How much will feeding more and wealthier people encroach on forests?

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Introduction

The growing forests in industrial nations encourage a hopeful vision of a Great Restoration of nature in the form of a spreading forest canopy.[1] The reforestation supports a vision of restoration even while population continues to grow, albeit at a slowing rate, and the human condition improves. The realization of this hopeful vision rather than an apocalypse of denuded forests and destroyed nature, however, depends heavily upon how people will eat, how farmers will till, and how each change of cropland encroaches on forests.

We examine eating, tilling, and encroachment to answer the big question: How much will growing crops to feed more and wealthier people encroach on forest to the year 2050?

To many, the answer is dire and the proscription of farming clear. For example in November 1999, journalist Ed Ayres[2] wrote in *Time* magazine, "Agriculture is the world's biggest cause of deforestation, and increasing demand for meat is the biggest force in the expansion of agriculture." Although grazing to produce meat will affect forests, we shall concentrate on the more distinct impact of crops. Crops encompass corn to feed cows, pigs, and chickens as well as wheat, rice, and vegetables for people to eat directly. More cattle on feed rather than pasture, as in the rise from 5% on feed in the USA in 1945 to 12% in 1970[3], and more poultry and swine that depend on feed increase the importance of crops in meat production.

On the ground, of course, farming and forests interact in more ways than can be captured in a popular generalization. Angelsen and Kaimowitz (1999)[4] summarized by Helmuth (1999)[5] analyzed the manifold ways. For example, the magnet of rice growing in an irrigation project in the Philippines drew people to lowlands and reduced pressure on forests. Laborious but profitable production of coca in plantations attracted farmers and reduced pressure on South American forests. Honduran farmers who lifted their maize yields by technology planted twice as much maize as those who did not--but the total land occupied by their cropping system fell because they no longer needed broad fallow areas.

Labor-saving machinery and new crops expand cropland sometimes and some places. The expansion of soybeans encroached on native vegetation, though not on forest, in the Brazilian campo cerrado. Unsurprisingly, small Ecuadorean farmers with chain saws cleared more forest than those without.

A generalization can explain these diverse outcomes. Labor-saving technology encourages cropland encroachment on forests when both labor and the demand for crops are elastic. Recurring farm surpluses, however, testify that cheap food often fails to increase demand. Already in the 17th century Gregory King (1648-1712) noticed that the inelasticity of farm crops could make a bumper crop worth less in total as well as per ton than a skimpy one.[6] For the USA, classic studies show the farm price elasticities of demand vary from a low 0.2 for potatoes to 0.4 to 0.7 for beef, chicken, and apples. In the long run, elasticity at the retail can rise to 0.7 to 1.0 for pork and beef.[7] So, Angelsen and Kaimowitz conclude their generalizations by writing that the best technologies for conserving forests are ones that "greatly improve the yields of products that have inelastic demand."

Drawing on the resources of the FAO to anticipate world agriculture towards 2010, Alexandratos (1995)[8] projected that those improved yields would temper farmers' need for more cropland. The FAO projection rests on analysis of commodities, countries, and land availability in detail; acknowledges prices but does not otherwise link to economies; estimates land balances and suitability; and uses knowledge and judgement of experts. It emphasizes developing countries. Past and projected production and cropland in the world, developed, and developing countries imply changes in yields. The recapitulation in Table 1 shows the important result that an expected 2.2 percent per annum (% p.a.) rise in yields in the developing countries will hold their expansion of cropland to 0.4% p.a. The conclusion: "Assuming some decline of agricultural land use in the developed countries (for which no land projections were made), it can be hypothesized that there will be only modest expansion of land in agricultural use for the world as a whole." Fortunately, yields rising faster in developing than developed countries show the poor closing the gap between themselves and the rich. Fifty years' expansion of the 1,510 M ha (million ha) of 1997 cropland at 0.2 to 0.3% p.a. equals 160 to 250 M ha of new cropland. Although the projected 250 M ha equals more than 4 times France's area, projecting *modest* expansion of cropland still does not foreclose the vision of broader forests, as we shall discuss later.

Table 1. Past and future changes of production, cropland area, and yields as percent per annum for the world, developing (Dev'g) and developed (Dev'd) nations. Source Alexandratos, pp. 80, 166.

Period	1970/90	1990/2010
World production	2.3	1.8
World cropland	0.2/0.3	M
Yield by difference	*2.0/2.1*	*M*
Dev'g production	3.3	2.6
Dev'g cropland	0.4/0.5	0.4
Yield by difference	*2.8/2.9*	*2.2*
Dev'd production	1.4	0.7
Dev'd land	-0.1/0	M
Yield by difference	*1.4/1.5*	*M*

Even the projected modest expansion of crops in table 1 depends on a slowing of the rise in yields from, say, 2.8 to 2.2 % p.a. in developing nations. Sustaining the recent rise of yields, of course, would spare land, building on the Great Reversal of agricultural land use that occurred about 1950. After gradually increasing for centuries, the worldwide area of cropland per person began dropping steeply about that time, when yields per ha began to climb. Waggoner (1994)[9] and Goklany (1999)[10] calculated not cropland encroaching on forests as population grew, but the rising yields and intensities of cultivation that would shrink or stabilize cropland during the next 50 years. Recent trends of yields do not preclude future rises and their benefits. In an example from the USA between 1967/92, changing preference for meat and, especially, rising feed grain yields spared about 21 million hectares in the USA alone, the area of fully 24 Yellowstone parks.[11] Increased efficiency of use of nitrogen fertilize relieves fears of environmental fall-out from intensive strategies that spare land.[12]

After this brief review of condemnations of farming's encroachment on forests, diverse effects of technology on encroachment, FAO's complex model that encompasses expert judgement, and demonstrations how rising yields can contain cropland expansion, how shall we distinguish our present analysis? Anticipating change through five decades, a time as long as the time since World War II, takes a robust method. We put our faith in extracting stable patterns or long-term regularities from the recent record. They must be logical enough for us to reason about their changes but simple enough to grasp. And they must be so sturdy that they are not blown this way and that by prices, interest rates, styles, and other fluctuations that set models adrift. We begin with the relation of cropland expansion to forest encroachment and go on to the large forces historically expanding cropland.

The cropland encroachment factor

Crops and forests can be visualized playing one of three games. If they are playing a zero-sum game, when crops win 1 ha, forests lose 1, making what we shall call the "encroachment factor" simply 1 and keeping the sum of cropland plus forest constant. In the second sort of game, if crops expand onto grassland or other land, as when soybeans expand onto the savanna of the Brazilian cerrado, the encroachment factor of crops on forest will be less than 1. The sum of cropland and forest will grow. Because the world holds about twice as much grass and other land as it holds forest, the sum of crops and forests can grow. And in the third game, other land uses may encroach on forests, shrinking the sum of crops and forests. Logging, urban development and even designating a forest as a park could shrink the sum of forest and crop. Agricultural uses of roads to new fields in the forest and expanding pastures could shrink them. In this third sort of game, an encroachment factor reckoned as loss in forest area per gain of cropland would exceed 1.

At the outset we know that globally forests shrank recently more than cropland expanded. In the *State of the World's Forests 1999* the FAO[13] reported global and national changes of forest areas 1990/95. In 1990 and 1995 the FAO also reported national areas of Arable and Permanent Crops, which we shall call cropland.[14] During 1990/95 the 56 million ha loss of global forests exceeded the 5 million gain of cropland tenfold. Do diverse regions show what game and encroachment factor connects crops and forests?

Tropical transitions

About two-thirds of the global *tropics* were encompassed within the *Forest Resources Assessment 1990*[15] that reported changing land use 1980/90. Because the Assessment categorized that two-thirds of the tropics entirely into seven classes, it created a zero-sum game among the seven. We simplify the seven by consolidating the "closed" and "open forest" plus "long fallow" into one class, simply *forest*. The Assessment's class "other land cover" includes permanent agriculture, cattle ranching, water reservoirs, etc., representing a complete loss of the cover and woody biomass; we call this composite class simply *clear*. The three land use classes called *forest* comprised 56% and the *clear* land 28% of the 3,068 million ha encompassed by the seven classes in 1980.

The changes among the class areas during 1980/1990 form a transition matrix for the tropical zone. The heroic assumptions that the two-thirds of the tropics covered by the assessment are representative, that the future use of land depends only on its present use, and that the changes during 1980/90 are stationary transition probabilities allow us to project the change on to 2050 (Figure 1). Through the seven decades *forest* shrinks an average 0.56% p.a. Although *clear* expands 0.90% p.a. during the first decade, it slows to only 0.49% p.a. during the final decade. During the simulated 1990/2050, *forest* loses slightly more than clear gains, causing the sum of the two to shrink slightly as if *clear* and *forest* were playing close to a zero-sum game. The huge absolute projected loss of about 400 million ha, about 1/4th of the forest, makes the familiar vision of future tropical landscape. The evidence falls short of proving a zero-sum game between crops and forests, however, because *clear* includes cattle ranching, water reservoirs, and other uses.[16] The projection of 1980/1990 does show the inevitable slowing of clearing as the forest shrinks while transition probabilities continue unchanged, but it mindlessly neglects people changing the probabilities to conserve forests.

The game between crops and trees in diverse nations

Changes in forest and cropland in ten nations that span climates and stages of development indicate the encroachment factor for varied circumstances. With Russia, Bangladesh, Brazil, Congo DR, China, Indonesia, India, Colombia, Mexico, Tanzania and the USA encompass about half global population and half global forests. Because the Russian land use record is not continuous, we omit its analysis. In the ten nations the pressure to expand cropland into forests, measured by population per ha cropland, ranges from 14 in Bangladesh down to 1 in the USA.[17]

Again we use the 1990/95 national changes of forest reported in the *State of the World's Forests 1999* and the national cropland areas reported by FAO as Arable and Permanent Crops.

If losses of forest match gains of cropland, the changes in the ten representative nations would lie on the diagonal line in Figure 2. The scattered points clearly show reality differs from a zero-sum game. The US gained forest, but less than it lost cropland, because other uses took land. Although Brazil gained cropland from the cerrado, it still lost more forest than it gained cropland. Indonesia and Bangladesh lost both cropland and forest. India and, especially, China gained both cropland and some forest, putting their points above the zero-sum line and indicating encroachment factors less than 1.

Continuing our search for pattern, we next look at the 135 nations with more than 50 thousand ha of forest in 1990. To compare these nations, which differ greatly in size, we divide the 5-year changes of cropland and forests of each nation by its forest area in 1990. The scattered points in Figure 2.1 of forest losses vs. cropland gains again show that the game between crops and trees was far from zero-sum. In 48 of 135 nations the sum of forest and cropland shrank, and in 15 it grew.

The game among all land uses in a single nation

If we examine all land, not just crop and forest, in one nation can we see why the two do not play a zero-sum game? We simplified the US Department of Agriculture[18] classes of USA land into seven: 1) Cropland used and 2) not used, 3) grassland and range, 4) forest, 5) rural parks and wildlife areas, 6) urban and 7) remainder. The park class, number 5, must be acknowledged separately from urban and remainder because it has grown ten-fold since 1945 and now occupies 10% of US land. The US Forest Service wrote that the 4% decline of timberland since 1952 "has been entirely the result of withdrawals of public timberland as wilderness or other land uses that do not permit commercial timber harvest."[19] Although much forest has become parks, only about half of USA parks are forested; eastern parks are heavily forested, while western parks include grassland and barren mountains. When we calculate the change in areas from 1987-95 we combine forest and park to capture the impact of park designation but ignore the roughly half of park that is not forest.

Among the 7 land classes, urban land changed fastest in relative terms. It rose an average 0.79% p.a. between 1987-92, a large percentage but small absolute change. The 0.35% p.a. increase of park raised the sum of forest and park by 0.09% p.a. Pasture scarcely changed. While the cropland actually used rose 0.40% p.a., unused cropland shrank, causing total used and unused cropland to shrink 0.17% p.a.

To detect zero-sum games, we again relate changes in forest to cropland. For 11 regions we relate the change in forest plus park, classes 4 + 5, to changes in used cropland, class 1 (Figure 3). In the Corn Belt the used cropland expanded into unused cropland and a smaller remainder, class 7, accommodated an expansion of forest. In the Southern Plains (Texas and Oklahoma) shrinking grassland and range matched expansions of both used cropland and forest. In the Northern Plains a great shrinkage of all cropland was matched by expanding grassland and range. In the Mountains the big change was shrinking forest matched by expanding park.

Going beyond crops vs. forests reveals more nearly zero-sum games. Change in used cropland was matched by the sum of unused cropland, grassland, and range (Figure 4). The swapping between forest and park in the Lake and Mountain states dominates Figure 5. Including all classes of land explains the departures from zero-sum games between crops and forests.

With so much evidence that crops and forest do not play a zero-sum game but instead gain and lose to other uses, how shall we connect projections of changing cropland to shrinking or expanding forests? The US proved 1 ha less cropland does not make 1 ha more forest, and Brazil proved that 1 ha less forest does not make 1 ha more cropland. We fall back on the physical principle that the encroachment factor will rarely exceed 1 because, strictly speaking, 1 ha cropland cannot encroach on more than 1 ha forest. The factor can readily be less than 1, however, because crops can expand onto grass and other land. The world holds about the same expanses of forest, grass, and *other* land. Thus, while remembering exceptions may occur and will matter greatly locally, we foresee an encroachment factor generally between 1 and 1/3 will modify the cropland changes we shall now project.

Changes of cropland

We promised to decompose trends in land use into forces with trends stable and comprehensible enough to project logically for a half century. We keep that promise on a foundation of how growing population and wealth as well as changing diets and farming affected cropland area from 1960 to the present.

The forces

An identity defines the extent of global cropland:

Cropland = Population x (Gross World Product/Population) x (Food/GWP) x (Agricultural Production/Food) x (Cropland/Agricultural Production)

In words, cropland can be calculated as the product of five forces, beginning with *Population*. *Wealth* (represented by GWP/Person) multiplies population. *Taste*, the proportion of wealth devoted to food (represented by Food/GWP) adds its modification, because the rich may spend relatively less on potatoes and buy more of their potatoes as chips. The *unfood* ratio, Agricultural production/Food, recognizes that farmers use land to grow cotton, tobacco, coffee and tea as well as food. Finally because yield can vary by multiples in producing crops from a specified area of land, its reciprocal, the *land* ratio, Cropland/Agricultural production, enters the identity.

Data to quantify the first two forces are straightforward, for the latter three less so. For population, we use UN reports, and for wealth the World Bank reports of Gross Domestic Product. However, to measure agricultural production, all crops must be converted into a common currency. Also diverse crops, say, potato, wheat, and apple must be converted into a single measure of food production. We might decide that people should have calories, protein, or even vitamins, and then convert all crops into one of those parameters. The FAO[20] weights commodities by the value or price people place on them. We shall use FAO's so-called Laspeyres indices based on the sum of price-weighted production of agricultural commodities after subtracting seed and feed weighted similarly. It measures disposable production for any use except seed and feed. We also use FAO's index of food production, which unlike cereal production alone, reflects changing taste and diet.[21]

We, of course, are interested in changes in cropland. For small changes in percent, such as those that occur annually, we can calculate the change in cropland as the sum of the changes of the five multiplying forces. Thus, our identity becomes, in % p.a.,

Δ Cropland (in ha) = Δ Population + Δ GWP/Person (in \$/person) + Δ Food/GWP (in index/\$) + Δ Agricultural production/Food (in index/index) + Δ Cropland/Agricultural production (in ha/index).

$$= \Delta \text{ Population} + \Delta \text{ Wealth} + \Delta \text{ Taste} + \Delta \text{ Unfood} + \Delta \text{ Land}$$

We now examine the values for this identity globally and in our representative nations. To lessen the effect of short-term fluctuations, such as oil price shocks, we use ten-year running averages, that is annual percentage changes calculated from 4 years before until 5 after each year.

Global Changes

The values for two component forces, population and wealth, have been consistently positive since 1960, as Figure 6 shows. The rises in population and wealth both decelerated but nevertheless continued. The annual 1.27% rise of population and 0.79% rise of wealth during the final period, 1990-8, add to a 2.47% annual increase in GWP.

The taste ratio Food/GWP should reflect richer people spending less of their income on food and deriving less of their nutrition from staples.[22] In fact, the taste ratio fell a rapid 3.57% when wealth rose 4.15% from 1961-70, and when wealth later rose more slowly, the taste ratio fell more slowly. A relative change or elasticity of -0.7 related the taste ratio to wealth. Mirroring wealth in Figure 6, the course of taste ratio has remained negative.

In the identity, the unfood ratio, Agricultural production/Food, modifies cropland. We omit its small 0.05% p.a. change from Figure 6. To illustrate the cause of the fall we note that, during just 1990-98, three of the four major non-food crops declined 0.4 to 4.0% per year and the fourth, coffee, rose only 0.7%. When people, for example, smoke less or wear synthetic threads, the unfood ratio declines a little in the identity and tempers the need for cropland.

The final force driving cropland is yield represented by its inverse, the land ratio of Cropland/Agricultural production. Although it fell slightly more slowly during the 1990s than the 1960s, it still fell 1.96% p.a.1990/98. The courses of global forces from population to yield add to slow cropland expansion and encourage the vision of expanding forests.

Brazil, India, and the USA

To explore variation among nations we turn to the ten exemplars mentioned above. Before an overview of all eleven, we examine Brazil, India, and the US, a nation with vast Amazonian forest, a populous developing nation, and a developed nation. We again examine the 10-year running changes of the forces driving cropland. Population growth in all gradually slowed from the 1960s to 1990s, but Brazil and India slowed from faster than 2% p.a. In Brazil GDP/Person grew explosively in the 1970s but soon slowed. In India it speeded up, while in the US it slowed with a couple of accelerations in the 1970s and 1980s.

Although the taste ratio mirrored the growth of wealth and generally declined, it rose in Brazil after the 1970s. The unfood ratio rose slightly in India and the US but fell in Brazil, where it indicates food became a larger share of agricultural production. While yields generally rose, yields as well as total production respond to changing demand, causing the land ratio to experience notable fluctuations. The land ratio shrank in Brazil in the 1980s, while remaining steady in the US, and then in the 1990s the two nations reversed their patterns. In India the land ratio fell steadily and even steepened from 2 to 3% p.a. shrinkage, as yields soared.

Ten nations

For an overview of all ten nations, we simplify the courses of the forces as the average annual percentage change calculated from their levels in the years 1971 and 1995, years for which we had GDP generally at hand. The nations appear listed in Table 2 from the greatest to least population per ha of cropland. Falls and rises of the taste ratio, Food/GDP, tempered rises and falls of wealth. More food per agricultural production lowered the unfood ratio considerably in Colombia, Mexico, and Brazil. Rising yields lowered the land ratio faster than 2% p.a. in six out of eight nations with the densest population per cropland.

The rising sum of wealth plus the taste ratio improved food per person in six of the eight nations for which data were available. It rose faster than 2% p.a. in China and Brazil, while falling 0.27% p.a. in Bangladesh and 0.75% p.a. in Congo DR. The sum of the five forces shrank cropland in three diverse nations and expanded it in seven, fully 2.59% p.a. in Brazil but only 0.13 in India. The experience incorporated in the preceding figures and Table 2 provide a foundation for projections to 2050, our final task.

Table 2. Average annual percentage changes of the forces driving cropland 1971/95 in ten exemplary nations.

	Pop	GDP/Pop	Food/GDP	Agr/Food	Land/Agr	Land
Bang'h	2.29%	1.04% [a]	-1.31% [a]	-0.06%	-2.42%	-0.46%
China	1.50%	7.93% [b]	-4.80% [b]	-0.03%	-3.45%	1.15%
Colombia	2.06%	2.27%	-1.44%	-0.23%	-3.20%	-0.55%
Tanz'ia	2.22%	[M]	[M]	-0.19%	-0.85%	0.74%
Ind'esia	1.96%	[M]	[M]	-0.06%	-3.41%	0.62%
Congo DR	3.25%	-4.52%	3.77%	-0.18%	-1.99%	0.33%
India	2.05%	2.53%	-1.58%	-0.05%	-2.82%	0.13%
Mexico	2.32%	-0.58% [c]	1.33% [c]	-0.26%	-2.15%	0.66%
Brazil	2.00%	2.51%	-0.49%	-0.45%	-0.97%	2.59%
US	0.96%	1.77%	-1.24%	-0.01%	-1.73%	-0.25%

Footnotes: We did not calculate changes for three nations with brief GDP records, and for three other nations we substituted other years for 1971. [a]GDP 1970/95, [b]GDP 1978/95, [c]GDP 1980/95, [M]Missing

A feasible, likely, attractive vision for cropland

The foundation

Parenthetically and briefly, we remark how weak a foundation supports reports of forest change. We expect that the foundation of data is weak not because of lacking effort, but because definition of a forest will always be arbitrary. Examples abound. Annex 2 of *State of Forests 1997* defines forest as land in developed nations with more than about 20% tree cover but in developing nations as an ecosystem with a minimum of 10% cover of trees or bamboos. *State of Forests 1999* reported 210 M ha of forest in the US, but the US Department of Agriculture estimated 262. Table 3 of *State of Forests 1999* estimates the global forest covered 3,511 M ha in 1990 whereas the long-running FAO categorization of all land into five classes estimated 4,318 M ha were forests and woodland. In 1994 FAO simply abandoned its five classes and now reports only arable and permanent crops with a residuum of other.[23] Kauppi et al. discuss the problem of indefinite estimates elsewhere.[24] Progress will likely depend on defining forests in quantities of such aspirations as cubic meters of wood, tons of carbon, or populations of desired flowers and creatures.

The vision and leverage to reach it

Which drivers of cropland, from population to agricultural efficiency, have the leverage to help realize our vision of growing crops to feed more and wealthier people while restoring forests? Slowing the growth of one of the five forces in the identity has the same effect on cropland as slowing another. However, opportunities, feasibility, and attraction for changing each vary. The diversity of their rates of change in Table 2 gives clues to the opportunities.

To examine the consequences and thus leverage of plausible changes in the five forces we offer a Reference scenario, Table 3, and then comment on alternatives. The UN's medium fertility scenario to 2050 implies an average annual increase of 0.91%, which we adopt for population.[25] The 1.80% p.a. for wealth is faster than the global 1.20 and nearly equal to the 1.77 in the US 1971/95. Added to 0.91 for population, 1.80 wealth lifts GWP at 2.71% p.a., slightly more slowly than the global 2.90 and the US 2.73 during 1971/95. The 2.71 is considerably slower than recent history in the developing nations of Bangladesh, Brazil, China, Colombia, and India but faster than in the Congo and Mexico. In 50 years the 1.80% p.a. increases wealth (i.e., GWP/Person) about two and a half times and GWP about four times.

For taste our Reference scenario specifies the taste ratio falling 1.26% p.a., which is -0.7 * 1.80 the wealth ratio. The -0.70 is the slope of the regression of log(Food/GWP)taste) on log(GWP/Person)wealth) for the data of Figure 6. This means 10% higher wealth will increase Food/Person 3%. The -1.26% p.a. taste ratio combines with wealth to lift Food/Person at 0.54% p.a., close to the global 0.51 of 1971/95. It would reverse the declines of Food/Person in Bangladesh and Congo and slow other nations to the rate of the USA during 1971/95.

Because the unfood ratio is already high at 95% of agricultural production, the Reference scenario leaves it unchanged.

In the Reference scenario, the land ratio falls 1.70% p.a., a little more slowly than the global 1.83% p.a. and American 1.73 of 1971/95. Globally and during 1961/80 and 1980/97, rising yields lowered the land per specific crop by the following % p.a.: wheat, 2.80 and 1.54; maize, 2.55 and 1.54; rice, 2.03 and 1.92 and soybeans, 1.84 and 1.76.

The sum of the forces adds to a projection of cropland shrinking to 2050 by 0.25% p.a., the reverse of Alexandratos' 0.2 to 0.3% p.a. increase. The 177 M ha spared is about 12% of present cropland and 3 times the area of France. If we symmetrically assume a reverse encroachment factor for reforestation of cropland of 1/3 to 1, the land spared from crops by 2050 might add potential for a round 100 M ha or twice the area of France, a 3% increase of the global 3,454 M ha of forest.

Table 3. A Reference scenario of forces changing cropland to 2050 AD. The right column shows the M ha shrinkage from 1997 cropland.

Population	Wealth	Taste	Unfood	Land	Shrink
Pop	GDP/Pop	Food/GDP	Agr/Food	Land/Agr	M ha
0.91%	1.80%	-1.26%	0%	-1.70%	-177

As mentioned above, slowing the growth of one of the five forces in the identity has the same effect on cropland as slowing another. In developing a technical vision for the world's forests for 2050, should we consider different targets for the five forces?

The UN's low fertility scenario corresponds to 0.55% p.a. This low rate would spare some additional 300 M ha. Population control has leverage, if we know how to grasp it.

In places and times, wealth has risen more slowly than our Reference of 1.80% p.a. However, we do not believe poverty is a tolerable lever. It is inhumane as well as inconsistent with moving other levers, such as slowing population growth and rising yields.

During 1971/95 Bangladesh and the Congo showed that Food/Person need not rise. If the taste ratio, Food/GWP, falls as fast as wealth rises, then Food/Person keeps constant. And many stay hungry. Hunger is another inhumane lever. However, the dietary changes in countries with already abundant calories offers some leverage, as our naming the taste ratio implies.

As we have noted, only a small share of agricultural production is not food. Although reasons for eliminating tobacco may be strong no particular reasons exist for eliminating cotton, coffee and tea. Pulling the unfood lever can affect forest encroachment little.

The fifth and final lever, yields and the land ratio, could be pulled harder. The Reference 1.70% p.a. fall of the land ratio is much slower than India's 2.82 and even Congo's 1.99. Sustaining yield increases at 2.00% p.a. is feasible with a will and could spare another 300 M ha or so by 2050, raising the total shrinkage to some 500 M ha or 9 times the area of France.

Peroration

We began with a vision of a Great Restoration of forests even while population continues to grow, and the human condition improves. Clouding the vision was the worry that growing crops to feed more and wealthier people would encroach on forest. Other uses encroach on forest, and crops can expand elsewhere than in forests. So although 1 new ha of crops can encroach on 1 ha of forest, we found that crops and forest do not always play a zero-sum game and put the factor connecting cropland expansion to forest encroachment between 1/3 and 1.

An identity shows cropland expansion in turn driven by five forces from population and wealth to dietary taste and crop yields. This identity connecting cropland expansion to driving forces is iron. Anyone forecasting expansion of cropland must be able to state in its terms the assumptions driving the expansion. For example, what plausible changes in the driving forces would cause the expansion of cropland projected in Table 1? Or what plausible forces plus encroachment factor would cause crops to encroach on the forest as much as Figure 1 projects? Tracked as a performance measure, the identity can also pinpoint a weakening force and restore its leverage to realize the envisioned Great Restoration.

Taking feasible, indeed likely values for the five forces for the next 50 years, we suggest that cropland will shrink globally by more than 10%. Although the global shrinkage of cropland cannot by itself prevent deforestation in some locales, it can make available 100 million ha or more for reforestation.

We do not rashly believe our vision will come true by itself. The gains in yields during the past 50 years, for example, were won by a belief that science could improve the human condition plus investment, experiment, and sweat. With similar investment, experiment, and sweat and continuing belief that science helps, farmers and all those who work with them need not let crops encroach on forests but can instead become the next century's best friends of the forest.

Notes

[1] Add reference to paper by Kauppi et al. for 1/2000 conference.

[2] Ayers, E. Will we still eat meat? Time magazine, November 1999:106-7.

[3] US Department of Agriculture. 1997. Agriculture Statistics. Tables VII-2 and VII-8.

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[14] http://apps.fao.org/cgi-bin/nph-db.pl

[15] Reported in a section "Conversion of forests to other land cover" in FAO (1997) State of the World Forests 1997.

[16] Forests lost 558 M ha, clear gained 508, and fragmented, shrub, and plantation together gained 50, making the ratio D forest/ D clear equal 1.1. If the gained 508 were 400 from crop and 108 from other cleared, then ratio D forest/ D crop would be 508/400 = 1.27, indicating a loss of forest to more than crops. On the other hand, if the gained 508 were 600 from crop and a loss of 92 from other cleared, then D forest/ D crop would be 0.85 because crops were encroaching on forests less than they were expanding.

[17] From Bang'h to Russia the people per ha are: Bang'h, 14.3; China, 9.1; Colombia, 7.8; Tanz'ia, 7.4; Ind'esia, 6.4; Congo DR, 5.6; India, 5.4; Mexico, 3.3; Brazil, 2.6; US, 1.4; Russia, 1.1.

[18] USDA Land use areas and definitions from http://usda.mannlib.cornell.edu/data-sets/land/89003/. The areas generally conform to the areas reported in annual USDA Agriculture Statistics. USDA analysts compiled the 1945-92 series by reconciling past reports. We analyzed the latest span of change, 1987/92.

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[23] http://www.fao.org/waicent/faostat/agricult/landuse-e.htm

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[24] Reference to Kauppi paper for January meeting.

[25] http://www.undp.org/popin/wdtrends/execsum.htm. UN projections of increases to 9.4 medium and 7.7 low fertility from 5.7 billion in 1995 correspond to 0.91 and 5.5% p.a. increase.

Figure captions

Figure 1. Changes of *forest* and *clear* tropical areas to 2050 extrapolated from 1980-1990.

Figure 2. Gains in cropland from 1990/95 compared to losses of forest in ten nations. If gains equaled losses in a zero-sum game, the data would fall on the diagonal line.

Figure 2.1. Gains in cropland and losses of forest in 75 nations. To present the diverse nations on a single scale, we expressed the changes as percentages of their 1990 forest area. The relative changes in 60 of the 135 nations with more than 50 thousand ha of forest lay outside the range of -6 to +6% in the figure. If gains equaled losses in a zero-sum game, the data would fall on the diagonal line.

Figure 3. Used cropland from 1987/92 versus losses of forest and parks in eleven US regions. If gains equaled losses in a zero-sum game, the data would fall on the diagonal line.

Figure 4. Used cropland from 1987/92 versus open land in eleven regions. If gains equaled losses in a zero-sum game, the data would fall on the diagonal line.

Figure 5. Rural parks and wildlife areas from 1987/92 versus losses of forest in eleven US regions. If gains equaled losses in a zero-sum game, the data would fall on the diagonal line.

Figure 6. Forces driving cropland change. Annual percentage changes calculated from 4 years before until 5 after each year

Figure 1

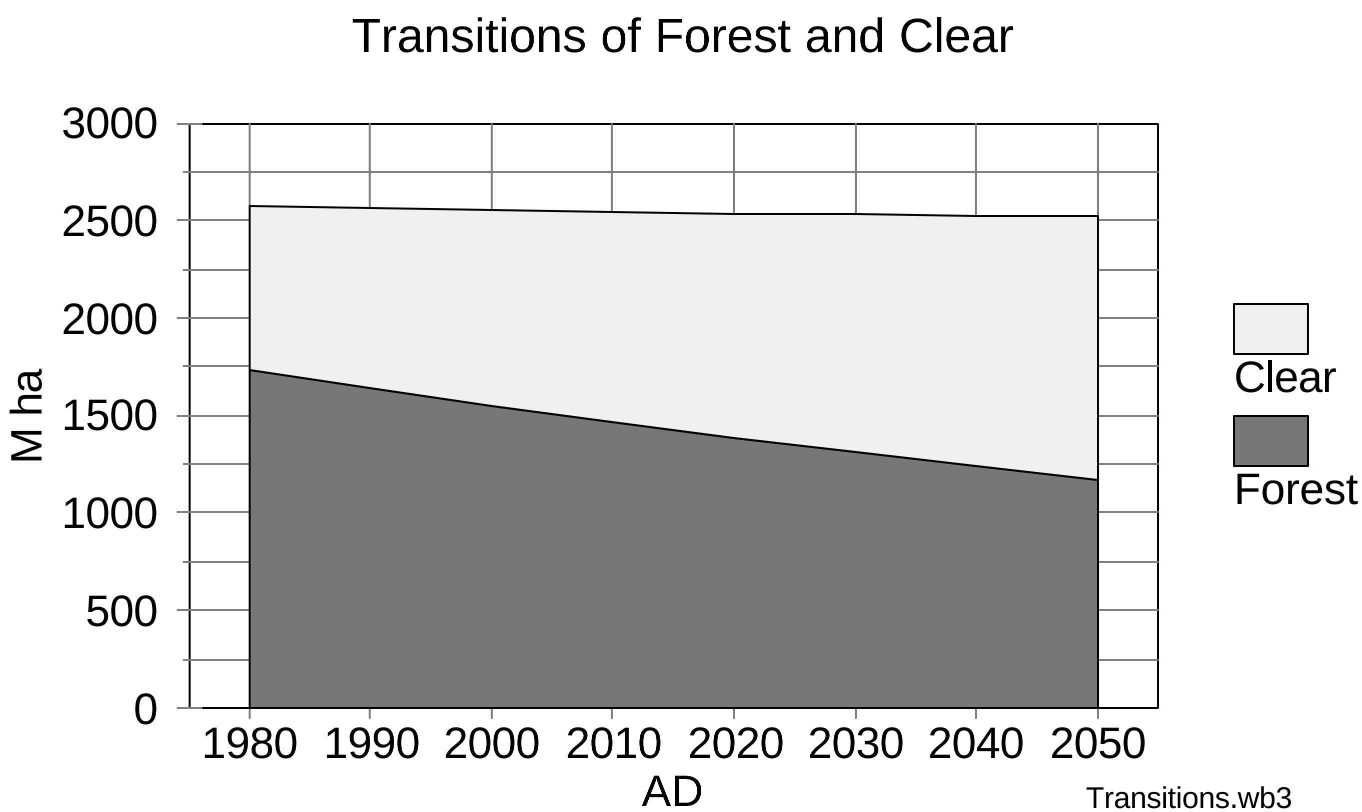

Transitions of Forest and Clear
3000
2500
2000
1500
1000
500
0
M ha
1980
1990
2000
2010
2020
2030
2040
2050
AD
Clear
Forest
Transitions.wb3

Figure 2

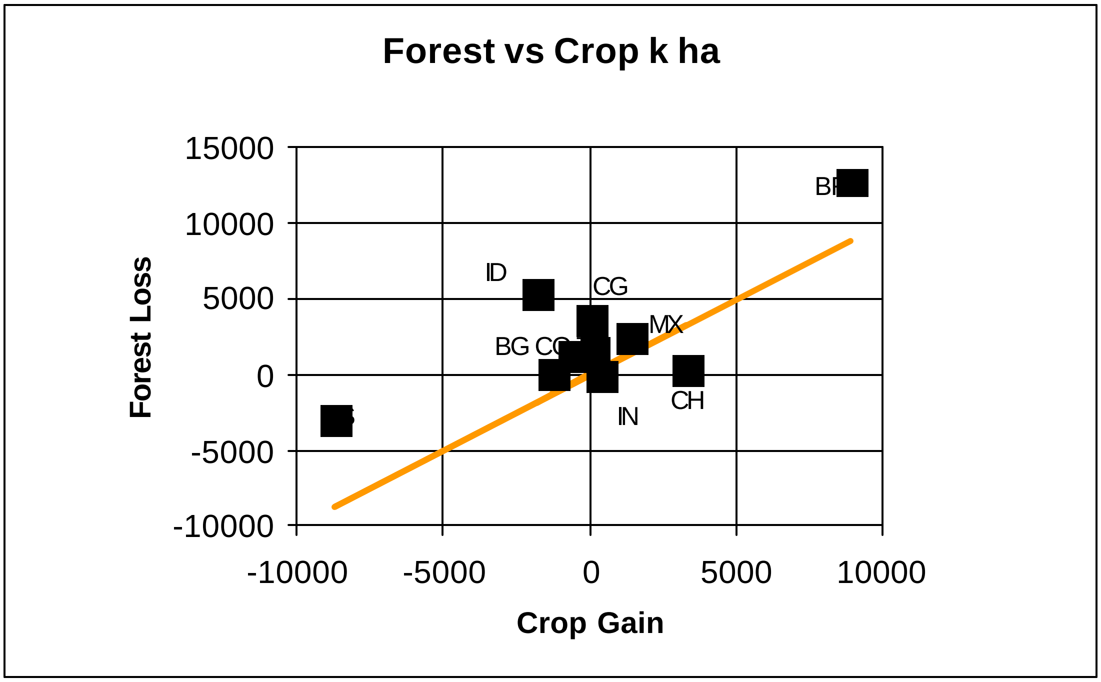
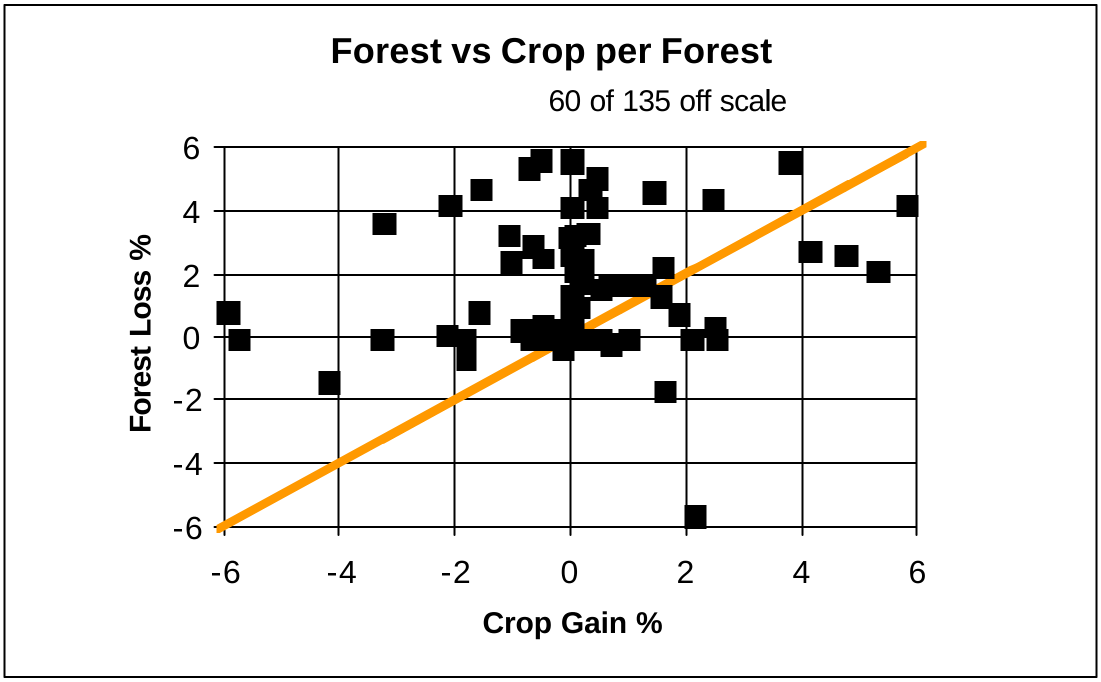
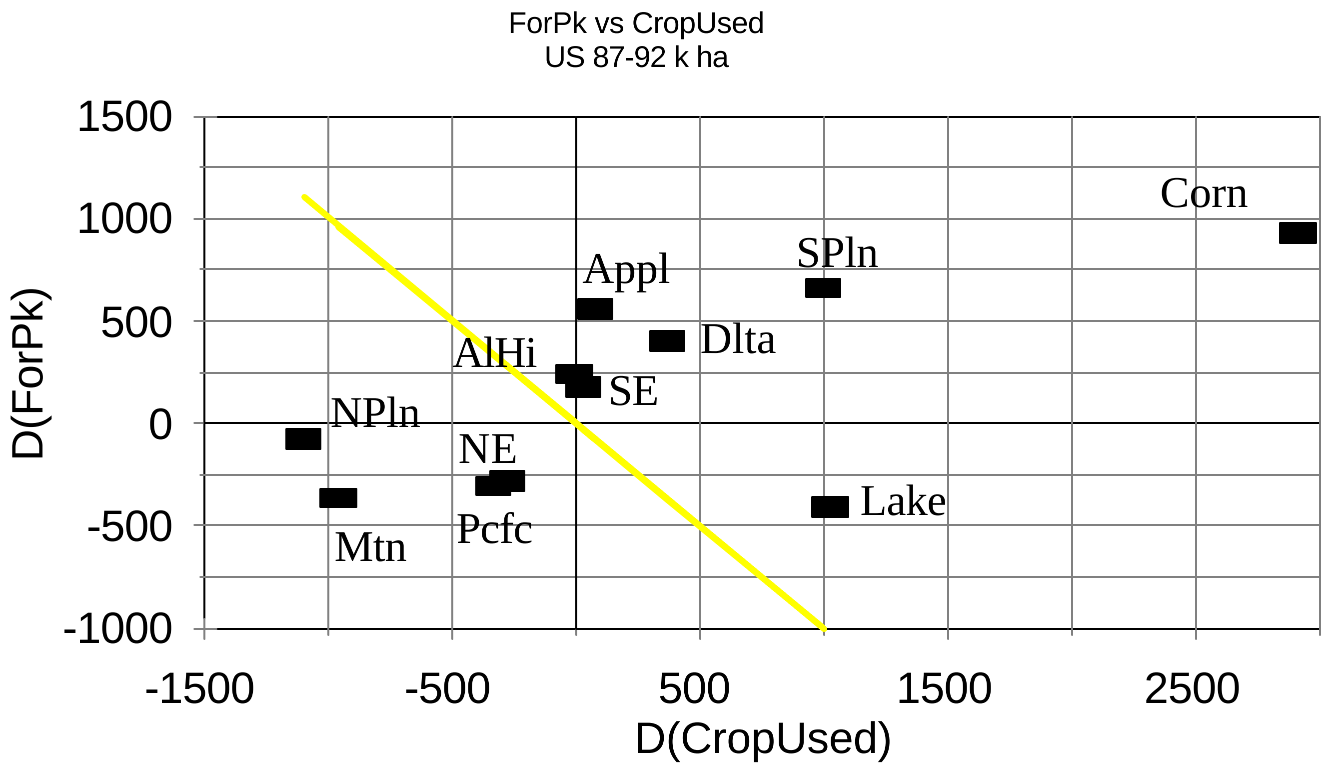

Forest vs Crop k ha
Forest Loss
Crop Gain
15000
10000
5000
0
-5000
-10000
-10000
-5000
0
5000
10000
ID
CG
MX
BG
CH
IN

Figure 2.1



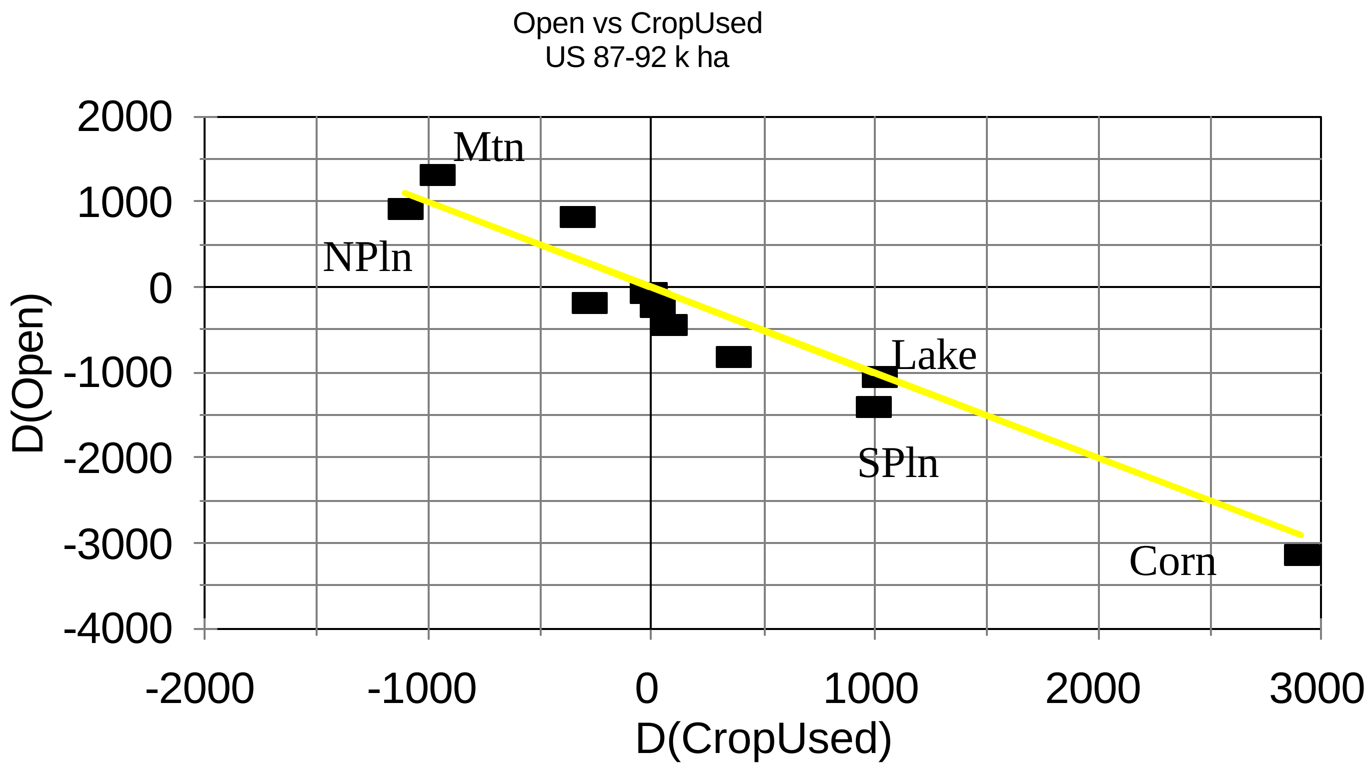
Forest vs Crop per Forest
60 of 135 off scale
Forest Loss %
Crop Gain %
6
4
2
0
-2
-4
-6
-6
-4
-2
0
2
4
6

Figure 3



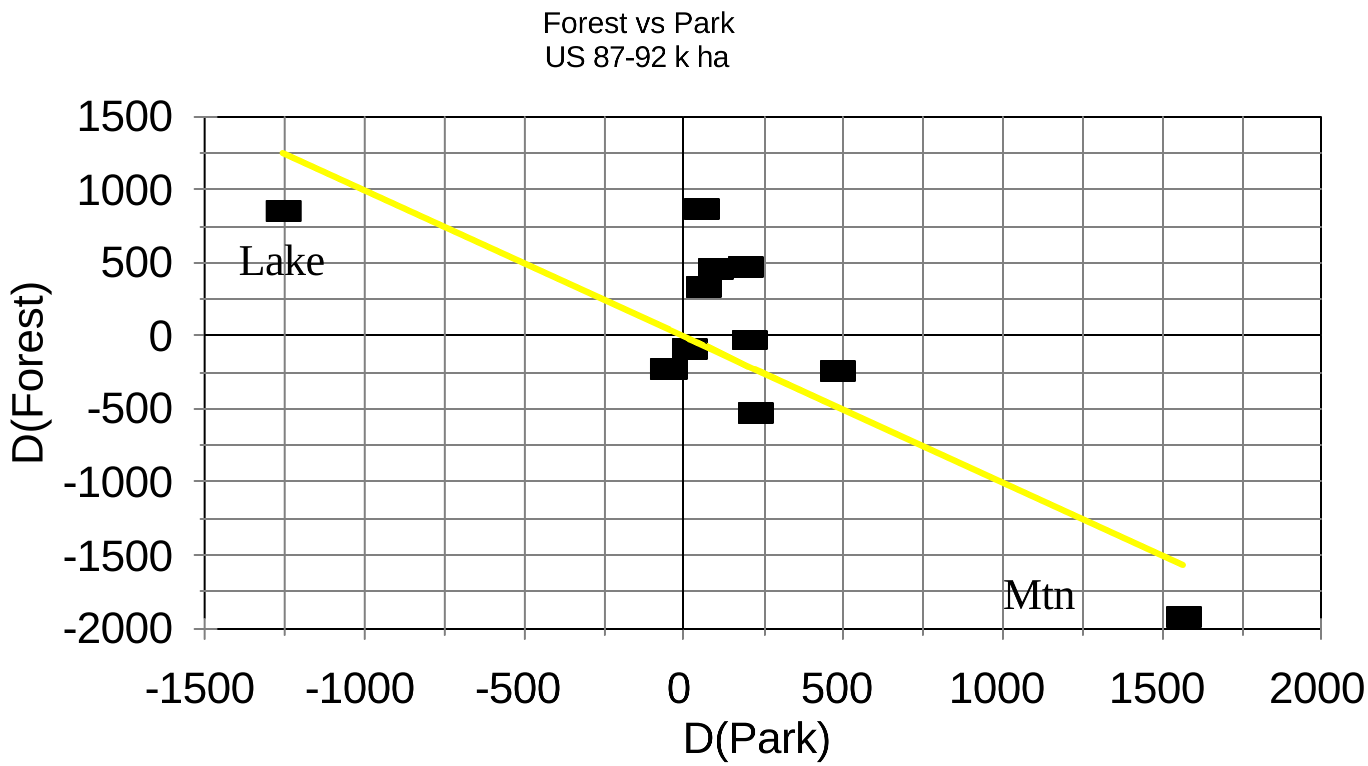
ForPk vs CropUsed
US 87-92 k ha
1500
1000
500
0
-500
-1000
D(ForPk)
-1500
-500
500
1500
2500
D(CropUsed)
Corn
SPln
Appl
Dlta
AlHi
SE
NPln
NE
Lake
Pcfc
Mtn

Figure 4



Open vs CropUsed
US 87-92 k ha
2000
1000
0
-1000
-2000
-3000
-4000
D(Open)
-2000
-1000
0
1000
2000
3000
D(CropUsed)
Mtn
NPln
Lake
SPln
Corn

Figure 5



Forest vs Park
US 87-92 k ha
1500
1000
500
0
-500
-1000
-1500
-2000
D(Forest)
Lake
Mtn
-1500
-1000
-500
0
500
1000
1500
2000
D(Park)

Figure 6