Figure 2-18 Demographic feedback loops

following figures the (+) and (−) signs in parentheses indicate the polarity of entire loops rather than of single relationships.) The positive loop on the left in Figure 2-18 expresses the tendency of every population to grow exponentially: the more births in the population each year, the larger the population; the larger the population, the more fertile people there will be; the more fertile people at any given level of average fertility, the more births there will be. Thus this loop, acting at any fertility level above replacement, generates an increasingly larger population as a function of time.

The negative loop on the right side of Figure 2-18 tends to counteract the exponential growth generated by the positive loop. At any given average life expectancy, the more people in the population, the more deaths there will be each year. The more deaths there are, the fewer people there will be the following year.

The relative strengths of the two loops depend on the average fertility, the life expectancy (which is a compendium of the average mortality at each age), and relative delays within each loop. The delays, caused by the population age structure, can be significant (15–70 years). If the strengths of the two loops are exactly equal, the population level will be constant; the size of the population will not change as time progresses. If the positive loop is stronger than the negative one, the population will increase exponentially. If the negative loop is dominant, the population will decrease exponentially.

Figure 2-19 shows the causal relationships that influence life expectancy in the world model. Life expectancy is a function of four factors: health services, food per capita, pollution, and crowding. Each factor affects the size of the population through a negative feedback loop; that is, each tends to act as a regulator to stabilize population by counteracting either an increase or a decrease in the population.

For example, let us trace through the operation of the feedback loop involving food per capita. If the population increases suddenly and no other change occurs in the system, the amount of food available per person will decrease. That decrease in available food in turn tends to decrease the average life expectancy somewhat, thus increasing the number of deaths in the population. With more deaths, the population level will tend to decrease, and the initial rise in population will be opposed. The loop also works in the opposite direction: a population decrease will result in more food per capita and an increase in life expectancy, thus tending to oppose the initial population decrease. The effectiveness of this population-regulating loop is highly variable. It has an important effect when average food per capita is close to the subsistence level, and it has virtually no effect when there is a large food surplus.

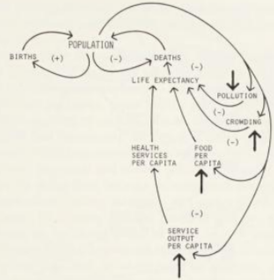

Figure 2-19 Feedback loops through life expectancy

Furthermore, the action of this loop is mediated by all the other interlocking loops in the system. For example, a larger population could also provide more labor to produce more food, leading to an influx of food (through the heavy arrow from the agriculture sector) sufficient to counteract this negative loop.

The negative feedback loops through health services per capita, pollution, and crowding* act on population in a similar way. Thus the human population is stabilized through the death rate by five negative feedback loops. One loop stems from the population age structure itself: the other four act through the external conditions of crowding, food supply, health services, and pollution. All these loops act, with varying efficiency, to keep the level of human population from rising indefinitely or from falling to zero. As conditions in the rest of the system change, the relative importance of each loop can change greatly.

The second half of the population sector, the feedback-loop structure controlling fertility, is shown in Figure 2-20. For simplicity, the five negative feedback loops on the death rate side in this diagram are represented by only a single loop proceeding from population through life expectancy and deaths back to population.

The maximum total fertility is a measure of the number of children a population could produce if it consistently tried to produce as many as possible. It is influenced in some way by each of the factors influencing life expectancy. As an approximation we made it a function of life expectancy itself, using the latter not as a direct causal factor but as an indicator of general health. Thus the four external factors that

*Under certain circumstances the crowding loop can also act as a positive feedback loop. See the discussion of this factor in section 2.5.