975): \* Familia que sólo se halla en ese tipo de distribución.*

Relationship	Species	Family*
Linear	1, 2, 3, 10, 11, 13, 19, 21, 32, 38, 47, 49, 58, 59	Bufoidea, Hylidae, Microhylidae*, Ranidae, Ambystomatidae, Plethodontidae, Salamandridae*, Sirens*
Logarithmic	4, 5, 6, 7, 8, 18, 22, 23, 24, 25, 26, 31, 40, 41, 43, 44, 45, 48, 52, 53, 55	Bufoidea, Hylidae, Ranidae, Ambystomatidae, Plethodontidae
Power	9, 12, 15, 16, 17, 20, 27, 33, 34, 54, 57	Hylidae, Pelobatidae, Ranidae, Ambystomatidae, Plethodontidae, Proteidae
Polynomial	35, 36, 37, 42, 46, 56	Ambystomatidae, Cryptobranchidae*, Plethodontidae, Proteidae

Spatial complexity in landscape or species distribution may also decrease spatial synchrony, and this could contribute to species extinction (e.g. Chen et al., 2006b).

The distance to nearest-neighbor is important for amphibians to maintain populations across space. The richness of amphibian species decreases significantly with increasing distance to nearest intermittent or permanent wetlands (Schurbon & Fauth, 2003). Evidence suggests that several amphibian species have difficulty dispersing more than a few hundred meters from their natal ponds (Semlitsch, 1998; 2000; Fauth, 1999). Based on the statistical distribution of distances to nearest-neighbor, we found at least four types of relationships in amphibians of Alabama. Distance to a neighbor (or a potential source for new colonizers) is critical for "rescue effect" or dispersal success (Foppen et al., 2000). Based on this, we may infer that species with a logarithmic distribution of distance to nearest-neighbor may have strong dispersal abilities and these species may re-colonize after local disturbances, such as local extinction. Alternatively, these local populations may be more stable because of quick re-colonization. On the other hand, species with power and linear relationships may not have strong dispersal ability and may be more sensitive to local disturbances. Species with a polynomial relationship may be more stable after local disturbances, because they have varied dispersal abilities. Hubbell (2001) indicated that weak dispersers are generally good competitors and often dominate the communities they colonize. This was partially supported in our study given that species with power relationships in the distance to nearest-neighbor usually had low clustering coefficients.

#### General implications for amphibian conservation at a large scale

The topological characteristics of animal species have not been used previously to address problems in the conservation of biodiversity at large scales. The above topological properties reveal some intrinsic features about amphibians in Alabama and also provide useful information for regional planning. The clustering coefficient may indicate that in order to conduct large scale conservation of amphibians, the intensive agricultural activities and urban growth in the entire region should be taken into consideration. Alabama has a long history of farming practices, such as cotton and cattle. Maintaining large and adequately connected (both physically and functionally) habitats for amphibians is a big challenge. If clustering of amphibians is taken into consideration, it is clear that it is necessary to maintain and preserve habitats across a large area, such as 300–500 km (the diameter of species networks). The current Alabama Natural Heritage Program (<http://www.alnhp.org/>) may help to promote public concern for large scale conservation in biodiversity. Landscape linkages should be enhanced through the development of formal policies (Semlitsch, 2002). For successful conservation at a large scale all occurrence localities should be taken as nodes of amphibian networks. The linkages (both long and short) which can promote regional connectivity should be conducted to different nodes (locations) for species movement along corridors (Bunn et al., 2000). Even small and seemingly unimportant landscape elements can contribute as high quality patches or function as linkage. Creating or conserving small elements across agricultural and urban lands and maintaining suitable spatial

complexity should be considered when such patches may enlarge the source areas or act as stepping-stones for species. Maintaining proper neighbor habitats (or nodes) for sub-populations is necessary for species "sink-source" dynamic processes and also for maintaining spatial complexity. The four types of relationships (linear, power, logarithmic and polynomial) in the distribution of distances from nearest-neighbor may provide new understanding of the species distribution patterns, tolerance to habitat loss, and dispersal (or competition) ability. Forestry and agricultural management practices, the mainstay of human activity in Alabama, should include a mixture of strategies for large scale conservation (Dobson, 2001), such as land planning and zoning for logging and prescribed burning or intensive agricultural development. The adoption of a topological approach would provide a hierarchical understanding of the complicated ecological distribution of biodiversity, allowing highly efficient use of management resources and improving outcome for biodiversity conservation at large scales.

#### Acknowledgements

This study was partially supported by the School of Agricultural and Environmental Sciences and COE of Alabama A & M University and Dept. of Energy DE-FC26-06NT43029. Special thanks to Dr. Z. Felix and Ms. K. A. Roberts for editorial work.

#### References

- Albert, R. & Barabasi, A.-L., 2000. Topology of evolving networks: local events and universality. *Physical Review Letters*, 85: 5234–5237.
- Albert, R., Jeong, H., Barabási, A.-L., 1999. Diameter of the world-wide web. *Nature*, 401: 130–131.
- 2000. Error and attack tolerance of complex networks. *Nature*, 406: 378–382.
- Alford, R. A. & Richards, S. J., 1999. Global amphibian declines: a problem in applied ecology. *Annual Review of Ecology and Systematics*, 30: 133–165.
- Beebee, T. J. C., Flower, R. J., Stevenson, A. L., Patrick, S. T. & Appleby, P. C., 1990. Decline of the Natterjack Toad (*Bufo calamita*) in Britain. Paleological evidence for breeding site acidification. *Biological Conservation*, 53: 1–20.
- Blaustein, A. R., Hoffman, D. D., Hokit, D. G., Kiesecker, J. M., Walls, S. C. & Hayes, J. B., 1994. DNA repair and resistance to solar UV-B in amphibian eggs: a link to population declines. *Proceeding of National Academy of Science of USA*, 91: 1791–1795.
- Boersma, P. D., 1997. Conservation Biology: a paradigm shift. *Newsletter of Society for Conservation Biology*, 11: 1.
- Brookings, T., Carlson, J. M. & Doyle, J., 2005. Three mechanisms for power laws on the Cayley tree. *Physical Review E*, 72: 56–120.
- Brown, J. H. & Kodric-Brown, A., 1977. Turnover rates in insular biogeography: effect of immigration on extinction. *Ecology*, 58: 445–449.
- Bunn, A., Urban, D. & Keitt T., 2000. Landscape connectivity: a conservation application of graph theory. *Journal of Environmental Management*, 59: 265–278.
- Burrough, P., 1981. Fractal dimension of landscapes and other environmental data. *Nature*, 294: 240–242.
- Camacho, J., Guimera R. & Amaral, L. A. N., 2002. Robust patterns in food web structure. *Physical Review Letters*, 88: 228102(1–4).
- Carter, E. A. & Carter, V. G. S., 1984. Extreme weather history and climate atlas for Alabama. Strode Publishers, Alabama, USA.
- Chase, M. K., Kristan, W. B., Lynam, A. S., Price, M. V. & Rotenberry, J. T., 2000. Single species as indicators of species richness and composition in California coastal sage shrub birds and small mammals. *Conservation Biology*, 14: 474–487.
- Chen, X., Barrows, C. W. & Li, B.-L., 2006a. Is the coachella valley fringe-toed lizard (*Uma inornata*) on the edge of extinction at thousand palms preserve in California of U.S.A.? *Southwestern Naturalist*, 51: 28–34.
- 2006b. Phase coupling and spatial synchrony of an endangered dune lizard species. *Landscape Ecology*, 21: 1185–1193.
- Chen, X., Li, B.-L., Scott, T. & Allen, M. F., 2006c. Tolerance analysis of habitat loss for multispecies conservation in western Riverside County, California, USA. *International Journal of Biodiversity Science and Management*, 2: 87–96.
- Chen, X., Li, B.-L., Scott, T., Tennant, T., Rottenberry, J. T. & Allen, M., 2005. Spatial characteristics of multispecies' habitats in southern California, USA. *Biological Conservation*, 124: 169–175.
- Condit, R., Ashton, P. S., Baker, P., Bunyavejchewin, S., Gunatilleke, S., Gunatilleke, N., Hubbell, S. P., Foster, R. B., Itoh, A., LaFrankie, J. V., Lee, H. S., Losos, E., Manokaran, N., Sukumar, R. & Yamakura, T., 2000. Spatial patterns in the distribution of tropical tree species. *Science*, 288: 1414–1418.
- Coomes, D. A., Rees, M. & Turnbull, L., 1999. Identifying aggregation and association in fully mapped spatial data. *Ecology*, 80: 554–565.
- Dobson, A. P., Rodriguez, J. P. & Roberts W. M., 2001. Synoptic tinkering: integrating strategies for large-scale conservation. *Ecological Applications*, 11: 1019–1026.
- Fauth, J. E., 1999. Interactions between branchiate mole salamanders (*Ambystoma talpoideum*) and lesser sirens (*Siren intermedia*): asymmetrical competition and intraguild predation. *Amphibia-Reptilia*, 20: 119–132.
- Foppen, R. P. B., Chardon, J. P. & Liefveld, W., 2000. Understanding the role of sink patches in source-sink metapopulations: Reed warbler in an agricultural landscape. *Conservation Biology*, 14: 1881–1892.

- Frontier, S., 1987. Applications of fractal theory to ecology. In: *Developments in Numerical Ecology*. (P. Legendre & L. Legendre, Eds.). Springer, Berlin. NATO ASI Series, 14.
- Gardner, T., 2001. Declining amphibian populations: a global phenomenon in conservation biology. *Animal Biodiversity and Conservation*, 24: 25–44.
- Gibbons, J. W., Scott, D. E., Ryan, T. J., Buhlmann, K. A., Tuberville, T. D., Metts, B. S., Greene, J. L., Mills, T., Leiden, Y., Poppy, S. & Winne, C. T., 2000. The global decline of reptiles, déjà vu amphibians. *Bioscience*, 50: 653–666.
- Green, D. G., Klomp, N., Rimmington, G. & Sadedin, S., 2006. *Complexity in Landscape Ecology*. Springer, Netherlands.
- Holomuzki, J. R., Collins, J. P. & Brunkow, P. E., 1994. Trophic control of fishless ponds by tiger salamander larvae. *Oikos*, 71: 55–64.
- Hubbell, S. P., 2001. *The unified neutral theory of biodiversity and biogeography*. Princeton University Press, New Jersey, USA.
- Jumarie, G., 2000. *Maximum entropy, information without probability and complex fractals: classical and quantum approach*. Kluwer Academic Publishers.
- Laurance, W. F., McDonald, K. R. & Speare, R., 1996. Epidemic disease and the catastrophic decline of Australian rain forest frogs. *Conservation Biology*, 10: 406–413.
- Li, B.-L., 2000. Fractal geometry applications in description and analysis of patterns and patch dynamics. *Ecological Modelling*, 132: 33–50.
- Mandelbrot, B. B., 1977. *Fractals, Form, Chance and Dimension*. W. H. Freeman and Co., San Francisco, USA.
- Mount, R. H., 1975. *The Reptiles and Amphibians of Alabama*. Auburn Printing Co., Auburn, Alabama, USA.
- Newman, M. E. J., 2003. Mixing patterns in networks. *Physical Review E*, 67: 026126 (1–13).
- Noss, R., 2002. Context matters: considerations for large-scale conservation. *Conservation in Practice*, 3(3): 1–7.
- Noss, R. & Harris, L. D., 1986. Nodes, networks, and MUM's: preserving diversity at all scales. *Environmental Management*, 10: 299–309.
- Osyling, A., Harte, J. & Green, J., 2000. Self-similarity and clustering in the spatial distribution of species. *Science*, 290: 671–672.
- Pough, F. H., 1980. The advantages of ectothermy for tetrapods. *American Naturalist*, 115: 92–112.
- Pounds, J. A. & Crump, M. L., 1994. Amphibian declines and climate disturbance: the case the Golden Toad and the Harlequin Frog. *Conservation Biology*, 8: 72–85.
- Ravasz, E. & Barabasi, A. L., 2003. Hierarchical organization in complex networks. *Physical Review E*, 67: 026112 (1–7).
- Rhodes, M., Wardell-Johnson, G. W., Rhodes, M. P. & Raymond, B., 2006. Applying network analysis to the conservation of habitat trees in urban environments: a case study from Brisbane, Australia. *Conservation Biology*, 20: 861–870.
- Ricotta, C., Grapow, L. C., Avena, G. & Blasi, C., 2001. Topological analysis of the spatial distribution of plant species richness across the city of Rome (Italy) with the achelon approach. *Landscape and Urban Planning*, 57: 69–76.
- Schurbon, J. M. & Fauth, J. E., 2003. Effects of prescribed burning on amphibian diversity in a southeastern US National Forest. *Conservation Biology*, 17: 1338–1349.
- Semlitsch, R. D., 1998. Biological delineation of terrestrial buffer zones of pond-breeding salamanders. *Conservation Biology*, 12: 1113–1119.
- 2000. Principles for management of aquatic-breeding amphibians. *Journal of Wildlife Management*, 64: 615–631.
- 2002. Critical elements for biologically based recovery plan for aquatic-breeding amphibians. *Conservation Biology*, 16: 619–629.
- Smallwood, K. S., Wilcox, B., Leidy, R. & Yarris, K., 1998. Indicators assessment for habitat conservation plan of Yolo County, California, USA. *Environmental Management*, 22: 947–958.
- Sjogren, P., 1991. Extinction and isolation gradients in metapopulations: the case of the pool frog (*Rana lessonae*). *Biological Journal of Linnean Society*, 42: 135–147.
- Solé, R. V. & Montoya, J. M., 2001. Complexity and fragility in ecological networks. *Proceedings of Royal Society of London B*, 268: 2039–2045.
- Strogatz, S. H., 2001. Exploring complex networks. *Nature*, 410: 276–286.
- Thompson, J. N., Reichman, O. J., Morin, P. J., Polis, G. A., Power, M. E., Sterner, R. W., Couch, C. A., Gough, L., Holt, R., Hooper, D. U., Keesing, F., Lovell, C. R., Milne, B. T., Molles, M. C., Roberts, D. W. & Strauss, S. Y., 2001. Frontiers of ecology. *BioScience*, 51: 15–24.
- Watts, D. J. & Strogatz, S. H., 1998. Collective dynamics of "small-world" networks. *Nature*, 393: 440–442.
- Whiles, M. R., Lips, K. R., Pringle, C. M., Kilham, S. S., Bixby, R. J., Brenes, R., Connelly, S., Colon-Gaud, J. C., Hunte-Brown, M., Huryn, A. D., Montgomery, C. & Peterson, S., 2006. The effects of amphibian population declines on the structure and function of Neotropical stream ecosystems. *Frontiers in Ecology and Environments*, 4: 27–34.
- Williams, R. J. & Martinez, N. D., 2000. Simple rules yield complex food webs. *Nature*, 404: 180–183.
- Wissinger, S. A., Whiteman, H. H., Sparks, C. B., Rouse, G. L. & Brown, W. S., 1999. Foraging tradeoffs along a predator-permanence gradient in subalpine wetlands. *Ecology*, 80: 2102–2116.