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The Effect of High Altitude on Fecundity and Fertility in the Himalayas: Myths and Realities

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Introduction

High altitude ecozones are among the most extreme environments to which human populations have adapted. Of the several physiological stresses encountered at high altitude, the pervasive influence of hypoxia (the low atmosphere partial pressure of oxygen) has engendered widespread interest. Traditional cultural mechanisms do not ameliorate the low partial pressure of oxygen found at high altitude and the consequent problem of delivering adequate oxygen to the tissues. Because of this, human biocultural adaptation to high altitude has long been a topic of considerable research importance.

This paper reexamines one well-known facet of the body of research on high altitude hypoxia, the effect of high altitude on fertility and fecundity. This has been a topic of interest since the Spanish Conquest of the Andes where the Spaniards became acutely aware of the symptoms of altitude sickness and, in particular, the reproductive difficulties experienced by Spanish women and animals at high altitude in Latin America. For example, in the Imperial city of Potosi (4000m) in Bolivia, all children born of Spanish parents died either at birth or within a fortnight and it was not until 53 years had passed that a European successfully gave birth to an infant who survived to baptismal age of 3 days.

Extensive experimental work with animals has reported the presence of an altitude effect on fecundity (the physiological capacity to bear children), and fertility (the actual number of children born) (Clegg 1981). Similarly, systematic studies of high and low altitude Andean populations were conducted to test the hypothesis that high altitude hypoxia reduces fecundity in chronically exposed human populations. However, since it is extremely difficult to measure fecundity directly in a "field" situation (i.e., outside of a laboratory), most studies have instead measured the fertility of high altitude natives under the

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assumption that in populations not consciously controlling fertility, differences in fertility reflect differences in fecundity. From these studies it has been widely reported in research reports and secondary textbooks that high altitude has a depressing effect on fecundity and fertility (Abelson 1972; Abelson et al. 1974; Hoff and Abelson 1976; Clegg 1981; Little 1981). As Hoff and Abelson (Ibid.: 144) wrote:

> "Hypoxia, which acts to reduce fecundity, appears to be the major component of reduced fertility at high altitude."

Although the initial research on human reproduction and altitude was conducted in the Andes, Himalayan native populations were eventually examined to provide comparative data.

The first serious research on the fertility of high altitude Himalayan populations was conducted in 1970-71 among the Sherpas of the Khumbu area of Eastern Nepal (see Fig. 1) (Weitz et al. 1978). Residing at altitudes of over 3500m, these Sherpas are the descendants of Tibetans who migrated to the area some three to four hundred years ago (Haimendorf 1864). They still speak at dialect of Tibetan and adhere to Tibetan Buddhism. A very low fertility was reported for this group, namely a completed family size (completed fertility ratio-CFR) of 4.8 for all women aged 50 or older. That is to say, all women over 49 years of age were reported to have borne on the average 4.8 births. This level of fertility is extremely low for a population which claimed not to be using contraception. These findings were consistent with informal observations of very low fertility among Tibetans in Chinghai Province, China and claims for a declining Tibetan population (Ekvall 1972).

A second fertility survey conducted with the same populations of Sherpas in Khumbu reported an even lower completed fertility ratio (CFR_{45+}) of 4.5 births for all married women aged 45 or over (Gupta 1980). This figure would be even lower if, as in the case of Weitz et al., all women, married and unmarried were included. This low fertility was compared with data collected from Sherpas living at low altitude (900-1800n) in the Kalimpong area of India where a significantly higher CFR_{45+} of 7.4 was reported. The study concluded that

> there is a suggestion of reduced fertility in the high altitude sample in several of the measures employed. Besides the significant reduction in the mean completed family size and the number of live births per married women, trends in the same direction are seen in the number of live births per mother over 30, the average number of live births, and the total fertility rate. ... Our findings agree with those obtained in the Andean studies, in which, while mortality does not seem to be related to altitude, fecundity in general shows a negative relationship (Ibid.: 113).

A third study compared Sherpas at high altitude (using the Gupta and Weitz CFR figures) with four Sherpa populations living at moderate altitude (2200m-2600m) (Bangham and Sacherer 1980). It reports a "much higher completed fertility rate" (CFR_{45+} = 7.8) at moderate altitude and states that the low fertility of Khumbu "is mostly attributable to lower fecundity." (Ibid.: 323).

Research conducted with other high altitude Himalayan populations subsequent to the Sherpa studies produced very different results. We shall first present this newer and contradictory evidence, examine the reasons underlying the different results, and then critique the validity of the Sherpa studies.

Goldstein (1981a,b) presented demographic data from Tsang village (3900m) in Limi, a remote high altitude Tibetan speaking valley in Humla District, N.W. Nepal on the Tibeto-Nepalese border. Based on field research conducted in 1974, 1976 and 1977, and based on the entire population rather than a sample, a CFR_{45+} of 7.4 was reported for married females. This CFR is significantly higher than that reported for the Sherpas by either Gupta or Weitz et al. ($p < 0.05$).

In these studies, it was argued (Goldstein, Ibid.) that the low fertility of the Khumbu Sherpas is not typical of high altitude Tibetan populations and, after comparing Limi with other Tibetan populations living at moderate altitude in the Himalayas, it was suggested that contrary to common belief, Tibetan populations generally have moderately high fertility. Thus, at one point in time, there was completely contradictory evidence from two high altitude Himalayan study areas.

The papers of Goldstein emphasized the importance of taking account of the manner in which socio-cultural factors act to reduce fertility, particularly the impact of mating systems such as fraternal polyandry, the marital union wherein two brothers share one wife. Fraternal polyandry was shown to relegate a substantial proportion of females to a life outside marital union and therein markedly reduced overall fertility (Goldstein 1976). In Limi, 19% of the females over 45 were unmarried and had a CFR of 1.8 versus 7.4 for married females of the same age (Goldstein 1981b). Because of this, the overall CFR_{45+} was only 6.3.

Given this, it is obvious that as more females are relegated to the status of never-married and therein excluded from regular or frequent sexual intercourse, the population CFR will decrease. The importance of considering socio-cultural factors which might produce such an effect cannot be overemphasized. The initial series of papers were testing the hypothesis that high altitude hypoxia, a physical environmental stress which cannot be mediated by cultural means, acts to reduce fecundity as measured by fertility. It is, therefore, essential to control for other non-biological confounding factors such as exclusion from exposure to intercourse (Davis and Blake 1956) so as to isolate the effects of altitude alone. Any socio-cultural factor that lowers fertility will artificially mask real fecundity levels leaving the erroneous impression that the low fertility observed is reflective of underlying low fecundity. The Limi data mentioned above demonstrate a difference of over one birth between the CFR_{45+} for "all women" and for only "married" women (i.e. for women at risk).

But even grouping females into the categories "ever" and "never" married may be inadequate because the category of "ever-married" can include females who have not been exposed to the risk of intercourse for a substantial portion of their reproductive years. For example, in many Tibetan groups it is not uncommon for some females to marry early but then get divorced after a year or two and remain unmarried for the rest of their lives. Since these females at best have only one or two children, when they are included with "ever-married" females the overall fertility rate drops. Similarly, among groups where widows do not remarry, fertility of "ever-married women" can be substantially reduced (Ross 1981). While intra-marital type factors were not relevant in the Limi analysis, their importance will be seen below in the Ladakh data.

Thus, in order to investigate the effect of hypoxia on fecundity (as measured by fertility), comparable "controlled" samples must be established in each population. In other words, women similarly exposed to the risk of intercourse (and thus conception) must be examined. This, as will be demonstrated below, can be done by controlling for factors such as age at first marriage (union) and by focussing on the CFR of what we call "fully married" women, i.e. women who have been exposed to the risk of conception for almost all of their biological reproductive span, given, of course, the normal age at first marriage. By focussing on such a category of women we avoid the possibility that two populations exhibiting very different CFRs do so because they contain very different proportions of women with reduced fertility. We shall refer to this measure as CFR-FM.

Demographic research that attempts to isolate the effects of social factors on reproduction, however, is complicated by other pitfalls. Depending on the society, it may be very difficult to accurately assess these confounding factors since peasants are often suspicious of strangers asking personal questions and since many of the statuses associated with reduced reproduction such as "divorced" carry pejorative connotations which may motivate subjects to conceal their "lower" status. Consequently, it is methodologically essential to go beyond a simple one-time interview schedule and utilize intensive community based research in which the investigator resides in the community for an extended period of time and develops rapport and mechanisms for cross-checking census information (Chen and Murray 1976; Campbell et al. 1979). This checking and rechecking is necessary not only for the demographic vital statistics (e.g. births, deaths), but also for the critical socio-marital history of females in the study.

Utilizing this perspective, this paper expands the corpus of Himalayan high altitude fertility data by presenting new demographic information collected by Goldstein and Tsarong in Ladakh, a high altitude Tibetan speaking district of Jammu-Kashmir State in India.

The Demographic Structure of Kyilung Village, Ladakh

Location and Methods

The demographic data presented below were collected during the course of a 16 month period from May 1980 to September 1981 as part of a larger study on the socio-cultural and economic organization of monasticism in the area.

Kyilung is a high altitude valley laid out along both sides of a tributary of the Indus River which is located near Leh, the capital of Ladakh. The lowest part of the valley is about 3560m in altitude and the highest section of the village is about 4085m although animals are herded and maintained for part of the summer at altitudes up to almost 4950m. The village contains 214 households and over 1000 persons belonging to two different ethnic groups: Buddhists (the original inhabitants) and Muslims (who began to settle there hundreds of years ago and who themselves are divided between Kashmiris and Baltis). For all practical purposes, the Buddhists are endogamous although the Muslims do sometimes take Buddhist brides. Thirty one percent of the households are Muslim and 69% Buddhist. All inhabitants speak Ladakhi, a Tibetan dialect, although the Buddhists write this with the traditional Tibetan orthography whereas the Muslims use the Urdu script.

During the summer of 1980 a household census was collected by a local research assistant. At that time reliable information could not be collected for some questions, e.g., the number of deceased children. Over the next year, as rapport developed, a second household census-fertility survey of the entire village (i.e. not a sample) was conducted by the investigators with the assistance of a locally born monk from the Kyilung monastery. Although women often became tearful when talking about their dead children, very detailed data were collected. At this point preliminary analysis was made and questionable items, e.g., women who reported low or no births, were checked by reinterviewing subjects and via conversations with relatives, neighbours and knowledgeable local monks. Similarly, the marital-demographic history of each household in the village was discussed with key informants to ascertain unusual marriage patterns that might affect fertility levels.

Using this methodology, a number of very serious errors among the initial reports were discovered, e.g., an older female who reported only one or two births but in fact had borne more children. However, she had divorced and had left the children with the husband. We also found several women who had married late (in their mid-thirties) and had not, therefore, been exposed to the risk of conception for the same length of time as had other "normally" married females. Thus, care was taken to identify and classify women whose reproductively active years had been constrained by cultural factors that lessened their exposure to the risk of conception. Ten different "socio-marital reproductive types" of women aged 45+ were abstracted on the basis of relevance to the issue of reduced risk of conception and these in turn were aggregated into three categories: fully married, never married, and reduced fertility.

A. "Fully Married"

1) Women who married at or before 24 are still married, and have had no intervening divorce. These women have had maximal exposure to risk of conception in this society.

1A) Women recently deceased (within past 5 years) but whose age at death was 45+ and whose marital status was category No. 1. Their fertility data were reported by a spouse and cross-checked with siblings, relatives, offspring, and neighbours.

2) Women who married at or before the age of 24, were widowed, but only late in life after the age of 40. Their exposure to risk of conception was reduced for only a small proportion of their reproductively active years.

3) Women married at or before the age of 24 who had been divorced early but had remarried within a few years. Exposure to the risk of conception was reduced for only a small portion of their reproductive span.

B. "Never Married"

4) Women who never married. These females represent the category with the greatest loss of reproductive potential since they were never in a culturally sanctioned marriage union. While sexual activity is certainly not limited to sanctioned marriage unions and these women do have children, exposure to sexual intercourse is restricted and their fertility is low.

5) Women who married at or before 24 years of age but divorced after a year of two and then remained unmarried.

C. "Reduced Fertility"

6) Women who married at or before 24 years of age but widowed early, before 33.

7) Women who married late in life, after 33.

8) Women who divorced early and remarried only late in life, after 33.

9) Women who divorced late in life (after 33) and did not remarry.

10) Women who were widowed late in life (over 40), but who were also married late in life (in their 30's).

Throughout this research, ages were collected using the traditional 60 year Tibetan "animal-element year" system which allows translation to the Western Calendar with an error of only ± 0.5 years.

Lyilung Fertility

Table 1 presents fertility data as measured by the average number of births for the entire female population of Kyilung village that is over 40 years of age. Completed fertility for all women 45-69 (married, never-married, etc.) is 6.1. However, when the potentially confounding social factors are taken into account, a different picture emerges.

Table 1 also illustrates the considerable difference in fertility associated with the different socio-marital reproductive categories. Since the amount of this reduction in categories Nos. 2 and 3 is only slight, we have grouped them together with categories 1 and 1A to form the larger category termed "fully" married women.

We divided the remaining categories into two groups: a category of "never-married women" (Nos. 4 and 5) and a category of women with reduced exposure (Nos. 6-10). When the data are aggregated in this manner, the CFR_{45+} for "fully" married women (Nos. 1-3) is 6.6, while the CFR_{45+} is only 2.0 for "unmarried women" (Nos. 4 and 5) and 3.9 for women with "reduced fertility" (No. 6-10).

Given the tremendous disparity in fertility associated with differential exposure to the risk of conception, the ideal technique to control for this critical factor would be to calculate for each woman the precise number of years "at-risk" and the part of the reproductive span when these "at-risk" and the part of the reproductive span when these "at-risk" years occurred. With this, any two populations, regardless of social practices, could be compared with respect to the number of births in relation to the number of years "at-risk". However, this level of detail was not possible and a less precise, but still highly effective and accurate strategy was developed which isolates and focusses on the group of women who have not experienced substantial loss of reproductive time, i.e. the category of fully married women. By focussing on this category, we are able to control for the confounding effect of reduced exposure to the risk of pregnancy and thus make fertility levels reflect fecundity more closely. It also allows us to construct and analyse comparable samples in populations having different social practices and patterns. The $CFR\text{-}CM_{45-69}$ of these "fully" married females in Kyilung (6.6) is not significantly different from the CFR_{45+} 7.4 of the equivalent fully married Limi females (ANOVA, $P > 0.05$).

Table 1 also indicates that there is a substantial difference in fertility between Muslims and Buddhists in all age categories over the age of 40. For married females 45-69, the 0.8 difference in fertility (6.4 versus 7.2) is not statistically significant ($P > 0.05$). However, Table 1 further demonstrates a basic difference in the marital patterns of Buddhists and Muslims. Muslim women lose virtually no time because of exclusion from exposure to the risk of intercourse i.e., all women are in the "fully married" category. Because of this, the difference in fertility between Buddhists and Muslims (the CFR_{45-69}) roughly doubles to 1.5 births (5.7 to 7.2) when all females 45-69 are considered. This difference is statistically significant (t test, $P > 0.05$).

Table 2 compares the Kyilung fertility data with that of Khumbu and Limi. It illustrates the relatively high completed fertility of "fully" married females in both Limi and Kyilung (7.4 and 6.6) in contrast to that reported for Khumbu CFR (4.5). Gupta's CFR_{45+} of 4.5 is over two births lower per married female than Kyilung, and almost three births lower than Limi.

The statistical significance of these differences was tested utilizing ANOVA and the Student-Neuman-Keuls Multiple Range Test (SNK). The Student Neuman Keuls Test determines both the presence of statistically significant differences between a multiplicity of populations and the precise point where this difference exists, e.g., which populations are significantly different (Sokol and Rohlf 1969; Zar 1974).

A special interactive computer programme was written in Fortran for this study.[2] This program requires only means, standard deviations and sample sizes for input and first computes an analysis of variance (ANOVA). If the ANOVA test reveals statistically significant differences, then the programme branches into the Student-Neuman-Keuls procedure to pinpoint where the differences exist.

The SNK Test was used to compare the CFRs of married women from Limi, Kyilung Buddhist, Kyilung Muslim and Khumbu.[3] The ANOVA test showed a significant difference among these means ($P < 0.05$) and the SNK Test showed that the Sherpa CFRs (Gupta's 1978; Weitz et al; 1978) are not consistent with data from the other high altitude populations, i.e., they are significantly lower.

Thus, while on the one hand there is a very strong concordance between the Gupta and Weitz et al. data for Sherpa of Khumbu, there is also an equally strong concordance between the Limi and Kyilung data and a statistical difference between the two sets (Limi-Lyilung versus Khumbu). Although it is possible that there is some very different biological pattern underlying this difference, we contend that this discrepancy is not the result of environmental-biological differences (e.g. hypoxia, hypothroidism) but rather is the result of analytical and methodological shortcomings in the Sherpa materials. In particular, the Sherpa studies did not systematically take into account the possibility that women in their sample had been excluded from the risk of conception (i.e. from sexual intercourse) for substantial amounts of their reproductive period due to social and cultural factors. Thus the low fertility of high altitude Sherpas vis-a-vis Limi and Ladakh is argued to be an artifact of the social determinants of <u>fertility</u> not underlying <u>fecundity</u>.

Let us briefly examine the problems inherent in these Sherpa data. Gupta (1978) conducted a fertility survey in Khumbu and Kalimpong sometime in the early to mid-1970's. The data from this survey, however, are very suspect. Table 5 lists the number of live births by the age of married women. For Khumbu women aged 45-49, a CFR of <u>5.7</u> is cited. But for those aged 50-54 a CFR <u>of</u> is reported and for those aged 55 and over, a CFR of only 3.3, a figure over two births lower than the CFR for women aged 45-49. This strongly suggests that the overall low CFR of 4.5 is the result of underreporting of births by the older women in his sample due either to faulty memory or outright informant misinformation. If this very low fertility for older women reflects some idiosyncratic historical process or event affecting the older women, it is not discussed in the paper.

Moreover, the sample size of the study is very small and papers not to have been selected by a random or systematic sampling method. For example, the study is based on 14 Khumbu women 50 years and over (Gupta 1978, Table 5). Weitz et al. (1978) however, in their Table 1, list the total Khumbu area as having 260 women over the age of 50. Given the figure, the Gupta sample comprises only 5% of the total women over 50 and thus even less of the total women over 45. With this very small and non-random sample, his CFR figures are unlikely to be representative of the total Khumbu population. Furthermore, his sample apparently does not exclude Tibetan refugees who fled from Tibet and settled in Khumbu in the early 60's.

Research among Tibetan refugees in Pokhara and Kathmandu (Nepal) suggested that among Tibetan refugees there are a disproportionate number of nulliparous and low-fertility females. On questioning, these Tibetan refugees corroborated this indicating that families with many children, particularly young ones, disproportionately decided to remain behind in Tibet. The difficulties of the flight to exile and the belief that their exile would be short as it had been earlier in this century, kept many females with large families in Tibet. The Tibetan refugees, therefore, represent a skewed sample and should have been excluded (or separated out) from the analysis (Goldstein 1981a,b).

Finally, and most critically, the Gupta study made no attempt to take into account varying exposure to the risk of intercourse within the category of ever-married women. For example, there is no differentiation between "ever-married" women and "ever-married" women who widowed early or divorced early and never remarried.

The low altitude Kalimpong Sherpa data reported in this study are also seriously flawed. The study does not indicate when or from where these migrants came and the CFR data reported again are inconsistent. For example, while the CFR_{45+} is 7.4, the CFR_{40-44} is only 5.4. It is highly improbable that Kalimpong women on the average had 2 births during the 5 year age interval 40-44 but less than 1 birth during each of the two immediately prior 5 year intervals (age 30-34 and 35-39). Moreover, they only averaged 1.5 births during the 25-29 year age interval (Gupta 1980: 109).

The data reported by Weitz et al. study are also problematic. First, this study lumped Tibetan refugees with indigenous Sherpas. When Professor Weitz very kindly recalculated his figures eliminating the refugees, the CFR_{50+} for all women increased from the original 4.8 to 5.2 (Weitz personal communication, 1980).

But a CFR_{50+} of 5.2 was still very low relative to the CFRs reported for Limi and Kyilung and the question of how to account for this anomalously low fertility still remained.

Weitz has argued for both a hypoxic effect and a further social and biological effect which reduced Khumbu fertility even lower than that of high altitude native Andean populations, e.g.:

> ... both fertility and birth weights appear to be lower at high altitudes.
>
> Although reduced, fertility in the altiplano (Andes) is still high. Completed family size ... average 6.7 births in Nunoa (Peru) similar in other areas of the altiplano. In comparison, completed family size in one well-studied area of low-altitude Peru was 8.3.
>
> Sherpa fertility is much lower -- completed family size is about 5.1. Part of the difference (between this and the Nunoan CFR) may be explained by various cultural factors that seem to lower Sherpa fertility. In the past, low iodine intake caused ... hypothyroidism, which is known to result in an extremely high level of spontaneous abortions (thus lowering the no. births). (Weitz 1981b, 1982).

We contend that if exclusion from exposure to intercourse were taken into account and a comparable category of "fully married" Sherpa women constructed, Khumbu Sherpa fertility would not be unusually low, i.e. when a Khumbu Sherpa sample population roughly approximating the Limi and Kyilung "fully married" samples is isolated, Sherpa fertility is equivalent to that of Limi and Kyilung.

However, the data reported in Weitz et al. does not directly permit such recalculation. First, as indicated earlier, the low fertility Tibetan refugees are included with Sherpas in all calculations. Second, there is no breakdown of women in the sample by virtue of present and past marital status (e.g. divorced, widowed, separated) or even a clear ever-married/never-married dichotmy. Third, no fertility figures are presented for "ever" and "never" married women as distinct categories. Instead the data are presented only with reference to socio-economic categories (higher and lower) and degree of village acculturation. However, because these socio-economic categories and village types contain different but unspecified proportions of Tibetan refugees, it is not possible to recalculate the data to construct a category of "fully married women" or even "ever-married" women. However, there is evidence suggesting that when a category of "fully married" women is constructed, it will show relatively high fertility. For example, this study cited a CFR_{50+} of 6.2 for married females in the higher socio-economic category, i.e., for the socio-economic category that included fewest Tibetan refugees.

Recently, Professor Weitz has reorganized the Khumbu data to segregate out Tibetan refugees and take into account different types of marital statuses (Weitz personal communication, 1981c). Sherpa females were divided into 7 marital categories: never-married; monogamous marriages; 1 marriage, widowed; 1 marriage, separated; serial monogamy; polyandrous marriages; and polyganous marriages. While this goes a long way toward addressing the issue of social exclusion from the risk of intercourse and thus conception, it still does not take into account reduced fertility within marital categories, e.g. monogamous women who married only later in life. Nonetheless, the new breakdown provides additional insight into what Khumbu Sherpa completed fertility would be if a "fully married" category could be constructed. For example, the CFR_{50+} for Sherpa women married monogamously of 6.5, a figure almost identical to that of Kyilung Buddhists (Ibid.). When we calculated a weighted CFR_{50+} for a composite category consisting of monogamously, polyandrously and polygynously married women (weighting for proportion of total population) we computed a CFR_{50+} of 6.3. We strongly suggest that in-depth anthropological research on family and marital history would increase this already relatively high CFR even further (as demonstrated in the Kyilung analysis) by identifying and excluding females within the marital types who have had reduced exposure to the risk of intercourse and thus conception.

When these new CFRs of 6.3 and 6.5 were compared with the CFRs of Limi and Kyilung, the initial statistically significant difference mentioned earlier (associated with the 4.8 figure) vanishes ($P > 0.05$). And when the CFRs of all of these are then compared (using the Student Neuman Keuls Multiple Range Test) with Gupta's 4.5 CFR_{45+}, Gupta's figure is statistically different from the others [Khumbu (Gupta) $<$ Khumbu (recalculated Weitz) = Kyilung (Buddhist) = Kyilung (Muslim) = Limi][2]. In other words, when even a roughly comparable sub-sample of Khumbu females was isolated which excluded all Tibetan refugees and women who have been divorced, widowed, never-married, etc., Khumbu fertility is not statistically different from that of the other high altitude Himalayan populations studied by Goldstein.

In the end, then, the unusually low fertility reported for high altitude Sherpas (Weitz et al. and Gupta) and utilized by Bangham and Sacherer does not reflect low fecundity produced by high altitude hypoxia or other biological-environmental factors such as hypothyroidism. Rather it reflects a failure of these studies to control for critical confounding factors affecting fertility.

A Comparison of the Fertility of High and Low Altitude Himalayan Populations

While the issue of the anomolously low fertility reported for the Khumbu Sherpas appears to be resolved, the more fundamental issue of whether the fertility (and, of course, fecundity) of these high altitude Himalayan populations is significantly different from that of low and moderate altitude Himalayan populations must be examined. As indicated earlier, both Bangham and Sacherer and Gupta have concluded that there is a significant difference in fertility between low and high altitude Himalayan populations that is caused by hypoxia produced low fecundity at high altitude.

The serious shortcomings of Gupta's high and low altitude data have been discussed above. The Bangham and Sacherer study suffers from equally fundamental shortcomings. Their sample of 75 women comes from 15 moderate altitude Sherpa villages in Helambu, Solu and the Upper Arun River (see Fig. 1) located at altitudes between 2200m and 2600m. As indicated in Table 3, they report a CFR_{45+} of 7.6 for Helambu, 8.5 for Solu-Arun, and 5.3 for Kagate (a sub-population in Solu comprising migrants from Helambu). The joint CFR_{45+} for these three populations is 7.8, a figure they report to be significantly different from the completed fertility of the high altitude Khumbu Sherpas (using the 4.5 and 4.8 CFRs). However, because of the size and character of the samples and the methods of data collection, the findings reported cannot be considered valid.

This study indicated that villages were visited for only a few days and interviews were conducted with whomever came to see them and would cooperate (Bangham 1978). In no case was the size of the total universe from which their sample came indicated and it is, therefore, impossible to determine the percent of the total that their sample represents. However, we know it must be extremely small because it averages out to less than 5 women per village studied. Because these five women were not selected by any random or systematic methodology (i.e. were self-selected) their reported data cannot be treated as representative of the larger populations. In fact, in one of their sites (Kagate), the entire sample of women aged 45+ consisted of only 4 individuals.

These very serious shortcomings are compounded by the fact that the misleadingly low fertility figures cited by Gupta (4.5) and Weitz et al. (4.8) are used for the high altitude contrast population. Thus, the finding of a statistically significant difference between high and moderate altitude Sherpas has no validity. In fact, when our recalculation of Weitz's marital fertility (6.3) is used for the high altitude Sherpa population, there is no statistically significant difference between the CFR reported by Bangham and Sacherer for the low altitude Sherpas (7.8) and the CFRs of Limi, Kyilung (Buddhist and Muslim) and Khumbu ($P > 0.05$).

Nonetheless, this does not mean that valid comparisons of fertility cannot be made across altitude zones in the Himalayas. To the contrary, a number of new and excellent cultural-demographic in-depth studies make such a comparison feasible.

Before discussing these, a comment must be made on how we shall operationally define "altitude" in this paper. It has been suggested that 2500m be used to demarcate high altitude since altitudes above that are required to produce evidence of hypoxic stress (Baker 1978).

We do not disagree with this but suggest that since there is a continuum of decreasing partial pressure of oxygen (pO_2) along an increasing altitude gradient, a tripartate division into "high", "moderate", and "low" altitude is more efficacious since a hypoxic effect on fecundity may only be measurable at very high altitudes or may operate differently at moderate and high altitude. We shall use 3400m for the beginning of our high altitude zone and 2000m for the moderate altitude zone. Table 3 presents the currently available fertility data for the Himalayas.

Ross (1981) conducted an 18 month indepth, cultural-demographic study of two contiguous villages at "moderate altitude", one Hindu (2300m) and one Tibetan (2500m), in Humla, a remote district in N.W. Nepal. This study reported a CFR_{45+} for all Tibetan females of 6.0, and a CFR_{45+} of 6.7 for ever-married females. However, when women were widowed before the age of 45 are excluded, the CFR increases to 7.0. A parallel effect is reported for the Hindu populations. Here the CFR_{45+} for ever-married is 6.2 (all females were ever-married). This increases to 7.4 when women widowed before the age of 45 are eliminated.

Another detailed long-term cultural-demographic study was conducted by Folmar (ms) in 1979-80 in the low altitude Nepalese hill village of Ghachok (1400m) located north of Polhara. It reported a relatively low CFR_{45+} of 5.5 for ever-married Caste Hindu women. However, when he excluded all women widowed before the age of 45 from the computation, the CFR_{45+} increased to 6.7. When he further excluded women who married after the age of 25 ($\bar{X}$ + 1 S.D.), the CFR increased still further to 7.2.

Several other studies (Macfarlane, Levine, Sacherer), present some demographic data but because it is not possible to isolate a "fully married" category analysis was limited to the Folmar and Ross data. Two techniques were used to test the relationship between the fertility of these high, low and moderate altitude populations. Fig. 2 presents a plot of altitude and CFR for the populations listed in Table 3 for which "fully married" categories could be constructed. It illustrates clearly the absence of any altitude related pattern. Correlation-regression analysis revealed no significant relationship between altitude and completed fertility rate ($P > 0.05$).

The Student Neuman Keuls Multiple Range Test was also used to compare the CFRs 9 populations in Table 3 for which standard deviations are published (with the exception of Gupta's Khumbu data). It also found no statistically significant difference between the high, moderate and low altitude populations. Further SNK tests excluding first Gupta's data and then Gupta's and Bangham and Sacherer's data were run, but there was still no statistically significant difference between the high, low and moderate altitude populations.

Consequently, while Gupta's and Bangham and Sacherer's findings of a statistically significant difference between low and high altitude populations in the Himalayas were technically correct, they are scientifically invalid due to the nature of the data on which they were based.

TABLE I. Kyilung Fertility by Age, Religion and Socio-Marital Type

Age	Religion	Mean no. births for "fully" married women	N	Mean no. births for "never-married" women	N	Mean no. births for "Reduced fertility" women	N	Mean no. births for all women	N
60-69	Buddhist	6.5 SD 2.99	24	5.0 SD 00	1	6.5 SD 2.12	2	6.4 SD 2.86	27
	Muslim	7.2 SD 2.39	9	-		-		7.2 SD 2.39	9
	Both	6.7 SD 2.82	33					6.6 SD 2.74	36
50-59	Buddhist	6.2 SD 3.15	29	1.5 SD .71	2	3.0 SD 2.0	5	5.5 SD 3.26	36
	Muslim	7.0 SD 3.58	6	-		-		7.0 SD 3.58	6
	Both	6.4 SD 3.18	35	-				5.7 SD 3.31	42
45-49	Buddhist	6.4 SD 2.6	17	1.5 SD 1.73	1	3.8 SD 2.5	4	5.2 SD 3.04	25
	Muslim	7.2 SD 2.36	14	-		-		7.2 SD 2.4	14
	Both	6.7 SD 2.49	31					5.9 SD 2.95	39
45-69	Buddhist	6.4 SD 2.93	70	2.0 SD 1.83	7	3.9 SD 2.39	11	5.7 SD 3.09	88
	Muslim	7.2 SD 2.55	29	-		-		7.2 SD 2.55	29
	Both	6.6 SD 2.84	99	2.0 SD 1.83	7	3.9 SD 2.39	11	6.1 SD 3.02	117
40-44	Buddhist	6.3 SD 2.55	21	1.3 SD 1.21	6	2.0 SD 0	1	5.1 SD 3.11	28
	Muslim	7.3 SD 1.98	8	-		-		7.3 SD 1.98	8
	Both	6.6 SD 2.41	29	-		-		5.6 SD 3.02	36

TABLE 11

COMPLETED FERTILITY RATIOS FOR LIMI, KYILUNG AND KHUMBU

GROUP	SOURCE	ALTITUDE	AGE	CFR MARRIED WOMEN[a]	N	CFR ALL WOMEN	N
Limi	Goldstein, 1981	3900m	45+	7.4 (SD 3.16)	17	6.3 (SD 3.69)	21
Kyilung:							
Buddhist		3500m to 4000m	45-69	6.4 (SD 2.93)	70	5.7 (SD 3.09)	88
Muslim				7.2 (SD 2.55)	29	7.2 (SD 2.55)	29
Both				6.6 (SD 2.86)	99	6.1 (SD 3.02)	117
Khumbu	Weitz et al. 1978	3500+m	50+	-	-	4.8 (SD 3.44)	110
	Gupta, 1978, 1980		45+	4.5 (SD 2.48)	19	-	-
	Weitz 1981c		50+	6.3 (SD NA)	44	4.8 (SD 3.44)	110

[a]All but Gupta's CFR reflect roughly equivalent "fully married" women.

TABLE III

COMPLETED FERTILITY RATIOS FOR HIMALAYAN POPULATIONS RESIDING AT HIGH, MODERATE AND LOW ALTITUDE

	GROUP	SOURCE	ALTITUDE	ETHNICITY	AGE	CFR FOR MARRIED WOMEN	N
HIGH ALTITUDE	Limi	Goldstein, 1980 1981	3900m	Tibetan	45+	7.4	17
	$Kyilung_1$	•	3800m	Ladakhi-Buddhist	45-69	6.4	70
	$Kyilung_2$		3800m	Ladakhi-Muslim	45-69	7.2	29
	Khumbu	Weitz 1981c	3400+m	Sherpa	50+	6.3	44
	All of the above					6.8	
	Khumbu	Gupta 1978, 1980	3400+m			4.5	
MODERATE ALTITUDE	Dhinga	Ross 1981	2500m[a]	Tibetan	45+	7.0	13
	Chaugan	Ross 1981	2300m	High Caste Hindu	45+	7.4	11
	Nyinba	Levine 1977	2900m	Tibetan	43+	6.3	19
	Helambu	Goldstein and Beall	2600m	Sherpa	45+	7.2	20
	All of the above					7.0	
	Solu-Arun	Bangham and Sacherer 1980	2400m	Sherpa	45+	8.5	26
	Helambu	Bangham and Sacherer 1980	2600m	Sherpa	45+	7.6	40
	Kagate	Bangham and Sacherer 1980	2400m	Sherpa	45+	5.3	4
LOW ALTITUDE	Ghachok	Folmar Ms.	1400m	Hindu-High Caste	45+	6.9	22
	Ghachok	Folmar Ms.	1400m	Hindu-Low Caste	45+	7.4	26
	Thak	Macfarlane 1976	1700m	Tibeto-Burman: Gurung	40+	5.6	12
	Mohoriya	Macfarlane 1976	1700m	Tibeto-Burman: Gurung	40+	5.9	18
	All of the above					6.2	
	Kalimpong (Gupta)	Gupta 1978, 1980	1400m	Sherpa	45+	7.4	69

[a]In cases where villages have a main and summer location, we use the altitude of the main village. In cases where a village or sample is spread out over a substantial altitude gradient, we used the average altitude.

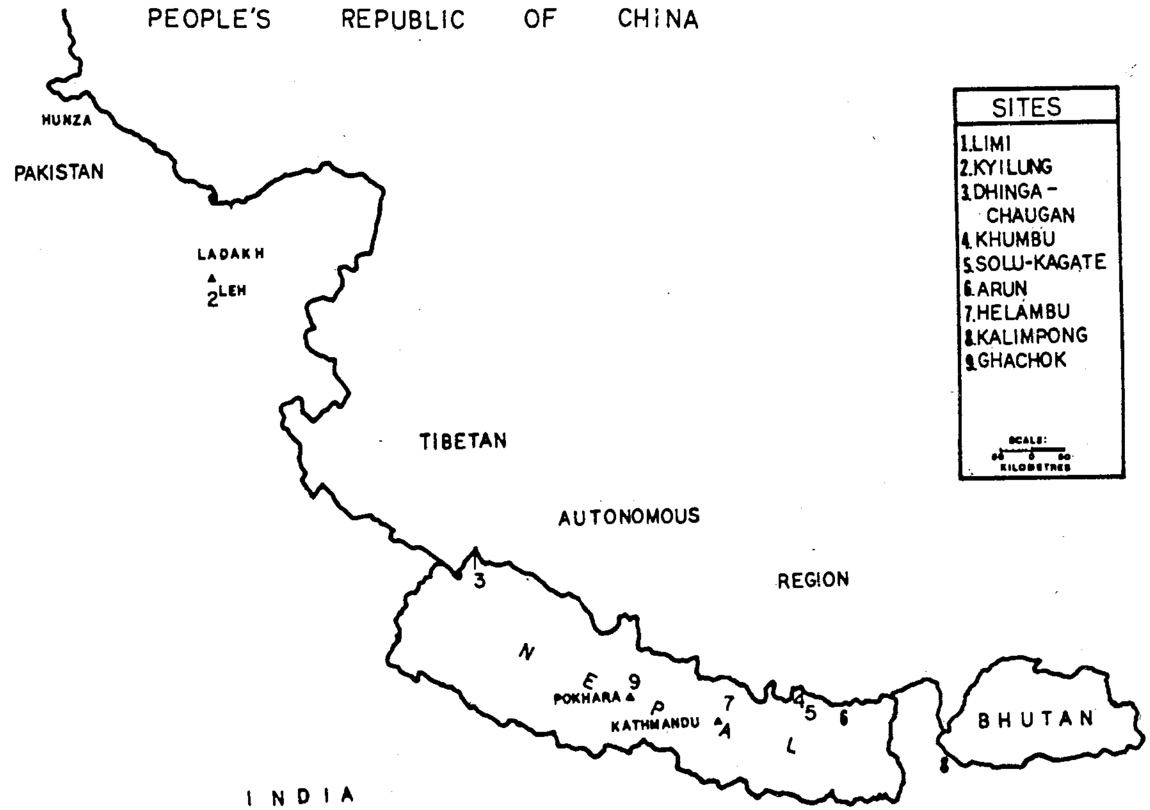

Figure 1: Map of main research sites in the Himalayas.

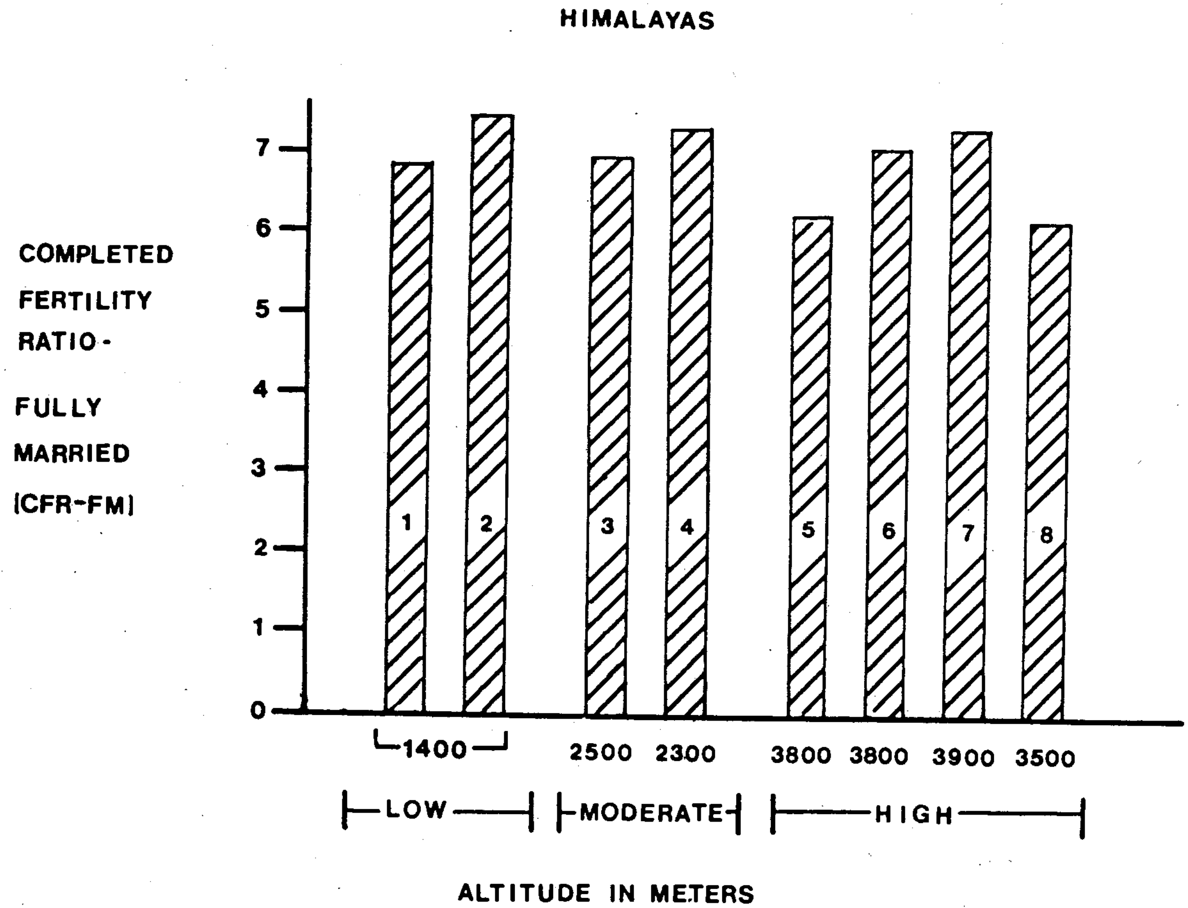

Figure 2: Compares the completed fertility of fully married (CFR-CM) women for eight populations residing at different altitudes in the Nepal and Indian Himalayas. Population 1= Ghachok (Nepal), High caste Hindu (Folmar, ms.); population 2= Ghachok (Nepal), Low caste Hindu (Folmar ms.); population 3= Dhinga (Nepal), Tibetan (Ross 1981); population 4= Chaugan (Nepal), High caste Hindu (Ross 1981); population 5= Kyilung (Ladakh, India), Ladakhi-Tibetan; population 6= Kyilung (Ladakh, India), Balti Muslim; population 7= Limi (Nepal), Tibetan (Goldstein 1981b); population 8= Khumbu (Nepal), Sherpa-Tibetan (Weitz 1981c).

Using the new cultural-demographic data and the recalculation of existing data, we found that the fertility of high altitude Himalayan women of post-reproduction age is moderately high and is not statistically different from the fertility of women residing at moderate and low altitudes once comparable "controlled" samples are constructed.

Conclusion

Based on this reexamination of the Himalayan data, it is concluded that the case for the presence of a hypoxic effect acting to reduce fertility and fecundity in long term resident native populations in the Himalayas is scientifically unproven. Of course, this does not imply that such an effect does not exist; it means only that new research taking into account the methodological and conceptual factors discussed in this paper is necessary. To test the effects of altitude on fecundity and fertility, the effects of confounding factors must be controlled. Until this is done, the evidence for a hypoxic effect is primarily anecdotal.

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1981b); population 8= Khumbu (Nepal), Sherpa-Tibetan (Weitz 1981c).

NOTES

1. Women over 70 (N=13) have been excluded from these computations because there is very definite evidence that their replies underreport fertility and because it was virtually impossible to obtain corroborative information for them on infant mortality, exclusion from the risk of conception, etc. For example, the self-reported number of births for married women over 70 is 3.9 (SD 3.84), a figure almost 3 births lower than that of married women 45-69. There is no historical event (cohort effect) that would account for this. We believe that this report of untypically low fertility is the result of an under-renumeration of births ending in infant mortality. For example, whereas married women 45-69 reported that 2.2 (N=99) of their births resulted in deaths, the married women 70+ reported only 0.6 (N=10) of their births resulted in death. There was also a higher percentage of nulliparous women in 70+ category, again indicating underreporting of births.

2. A special interactive computer programme was written in Fortran for this study. This programme requires only means, standard deviations and sample sizes for input and first computes an analysis

of variance (ANOVA). If the ANOVA test reveals statistically significant differences, then the programme branches into the Student-Neuman-Keuls procedure to pinpoint where the differences exist. John Blangero, a Ph.D. candidate in physical and medical anthropology in the Department of Anthropology, Case Western Reserve University, wrote the computer programme for the SNK test.

3. The lower CFR of 6.3 was used in his computation. Since Weitz (1981c) did not provide S.D. figures, we used the ones cited in his 1978 paper for the 4.77 and 6.2 CRFs.

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