

experiments, such as the European Space Agency's Eddington and NASA's Kepler⁹ missions, will also search for extrasolar planets through their transit signatures. Avoiding the data deterioration caused by the Earth's atmosphere, these aim to locate planets as small as, or smaller than, the Earth. The success of Konacki *et al.*³ should inspire even greater enthusiasm for the promising projects soon to come.

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1. Udalski, A. *et al. Acta Astron.* **52**, 1–37 (2002).
2. Udalski, A. *et al. Acta Astron.* **52**, 115–128 (2002).
3. Konacki, M., Torres, G., Jha, S. & Sasselov, D. D. *Nature* **421**, 507–509 (2003).
4. Mayor, M. & Queloz, D. *Nature* **378**, 355–359 (1995).
5. Goldreich, P. & Tremaine, S. *Astrophys. J.* **241**, 425–441 (1980).
6. Murray, N., Hansen, B., Holman, M. & Tremaine, S. *Science* **279**, 69–72 (1998).
7. Henry, G., Marcy, G., Butler, R. & Vogt, S. *Astrophys. J.* **529**, L41–L44 (2000).
8. Charbonneau, D., Brown, T., Latham, D. & Mayor, M. *Astrophys. J.* **529**, L45–L48 (2000).
9. Lissauer, J. *Nature* **419**, 355–358 (2002).

Biodiversity

The threat of small households

Nico Keilman

Many studies have suggested that the increasing global human population is having a negative effect on biodiversity. According to new work, another threat comes from the rising number of households.

Households in many countries have become smaller in recent decades. Between 1970 and 2000, the average number of occupants in households in less developed countries fell from 5.1 to 4.4. And in more developed nations, the decrease was from 3.2 to 2.5 people per household over the same period (the decline began earlier; Fig. 1). From their analysis of household dynamics in biodiversity 'hotspot' areas, Liu and colleagues¹ now argue (page 530 of this issue) that the decline in household sizes has unintended negative effects. The global human population has risen, not fallen, so smaller households means more households — and a higher demand for natural resources. This is in addition to the increased demand resulting purely from population growth.

Even before the writings of Thomas Malthus in the late eighteenth century, the balance between population and natural resources was a recurrent theme. Since ancient times, statesmen and philosophers have expressed opinions about such issues as the optimum number of people and the disadvantages of excessive population growth². Although some theorists see population expansion in a positive light^{3,4}, there is increasing concern about the negative consequences for resources⁵. Other things being equal, a larger population implies a greater demand for food, water, arable land, energy, building materials, transport and so on — a link that was first quantified some 30 years ago⁶. A population's age structure also influences economic growth and hence resource use: a rapid growth of the young age segments decelerates economic growth⁷.

More recently, scholars have acknowledged that another demographic variable — the number of households — also has an important role in resource consumption^{8–11}.

Even when the size of a population remains constant, more households imply a larger demand for resources. Household members share space, home furnishings, transportation and energy, leading to significant economies of scale. For instance, two-person households in the United States in 1993–94 used 17% less energy per person than one-person households¹¹.

To appreciate the different effects of population size and number of households on resource consumption on a larger regional scale, consider the following example⁸. In more developed regions, energy consumption increased by 2.1% per year over the period 1970–90. Population growth can explain 0.7 percentage points of this growth in energy usage, while changes in per capita energy use explain the remaining 1.4 points. However, an alternative analysis decomposes the growth in energy consumption into a factor that describes the growth in number of households and a factor describing per household energy use. This analysis shows that the household growth factor explains

1.6 percentage points of the energy-consumption increase — more than twice as much as the population growth factor.

Liu and colleagues¹ now draw our attention to household dynamics in biodiversity hotspot areas — regions that are rich in endemic species and threatened by human activities. They find that, during the years 1985–2000, the number of households in 76 hotspot countries increased by 3.1% per year, substantially faster than did the population (1.8% per year). So, average household size fell by about 1.3% per year. These changes relate to the group of 76 countries as a whole. For individual hotspot countries, more than 80% showed a pattern of greater growth in household numbers than in population. In 65 non-hotspot countries, however, population increased at roughly the same tempo as household numbers during 1985–2000.

Many of the world's most populated countries are hotspot countries (such as China, India, Indonesia, Brazil and Bangladesh). And most of the hotspot countries studied by Liu *et al.* (65 out of 76) belong to the group of less developed nations. We know that falling birth rates were an important driving force behind reductions in average household size in less developed countries in the 1990s (ref. 12). Despite these falling birth rates, however, the population in such countries did increase (because of decreased death rates, for instance). All of this might explain why increases in the number of households were relatively pronounced in hotspot countries¹.

Liu *et al.* also refer to projections of population size and the number of households over the next 15 years. These projections suggest that the divergence in population growth and household numbers will become more pronounced. So, the authors argue, it is crucial to consider average household size when assessing threats to biodiversity. Quantifying the impact of falling household sizes, and increasing household numbers, on biodiversity changes should have high research priority.

Small households have adverse effects on resource consumption both because they are less energy-efficient in themselves and

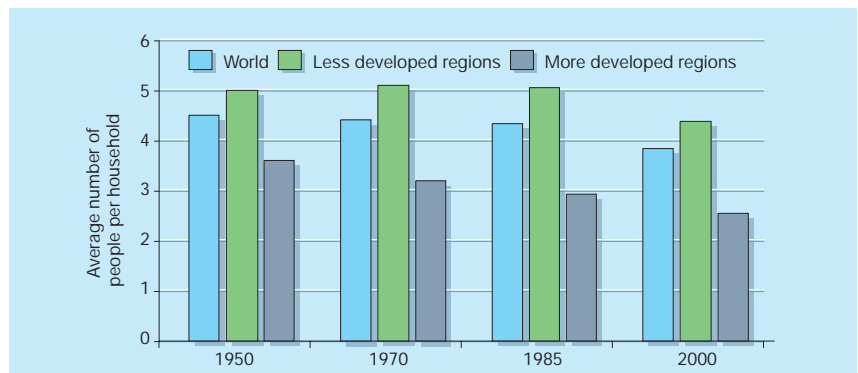


Figure 1 Decline and fall in household sizes. Data for 1950 and 1970 are taken from ref. 8; data for 1985 and 2000 are from ref. 17.

because they often reflect an increase in the number of households. If this increase could be stabilized at roughly the same level as population growth, the adverse effects might also stabilize. But could this be achieved? That depends on possible explanations for why household sizes have fallen in the first place. Some of these explanations are as follows. First, all other factors remaining the same, falling birth rates reduce population size, but do not affect the number of households; hence, household size is reduced. Second, increased material standards of living have an effect. Extended households are observed in countries in an early stage of development¹³. When these countries attain a higher standard of living, some institutions — such as social-security systems — provide the assurance against risks that were formerly supplied by the extended household.

Third, social, economic and cultural theories of demographic behaviour point to a variety of reasons why individuals prefer to live in small households^{14–16}. These include less adherence to strict norms; less religiosity and increased individual freedom on ethical issues; female education, which has led to women having greater economic independence and also facilitates divorce; more assertiveness in favour of symmetrical gender roles; the contribution of women to the labour market; increased economic aspirations; and residential autonomy. Fourth, population ageing reduces household size. This is a direct consequence of two facts: increased longevity leads to longer periods of time when children do not live with their parents; and the greater mortality of men, together with

the usual age difference between spouses, results in many widows who live alone.

Smaller households, then, are the result of processes that cannot be reversed (such as modern contraception and liberalization from norms) or that we value for a number of reasons (such as women's emancipation). So policy interventions will have to focus on the average household resource consumption, in order to combat the adverse effects of smaller households. ■

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- Liu, J., Daily, G. C., Ehrlich, P. E. & Luck, G. W. *Nature* **421**, 530–533 (2003); advance online publication, 12 January 2003 (doi:10.1038/nature01359).
- Cohen, J. *How Many People Can the Earth Support?* (Norton, New York, 1995).
- Boserup, E. *Population and Technological Change* (Univ. Chicago Press, 1981).
- Simon, J. *The Ultimate Resource 2* (Princeton Univ. Press, 1996).
- Population, Environment and Development: The Concise Report* (United Nations, New York, 2001). <http://www.un.org/esa/population/publications/concise2001/C2001English.pdf>
- Ehrlich, P. & Holdren, J. *Science* **171**, 1212–1217 (1971).
- Crenshaw, E., Ameen, A. & Christenson, M. *Am. Soc. Rev.* **62**, 974–984 (1997).
- MacKellar, F. L., Lutz, W., Prinz, C. & Goujon, A. *Pop. Dev. Rev.* **21**, 849–865 (1995).
- Cramer, J. *Demography* **35**, 45–65 (1998).
- Jiang, L. *Population and Sustainable Development in China* (Thela Thesis, Amsterdam, 1999).
- O'Neill, B. & Chen, B. *Pop. Dev. Rev. (Suppl.)* **28**, 53–88 (2002).
- Bongaarts, J. *Pop. Stud.* **55**, 263–279 (2001).
- Goode, W. *World Revolution and Family Patterns* (Free Press, New York, 1963).
- Van de Kaa, D. *Pop. Bull.* **42**, 1–59 (1987).
- Lesthaeghe, R. in *Gender and Family Change in Industrial Countries* (eds Mason, K. & Jensen, A.) 17–62 (Clarendon, Oxford, 1995).
- Verdon, M. *Rethinking Households* (Routledge, London, 1998).
- United Nations Centre for Human Settlements (Habitat) *Cities in a Globalizing World* (Earthscan, London, 2001).

particles were effectively hard spheres, with no Coulomb repulsion. Then, entropy — generally considered to be a measure of disorder — favours the f.c.c. crystal, as the number of configurations available to a particle localized about a lattice site in the f.c.c. crystal exceeds those accessible in a disordered fluid or the b.c.c. crystal¹³.

Although hard-sphere behaviour of polymer-based colloids could be achieved in model systems, there was a drawback: those colloids were opaque at even moderate densities, so little could be learned about their structure from light scattering. More transparent dispersions were sought, such as silica spheres coated with short hydrocarbon chains in a nonpolar solvent that eliminates surface charge⁴. In the 1980s, these organophilic silicas and the aqueous lattices sufficed for many studies of fluid-to-crystal transitions and other colloidal phenomena. But small silicas could not easily be made highly uniform in size and there can be extra, van der Waals attractions between the larger ones, so better colloidal hard spheres were sought. Eventually a standard emerged: poly(methylmethacrylate) (PMMA) spheres coated with a low-molecular-weight polymer⁵.

In a solvent that also contains soluble polymer, neighbouring spheres are pushed together by osmotic pressure due to expulsion of polymer chains from small gaps between the particles. This attractive force increases roughly linearly with polymer concentration and can easily cause a dilute gas-like dispersion to condense into a colloidal fluid, and then into a solid f.c.c. crystal. In reality, the hard spheres pass through an intermediate, random hexagonal close-packed (r.h.c.p.)⁶ phase and only slowly convert to the f.c.c. structure. For larger colloids or smaller polymer chains, the transition directly from 'gas' to f.c.c. crystal is more favourable⁷.

Thus long-range attractions or repulsions yield condensed phases with low density and coordination number, such as dense fluid or b.c.c. crystal phases. Short-range repulsions and attractions produce denser f.c.c. crystals with higher coordination number. But crystals with lower coordination numbers than the b.c.c. phase or more complex structures have not been achieved with spheres of a single size. Yethiraj and van Blaaderen¹ confront this issue by devising a model system in which the forces between particles can be tuned, combining a soft repulsion with a long-range, anisotropic attraction.

The authors laced PMMA spheres (with radii between 1 and 2 μm) with fluorescent dye and dispersed them in an organic mixture whose refractive index and density were chosen to aid confocal imaging of the spheres. The solvent also preserves sufficient dielectric contrast for an applied electric field to induce strong dipole–dipole inter-

Condensed-matter physics

Tunable colloidal crystals

William B. Russel

Microscopic particles dispersed in a solvent — a colloidal dispersion — can be a useful model for phase transitions and crystal nucleation. A colloid that can be 'tuned' using an electric field is a valuable new tool.

Fundamental advances in colloid science often depend on physical models, which are made by dispersing carefully tailored particles, less than a micrometre in size, in pure aqueous or organic liquids. Such dispersions can be characterized by methods such as light scattering and confocal microscopy, and the physical and chemical interactions between the particles, responsible for intriguing phases such as colloidal crystals (which behave like atomic solids), can be precisely controlled. On page 513 of this issue, Yethiraj and van Blaaderen¹ describe a new model system that can be tuned with an electric field to display phase transitions and unexpected crystalline structures.

Colloidal crystals first attracted interest

in the 1960s. In studies of the light scattered from dilute dispersions, a transition was detected from a disordered fluid to an ordered body-centred-cubic (b.c.c.) crystal when the screened (or reduced) Coulomb repulsions between the colloidal particles extended to length scales greater than the lattice spacing². In fact, this transition can be controlled: adding a small amount of salt decreases the range of the repulsive force, because the salt dissociates into ions that enhance the screening. As a result, the volume fraction (or density) of particles at the transition increases, and a denser, face-centred-cubic (f.c.c.) crystal structure is favoured. Adding even more salt leads to 'hard-sphere' transitions — as though the