and diffuse double-layer structure effects (*12*). Electrochemical experiments at the single-molecule level can provide information complementary to spectroscopic experiments and might allow one to examine kinetic models at a level at which continuous approximations are not appropriate.

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High Sex Ratios in China's Future

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In China in recent years, male live births have exceeded those of females by amounts far greater than those that occur naturally in human populations, a trend with significant demographic consequences. The resulting imbalance in the first-marriage market is estimated to be about 1 million males per year after 2010. These "excess" males were not easily accommodated in models with substantial changes in first-marriage patterns. The current sex ratio at birth has little effect on a couple's probability of having at least one son, so future increases in the sex ratio may well occur, especially given increasing access to sex-selective abortion.

Among the reasons that China fascinates demographers are the recent rapid fall of its total fertility rate (*1*) and the remarkable rise in the reported sex ratio at birth (SRB). The SRB is the number of live male births for every hundred live female births in a reference period, usually a year, and historically the human SRB is near 105, changing little with parity (the number of children a mother has borne) (*2*). In China, the SRB for all births rose to 113.8 in 1990, and the SRB for higher parities was even higher (*3*, *4*). This imbalance of the sexes implies many millions of "missing" females (*5*). Some of these are unreported births, but a substantial number are missing because of high early female mortality or selective abortion (6–8). A pattern of declining fertility and high male bias in sex ratio at birth is also observed in countries such as India, Bangladesh, and South Korea (9).

We examine three demographic consequences of the sharp rise in China's SRB. First, the timing and size of the coming imbalance in the first-marriage market in China. Second, the effect of today's high SRB on the probability that an individual couple will have at least one son; presumably this is what couples with a strong son-preference aim to increase. Third, the effect of SRB on the "no-son dependency ratio" (NSDR), which measures the social "burden" presented by elderly people who have no son.

The prospects of marriage depend on many factors; we focus on the supply of potential mates, which depends on the SRB, marriage patterns, and population age structure. We measure the relative size of potential mating pools by a sex ratio R_F of potential first-marriage partners, computed as the ratio of male numbers weighted by age-specific first-marriage frequencies for males to female numbers weighted by the corresponding frequencies for females (*10*).

China's pattern of nearly universal marriage makes R_F particularly apropos (*1*, *4*). We projected China's population, starting with the 1990 census population holding fertility, mortality, and first-marriage frequencies constant at 1990 levels (*4*). In the projection, population vital rates are used to construct matrices that project births to females and the mortality of successive cohorts (*11*). Changes in mortality at late ages, or equal changes in mortality for both sexes at younger ages, would not qualitatively alter the conclusions. Fertility change in China depends strongly on government policy, which is not expected to change soon (*12*, *13*); the assumption of a different but constant fertility would not qualitatively change our results. Our projection uses parity-specific values of the SRB held constant at the 1990 level, a conservative assumption judging by recent trends (*3*, 6–8). Even if the SRB were to fall, the phenomena we describe below are unavoidable in the medium term.

The ratio R_F is projected to be unbalanced through 2050 (Fig. 1). It rises to a peak over the next decade and declines rapidly by 2005, after which it rises towards a high level by 2050. The first peak is driven by the recent decline in fertility: Men marrying in a particular year come from earlier and larger birth cohorts than their younger partners. When fertility is constant for some years, this imbalance disappears. Beyond about 2005, however, marriage markets will be dominated by cohorts that had historically high sex ratios at birth. Starting about 2010, the recent high SRB will cause the marriage market ratios to go out of balance. If the upward trend in the SRB continues, the imbalance will be greater than shown in Fig. 1. For first marriages, which traditionally involve about 96% of each cohort (*1*, *4*), we find an imbalance in R_F of over 8% of males by 2020. This translates into about 1 million excess males per year in the market for first marriages.

What will happen to this "excess" of unmarried males? To marry, they will have to find mates outside the traditional cultural patterns that are summarized by the first-marriage frequencies. We explored the effect of two alternative changes (Fig. 2) in these patterns. In one, male marriage is delayed by 2 years at every age; in the other, age preferences for males and females are greatly relaxed by an increase in the variance in the age pattern of male and female marriage frequencies by a factor of 4. As shown in Fig. 3, neither change greatly alters the projected imbalance in R_F after 2010. Furthermore, historical evidence suggests that such large shifts in marriage patterns may face substantial social, economic, and cultural obstacles (*14*). The imbalance in the marriage market in China is the opposite of that found in the highly industrialized countries, where higher female life expectancy generates an "excess" of females [3 to 5% overall and more in some subgroups (*15*, *16*)].

The strong preference for sons in China

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(*17*), together with the policy of fertility limitation, is likely to be a force driving the increase in the SRB. One reason for a preference for sons is the special role of sons as providers of old-age security to their parents (*7*, *17*). From the standpoint of an individual couple, it is interesting to ask whether the current high SRB has a significant effect on the probability of having at least one son. As a point of reference, if the SRB was fixed at 105 for all parities in 1990, the probability of having at least one son would have been 0.665. If we assume that each parity has the corresponding SRB recorded in 1990, the probability of having at least one son increases to 0.674 (*18*). However, the SRB for a birth may depend on prior family composition if, for example, the decision to use sex-selective abortion at the second conception depends on the sex of the first child. With 1990 values of the SRB by both parity and composition (*18*), the probability of having at least one son does increase but only to 0.684. This increase in the probability (relative to its value at an SRB of 105) is small from the perspective of a single couple. An increase of 10 percent in the probability of having at least one son will require an overall SRB of about 170, which is much greater than the SRB in 1990. It is now easy to achieve a very high SRB with selective abortion based on modern technologies for detecting the sex of a fetus (6–8).

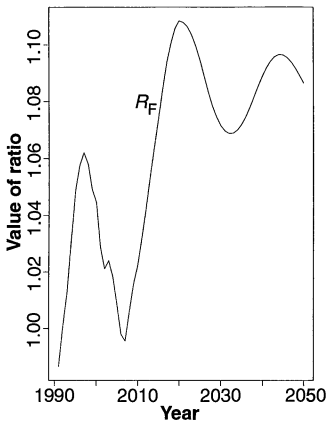

Fig. 1. Sex ratio R_F of potential first-marriage partners. Projected values were derived with the use of 1990 vital rates.

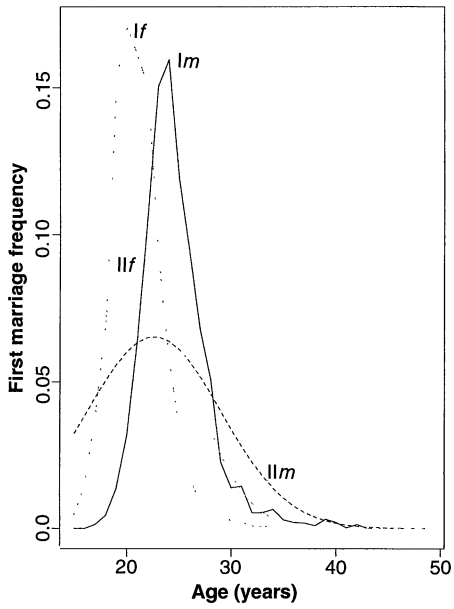

Fig. 2. Alternative first-marriage frequencies for males (*m*) and females (*f*) by age. The curves labeled I have the same female pattern as in the 1990 data (*9*), whereas male marriage is delayed by 2 years at every age; the male curve labeled I is a rightward translation of the 1990 male frequency curve. In 1990, the mean age at marriage for males was 21.61 years and for females was 20.01 years; the variance for males was 10.42 and for females was 6.53. The curves labeled II show the effect of leaving the mean ages at first marriage unchanged but increasing the variance of both curves by a factor of 4.

Longer life spans and concerns about old-age dependency confront China as they do other countries (*19*). A couple may care most about the probability of not having a son, whereas society or government is more concerned with the potential burden of elderly people who have no son. Government concern is reflected in state programs that target social security programs at people who have no son (*13*, *19*). This policy is explicitly supposed to reduce the desire of couples to have at least one son. Because the government measures the social security burden by the number of elderly who have no son, it is pertinent to ask if current elevated SRB values result in a lower burden than would the historically expected SRB.

We used the 1990 fractions of births in each parity and two sets of SRB values (all other vital rates were fixed at their 1990 values) to project the NSDR, defined as population aged 65 and over without a son, divided by working age (age 20 to 64) population. The solid line in Fig. 4 is a projection of the NSDR based on 1990 SRB values, held constant in the future. The dashed line in Fig. 4 shows what the NSDR would be if the SRB were simply set to 105 for each parity. The trend in the curves is due to fertility decline and lowered mortality. The tiny difference between the solid and dashed lines implies that even the historically high SRB in 1990 has little effect on the NSDR. Governmental emphasis on the NSDR may reinforce a preference for sons while obscuring the true potential burden measured by the total dependency ratio, which is about three times as large.

The trend toward a high SRB resulting from a strong preference for sons coupled with pressures to reduce fertility has also been marked in India (6–8) by a steady increase in the percentage of the population that is male. Technologies for sex-selective abortion are increasingly available in both China and India (*3*, 5–9). Infant and unborn females thus appear to have a disparately low value in countries that constitute 40% of the world's population. The status of these females

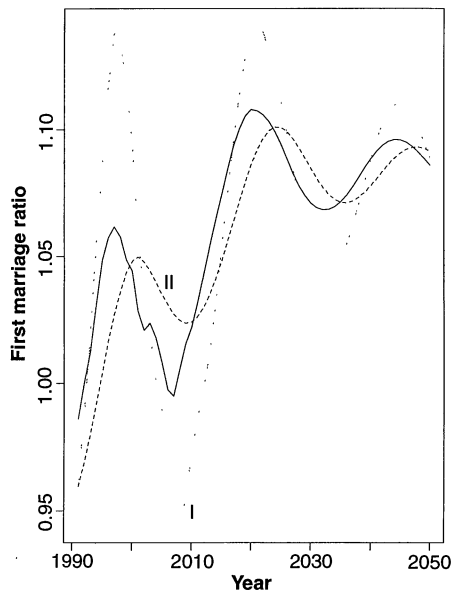

Fig. 3. The solid line is the original projection with 1990 first-marriage frequencies. Changed marriage patterns affect the amplitude of R_F but not the ultimate level or the overall trend.

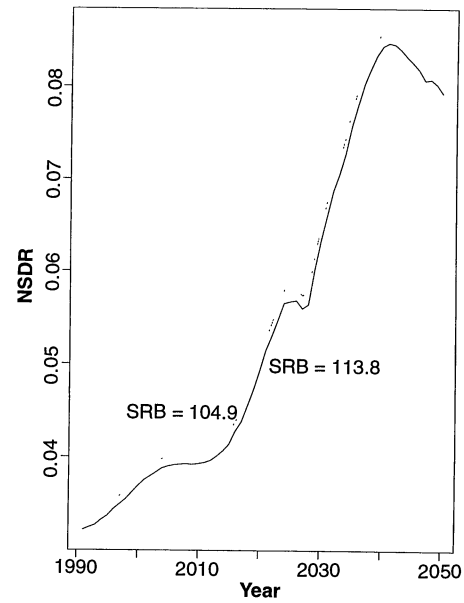

Fig. 4. Solid line, NSDR with the use of 1990 parity-specific SRB (*9*). Dashed line, same ratio, but with an SRB of 105 for all parities. The smallness of the difference between the lines is the main feature of interest.

deserves scholarly attention, ethical and moral concern, and governmental initiatives. In the longer term, masculinization of births will result in large cohorts of young unmarried males, posing social and cultural challenges in countries that are already undergoing rapid economic and political change. The trends we note are likely to complicate efforts to increase the social and economic status of women and their control over reproductive decisions.

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Shifting Dominance Within a Montane Vegetation Community: Results of a Climate-Warming Experiment

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In experimentally heated plots that each span a soil moisture gradient in a Rocky Mountain meadow, aboveground biomass of *Artemisia tridentata* (a sagebrush) increased in the drier habitat and that of *Pentaphylloides floribunda* (a shrub cinquefoil) increased in the wetter habitat relative to control plots. In contrast, aboveground forb biomass decreased in the wet and dry habitats of the heated plots. These results, combined with evidence for enhanced sagebrush seedling establishment rates in the heated plots, suggest that the increased warming expected under an atmosphere with a concentration of carbon dioxide twice that of pre-industrial levels could change the dominant vegetation of a widespread meadow habitat.

Studies point to the likelihood of future changes in the composition of plant communities under climate change (*1*). In both montane and high-latitude ecosystems, such changes could be especially dramatic because of the sensitivity of regional climate to snow or ice cover (*2*) and the sensitivity of vegetation growth and nutrient availability to timing of snowmelt, length of growing season, soil and air temperatures, and midsummer soil drying (*3*, *4*). In this report, we describe results from an in situ climate manipulation experiment designed to study the responses of montane meadow vegetation to climate warming.

Investigations of the ecological effects of climate change have included both controlled-climate laboratory studies (*5*) and field experiments with either plastic enclosures (*6*), snow fences (*4*), buried electric-resistance wires (*7*), or overhead radiators (*8*). We chose overhead radiators to simulate the increase in downward infrared radiation (IR) incident on vegetation and soil that is expected to occur under global warming (*9*).

Our study site was an ungrazed subalpine meadow at the Rocky Mountain Biological Laboratory (RMBL), Gunnison County, Colorado, USA (38°53′N, 107°02′W; elevation, 2920 m). Typical of many montane regions, the area is characterized by a mosaic of habitats, and species composition varies over small spatial scales (*10*). Conifer and aspen stands are interspersed with both wet and dry meadows that support diverse assemblages of forbs, graminoids, and shrubs. Within our study plots, there were approximately 100 angiosperm species, most of which were long-lived perennials (*11*). Sagebrush (*A. tridentata*) infiltrates in drier areas of the meadow because the site is at the upper elevational boundary of a tongue of Great Basin desert shrub habitat (Fig. 1A).

Annual precipitation at RMBL over the past decade has averaged 0.75 m, over 80% of that as snow. Total snowfall during the 1990 to 1991, 1991 to 1992, 1992 to 1993, and 1993 to 1994 winters was 0.69, 0.47, 0.99, and 0.68 m (water equivalent), respectively (*12*). Snowmelt (*13*) typically ends in May or early June (Table 1). Total precipitation from June through August was 0.10, 0.11, 0.05, and 0.04 m in 1991, 1992, 1993, and 1994, respectively. As a result of the low rainfall in 1993 and especially 1994, summer soil moistures were lowest in those years (Table 1), despite an exceptionally late melt in 1993 and an above normal snowfall during the 1992 to 1993 winter. Mean daily summer air temperature is about 10°C.

We established 10 3-m by 10-m experimental plots in 1990, each spanning an elevational, microclimatic, and vegetational gradient from a dry ridge downhill to a moist swale (Fig. 1, B and C). Electric heaters suspended 2.6 m above five of the plots provided a nearly uniform IR flux over those plots (*14*). At the onset of heating, 6 January 1991, we set the heater output at 15 W/m^2 incident on the soil surface; on 24 May 1993, we raised it to 22 W/m^2 (*15*). We monitored soil temperature and mois-

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