

Gerald Jurasinski – Why hexagons?

Systematic grids – optimising cell arrangement

Squared or rectangular grids of varying size and extent are applied in ecological research and implemented to study different problems (see above). However, whereas in environmental research equidistant sampling grids (as hexagonal or triangular grids) are more common (Yfantis et al. 1987; Van Groenigen 2000; Zio et al. 2004) they are hardly used in ecology even though the hexagonal grid provides several advantages. These are discussed in the following.

Beierkuhnlein (1999) applied regular rectangular grids at landscape scale to characterise spatial pattern in vegetation through the calculation of resemblance measures between neighbouring plots. They faced the following problems. First, adjacent plots are not equidistant (fig.1a). This is problematic if distance or similarity measures (such as Euclidean, Bray-Curtis, χ^2 -distance or Sørensen, Jaccard and Ochiai indices) are computed between adjacent cells in the grid to describe spatial pattern because they calculate a similarity/distance in data space. Therefore the results can only be taken and displayed consistently if the compared plots all share the same geographic distance. The reason is that similarity is likely to decrease with distance. This phenomenon of distance decay was first published by Tobler (1970) and has been reformulated in an ecological context by Nekola & White (1999). In a square grid it is unclear how much of the variation in similarity is explained by spatial configuration alone, when the similarity values between neighbours in the horizontal and vertical direction are compared with the values in diagonal direction. Second, if the similarities are calculated between one plot and all its neighbours, two results in the diagonal between two adjacent plots (see Fig. 1a) will be created. It is not feasible to calculate their mean because the results derive from two different pairs of plots. Beierkuhnlein (1999) suggest that this problem may be overcome by using a moving window technique. A different approach is implemented by Lennon et al. (2001, see also Williams (1996) or Gaston et al. (2001)), who average the dissimilarities between a focal cell of a square grid to the eight surrounding cells, thus disregarding the problem of distance decay. When implementing hexagonal (triangular) grids the mentioned problems do not apply because all cells are equidistant and every pair of neighbouring cells is unique (see Fig. 1b).

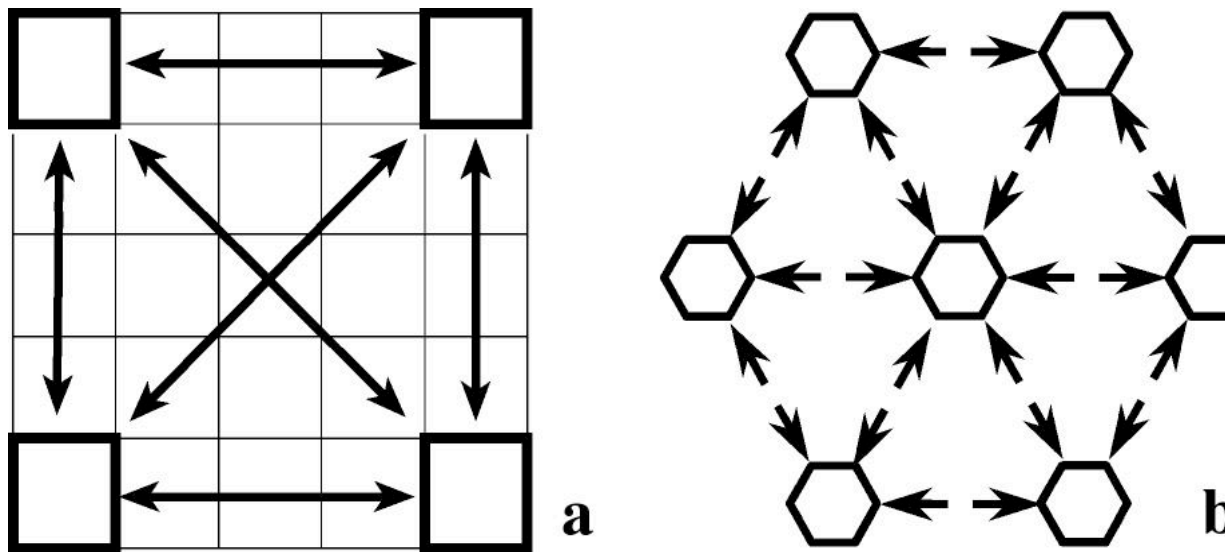


Fig. 1 Square grid (a) versus Hexagonal grid (b). For explanations see text

A further argument supporting the application of hexagonal grids can be seen in cartography. White et al. (1992) developed the EPA (Environmental Protection Agency of the US) EMAP (Environmental Monitoring and Assessment Programme) grid, which is hexagonal, through consequent deduction following cartographic principles. They tried to realise the least possible deviation in area when subdividing the grid from a spherical tessellation. Distortion in shape is kept low over the extent of a face when hexagons are used for a projection surface. A countrywide project for vegetation mapping and monitoring in Hungary is under way. It is called MÉTA and is as well based on a hexagonal grid which covers the whole country with a resolution of 35 ha (Molnár unpubl.). Another project applying a large scale hexagonal grid for monitoring purposes was conducted in Flanders, Belgium by (De Clercq & De Wulf 2004). The main purpose of such large scale projects is mapping. These can be realised in well developed countries and for long term inventories where educated staff (although often linked with voluntary work) as well as the institutional support is given, but they face many technical restrictions in less developed regions. However, those regions may experience the most serious and rapid changes in land-use and hence in biodiversity during the next decades (Balmford & Bond 2005; Millennium Ecosystem Assessment 2005; Secretariat of the Convention on Biological Diversity 2006). Pragmatic methods for medium scale studies, with relatively low resource demands, are therefore urgently needed (UNEP 2004).

The implementation of equidistant grids for modelling purposes may as well bear some advantages. The spatio-temporal changes in spatial patterns of biodiversity as well as in range sizes and geographical distributions in relation to global change (comprising land-use and climate change) are an issue of major interest (e.g. Theurillat & Guisan 2001; Walther et al. 2002; Thuiller 2003). Beyond

monitoring, science and the public is interested to know what might happen in the future. Modelling can be used to estimate future developments. Beside studies which model physiological changes under climate change (e.g. Delucia et al. 2000; Dullinger et al. 2004) there are investigators which implement systematic grids to model variation in spatial pattern (e.g. Hovestadt et al. 2000; Parrott 2004). The grids used in those models are still mostly squared. However, hexagonal grids might be very well suited for the modelling of change in vegetation pattern because every cell has six equidistant neighbours with which it shares the same length so migrating moves can be computed directly (Beecham & Farnsworth 1998; Oom et al. 2004). Furthermore shared length with adjacent cells (and therewith connectivity) is maximal in the hexagonal grid (Pagnutti et al. 2005).

Surprisingly hexagonal grids are rarely to be found in ecological field studies despite of papers communicating research for which field data was recorded based on the EPA EMAP grid (e.g. Stapanian et al. 1997; Polasky et al. 2000; Lawler et al. 2003). Apart from the EPA EMAP grid in only few studies hexagonal grid designs are applied (e.g. Hobson et al. 2002). In contrary to the low number of applications of hexagonal grids Noss (2003) suggests that planning units for reserve design should preferably be on a hexagonal grid. These units shall be of appropriate and identical size “to capture relatively homogenous segments of a heterogeneous landscape” (ibid.).

All the large scale monitoring projects mentioned implement gapless grids which cover the whole area under study. Data representing certain features of a grid cell (as species richness or richness of landscape structure) are derived from one or several sampling locations inside the cell. Often data are accumulated or summarised. We propose a different strategy of data recording in hexagonal grids. Sampling takes place on regularly spaced units of the grid (fig.2). Spatial patterns of beta-diversity are explained through the calculation of (dis)similarity and distance measures between sampled grid cells.

Hexagonal plots – billions of bees cannot be wrong

We have shown advantages in the application of equidistant grids. But what is the appropriate shape of the sampling unit? We propose to use hexagonal plots. The first reason is consistency. It is neither possible nor expedient to conduct complete sampling in larger areas but if modelling is intended it might be useful if the grid is a complete one even though data recording is only done on evenly spaced sample plots. Furthermore it provides for iterative gap filling. If interesting patterns are found after the analysis of the primary data set, additional data can be recorded and used to understand these in more detail.

There have been various attempts to find a proper plot-shape for vegetation analysis. Mueller-Dombois & Ellenberg (1974) proposed a nested quadrat to incorporate questions of scaling into the analysis. Shmida (1984) redeveloped the basic idea and proposed a nested design with different plot sizes and shapes inside a large rectangular plot (Whittaker-Plot). Later Stohlgren et al. (1995)

introduced a Modified-Whittaker plot to correct some "design-flaws" after they experimented with a long-thin rectangular plot stimulated by Bormann's work (Bormann 1953). Bormann showed that a long-thin rectangular plot contains more species than a square or circle plot of the same area especially if the vegetation is rather heterogeneous. The Modified-Whittaker plot is now a standard method (e.g. Shackleton 2000; Campbell et al. 2002; Barnett & Stohlgren 2003) to assess mean species cover or to analyse plant diversity patterns at multiple spatial scales. It is appropriate if the variation in vegetation is studied but it seems to be "obviously inadequate for evaluating areal aspects of scale" (Podani et al. 1993). If a larger area is surveyed to reveal spatial patterns it is not suitable because in this case the sampling location itself should be rather homogeneous. Preferably the plot shape should be isodiametric to minimise vegetational heterogeneity captured by a single plot (ibid.).

Hexagonal plots show a smaller perimeter area ratio than square or rectangular plots. In this regard circular plots would be ideal. But it is hard to mark them out in the field unless working in open ecosystems like grasslands where compasses could be used or on very small plots. Schmidtlein (2003) used overlapping circular plots arranged in a triangular grid system for data recording but during calculation they turned to hexagons (because of the overlapping). So why not use hexagonal plots from the beginning as they are consistent with the hexagonal grid and have some more benefits: the lines which are used to mark out the plots in the field easily serve as a tool to assess quantitative data on structure.

The six equilateral triangles which build the hexagonal plot can also be used to record frequencies and it is very easy to set it up in the field with ropes and sticks. Beginning with a first triangle with one corner at the centre of the sampling unit and the reverse side facing North, the following segments can be set one after the other simply by adding two further ropes. The regular subdivision of a circle would be a far more complicated task as there would be no corners to relate to. Regularly shaped polygons with more than six corners show an ever decreasing perimeter area ratio, however, they are not consistent with the hexagonal grid. Furthermore, the effort for marking them in the field is increasing.

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