tion in growth rate occurs by means of a decrease in the birth rate or an increase in the death rate. In animal populations the principal mechanism appears to operate through the death rate:

> Populations are self-governing systems. They regulate their densities in relation to their own properties and those of their environments. This they do by depleting or impairing essential things to the threshold of favourability, or by maintaining reactive inimical factors, such as the attack of natural enemies, at the limit of tolerance. [A. J. Nicholson; quoted in Kormondy 1969, p. 105]

To what extent does the concept of a density-dependent growth rate apply to human populations? If it does apply, should it be represented as an influence that increases the death rate, decreases the birth rate, or both?

The first published world model World2 (Forrester 1971, p. 43) contained a density factor called the crowding ratio, a simple measure of population divided by land area. It was hypothesized that the crowding ratio influenced both the birth rate and the death rate, but through nonlinear multipliers rather than through the simple linear multiplier (K−N/K). These nonlinear multipliers were intended to represent the effect on the population growth rate of a number of possible biological and social responses to increasing density.

> Crowding is here assumed to include psychological effects, social stresses that cause crime and international conflict, the pressures that can lead to atomic war, epidemics, and any effects from too many people that are not more appropriately defined into the other influences that are represented in the model. [Forrester 1971, p. 43]

The World2 crowding ratio, as its author admits, is a simple, preliminary representation of an extremely complex set of phenomena about which very little is known. As Figure 2-40 indicates, even among groups of nations with some common cultural, climatic, or economic base, the relationship between population density and population growth rate is ambiguous, if indeed there is a discernible relationship at all. Furthermore, the statistics relating the density and the growth rates of specific subpopulations of the earth, which may effectively draw on resources outside their own boundaries, may have no relevance to the impact of the total population density on the entire global system, for the latter must be self-contained. On the other hand, although no clear influence on aggregate growth rates is apparent, some of the crowding effects cited by Forrester—stress, alienation, epidemics, social conflicts—are plausible mechanisms for population self-regulation, mechanisms that have been suggested by others, that have been observed in animal populations, and that deserve further study.

We assumed in World3, as Forrester did in World2, that there is a crowding modifier on the human death rate (the effect of crowding on the birth rate will be discussed later).* We included it because we believe there may be some important biological-sociological feedback from population size to population health beyond the obvious feedbacks through food and health services. There seems to be little direct evidence that such a modifier does or does not exist. Because we know little about the possible magnitude of this factor, we assigned to it only a weak influence on the total behavior of the model. Several models of the mechanism behind the crowding factor might be imagined—most of them more complicated than a simple, immediate feedback from average population density. Some of the possible mechanisms will be discussed here to suggest alternatives to modelers who would like to explore this relationship further. The *last* mechanism described is the one actually included in World3.

*In many animal populations, self-regulation under crowded conditions occurs through fetal and very early infant mortality. In field studies this effect may be interpreted as a lower birth rate; we would classify it as a higher death rate.

Country	Population Density (persons/km²)	Net Growth Rate (%/year)
Netherlands	319	1.0
Norway	12	0.7
United Kingdom	228	0.5
El Salvador	165	3.0
Brazil	11	2.8
Chile	13	1.9
Japan	280	1.2
United States	22	1.0
USSR	11	0.9
Rwanda	136	2.9
Tanzania	14	2.6
Zambia	6	2.9
Hong Kong	3829	2.4
Taiwan	390	2.3
Laos	13	2.5
Lebanon	248	2.5
Turkey	43	2.5
Jordan	24	3.3

Figure 2-40 Population densities and net population growth rates, 1970
Source: Appendix D to this chapter.

1. Increased competition for a decreasing share of resources. One explanation for sigmoid growth curves in animal populations is that the growing population exerts an increasing pressure on some limited resource (food supply or nesting space, for example). As the average resource available per individual declines, the competition for the resource increases, resulting in a higher death rate for poor competitors through overt violence. In human populations, however, numerous economic and technological methods exist for resolving an increased competitive pressure on resources without necessarily causing a rising death rate. In fact, most of the rest of the world model is designed to represent these adaptive processes. If at some time the