

HARPER

Population Biology of Plants

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infinite life may be fitter in populations that experience most selection when these populations are in decline. Long juvenile periods and intermittent seed production characterize species in advanced succession — *K* species. In advanced succession it can be envisaged that the last seed produced by a parent before death may sometimes have the highest reproductive value. Physiological and genetic potential for quite profound changes in life-cycle strategy exist within plant populations.

Chapter 23

The biological diversity of a community has ecological and evolutionary meaning only in so far as it is sensed by the individuals within it: an imposed anthropomorphic scale may be irrelevant. Diversity exists as the somatic and phenotypic variation within a genet, differences of age and between genotypes of a species as well as diversity at the species level. Differences between organisms determine whether they can persist together as neighbours or engage in an exclusive struggle for existence. The form and life cycle of a plant determine how it senses the heterogeneity of the environment, both in space and time. Some growth forms enforce clonal monotony on a community, others maximize the genet's experience of a variety of neighbours.

The branches in food chains are essentially unstable and evolved biological specialization is required to give them stability. Predators may permit a vegetational diversity that disappears when the predator is removed, but this is not a general rule. It depends on the relative aggressiveness and palatability of the plants involved.

Chapter 24

Natural populations characteristically contain genetic diversity, even when there is close inbreeding or apomixis. This can be interpreted as balanced polymorphism or sometimes as a transient polymorphism in communities subject to repeated hazards and cyclic phenomena or to the disruptive selection imposed by the variety of interspecific neighbours. Natural environments are heterogeneous both in space and time and this makes for dilemmas in evolution under natural selection. Life in a successional environment or a mosaic habitat may force a variety of solutions such as genetic and somatic polymorphism, plasticity, speciation, heterozygotic advantage. An evolutionary process driven by effects on individual fitness cannot be expected to maximize performance in groups, such as is required in agriculture and forestry.

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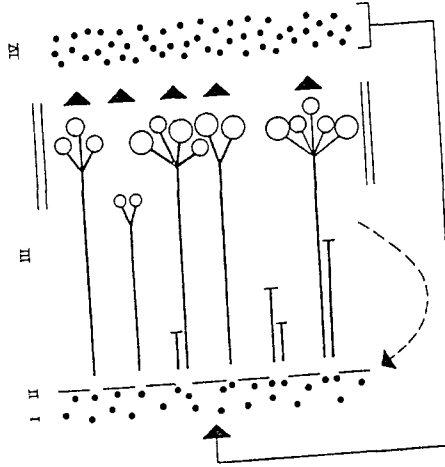
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6

The Influence of Density on Yield and Mortality



The presence of a plant changes the environment of its neighbours and may alter their growth rate and form. Such changes in the environment, brought about by the proximity of individuals, may be called "interference", a blanket term which does not define in any way the manner in which the alterations in environment are produced and includes negative effects due to the consumption of resources in limited supply, the production of toxins, or changes in conditions such as protection from wind and influences on the behaviour of predators. Higher plants react

THE EFFECTS OF NEIGHBOURS to stresses of density by plastic responses as well as an altered risk of death. The population-like structure of an individual plant fits it admirably to respond to stresses by varying the birth rate and the death rate of its parts, leaves, branches, flowers, fruits, rootlets, etc. Such variation is impossible for most animals except as the analogous variation of the number of individuals in a coral or sponge or the number of colonial Hymenoptera in a colony. Some resemblance to the plastic reaction of higher plants to density is found in fish, in which density stress may be reflected in the size that individuals attain, the time required to reach maturity and the number of eggs produced. However, such animals have nothing comparable to the birth and death of parts that is so characteristic of the growth of a plant.

Most experimental studies of the reactions of plants to density have been made on stands of single species — the logical starting point for approaching any understanding of the stresses present in the more normal species-diverse communities of nature. Many of these studies have been made by agronomists or foresters to discover ideal densities for crop or forest yields.

The influences of density on growth

A typical yield/density response for a plant population is illustrated in a study of *Trifolium subterraneum* made by Donald (1951). He sowed seeds in pure stands over a wide range of density to give seedling densities from 6 to 32 500 per/m², a range likely to include that of any artificial or natural seeding of this species. Seven densities were included in the experiment and plants were harvested after 62, 131 and 181 days. The results, like those in most comparable experiments, refer only to the above-ground parts of the plants and are shown in Fig. 6/1a and b as the yield of dry matter per unit area.

The weight of a population at the time of sowing is the total weight of the embryos and the relationship between "yield" and density is of course at that time perfectly linear. However, with the passage of time the population departs from this linear relationship and the yield per unit area becomes independent of the number of seeds sown over a very wide range of densities. Plants at high densities meet stress from neighbours early in their development, whereas plants at lower densities do so only when they have grown larger. Variations in sowing density are therefore very largely compensated by variations in the amount of growth

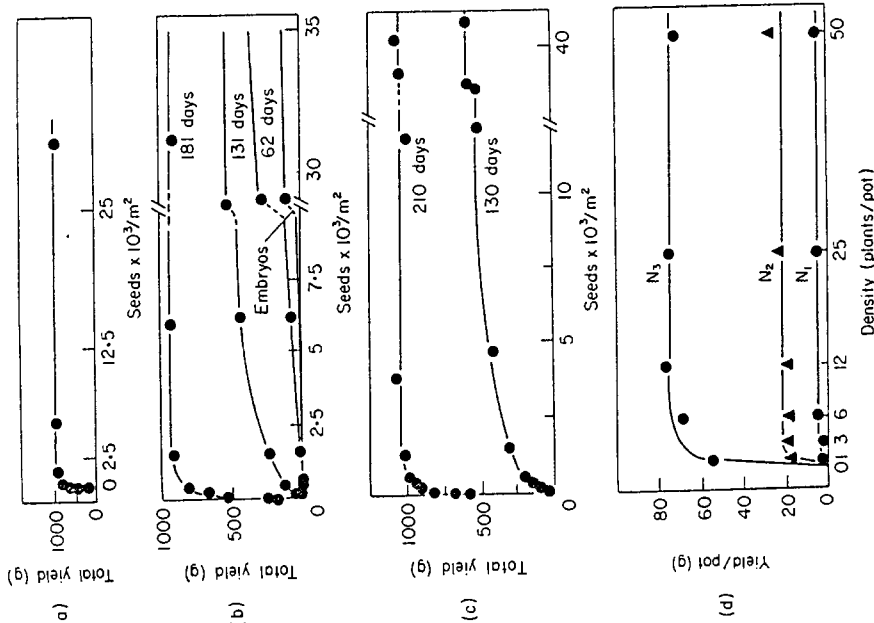


Fig. 6/1. Some relationships between yield of dry matter per unit area and the density of seeds sown.

(a) *Trifolium subterraneum* at the post flowering stage

(b) *Trifolium subterraneum* at various stages in development (note the break in the scale of density)

(c) *Lolium lolaceum* at two growth stages.

(d) *Bromus unioloides* at three levels of nitrogen fertilization.

(From Donald, 1951)

made by individual plants. At the time of the last harvest (181 days) changes in mean plant weight exactly compensated for changes in density over the range from 1500 to 32 500 seedlings/m². In a similar experiment involving *Lolium lolaceum* essentially the same picture was obtained (Fig. 6/1c) and this type of relationship between density and dry

matter production has been found to hold for a wide range of species. It has been called the "law of constant final yield" (Kira *et al.*, 1953).

In its initial growth from seed the yield of a population is determined by the number of plants present (the investment) but eventually the resource-supplying power of the environment comes to dominate the rate at which the members of the population grow and ultimately sets the limit to yield, irrespective of plant density. The population then behaves more and more as an integrated system — reacting independently of the number of its individuals — the behaviour of the plant becomes subordinated within that of the population (Harper, 1964).

Any influence that slows down the rate of plant growth might be expected to delay the onset and reduce the intensity of density stress between plants. This is shown in an experiment (Clatworthy, 1960) in which *Trifolium repens* and *T. fragiferum* were sown at a range of densities in pot culture and maintained either freely supplied with water but freely drained or with the water table maintained close to the surface or with the water table at the soil surface. Waterlogging inhibited plant growth but under freely drained conditions the plants grew rapidly and showed a marked plastic response to density (Fig. 6/2a and b). With impeded drainage the plants were small, even at low density, and the intensity of interference between them was reduced. Under fully waterlogged conditions the plants were small and stunted and the mean weight per plant was quite unaffected by density. In this experiment the restriction on growth was a supra-optimal supply of water. Similar experiments have often been made in which a resource has been applied at sub-optimal levels. For example, Donald (1951) sowed *Bromus unioloides*, at a range of densities, in pots of soil provided with three levels of nitrogen fertilizer: (i) no nitrogen; (ii) 150 mg nitrogen as NH_4NO_3 applied in three equal doses; and (iii) 700 mg nitrogen per pot as NH_4NO_3 applied in five equal doses during the growing season. The effects of these treatments on the final yield of the populations are illustrated in Fig. 6/1d. The law of constant final yield again applied to dry matter production per unit area but the more nitrogen was added, the higher was the plateau yield. The yield of a population was then independent of the number of plants present but dependent on the level of supply of nitrogen. As the nitrogen resources of the soil in this experiment were almost completely exhausted by the growth of the grass, nitrogen was probably in limiting supply and responsible for determining the plateau yield.

The presentation adopted for the data in Fig 6/1a, b, and c and 6/2a

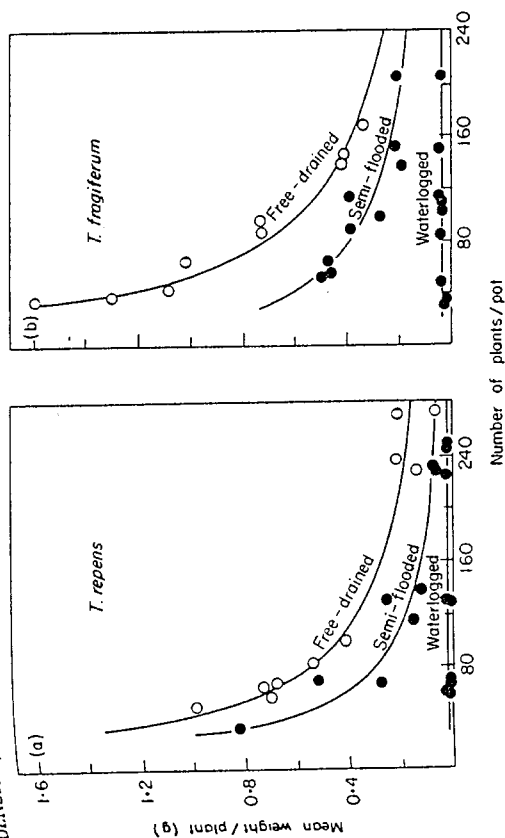


Fig. 6/2. The effect of plant density upon the mean dry weight of plants of (a) *Trifolium repens* and (b) *T. fragiferum* grown in pure stands under three water regimes. (From Clatworthy, 1960)

and b is not wholly satisfactory for the accurate comparison either of species or of environments and a considerable literature has built up concerning the most appropriate ways of analysing yield/density responses. Kira *et al.* (1953) suggested plotting the log of mean plant weight against the log of density. This treatment has been applied to Donald's data for *Trifolium subterraneum* in Fig. 6/3. The relationship between mean plant weight and density on log scales is represented by a horizontal line which slides upwards with the passage of time. As the plants grow and interfere with each other a segment of this line at highest plant density becomes inclined and the whole density range is now represented by two intersecting lines, one horizontal at the mid and low density range and the other inclined at high densities. Over the range of densities at which the line remains horizontal there is no interference between individuals. As growth proceeds this zone of no interference becomes progressively shorter and eventually disappears; the inclined section of the line increases in slope, approaching 45° , and extends to lower and lower densities. The slope of the inclined line increases from 0 and approaches a value of 1 when yield has become independent of density.

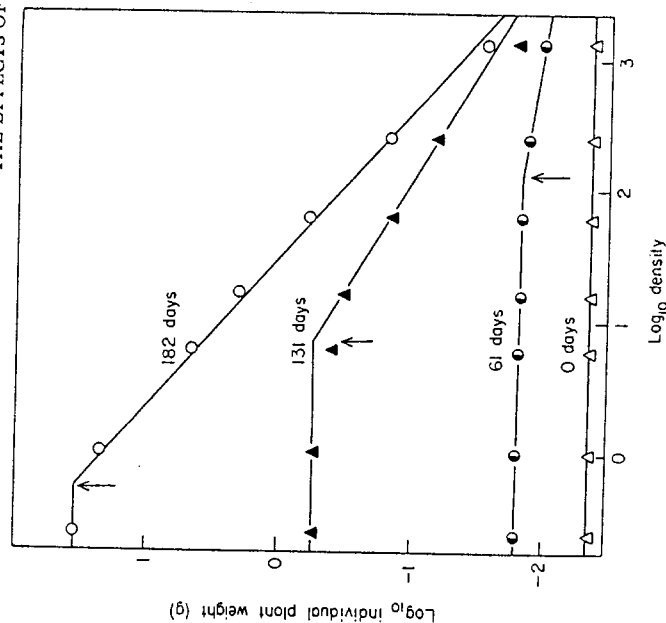


Fig. 6/3. The influence of density on the weight of plants of *Trifolium subterraneum* at successive dates from sowing. Data obtained from Donald (1951) and presented according to the log/log transformation of Kira *et al.* (1953). The arrows show the density at which plants of different ages begin to affect each other's growth.

There is a special elegance about this way of expressing the data but it creates some difficulties. In particular two linear regressions have to be used for what is a continuous density sequence and the sharpness of their transition is almost certainly an artefact of the form of presentation.

Later, Shinozaki and Kira (1956) noticed that there was a linear relationship between the reciprocal of mean plant weight and density (Fig. 6/4). This linearity ("The Reciprocal Yield Law") has now been established for a very wide range of plant species (see also Holliday, 1960 for other crop species). It is open to the criticism that unless properly weighted, very small plants at high densities contribute disproportionately large amounts of information to the regression analyses. However properly weighted, the equation $\frac{1}{w} = Ad + B$ may be used to fit a curve to a graph of log mean plant weight plotted against log density

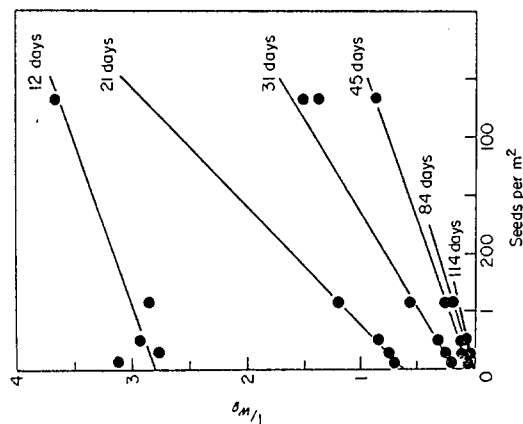


Fig. 6/4. The relationship between the density of sown seed and the reciprocal of mean plant weight in an experiment with soya beans. (From Shinozaki and Kira, 1956)

(see Fig. 6/5a and b). This treatment gives an excellent fit to the data, and has been applied with considerable success to the density response of many species, implying that a single rather simple rule underlies the growth of plant populations and providing a convenient generalization for further experimental tests.

An experimental comparison of the yield/density relationships of closely related species was made between *Bromus rigidus* and *B. madritensis* in pot culture (Harper, 1961). These two annuals of Mediterranean climates commonly occur together on Californian range lands. The relationship between density and mean weight conforms well to the reciprocal yield law of Shinozaki and Kira (Fig. 6/6). The seed capital of the two species is very different, *B. rigidus* having markedly larger embryonic capital and endospermic reserves and a higher absolute growth rate than *B. madritensis*. In the period up to the first harvest, when the plants were growing relatively unstressed by density, populations of *B. rigidus* made considerably greater growth than those of *B. madritensis*. As the plants grew and density stress became an increasing force, the development of the two species populations became constrained within the same limits so that at the second and third harvests the yield per

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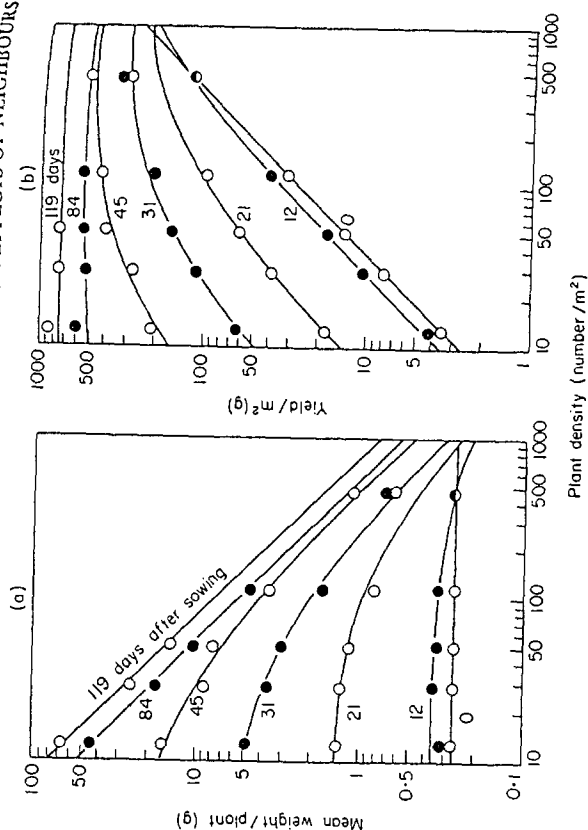


Fig. 6/5. The relationship between sowing density and yield of soybeans. Note logarithmic scales. The fitted curves are reciprocal yield equation $\frac{1}{w} = Ad + B$
 (a) data for mean yield per plant
 (b) as (a) but for yield per m².
 (From Shinozaki and Kim, 1956)

unit area became independent of which species was present. This experiment included an equi-proportioned mixture of the two species and this also approached the same yield as the species in pure stand. The yield per pot became independent of density, of species, and of species combinations. The whole experiment included treatments involving added nitrogenous fertilizer and the effect of this was to increase the yield per pot *irrespective of the species, combination or density* (Fig. 6/7).

Although the reciprocal yield law has been found to apply to the garden turnip (*Brassica napus*), the Azuki bean (*Phaseolus caryanthos*), the carrot (*Daucus carota*) and a 13 year-old stand of pines (*Pinus densiflora*) which had been sown at a range of densities when 1 year old, there are some conspicuous exceptions to the law. At very high densities a stand of plants is often composed of such thin, weak individuals that they collapse (lodge) and the growth rate then declines sharply. Diseases

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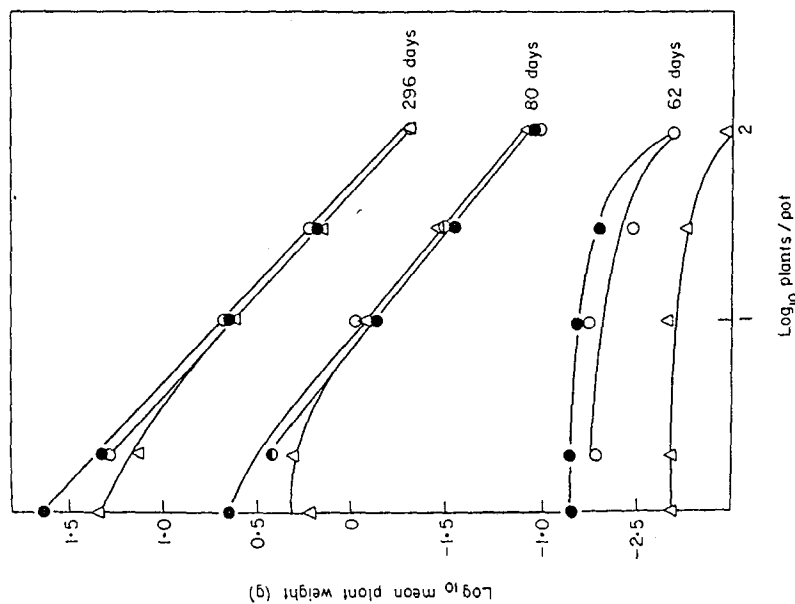


Fig. 6/6. The relationship between the density of sown seed and mean yield per plant in populations of *Bromus rigidus* and *B. madritensis* in pure stands and in a mixture of the two species.

● = *B. rigidus*.

△ = *B. madritensis*

○ = mixture of the two species — the mean weight per plant is shown taking the two species together.

(Adapted from Harper, 1961)

may develop in high density stands and a large number of individuals may then die. If this death occurs late the remaining living plants may have insufficient time to exploit the resources that are freed by the death of their neighbours. An interesting example of departure from the reciprocal yield law is the reaction of peach seedlings (*Prunus persica*) to density in experiments in a glasshouse and outdoors. The outdoor population showed the characteristic linear response between the reciprocal

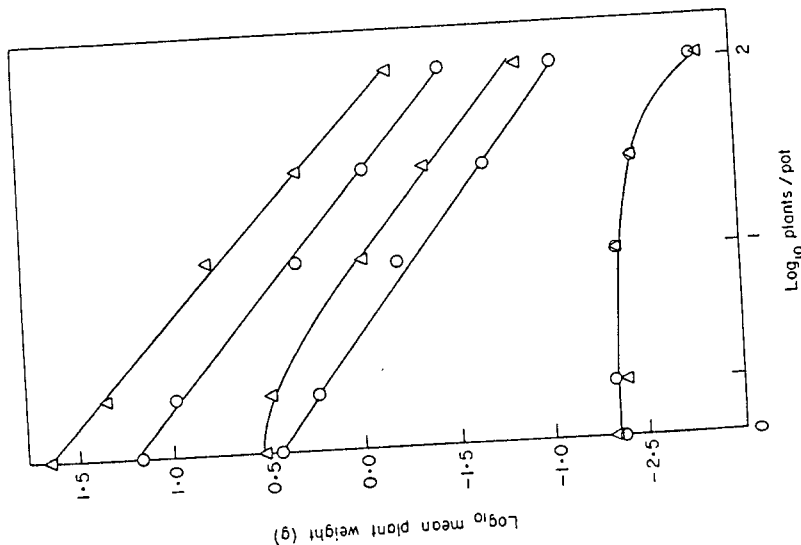


Fig. 6/7. The relationship between the density of sown seed and mean yield per plant in populations of *Bromus rigidus* and *B. madritensis* at two fertilizer levels.
 Δ = Low fertility
 \circ = High fertility
 Data are the means of the yields of the two species (cf. Fig. 6/6).
 (Adapted from Harper, 1961)

of mean plant weight and plant density but the glasshouse population behaved very differently (Hirano and Kira, 1965). There had been previous claims that the peach root produces autotoxic exudates (cf. Proebsting and Gilmour, 1941) and Hirano and Kira favoured the view that the density effect of peaches in their glasshouse experiments could be accounted for in this way. However, it seems odd that the effect was not found when the plants were grown in the open and that a more normal yield/density effect could be obtained by applying fertilizer to the plants grown under glass.

Plant-to-plant variation

In most studies of the relationship between density and plant weight, changes in *mean* plant weight are reported. Such means are obtained by sampling and weighing a population of plants and dividing the weight by the number of plants present (or by the number of plants sown at the start of the experiment). This of course obscures any plant-to-plant variation. When plants are weighed individually it is found that populations growing under density stress have a skewed distribution of plant weight. The skewing of the frequency distribution increases both with the passage of time and with increasing density; an example is shown in Fig. 6/8 from an experiment in which *Linum usitatissimum* was sown at 3 densities and harvested at 3 stages of development (Obeid *et al.*, 1967). The frequency distribution of plant weights became strikingly skewed particularly by the time of the last harvest: at this time a hierarchy of individuals had established with a few large dominants and a large number of suppressed plants. Koyama and Kira (1956), showed that such skewed distributions represent stages in the development of log-normal distributions, and the log transformed data from the *Linum* experiment has a normal distribution. The development of such a hierarchy is not just an artifact of experimental studies of single species, similar log-normal distributions of plant weight have been found in a number of natural populations (Ogden, 1970), see Fig. 6/9. It is obviously dangerous to assume that average plant performance represents the commonest type of plant performance. Apparently the commonest type of plant found in experimental and natural populations is the suppressed weakling. Similar hierarchical development of plants in even-aged stands has been shown by Kira (1965), for *Trifolium subterranean*, and the log-normal distribution of plant weight appear to be the regular form of frequency distribution of plants in density-stressed populations. Even in the absence of density stress, populations may ultimately develop log-normal frequency distributions (Koyama and Kira, 1956) — density stress exaggerates and accelerates this trend.

The place that an individual occupies within the hierarchy of a plant population seems to be largely determined in the very early stages of plant development. The weight of an individual is a function of (a) its starting capital (the embryonic weight + some fraction of the endospermic reserves), (b) the relative growth rate of the genotype of the individual in the environment provided, (c) the length of time for which this

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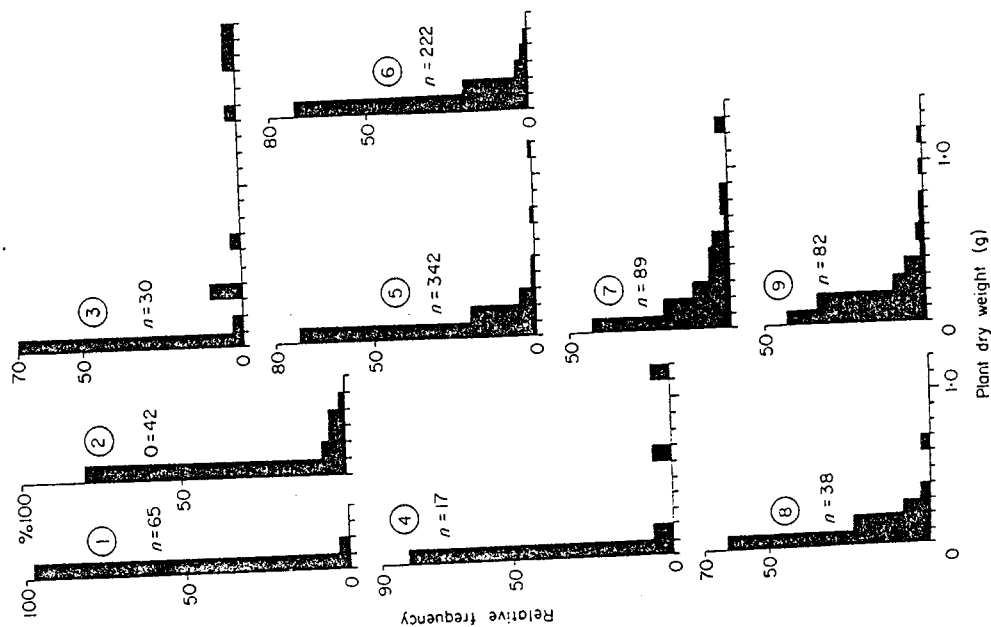


Fig. 6/8. The frequency distribution of individual plant dry weight in some mixed annual weed populations in an arable field in N. Wales. n = density of individuals per 0.5 m^2 approx. 1. Gramineae; 2. *Atriplex patula*; 3. *Polygonum aviculare*; 4. all other species; 5. *Slachys arvensis*; 6. *Stellaria media*; 7. *Spergula arvensis*; 8. *Senecio vulgaris*; 9. *Polygonum persicaria* and *P. lapathifolium*. (From Ogden, 1970)

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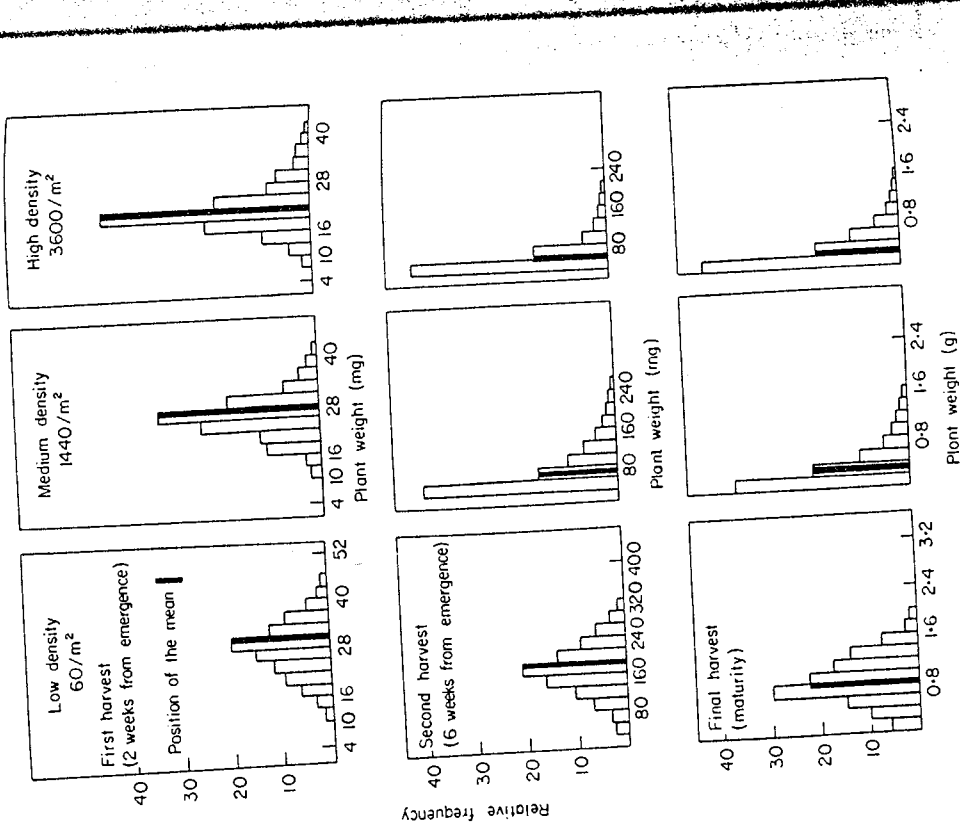


Fig. 6/8. The frequency distribution of plant weights within populations of *Linum usitatissimum* sown at three densities and harvested at three stages of development. (From Obaid *et al.* 1967). Reproduced from *Crop Science* 7, 471-473, by permission of the Crop Science Society of America.

growth rate is continued and (d) restrictions on the rate or time of growth imposed by the presence, character and arrangement of neighbours in the population. An attempt was made to distinguish between the role of these sources of variation (Ross and Harper, 1972). Populations of *Dactylis glomerata* were grown from seed randomly dispersed on the

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sisted of plants which had barely exceeded their embryonic capital even 35 days after emergence.

Plants in such an experiment may be grouped according to the time at which an individual emerges relative to the rest of the population. The position in the emergence ranking that in individual would have occupied in a population in which a hundred seeds had been sown is called the "percentage emergence ranking". When the mean log plant weight for each emergence group is plotted against the percentage emergence ranking for that group, a highly significant linear relationship is obtained (Fig. 6/11). This suggests that the amount of growth made by an individual is more directly determined by its order in the sequence of emergence than by the actual time at which it emerges. *The advantage which an early emerging seedling gains is far greater than can*

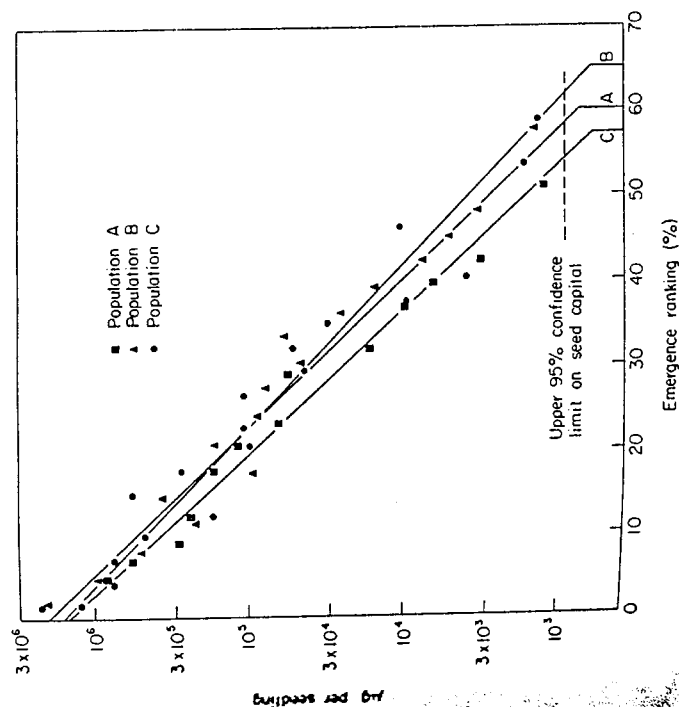


Fig. 6/11. The influence of the time of emergence of a seedling of *Dactylis glomerata* on its growth in a dense population. The time of emergence is expressed as an emergence ranking — all of the seedlings in the population being classified according to the time at which they emerged relative to the rest. (From Ross and Harper, 1972)

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surface of soil in seed trays, at a mean density of $ca\ 3\ seeds/cm^2$. An area of approximately $100\ cm^2$ was marked out in the centre of each tray and photographed to give an accurate record of the position of each seed. Each day the trays were examined for seedling emergence within the marked area and, when a group of approximately 10 plants had emerged since the last observation, each of the plants in that group was appropriately marked and its emergence class recorded. In this way all the seedlings were allocated to emergence classes. After 7 weeks' growth, each plant was harvested. 95% of the variance in individual plant weight was accounted for by the regression on the number of days, t , from emergence to harvest of the members of that group ($w = 0.26t - 2.02$ ($P < 0.001$)). The size that the plants in each emergence group would have attained if they had not suffered interference from neighbours and if their weights had been simply a function of the time allowed for growth is shown as a broken line in Fig. 6/10. The weights of later emergence groups fell well below this line and the last group to emerge con-

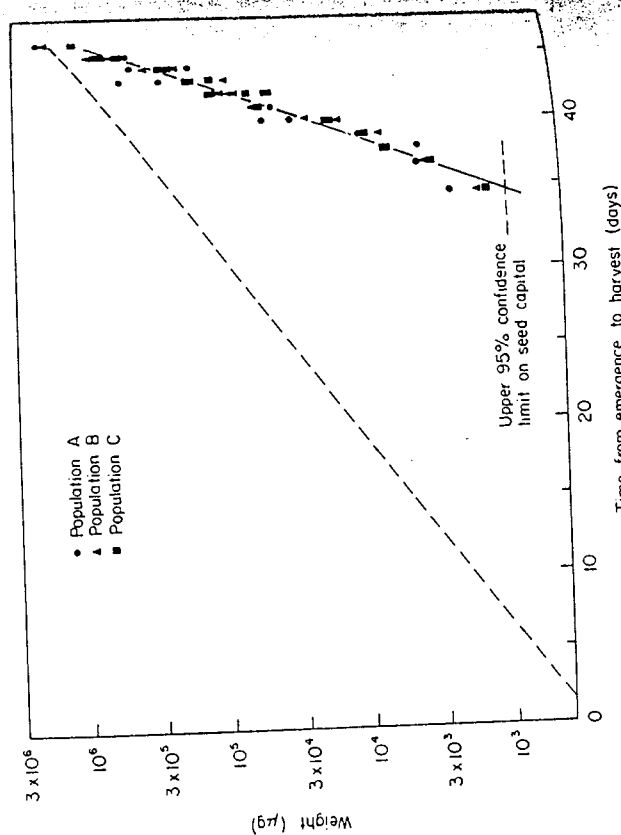


Fig. 6/10. The influence of emergence time on the dry weight per plant of *Dactylis glomerata* in a dense population — for explanation see text. (From Ross and Harper, 1972)

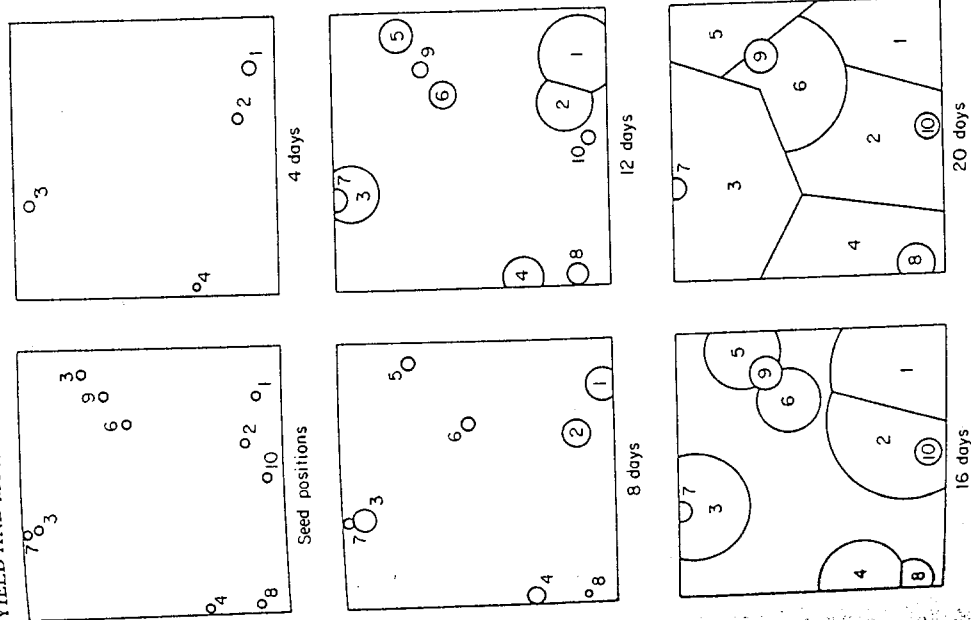


Fig. 6/11. Diagrammatic model of the pre-emption of space (= resources) by developing seedlings. (From Ross, 1968)

which they then maintained for at least 3 weeks (Fig. 6/12). Such behaviour is consistent with the view that the growth made by a plant is determined early in its life by the capture of space (or the resources supplied by that space).

A model illustrating the effect of the timing of seedling emergence on space capture can be envisaged in which 10 randomly placed seedlings

166 be accounted for merely by the greater time that it has been allowed to grow. The advantage must be due, at least in part, to the capture of a disproportionate share of the environmental resources by the individual, that emerge early and a corresponding deprivation of those that emerge late.

The way in which such pre-empting of resources (space capture) occurs was examined by growing plants under "restricted" and "unrestricted" conditions. Plants in the "unrestricted" treatment were grown from a single seed sown in the centre of a 7.4 cm diameter pot. Plants in the "restricted" populations were also grown from a single seed, sown in a small bare zone of 2.1 cm radius: from the edge of this zone to the edge of the pot further seeds were sown at a density of $2.5/\text{cm}^2$. The growth of individual seedlings was followed by a non-destructive harvesting method. Plants growing in the "restricted" and "unrestricted" conditions initially maintained the same growth rate but those in the "restricted" population then departed from the "unrestricted" growth rate and adopted a new, but still exponential, growth rate

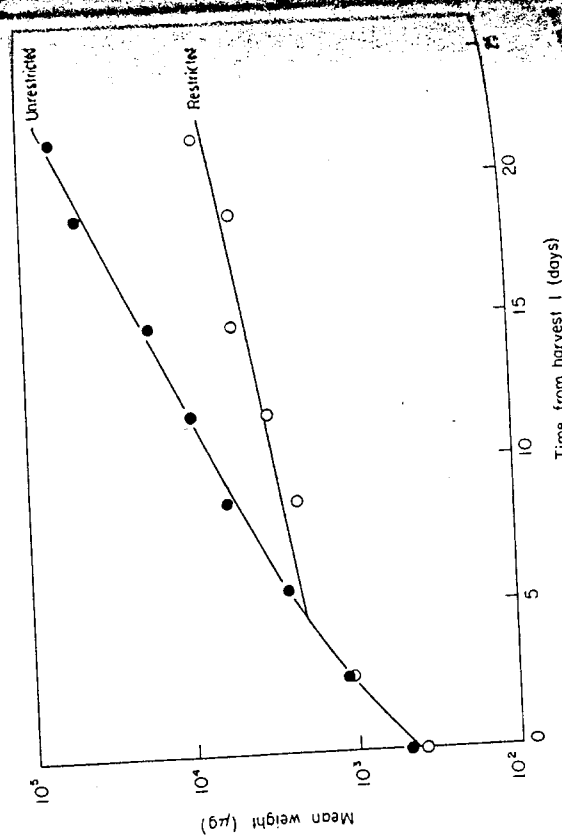


Fig. 6/12. The growth of seedlings of *Dactylis glomerata* grown without neighbours (unrestricted) compared with seedlings grown in the centre of a bare area surrounded by a disk of other seedlings at a radius distance of 2.1 cm (restricted). (From Ross and Harper, 1972)

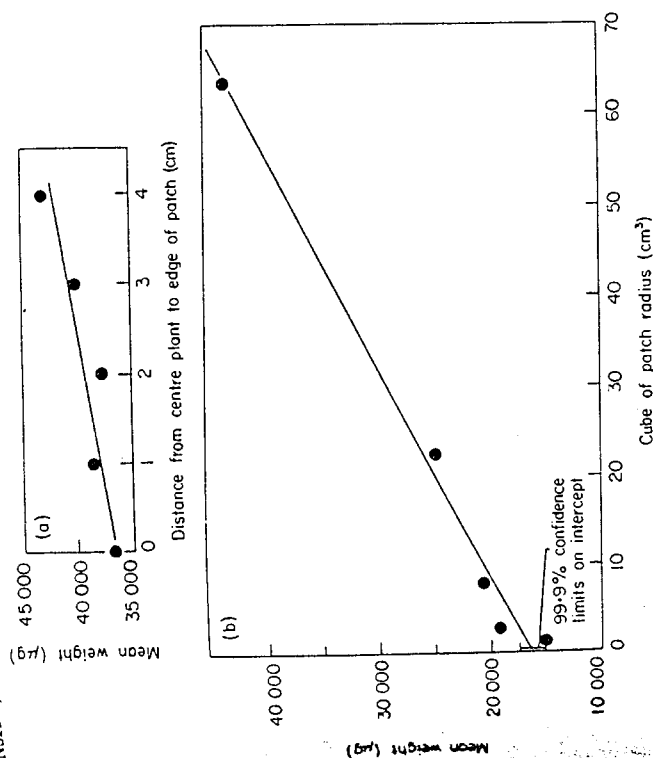


Fig. 6/13. The influence of the proximity of neighbours on the development of seedlings of *Dactylis glomerata*.

(a) The relationship between seedling growth and its distance from the edge of a bare patch.

$$w = 36.44 + 1.308 (d) \quad (\text{see Fig. 6/14b})$$

(b) as (a) but showing the relationship with the cube of the radius of the bare patch
 $w = 16.298 + 0.42r^3$ (see Fig 6/14a)
 (From Ross and Harper, 1972)

prising (although it is usually more convenient to describe plant density in terms of the area rather than the volume that a population occupies). In a stand of carrots (*Daucus carota*) sown in close rows (Mead, 1966) 20% of the variation in individual plant weight could be accounted for by the differences in area available to each plant. The "available area" was calculated by joining the perpendicular bisectors of the lines between each plant and its neighbour in the same row and in adjacent rows, and taking the area of the resulting polygon as the available area. Further evidence that individual neighbours in a plant population may affect each other's growth comes from a study (Yoda *et al.*, 1957) of sweet corn (*Zea mays*) grown in rows. There was a clear negative cor-

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are all assigned the same relative growth rate and the emergence of the 10 seedlings is spread over 10 consecutive days. The area of the space which each seedling pre-empt is presumed to be proportional to the weight of the seedling. A plant is assumed to stop growing when its potential space is completely captured by neighbours — for example, in Fig. 6/13 the potential space of plant 7 has been captured by plant 3. The sequence of diagrams in Fig. 6/13 shows the areas theoretically occupied by seedlings 4, 8, 12, 15 and 20 days after emergence of the first seedling.

Ross's experiments and models (see also Ross, 1968) suggest that the timing of emergence of seedlings in a population is of far more importance than their relative spatial position, and in randomly distributed populations he was not able to extract a significant proportion of plant to plant variance by regressions on the distance from nearest neighbour or on the weights of neighbours within encircling zones. He attempted experimentally to vary the space available to a plant and its proximity to neighbours by sowing seeds of *Dactylis glomerata* at random at a density of 3.3 seeds per cm² on trays of soil but, by using templates during sowing, left empty circular zones within the sown area (see Fig. 6/14). He allowed one seedling to grow in each empty zone but it was placed at different distances from the edge of the zone. He also varied the size of the empty zones. The space available had a more critical effect on seedling growth than the position of the seedling within that space (Fig. 6/15). The weight of a seedling developing in a bare zone was a function of the cube of the radius of that zone; as a plant exploits a volume of space above and below ground this cubic relationship is perhaps not sur-

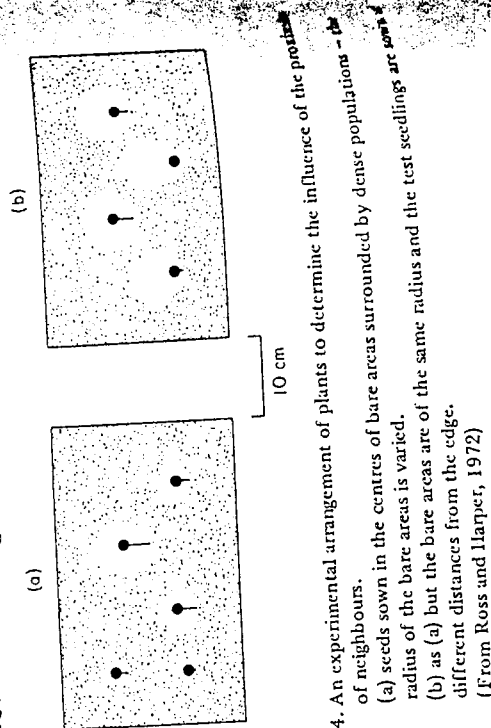


Fig. 6/14. An experimental arrangement of plants to determine the influence of the proximity of neighbours.

(a) seeds sown in the centres of bare areas surrounded by dense populations — the radius of the bare areas is varied.

(b) as (a) but the bare areas are of the same radius and the test seedlings are sown at different distances from the edge.
 (From Ross and Harper, 1972)

In herbaceous monocultures, however, the changes in the distribution of weight and height frequencies with the passage of time indicate that in a juvenile population most of the individuals reach into the canopy, but as the plants grow larger, fewer and fewer individuals do so" (Ogden, 1970).

The growth rate of a young plant is greatest if it (a) establishes before its neighbours, enabling it to pre-empt resources, (b) is well separated from its neighbours and (c) has weak neighbours. The hierarchy of size seen in the log-normal distribution of plant weights seems to derive, at least in part, from a series of small but cumulative differences in space and time amongst the individual. The sharper distinctions that occur between individuals of different species ensure that when they grow together a hierarchy becomes even more clearly defined. It is likely that intra-specific variations — e.g. somatic and genetic seed polymorphisms will sometimes give bimodal or multimodal hierarchies.

The influences of density on mortality

When plant populations are grown at high density, some individuals often die. Such mortality has often been disregarded in analyses of the relationship between yield and density: yield is commonly expressed in relation to the density of seeds sown or the density of seedlings established at the start of an experiment and changes in density are ignored.

Two categories of mortality can be recognized, density-independent and density-dependent. The term "density-dependent" was used by Smith (1935) to describe an increasing risk of death associated with an increasing density of animal populations. This remains general usage, though Haldane (1953) pointed out that it is perhaps more proper to distinguish between those density effects that hinder population growth and can thus act as regulators and those that may increase population growth and lead to instability — negative and positive density-dependent. The term "self-thinning" has been used for density-dependent mortality in plant populations (Harper *et al.*, 1962; Yoda *et al.*, 1963) and is contrasted with "alien-thinning" where mortality in one species can be ascribed to the stress from the density of an associated species.

In practice, density-independent and density-dependent mortality are not easy to separate. The mortality risk to a seedling from being hit by a triadrop or hailstone might be thought to be density-independent. Presumably the risk of being hit is independent of density but whether a

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relation between the weights of individuals and their first, third and fifth neighbours, and a positive correlation with their second and fourth neighbours. This suggests that within a row of plants, once a difference between two neighbours has been triggered, it is progressively exaggerated.

Although the frequency distribution of plant weights in a population tends to be strongly skewed this is not necessarily true of plant height. The height of individuals in populations of annual plants (Koyama and Kira, 1956) and trees (Kuroiwa, 1960) is more or less normally distributed or even negatively skewed (i.e. skewed in the opposite direction to the weight frequency). The difference between the frequency distributions of weight and height is shown for a natural stand of *Elatostema rugosum* (Fig. 6/16). This situation suggests that at least some of

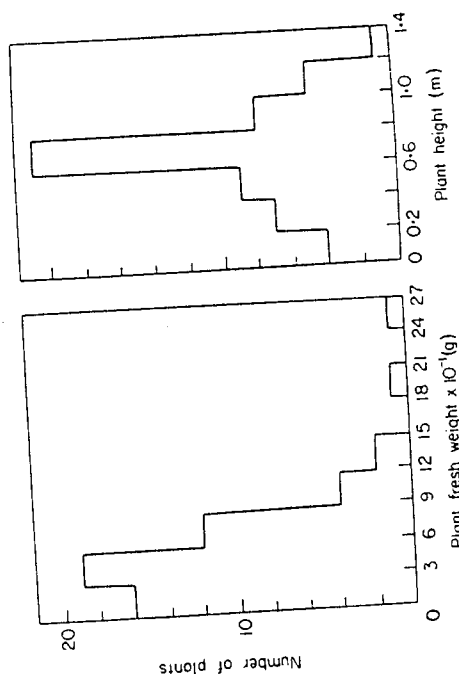


Fig. 6/16. Frequency distributions of weight and height in a natural stand of *Elatostema rugosum*. (From Ogden, 1970)

the abundant low weight individuals in dense populations tend to maintain their height, struggling into the canopy that is created by the few large plants. In populations of *Helianthus annuus* L. (Hiroi and Moni 1964), the suppressed plants are lank and etiolated with a relatively increased proportion of non-photosynthetic to photosynthetic tissue (stem to leaf) (Ogden, 1970). In natural vegetation, the frequency distributions of height are much more complex and "plant communities are so varied in composition and structure that it is difficult to generalise

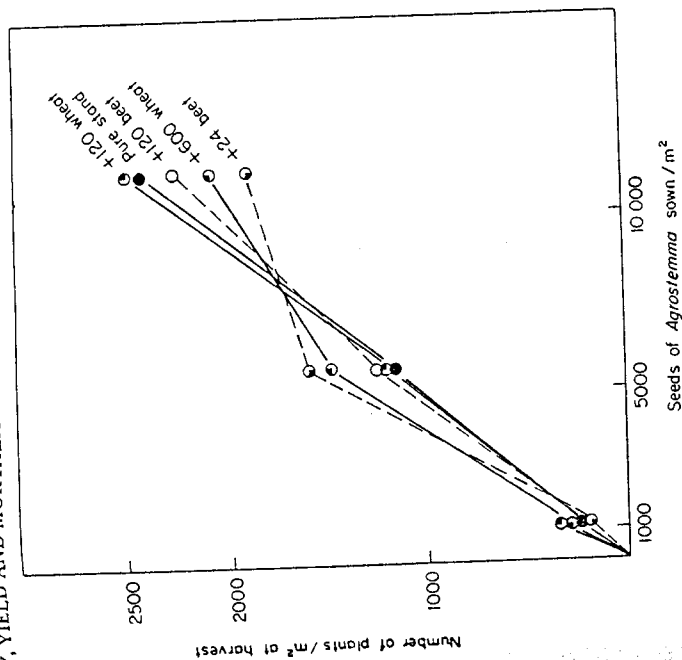


Fig. 6/17. The relationship between number of seeds sown and number of mature plants produced by *Agrostemma githago* in pure stand and in the presence of wheat and sugar beet. (From Harper and Gajic, 1961)

density in petri dishes, apparently because accumulated respiratory CO_2 regulates germination. Such an effect is unlikely to be significant under field conditions but other factors may act to produce the same result: for example when a soil has developed a capped surface (e.g. a clay soil drying after heavy rain) seedlings often emerge in clusters, suggesting that a group acting together may be able to break a crust that an isolated seedling cannot penetrate (Chapter 5). Such evidence of positive density-dependence in plant populations of a single species is very much the exception — most density responses are negative, reduced plant size or increased death risk.

A mortality risk that increases with increasing density has regulating properties. It is a negative feedback which acts to constrain population within narrower limits than the range of starting densities. It acts as a buffer that can maintain

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seedling dies after being hit is a function of its size and vigour, both of which are strongly affected by density. The mortality risk of being eaten by a predator might be thought to be largely density-independent but the vigour with which some predators search for a particular prey declines as the prey becomes less abundant and they may desert a particular source of food when the work involved in finding it becomes excessive. Wood pigeons (*Columba palumbus*) cease to predate when the density of a food falls to a level at which the birds can no longer search quickly enough to pick up a sufficient quantity. The risk of predation is then less at low seed densities than at high (see Chapter 16). This is also true of the birds' predation on the leaves of white clover (*Trifolium repens*). Limited search ranges of some phytophagous insects may ensure that epidemics break out only on dense populations, but where inter-plant distance is high the plants may escape attack (see Chapter 13).

Density stress changes the form of plants and will therefore usually change the way in which they respond to a hazard — few causes of mortality are likely to be wholly free of some influence of density, but there are examples. When the cornfield annual *Agrostemma githago* was grown in experimental field plots at a range of densities from 1076 to 10760/m² there was no change in the chance that a seed would produce a mature plant; the mortality risk was constant at 77% at all densities, and all the variation in density was absorbed in plastic responses in plant weight, branching, capsule number, etc. However in the presence of a constant density of a second species, beet (*Beta vulgaris*) or wheat (*Triticum sativum*) the mortality of *Agrostemma* became strongly density-dependent (Fig. 6/17), (Harper and Gajic 1961).

Occasionally population density may actually enhance seedling establishment, though such positive density effects usually involve only the early stages of germination and establishment. In experiments with *Rumex crispus* and *Rumex obtusifolius* two densities of seed were sown in soil at widely different water regimes. When the conditions were adverse for seedling establishment, doubling the sowing density more than doubled the number of seedlings. However when conditions favoured seedling establishment, doubling the number of seeds resulted in less than a doubling of seedling numbers (Harper and Chancellor, 1959). Positive density-dependence has been found in the germination of seeds under artificial conditions, for example in petri dishes (Knapp, 1951); seed of *Trifolium subterraneum* germinates more readily when sown

populations more constant than would be produced by natural variations in seed production and dispersal.

An example of density-dependent mortality comes from an experiment in which seeds of species of *Papaver* (cornfield poppies) were sown at densities ranging from 0 to 3140/m². The highest density of mature plants obtained with increasing density (Fig. 6/18). Such density-dependent mortality is well known in forest nurseries where it is usually associated with pathogenic activity (e.g. Gibson (1956) showed that *Rhizoctonia* was responsible for killing a higher proportion of seedlings in overcrowded plots).

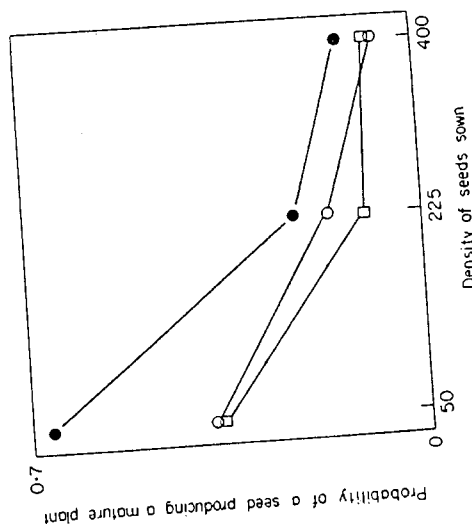


Fig. 6/18. The relationship between the density of seed sown and the chance that a seed will produce a mature plant — summarizing the behaviour of five species of *Papaver* in three differently shaded parts of an experimental garden. (From data in Harper and McNaughton, 1962)

Japanese workers have made the most thorough studies of density-dependent mortality in plants, in particular at Osaka City University (Kira, Shinozaki, Yoda, Ogawa and others) and at Tokyo (Monsi, Iwasa and others). Some examples of the relationships between sowing density and population density over time are shown in Fig. 6/19a, b and c. The data take a characteristic form; mortality occurs at high but not at low densities; the mortality continues with time and is not a sudden happening at a particular growth stage; the higher the density the sooner do

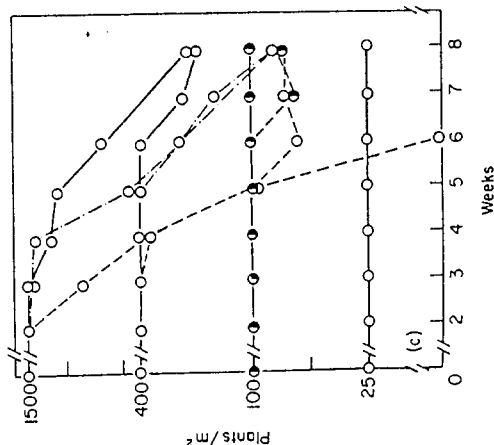
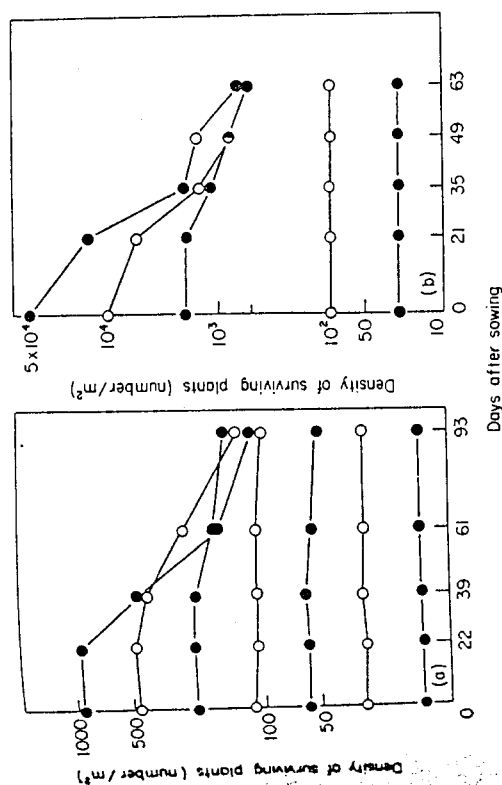


Fig. 6/19. Survival curves for populations of annual crop plants sown at a range of densities. (a) Soybean (*Glycine soja*); (b) Sesame (*Sesame vulgaris*). (From Yoda et al., 1963)

(c) Sunflower (*Helianthus annuus*) — full light intensity
— · · · 60% light and — — — 23% light. (From Ifiro and Monsi, 1966)

the first deaths occur. The severity of the self-thinning is affected by environmental conditions: populations of *Helianthus annuus* thin more rapidly if the light intensity is low (Hiroi and Monsi, 1966): some populations with very high starting densities of sunflower, grown at low light intensity, thinned to extinction within 6 weeks.

The time sequence of the thinning process can be seen clearly by plotting initial and surviving densities as the axes of a graph (Figs 6/20a and b). Soon after seedling emergence the numbers of plants are nearly linearly related to sowing density — mortality up to this point is nearly density-independent. As the plants grow, thinning at the higher densities leads to an asymptotic population density and the asymptote itself falls as the time passes. Sometimes fewer survivors remain from very high than from intermediate sowing densities.

The time trend of the self-thinning process can also be analysed by following the change in the log of plant numbers. A linear relationship between log numbers and time implies a constant exponential decrease — a risk of death to the individual which, like the decay of an isotope, remains constant over time. A hollow curve (Deevey type III) is obtained if the risk of early death is higher than that later in life. Self-thinning data are shown in Fig. 6/21a and b for three species: *Erigeron canadensis*, an early successional cornfield weed, and two crop species, *Fagopyrum esculentum* and *Sesame vulgaris*. The survivorship curves tend to be concave at first and then approach linearity. The number of such studies is still too small to allow wide generalization but they suggest that, after a seedling period in which the mortality risk is high, a nearly constant and lower risk is maintained for the rest of the life of the populations.

In natural self-thinning stands of fir near Leningrad, Sukatschew (1928) noticed that the residual density after self-thinning was greatest on thin, poor soils and that lower densities, though of bigger trees, were found on the deeper richer soils (Table 6/I). He designed an experiment to examine this phenomenon under controlled conditions. He sowed seeds of an annual, *Matricaria inodora*, at two densities in fertilized and unfertilized soil. Mortality occurred in the populations and was density-dependent, the risk of a plant dying being greater at the higher density. At both densities, however, the mortality risk was greater in the fertilized soils (Table 6/II). This result is at first sight surprising although clearly paralleled his field observations on the firs. Apparently, the application of fertilizers increased the rate of growth of the experiment

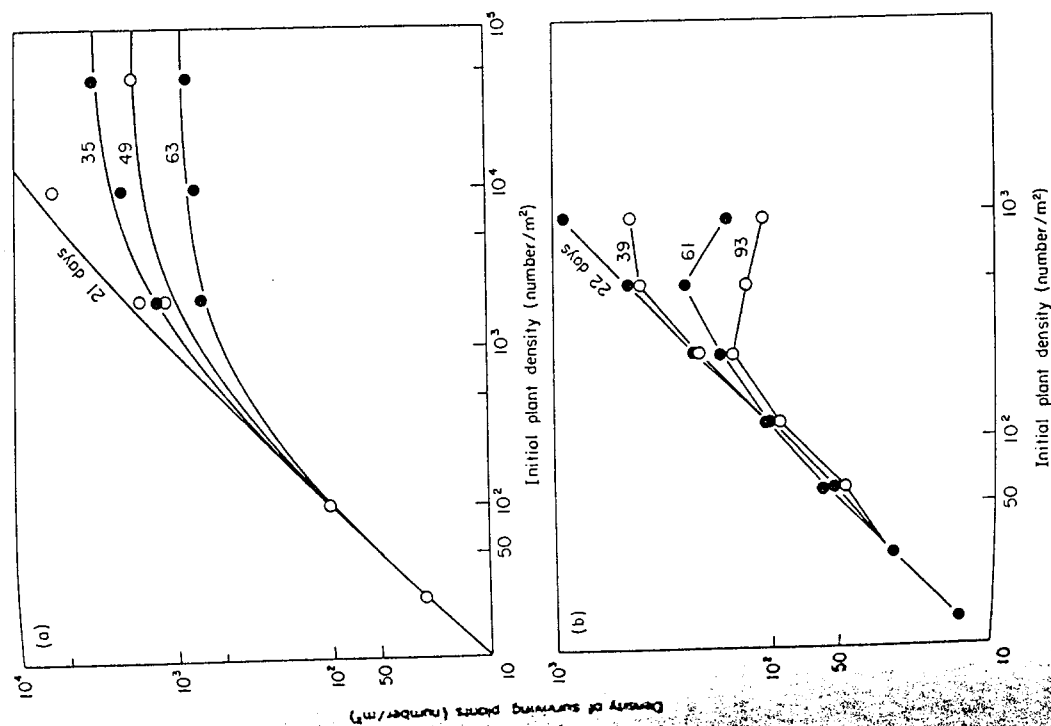


Fig. 6/20. The relationship between initial plant density and the density of survivors after various periods of time.

(a) Buckwheat (*Fagopyrum esculentum*)

(b) Soybean (*Glycine soja*)

(From Yoda *et al.*, 1963)

6. DENSITY, YIELD AND MORTALITY

Table 6/I

The density of trunks of fir in Leningrad forests on five natural soil types. The populations were self-thinning. (From Sukatschew, 1928)

Types of soil condition	At age 20 years			At age 60 years		
	Predominant trunks	Oppressed trunks		Predominant trunks	Oppressed trunks	
I (best)	5600	—		1300	640	
II (poorer)	5850	—		1600	680	
III (poorer)	6620	—		1950	650	
IV (poorer)	7480	—		2280	720	
V (worst)	8400	—		2780	760	

Table 6/II

Density dependent-mortality in *Matricaria inodora* at 2 levels of soil fertility. (From Sukatschew, 1928)

Soil culture (3 cm interplant distance)	% decrease in numbers	
	Non-fertilized soil	Fertilized soil
High density culture (10 cm interplant distance)	5.8	25.1
Low density culture (10 cm interplant distance)	0.0	3.1

of plants with the result that there was greater population pressure or density stress and under these conditions more plants died.

A particularly important study of self-thinning was made by Yoda *et al.* (1963) who showed that the rate of growth of individuals in a population and their death risk were correlated and dependent on fertility. They followed the development of dense populations of a number of species through an annual growth cycle, taking destructive harvests at intervals so that both the mean plant weight and the numbers of survivors could be determined on replicate plots. When the log of mean plant weight (i.e. of the survivors) was plotted against the log of the density of survivors, the values for successive harvests were found to lie around a line of slope of ca -1.5. If all the populations at all the sampling dates had equal weights per unit area a slope of -1.0 (45°) would have been obtained.

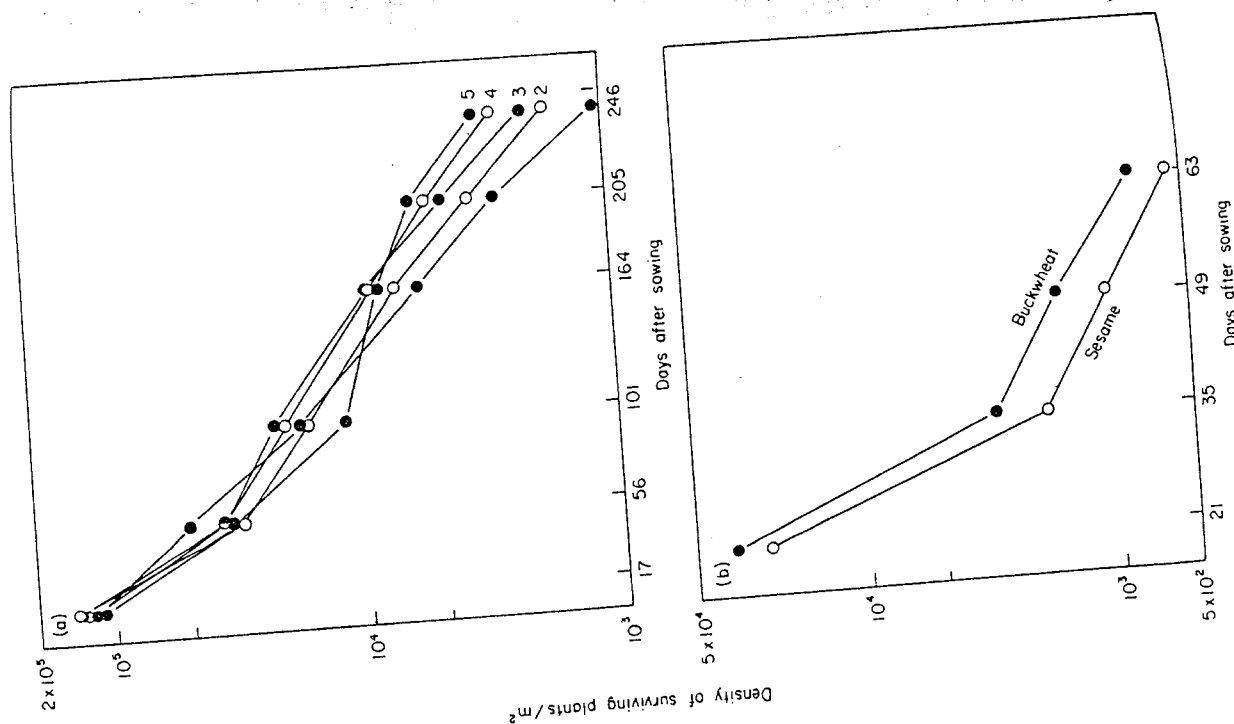


Fig. 6/21a. The time trend of self thinning in field populations of *Erigeron canadensis* 5, 4, 3, 2, 1 are plots receiving increasing levels of fertilizer. (From Yoda *et al.*, 1963)
b. The decline in the asymptotic density with time in populations of buckwheat (*Fagopyrum esculentum*) and sesame (*Sesame vulgaris*). (From Yoda *et al.*, 1963)

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A slope of -1.5 implies that while the number of individuals present in the population is decreasing, the weight of the population as a whole increases; the rate of growth of individuals more than compensates (and is probably responsible for) the fall in numbers. This relationship between mean weight and density of survivors can be written $w = cp^{-1.5}$. A number of examples of such self-thinning are shown in Fig. 6/22a and b.

It is useful to compare the self-thinning graphs of 6/22 with the yield-density graphs of Figs 6/3 and 6/4. In Fig. 6/22 changes are recorded in populations that have been started at one constant density and the graphs show the changes in numbers and mean plant weight with the

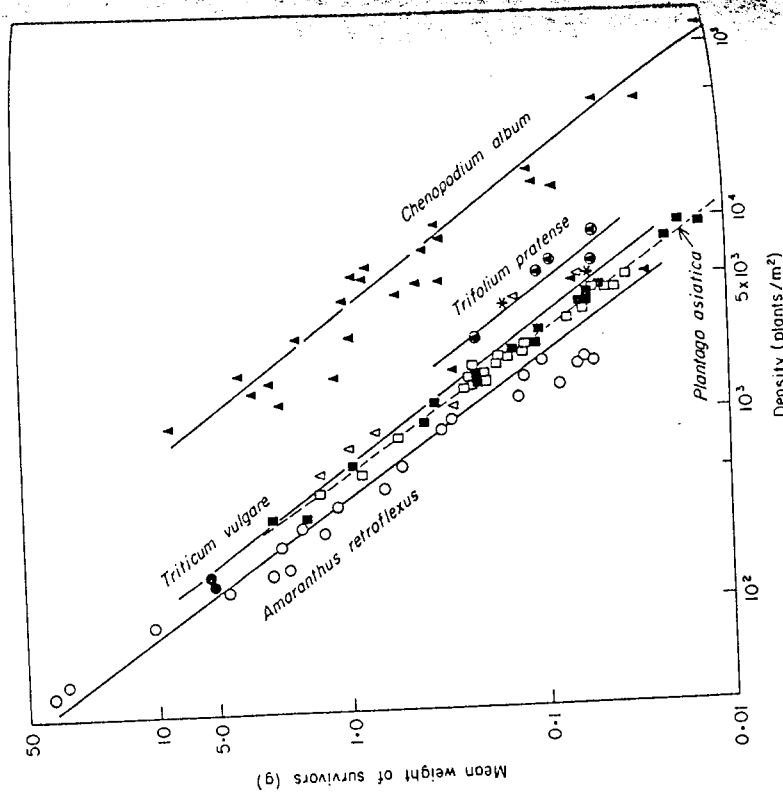


Fig. 6/22a. Changes in plant density and in mean plant weight with the passage of time. Data for *Chenopodium*, *Amaranthus*, and *Plantago* from Yoda *et al.*, (1963); data for *Trifolium* and *Triticum* from Harper and White (1970) after data of Black and Puckeridge.

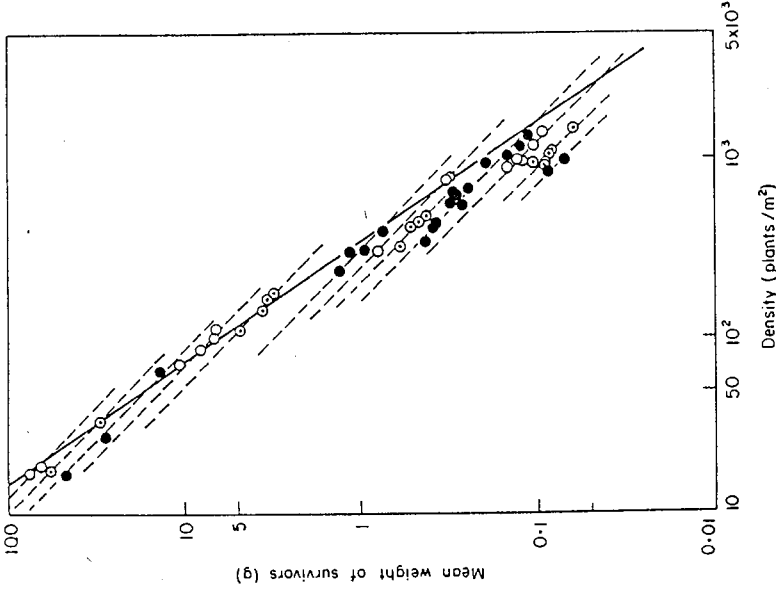


Fig. 6/22b. As Fig. 6/22a but *Amaranthus artemisiifolia* *elatior*. Each group of points along a dotted line represents plants at the same stage of growth and on soils of the same fertility level. (From Yoda *et al.*, 1963)

passage of time. In contrast, Figs 6/3 and 6/4 show the changes in plant weight that occur over a range of sown densities. In Figs 6/22a and b the regression lines represent time courses, whereas in Figs 6/3 and 6/4 different stages in time are represented by different curves. Moreover in Figs 6/3 and 6/4 the performance of populations was expressed in relation to the starting density and mortality was ignored.

An especially detailed study was made (Yoda *et al.*, 1963) of a homogeneous stand of *Erigeron canadensis* — a species that occurs naturally in the second year of old field successions in Japan. Field plots were cleared of existing vegetation and seeds of *Erigeron* were distributed as evenly as possible at a rate of $1-2 \times 10^5$ seeds/m² on an area of

together the data for the five fertility levels and the five dates of harvest, a plot of log mean plant weight against log density of survivors gives a series of points which are clustered along a common line. The fitted regression for all the data (except the first harvest) has a slope of -1.66 . This is 3° greater than and does not differ significantly from a slope of -1.5 . During the 9 months of the experiment the populations declined dramatically from an average density of 122 400 seedlings/m² to ca 1060 plants/m², so that the adult population represented less than 1% of the seedling population. The data present a vivid picture of a population of rapidly growing plants from which individuals are continually being lost in the self-thinning process, a population that is dynamic both in numbers and the size of individuals. Increased fertility stimulated the rate of growth of survivors and increased the number of plants dying.

A similar experiment was made (White and Harper, 1970) using seed of commercial varieties of *Raphanus sativus* and *Brassica napus* — species chosen because they could be relied on to give rapid, even germination. Seeds were sown at a density of 180 per 20 cm diameter pot and after 2 weeks the number of seedlings was counted and reduced to 150 per pot (ca 4.8×10^3 seedlings per m²). Harvests were taken 6½, 13 and 17 weeks after sowing — the plants did not flower during this period. The relationship between the mean weight per plant and the surviving density is shown in Fig. 6/24. The calculated regression for all species, mixtures, fertility levels and harvest times is $\log w = 2.28 - 1.45 \log p$ or $w = 190 p^{-1.45}$. This is obviously again closely similar to the $3/2$ power law of Yoda *et al.* and again the greatest thinning occurred on the most fertile soil. The species scarcely differed in their relationship to each other though *Raphanus* suffered slightly greater mortality than *Brassica*.

The $3/2$ power law has been tested mainly with annual plants but there is evidence that it holds true for forest trees as well. The empirically derived thinning tables used by foresters to optimize timber production conform rather well with the $3/2$ thinning rule. Management tables have been produced for a number of different forest tree species on different soil types. They provide advice on the thinning regimes which, with the initial planting densities commonly used, provide the fastest growth in girth consistent with maximal production of timber volume per unit area. Forestry management tables are concerned with timber volumes rather than with mean plant weight and so the log of mean volume per tree has been plotted against the log of the surviving density after the thinning regime recommended for each species

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sandy, infertile soil on which there was already a marked fertility gradient. The existing gradient was exaggerated by applying a mixed NPK fertilizer on a sequence of plots in the ratio 5:4:3:2:1. The density of seedlings was subsequently determined by placing small quadrats 10 cm by 10 cm within the plots and the average dry weight of the plants was determined at each harvest by sampling 100 random individuals from each plot. The results show clearly the "Sukatschew effect", i.e. self-thinning was most intense on the high fertility plots (Fig. 6/23). Taking

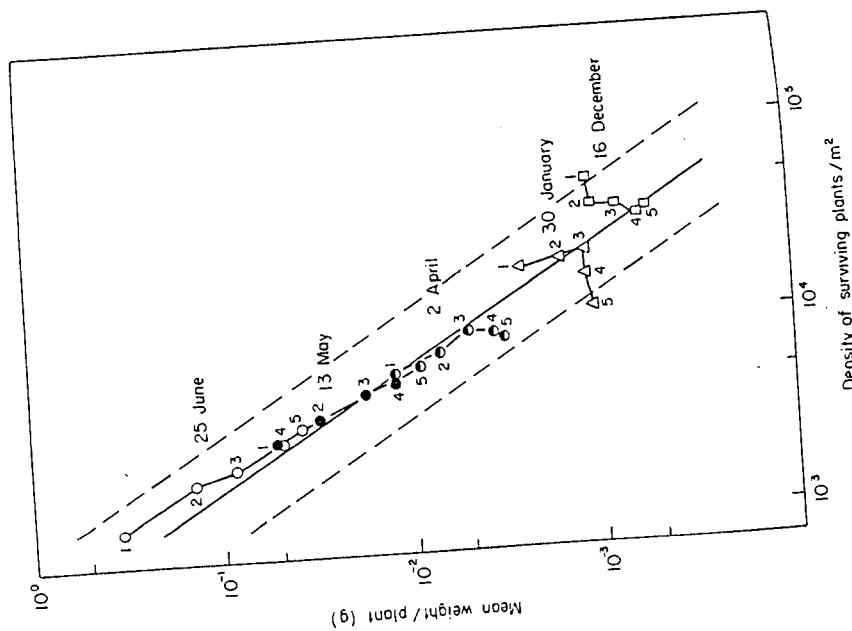


Fig. 6/23. Changes in numbers and individual plant weight of *Erigeron canadensis* with increasing fertility. The numbers 1, 2, 3, 4 and 5 represent a gradient of decreasing fertility. (From Yoda *et al.*, 1963, redrawn with calculated regression and 0.95 confidence limits — the first harvest, Nov. 7, is omitted).

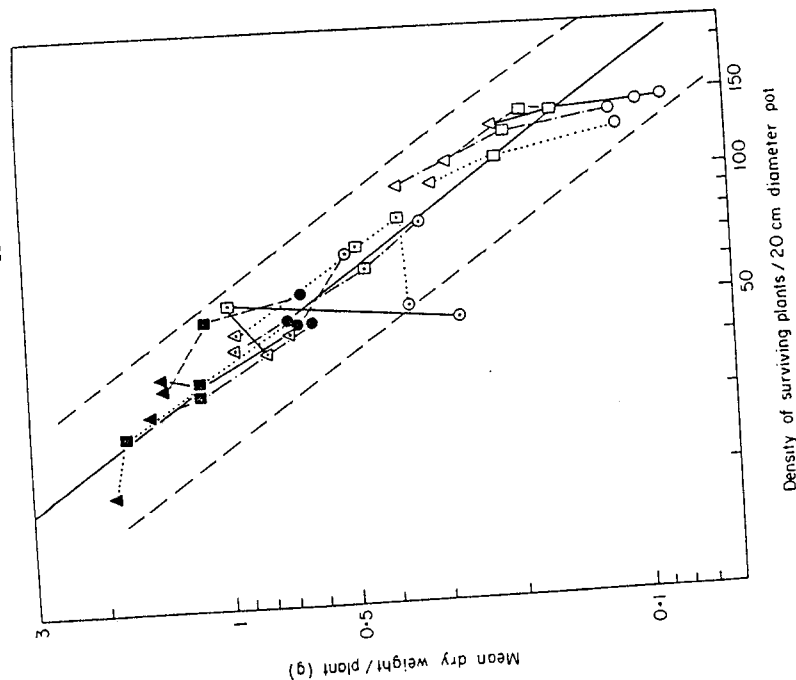


Fig. 6/24, *Raphanus sativus* ... in pure stands and in mixtures — — — and — — — —. The regression lines are given for $P = 0.05$.
 o = low fertility, □ = medium fertility, Δ = high fertility.
 o, □, Δ = first harvest, o, □, Δ = second harvest, ●, ■, ▲ = third harvest.
 (From White and Harper, 1970)

(Fig. 6/25a and b). There is again a striking linear relationship but with gradients ranging from -1.72 to -1.82 that are considerably steeper than expected under natural self-thinning, but it must be remembered that in these tables it is useful volume of timber that is the variable, not the mean weight of the individual, and this may be sufficient to steepen the regression slope.

The thinning lines for the various species shown in Fig. 6/25a and b are quite distinct. The mean volume expected at a particular density differs from species to species. These differences are themselves of course

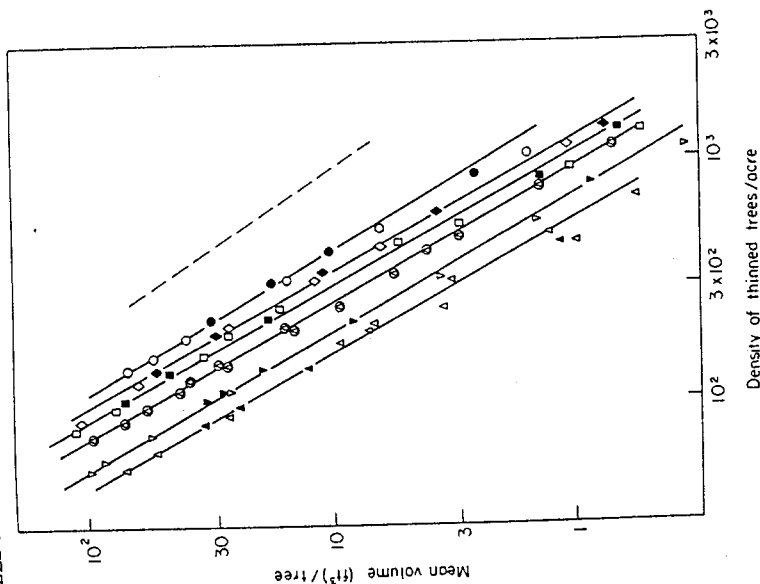


Fig. 6/25. The relationship between the density of trees and their mean volume in fully stocked stands up to 100 years after planting. Calculated from data in Forestry Management Tables (Bradley *et al.*, 1966). For each species two or three sets of yield class data (Y.C.) are given — these represent sites of different yielding ability and are essentially comparable with the fertility levels in Figs 6/22b and 6/23. Noble fir, Y.C. 240 (o); Y.C. 160 (●); western hemlock, Y.C. 260 (□), Y.C. 180 (●); Sitka spruce, Y.C. 260 (□), Y.C. 200 (●); Scots pine, Y.C. 160 (Δ), Y.C. 100 (▲); European larch, Y.C. 140 (○), Y.C. 80 (○); sycamore/ash/birch (joint tables), Y.C. 120 (Δ), Y.C. 80 (▲). The data for the separate yield classes lie along common thinning lines, whose gradients range from -1.72 to -1.82 . A slope of gradient -1.5 is shown at right for comparison. (From White and Harper, 1970)

of considerable interest. Does the parameter c which defines the position of a species on the graph describe some quality of canopy shape which affects the degree of mutual interference between individuals? Among the species represented in Fig. 6/25a and b the highest volume per tree at any given survival density is obtained from *Abies nobilis* — a tree of

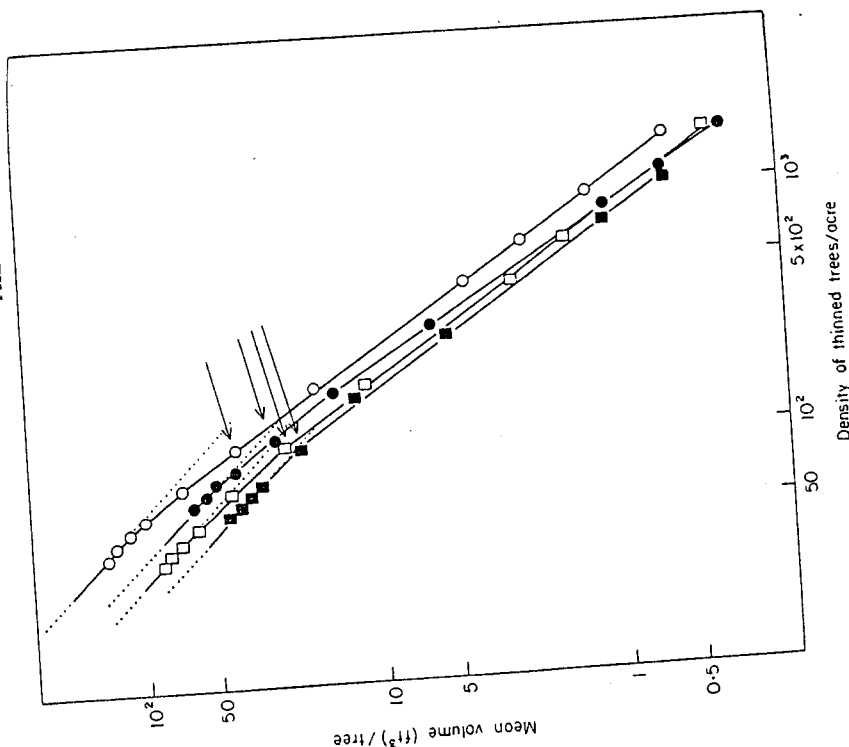


Fig. 6/25b. Relationships between density and mean volume per tree for beech and oak in fully stocked stands for up to 150 years of age. The data have been recalculated from Forestry Management Tables (Bradley *et al.* 1966) which predict yields obtained in accordance with the thinning practices advocated. Two sets of yield class data are given for each species: beech, Y.C. 100 (○), Y.C. 60 (△); oak, Y.C. 60 (□), Y.C. 40 (●). At points of maximum mean annual increment (indicated by arrows for each yield class) the slopes change from a gradient of -1.5 to -1. (From White and Harper, 1970)

markedly pyramidal shape. The order in which the species fall by the same criterion is: *Abies nobilis* (strikingly pyramidal) > *Tsuga heterophylla* (tapering crown) > *Picea sitchensis* (broadly pyramidal) > *Pinus sylvestris* (crown often flattened and irregular) > *Larix decidua* (irregularly pyramidal) > sycamore, ash and birch (deciduous and round-

crowned). This order suggests a topological series and that tree geometry is important in determining thinning relationships.

The forestry thinning tables for different "yield classes" give points that lie on the same thinning lines — variations in soil quality have the same effect as in the experiments with annuals (Fig. 6/23) of moving points up and down a common thinning line, not shifting the position of the line.

The yield/density relationship for long-lived stands of oak (*Quercus robur*) and beech (*Fagus sylvatica*) have slopes of -1.48 to -1.62 (Fig. 6/25b), values much closer to the ideal slope of -1.5. However, in the oldest stands the gradient changes to a value of -1.0. In these old forests the total volume of timber per unit area has become constant — any thinning that is practised permits the remaining trees to increase in size but only sufficiently to compensate for the volume removed at thinning. Further examples of the $3/2$ power law in natural and artificially thinned populations can be found in White and Harper (1970).

The mechanism of the self-thinning phenomenon is only dimly understood. The plants that are most likely to die in natural (as in forest) thinning are the smallest and "weakest". The clearest direct evidence that this is the case comes from an experiment made on populations of *Trifolium subterraneum* by Black (1958). This species produces a rather wide range of seed sizes even from a single plant. Samples of large and small seeds were sown in pure stands and in equiproportioned mixtures all at high density. Self-thinning occurred in the seedling population after about 40 days' growth. The populations from large seeds suffered more rapid mortality than those derived from small seeds (Fig. 6/26).

The size of the seedlings is closely related to the size of the seeds and the real growth rate is a function of the seedling size, particularly cotyledon area. Apparently the faster-growing, larger, and more vigorous seedlings produced a density stress amongst themselves which resulted in a greater mortality than in the populations of the same density but of the smaller and slower growing seedlings. When small and large seeds were sown together, the mortality was concentrated almost exclusively amongst the plants derived from the small seeds: the stress of density was absorbed by the death of the smaller members. Not only did the plants from large seeds come to dominate the canopy of the mixed stands but at the end of the experiment (after 120 days) the plants from the small seeds were intercepting only ca 3% of the total light intercepted by the canopy of the mixture (Fig. 6/27). It is not possible to make the rigid argument

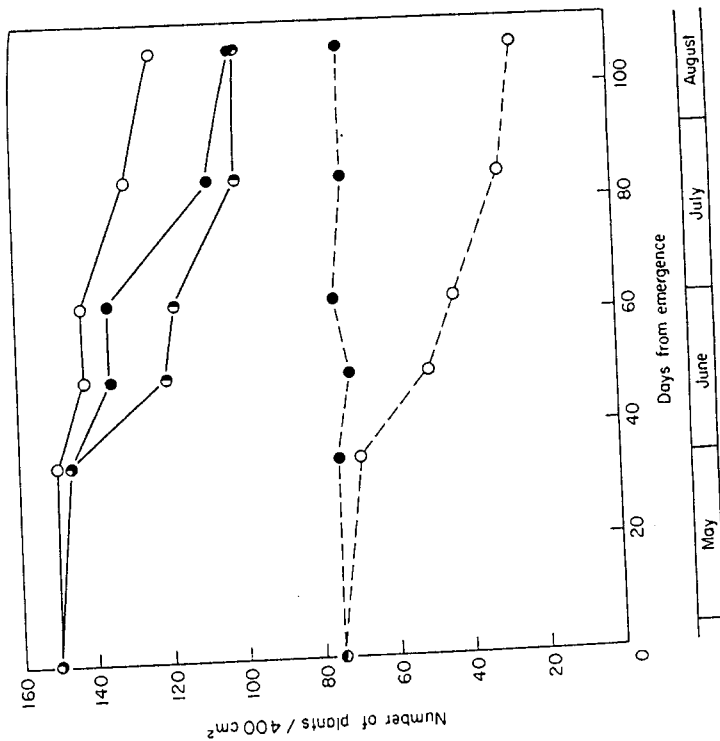


Fig. 6/26. Changes in plant numbers in populations of *Trifolium subterraneum* derived from large seeds = ●, small seeds = ○ and mixed swards = ○ and also for both components within a mixed sward = ● — — — ○. (From Black, 1958)

that the plants that died did so because they were starved of light, but this seems the most probable direct or indirect cause.

If the self-thinning process involves the progressive elimination of the weakest individuals it immediately becomes pertinent to ask questions about the nature of the hierarchy of size or vigour that develops in a growing population. It has already been pointed out that plant populations growing under density stress develop a log-normal distribution of weights (Figs 6/8, 6/9) and that this may arise because of differences in "space occupancy" at very early stages in establishment. Self-thinning removes the smaller individuals from the population and tends to stabilize the degree of skewness.

Many of the weaker individuals in a population extend their foliage

the top of the canopy but do this by means of long, spindly stems and a proportionately greater respiratory burden. Their net assimilation rates may therefore be expected to be lower than that of the dominant plants in the canopy. It may be that the self-thinning process involves changes in the net assimilation rates of the individuals and that the plants that die are those with very low or negative net assimilation rates.

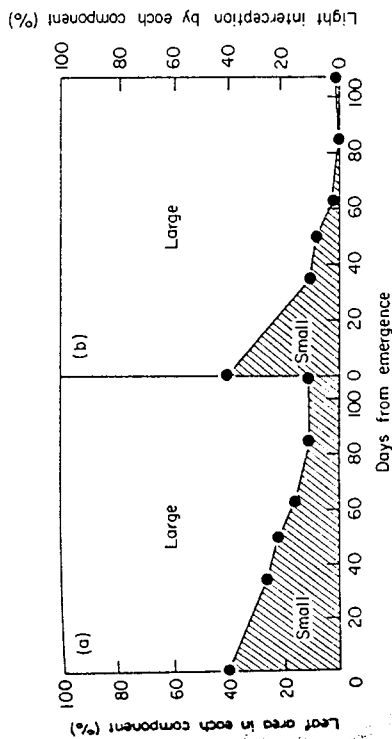


Fig. 6/27. The percentage of the leaf area (a) and the percentage of the light interception (b) of plants of *Trifolium subterraneum* from large and small seeds grown in a mixed sward. (From Black, 1958)

it would be of the greatest interest to determine the frequency distribution of net assimilation rates among the individuals of a self-thinning population.

Considerable support is given to the above interpretation of the self-thinning process by some data obtained by Hiroi and Monsi (1966; analysed by White and Harper, 1970). Sunflowers (*Helianthus annuus*) were grown at starting densities of 1600 and 400 plants/m² and thinned so that they received 100, 60 or 23% to full daylight. The number of survivors and their mean weight were measured in replicate plots over a period of 10 weeks. The self-thinning lines closely followed the 3/2 power law, but were displaced and the gradients slightly reduced at lower light intensities (Fig. 6/28). The lower the light intensity, the more rapid was the thinning with the result that (i) at any given density of survivors the plants were heavier if the light intensity was higher and (ii) at any given weight of plants the number of survivors was greater at

ing where other supply factors dominate the chances of survival.

Mortality in experimental populations of single species is a steady process in which, after the seedling phase, the risk of death does not change appreciably with age. It appears that one of the consequences of the growth of individuals is to generate a density stress which continues to expel a more or less constant proportion of the survivors in unit time. The same effect extends to control the death rates of the parts of individual plants.

Grasses, like most clonal plants, have a clearly defined modular structure in which the genet develops as a population of tillers. Each tiller is itself a population of leaves. Under stress, leaves may die or whole tillers or whole genets. A series of populations of *Lolium perenne* were sown at densities ranging from 330 to 10 000 seeds/m² under three light intensities (full, 2/3 and 1/3 of full daylight). As seedlings emerged they were loosely marked with a cotton loop so that the later developing tillers could be related to the original seedling even if the connections between the parts of the genets disappeared. Seven harvests were made over 180 days and records were taken of the number of surviving genets, the number of surviving tillers, the weight per genet and the weight per tiller (Kays and Harper, 1974). The results are shown in Figs 6/29, 6/30 and 6/31. Figure 6/29 shows that during the course of the experiment there was a continual death of genets. The higher the density the sooner was the onset of mortality. The denser populations had lost 60–70% of their members after 180 days. During the last 60 days all the populations were losing genets at about the same rate so that, although mortality started at different times at different densities, the half-life of a population rapidly became independent of the starting conditions. During the period when genets were being lost from the populations, the number of tillers was changing independently and after 180 days the number of tillers per unit area was almost independent of the starting density — there was no significant difference in tiller density per plot after 130 days in any one light regime. The populations were adjusting the effective density of tillers per plot throughout the experiment and the number present at any time was the consequence of (i) differential mortality of genets, (ii) differential birth rates of tillers per genet and (iii) differential death rates of tillers.

The populations at the three light intensities behaved differently (Fig. 6/30, b and c) but in all cases the three processes (i), (ii) and (iii) combined to bring the mean density of tillers per unit area to a value that

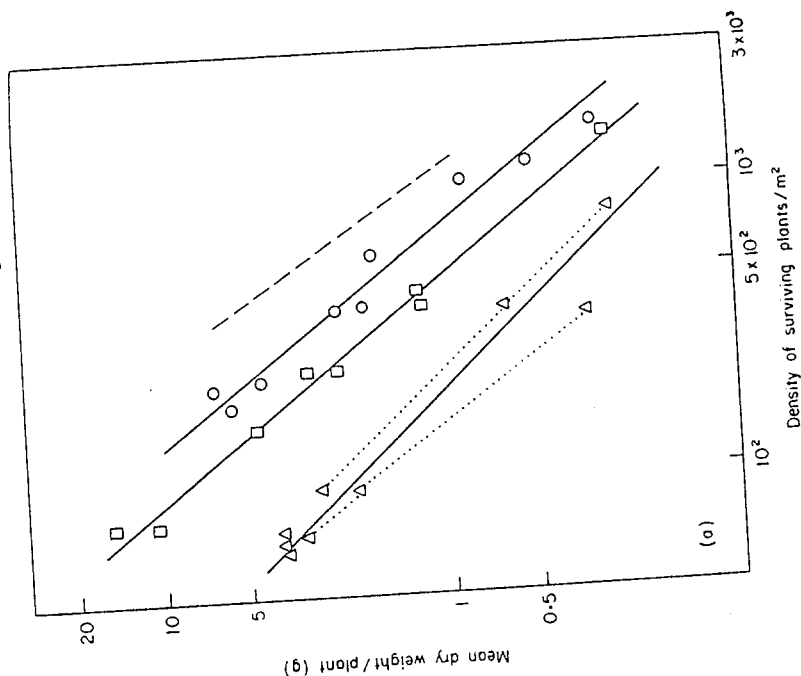


Fig. 6/28. Changes in numbers and mean plant weight in *Helianthus annuus* populations grown at 100% (○) 60% (□) and 29% (△) light intensity over a period of 10 weeks. (From White and Harper, 1970 calculated from data of Hiroi and Monsi, 1966)

high than at low light intensity. Such a reaction to light contrasts completely with the reaction of plant populations to nutrient supply.

Changes in the level of fertility had the effect of moving points up or down a common self-thinning line whereas changes in the light intensity altered the position of the line (the value of c). These observations are wholly compatible with the view that self-thinning involves the death of individuals whose net assimilation rate falls below some critical value shading of the population increases the proportion falling in this category.

Most experiments on self-thinning have been made under conditions in which light might be expected to be in limiting supply within canopy. It is not difficult to envisage comparable self-thinning processes occur

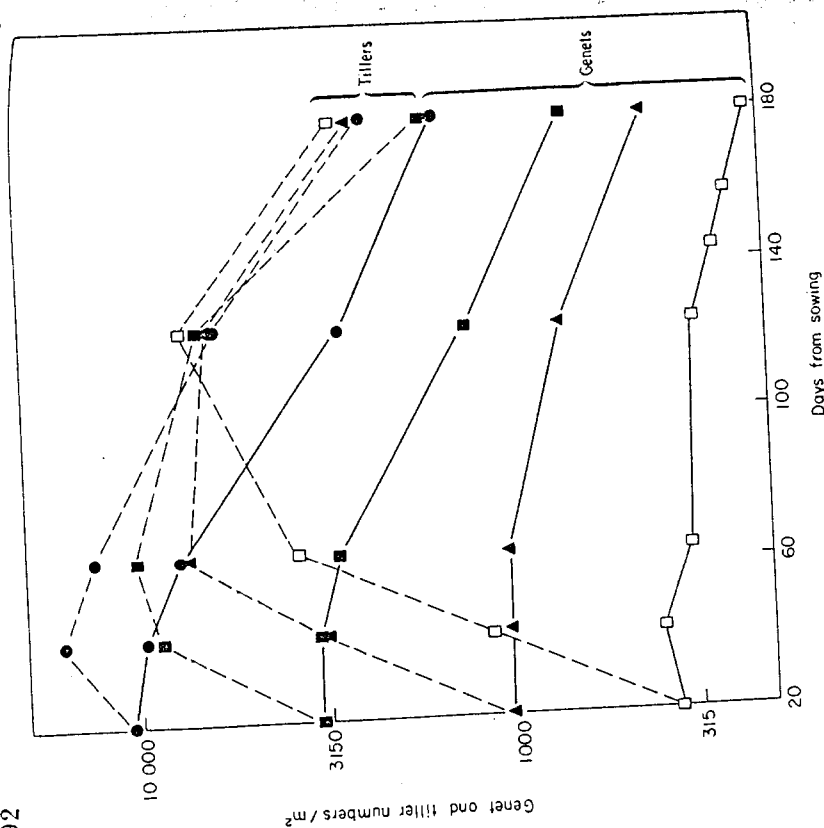


Fig. 6/29. Changes in the density of tillers — — — and of genets — in populations of *Lolium perenne* sown at a range of densities. (From Kays and Harper, 1974)

was characteristic of the light regime but quite independent of the starting density of seeds. In the most shaded regime the tillers were smaller and their density was lower than in full light.

Figure 6/31 shows the relationship between the density of surviving genets at the various sampling times and the mean weight per genet. The populations grew and self-thinned as if constrained by a $3/2$ thinning law. However, at the lowest light intensity the thinning line approached a slope of 45° , i.e. the growth rate of the genets was just sufficient to compensate for the effects of thinning. This exactly parallels the results from the sunflower experiments (Fig. 6/28).

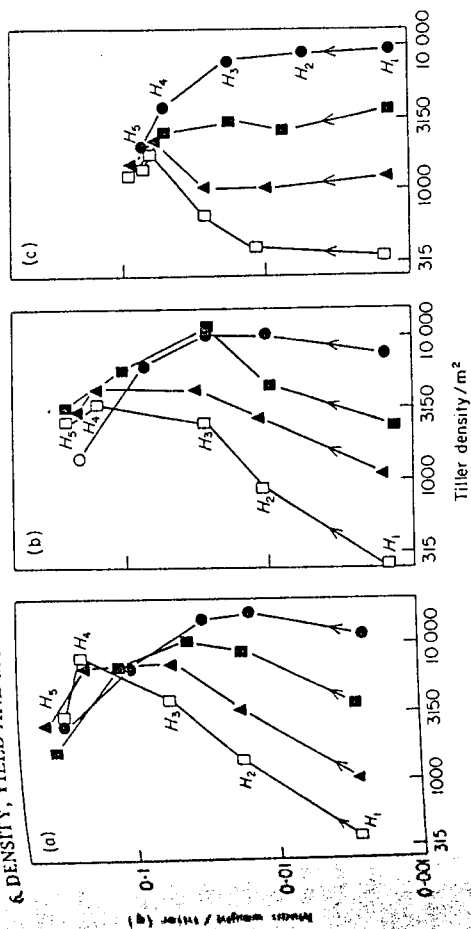


Fig. 6/30. The relationships between tiller density and mean weight per tiller in populations of *Lolium perenne* grown at three light intensities (a) 100%, (b) 60% and (c) 30% of full daylight. H_1, H_2 , etc. are successive harvests. (From Kays and Harper, 1974)

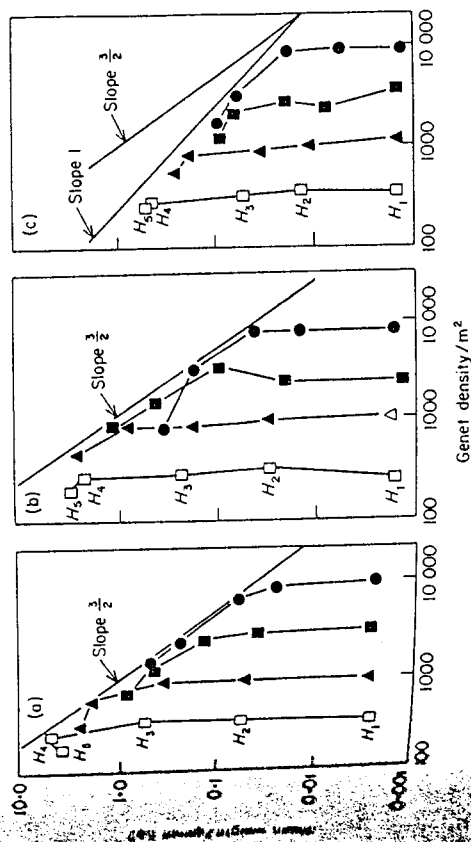
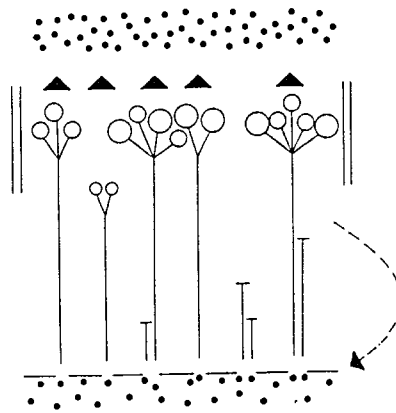


Fig. 6/31. The relationships between the density of genets and the mean weight per genet in populations of *Lolium perenne* grown at three light intensities (a) 100%, (b) 60% and (c) 30% of full daylight. H_1, H_2 , etc. are successive harvests. (From Kays and Harper, 1974)

Of course the behaviour of populations of a single species grown in pots or field plots is far removed from the complexities of natural systems. In particular, in such experimental studies extremes of water stress can usually be avoided that may be critically important in the field. The relevance of the experiments to the interpretation of natural vegetation is comparable to the relevance of a test tube study of an enzyme to the understanding of the functions of cells or the study of a root segment in a manometer to understanding the activities of a root system on a whole tree. The relevance comes largely from the act of faith that complex systems may be understood by breaking them down into parts and then reassembling them. This is not to deny that the whole is more than the sum of its parts but an act of faith that the remainder consists of interactions that are themselves appropriate objects of study. The parts of population biology that are discussed in this chapter establish that growth and death are interrelated at the population level in a sufficiently integrated fashion for formal mathematical relationships to be derived. Some of these may be species-specific but many have generalities far beyond the species level. The generalizations that emerge provide an appropriate base from which to extend into study of the greater complexity.

7

The Influence of Density on Form and Reproduction



Higher plants are plastic in size and form: this plasticity derives mainly from their population-like structure (see Chapter 1). Much of the fine specific control that determines the difference between species is dependent on the form of the repeating units of construction, particularly leaves and flowers. The size and form of these units is usually tightly canalized and changes only fractionally over widely varied environmental conditions. In contrast, the number of the units and thus the size of the whole plant varies greatly both with age and with conditions. Thus whole zoologists commonly use aspects of the size of whole organisms,

extremely rare or absent in nature (Maynard Smith, 1964) may be the most proper type of selection for improving the productivity of crop and forest plants. Plant breeding would then be concerned to undo the results of selection for the selfish qualities of individual fitness and focus on the performance of populations.

References

- Abbott, H. G. and Quink, T. F. (1970). Ecology of eastern white pine seed caches made by small forest mammals. *Ecology* 51, 271-278.
- Aberg, E., Jolinson, I. J. and Wilsie, C. P. (1943). Associations between species of grasses and legumes. *J. Am. Soc. Agron.* 35, 357-369.
- Abeywickrama, B. S. (1949). "A study of the variation in the field layer vegetation of two Cambridgeshire woods". Ph.D. thesis, University of Cambridge.
- Abrahamson, W. G. and Gadgil, M. D. (1973). Growth form and reproductive effort in golden rods (*Solidago*, Compositae). *Am. Nat.* 107, 651-661.
- Adair, C. R. and Jones, J. W. (1946). Effect of environment on the characteristics of plants surviving in a bulk hybrid population of rice. *J. Am. Soc. Agron.* 38, 708-716.
- Adams, M. W. (1967). Basis of yield component compensation in crop plants with special reference to the field bean, *Phaseolus vulgaris*. *Crop Sci.* 7, 505-510.
- Adams, S., Strain, B. R. and Adams, M. S. (1970). Water-repellent soils, fire and annual plant cover in a desert scrub community of southeastern California. *Ecology* 51, 696-700.
- Alder, G. M. (1970). "Age-profiles of aspen forests in Utah and northern Arizona". M.S. thesis, University of Utah.
- Allard, R. W. and Adams, J. (1969). Population studies in predominantly self-pollinating species. XIII. Intergenic competition and population structure in barley and wheat. *Am. Nat.* 103, 621-645.
- Allard, R. W., Babel, G. R., Clegg, M. T. and Kahler, A. L. (1972). Evidence for coadaptation in *Avena barbata*. *Proc. Natn. Acad. Sci. U.S.A.* 69, 3043-3048.
- Allard, R. W., Jain, S. K. and Workman, P. L. (1968). The genetics of inbreeding populations. *Adv. Genet.* 14, 55-131.
- Allee, W. C., Emerson, A. E., Park, T. and Schmidt, K. P. (1949). "Principles of Animal Ecology". Saunders, Philadelphia.

- Allen, J. A. and Clarke, B. (1968). Evidence for apostatic selection by wild passerines. *Nature, Lond.* 220, 501-502.
- Amen, R. D. (1966). The extent and role of seed dormancy in alpine plants. *Q. Rev. Biol.* 41, 271-281.
- Amen, R. D. (1968). A model of seed dormancy. *Bot. Rev.* 34, 1-31.
- Anderson, M. C. (1964). Light relations of terrestrial plant communities and their measurement. *Biol. Rev.* 39, 425-486.
- Anderson, M. C. (1966). Some problems of the simple characterization of the light climate in plant communities. In "Light as an Ecological Factor" (R. Bainbridge, G. C. Evans and O. Rackham, eds) *Symp. Br. Ecol. Soc.* 77-90.
- Ando, T., Sakaguchi, K., Narita, T. and Satou, S. (1962). Growth analysis on the natural stands of Japanese Red Pine (*Pinus densiflora* Sieb. et Zucc.) I. *Bull. Gov. Forest exp. Stn.* 144, 30 pp.
- Andres, L. A. and Goeden, R. D. (1975). The biological control of weeds by introduced natural enemies. In "Biological Control" (C. B. Huffaker, ed.), pp. 143-164. Plenum Press, New York.
- Andrewartha, H. G. (1957). The use of conceptual models in population ecology. *Cold Spring Harbour Symp. Quant. Biol.* 22, 219-36.
- Andrewartha, H. G. and Birch, L. C. (1954). "The Distribution and Abundance of Animals". University of Chicago Press, Chicago.
- Antonovics, J. (1972). Population dynamics of the grass *Anthraxanthum odoratum* on a zinc mine. *J. Ecol.* 60, 351-366.
- Arber, A. (1950). "The Natural Philosophy of Plant Form". Cambridge University Press, London.
- Archer, M. (1973). The species preferences of grazing horses. *J. Br. Grassl. Soc.* 28, 123-138.
- Arnold, G. W. (1962). Effects of pasture maturity on the diet of sheep. *Aust. J. agric. Res.* 13, 701-706.
- Arnold, G. W. (1964). Some principles in the investigation of selective grazing. *Proc. Aust. Soc. Anim. Prod.* 5, 258-271.
- Arnold, G. W., Ball, J., McManus, W. R. and Bush, I. G. (1966). Studies on the diet of the grazing animal. I. Seasonal changes in the diet of sheep grazing on pastures of different availability and composition. *Aust. J. agric. Res.* 17, 543-556.
- Arthur, A. E. (1969). "Variation in natural populations of *Papaver dubium*". Ph.D. thesis, University of Birmingham.
- Arthur, A. E., Gale, J. S. and Lawrence, K. J. (1973). Variation in wild populations of *Papaver dubium*. VII. Germination time. *Heredity* 30, 189-197.
- Ashby, E. and Wangermann, E. (1951). Studies in the morphogenesis of leaves. VII Part I. Effect of light intensity and temperature on the cycle of ageing and rejuvenation in the vegetative life history of *Lemna minor*, and Part II. Correlative effects of fronds in *Lemna minor*. *New Phytol.* 50, 186-209.
- Ashby, E., Wangermann, E. and Winter, E. J. (1949). Studies in the morphogenesis of leaves. III. Preliminary observations on vegetative growth in *Lemna minor*. *New Phytol.* 48, 374-381.

- Ashton, D. H. (1956). "Studies on the autoecology of *E. regnans*". Ph.D. thesis, University of Melbourne, Australia.
- Ashton, P. H. (1956). Speciation among tropical forest trees: some deductions in the light of recent evidence. *Biol. J. Linn. Soc.* 1, 155-196.
- Askew, R. R. (1962). The distribution of galls of *Neuroterus* (Hym. Cynipidae) on oak. *J. Anim. Ecol.* 31, 439-445.
- Aspinall, D. (1960). An analysis of competition between barley and white persicaria. II. Factors determining the course of competition. *Ann. appl. Biol.* 48, 637-654.
- Auclair, A. N. and Cottam, G. (1971). Dynamics of black cherry (*Prunus serotina* Ehrh.) in Southern Wisconsin oak forests. *Ecol. Monogr.* 41, 153-177.
- DeBach, P. (1964). "Biological Control of Insect Pests and Weeds". (P. DeBach, ed., assisted by E. I. Schlinger). Chapman and Hall, London.
- Baumer, K. and De Wit, C. T. (1968). Competitive interference of plant species in monocultures and mixed stands. *Neth. J. agric. Sci.* 16, 103-122.
- Bailey, R. J., Rees, H. and Jones, L. M. (1976). Interchange heterozygotes versus homozygotes. *Heredity* 37, 109-112.
- Baker, H. (1937). Alluvial meadows: a comparative study of grazed and mown meadows. *J. Ecol.* 25, 408-420.
- Baker, J. R. (1938). The evolution of breeding seasons. "Evolution", Essays presented to E. S. Goodrich (Oxford) 161-177.
- Baker, D. (1960). A comparative life-history study of *Cirsium arvense* (L.) Scop. and *Tussilago farfara* (L.), the most troublesome weeds in the newly reclaimed polders of the former Zuiderzee. In "The Biology of Weeds" (J. L. Harper, ed.) *Symp. Br. ecol. Soc.* 1, 205-222.
- Bandeem, J. D. and Buchholtz, K. P. (1967). Competitive effects of quack grass upon corn as modified by fertilisation. *Weeds* 15, 220-223.
- Baralis, G. (1965). Aspects ecologiques des mauvaises herbes dans les cultures annuelles. C. r. 3ème Conf. COL-UMA, Paris.
- Baralis, G. (1968). Ecology of blackgrass. *Proc. 9th Br. Weed Control Conf.* 6-8.
- Barber, S. A., Walker, J. M. and Vasey, E. H. (1962). Principles of ion movement through the soil to the plant root. *Trans. Int. Soil Sci. Comm.* II and IV, New Zealand, 121-124.
- Barclay-Estrup, P. (1970). The description and interpretation of cyclical processes in a heath community. II. Changes in biomass and shoot production during the *Calluna* cycle. *J. Ecol.* 58, 243-249.
- Barger, G. and Blackie, J. J. (1937). Alkaloids of *Senecio*. III. Jacobine, Jacodine and Jaconine. *J. chem. Soc.* 584-586.
- Barker, J. S. F. (1971). Ecological differences and competitive interaction between *Drosophila melanogaster* and *Drosophila simulans* in small laboratory populations. *Oecologia* (Berl.) 8, 139-156.
- Barker, J. S. F. (1973). Natural selection for coexistence or competitive ability in laboratory populations of *Drosophila*. *Egypt. J. Genet. Cytol.* 2, 288-315.
- Barrett, L. I. (1931). Influence of forest litter on the germination and early survival of chestnut oak, *Quercus montana* Willd. *Ecology* 12, 476-484.
- Barrow, M. D., Costin, A. B. and Lake, P. (1968). Cyclical changes in an Australian

- fjeldmark community. *J. Ecol.* 56, 89–96.
- Bartholomew, B. (1970). Bare zone between California shrub and grassland communities: the role of animals. *Science, N.Y.* 170, 1210–1212.
- Bartholomew, B., Eaton, L. C. and Raven, P. H. (1973). *Clarkia rubicunda*: a model of plant evolution in semi-arid regions. *Evolution* 27, 505–517.
- Bazzaz, F. A. and Harper, J. L. (1976). Relationship between plant weight and numbers in mixed populations of *Simulium arvensis* (L.) Rabenh. and *Lepidium sativum* L. *J. appl. Ecol.* 13, 211–216.
- Beard, J. S. (1946). The Mora forests of Trinidad, British West Indies. *J. Ecol.* 33, 173–192.
- Beasley, J. (1969). Dependence of desert rodents on winter annuals and precipitation. *Ecology* 50, 722–724.
- Bell, A. D. (1974). Rhizome organisation in relation to vegetative spread in *Medeola virginiana*. *J. Arnold Arboretum* 55, 458–468.
- Bell, A. D. (1976). Computerized vegetative mobility in rhizomatous plants. In “Automata, Languages and Development” (A. Lindemayer and G. Rosenberg, eds). North-Holland, Amsterdam.
- Belyea, R. M. (1952). Death and deterioration of balsam fir weakened by spruce budworm defoliation in Ontario. *J. Forestry* 50, 729–738.
- Benecke, P. and Mayer, R. (1971). Aspects of soil water behaviour as related to beech and spruce stands. — Some results of water balance investigations. In “Integrated Experimental Ecology” (H. Ellenberg, ed.), pp. 153–163. Chapman and Hall, London.
- Bent, A. C. (1939). Life histories of north American woodpeckers. *U.S. National Museum, Bulletin* 174, Washington, D.C.
- Berg, R. Y. (1975). Myrmecochorous plants in Australia and their dispersal by ants. *Aust. J. Bot.* 23, 475–508.
- Bergh, J. P. van den (1968). An analysis of yields of grasses in mixed and pure stands. *Versl. Landbouwk. Onderz.* 714, 1–71.
- Bergh, J. P. van den and de Wit, C. T. (1960). Concurrentie tussen timothee en reukras. *Inst. voor Biol. en Scheikundig Onderz. Landbouwk. Wageningen. Mededeling* 121, 155–165.
- Beukema, J. J. (1968). Predation by the three-spined stickleback (*Gasterosteus aculeatus* L.): the influence of hunger and experience. *Behaviour* 31, 1–126.
- Beveridge, A. E. (1964). Dispersal and destruction of seed in central North Island Podocarp forests. *Proc. N.Z. ecol. Soc.* 11, 48–55.
- Bingham, J. (1967). Investigations on the physiology of yield in winter wheat, by comparisons of varieties and by artificial variations in grain number per ear. *J. agric. Sci.* 68, 411–422.
- Birch, L. C. (1948). The intrinsic rate of natural increase of an insect population. *J. Anim. Ecol.* 17, 15–26.
- Bishop, J. A. and Korn, M. E. (1969). Natural selection and cyanogenesis in white clover. *Heredity* 24, 423–430.
- Blaak, G. (1972). Prediction of precocity in the oil palm (*Elaeis guineensis* Jacq.) *Euphytica* 21, 22–26.
- Black, C. C. (1971). Ecological implications of dividing plants into groups with

- distinct photosynthetic production capacities. In: “Advances in Ecological Research” (J. B. Gragg, ed.), Vol. 7, pp. 87–114. Academic Press, London and New York.
- Black, C. C., Chen, T. M. and Brown, R. H. (1969). Biochemical basis for plant competition. *Weed Sci.* 17, 338–344.
- Black, J. N. (1956a). The influence of seed size and depth of sowing on pre-emergence and early vegetative growth of subterranean clover (*Trifolium subterraneum* L.). *Aust. J. agric. Res.* 7, 98–109.
- Black, J. N. (1956b). The distribution of solar radiation over the earth's surface. *Arch. Met. Geophys. Bioklim.* B 7, 165–189.
- Black, J. N. (1957). The early vegetative growth of three strains of subterranean clover (*Trifolium subterraneum* L.) in relation to size of seed. *Aust. J. agric. Res.* 8, 1–14.
- Black, J. N. (1958). Competition between plants of different initial seed sizes in swards of subterranean clover (*Trifolium subterraneum* L.) with particular reference to leaf area and the light microclimate. *Aust. J. agric. Res.* 9, 299–318.
- Black, J. N. (1959). Seed size in herbage legumes. *Herb. Abstr.* 29, 235–241.
- Black, J. N. (1960a). The relationship between illumination and global radiation. *Trans. R. Soc. S. Aust.* 83, 83–87.
- Black, J. N. (1960b). The significance of petiole length, leaf area, and light interception in competition between strains of subterranean clover (*Trifolium subterraneum* L.) grown in swards. *Aust. J. agric. Res.* 11, 277–291.
- Black, J. N. (1960c). An assessment of the role of planting density in competition between red clover (*Trifolium pratense* L.) and lucerne (*Medicago sativa* L.) in the early vegetative stage. *Oikos* 11, 26–42.
- Black, J. N. (1963). The interrelationship of solar radiation and leaf area index in determining the rate of dry matter production of swards of subterranean clover (*Trifolium subterraneum* L.). *Aust. J. agric. Res.* 14, 20–38.
- Black, J. N. and Wilkinson, G. N. (1963). The role of time of emergence in determining the growth of individual plants in swards of subterranean clover (*Trifolium subterraneum* L.). *Aust. J. agric. Res.* 14, 628–638.
- Black, M. (1969). Light-controlled germination of seeds. In “Dormancy and Survival” (H. W. Woolhouse, ed.) *Symp. Soc. exp. Biol.* 23, 193–217.
- Black, M. and Wareing, P. F. (1955). Growth studies in woody species. VII. Photoperiodic control of germination in *Betula pubescens* Ehrh. *Physiologia Pl.* 8, 300–316.
- Blackburn, W. H. and Tueller, P. T. (1970). Pinyon and Juniper invasion in black sagebrush communities in East-Central Nevada. *Ecology* 51, 841–848.
- Blackman, G. E. and Wilson, G. L. (1951a). Physiological and ecological studies in the analysis of plant environment. VI. The constancy for different species of a logarithmic relationship between net assimilation rate and light intensity and its ecological significance. *Ann. Bot.* 15, 64–94.
- Blackman, G. E. and Wilson, G. L. (1951b). Physiological and ecological studies in the analysis of plant environment. VII. An analysis of the differential effects of light intensity on the net assimilation rate, leaf-area ratio, and relative growth rate of different species. *Ann. Bot.* 15, 374–408.

REFERENCES

- Blackman, G. E. and Wilson, G. L. (1954). Physiological and ecological studies in the analysis of plant environment. IX. Adaptive changes in the vegetative growth and development of *Helianthus annuus* induced by an alteration in light level. *Ann. Bot.* 18, 72-94.
- Bleasdale, J. K. A. (1966). Plant growth and crop yield. *Ann. appl. Biol.* 57, 173-182.
- Bleasdale, J. K. A. and Nelder, J. A. (1960). Plant population and crop yield. *Nature, Lond.* 188, 342.
- Böcher, T. W. (1961). Experimental and cytological studies on plant species. VI. *Dactylis glomerata* and *Anthoxanthum odoratum*. *Bot. Tidsskr.* 56, 314-355.
- Boddington, M. J. and Metterick, D. F. (1974). The distribution, abundance, feeding habit and population biology of the immigrant trichid *Dugesia polychroa* (Platyhelminthes: Turbellaria) in Toronto harbour, Canada. *J. Anim. Ecol.* 43, 681-699.
- Bode, H. R. (1958). Beiträge zur Kenntnis allelopathischer Erscheinungen bei einigen Juglandaceen. *Planta* 51, 440-480.
- Boller, E. F. and Bush, G. L. (1974). Evidence for genetic variation in populations of the European cherry fruit fly, *Rhagoletis cerasi* (Diptera: Tephritidae) based on physiological parameters and hybridization experiments. *Entomologia exp. appl.* 17, 279-293.
- Bormann, F. H. (1960). Individuality in forest trees. *Dart. Alumni Magazine* February issue 1960, 43-45.
- Bormann, F. H. (1961). Intraspecific root grafting and the survival of eastern white pine stumps. *For. Sci.* 7, 248-255.
- Bormann, F. H. (1966). The structure, function and ecological significance of root grafts in *Pinus strobus* L. *Ecol. Monogr.* 36, 1-26.
- Bormann, F. H. and Graham, B. F. (1959). The occurrence of natural root grafting in eastern white pine, *Pinus strobus* L., and its ecological implications. *Ecology* 40, 678-691.
- Borthwick, H. A., Hendricks, S. B., Toole, E. H. and Toole, V. K. (1954). Action of light on lettuce-seed germination. *Bot. Gaz.* 115, 205-225.
- Bosch, G. A. (1971). Redwoods: a population model. *Science, N.Y.* 172, 345-349.
- Bosch, R. van den and Telford, A. D. (1964). Environmental modifications and biological control. In "Biological Control of Insect Pests and Weeds" (P. de Bach ed.) Chapter 16. Chapman and Hall, London.
- Botkin, D. B., Jordan, P. A., Dominick, A. S., Lowendorf, H. S. and Hutchinson, G. E. (1973). Sodium dynamics in a northern ecosystem (moose, wolves, plants). *Proc. Natn. Acad. Sci. U.S.A.* 70, 2745-2748.
- Bouvkamp, J. C. and McCully, J. E. (1972). Competition and survival in female plants of *Asparagus officinalis* L. *J. Am. Soc. hort. Sci.* 97, 74-76.
- Bradley, R. T., Christie, J. M. and Johnston, D. R. (1966). Forest Management Tables. *Bookl. For. Comm.* 16, 1-218.
- Bradshaw, A. D. (1959). Population differentiation in *Agrostis tenuis* Sibth. II. The incidence and significance of infection by *Epichloe typhina*. *New Phytol.* 58, 310-315.
- Bradshaw, A. D. (1965). Evolutionary significance of phenotypic plasticity in

REFERENCES

- plants. *Adv. Genet.* 13, 115-155.
- Bradshaw, A. D. and Jain, S. K. (1966). Evolutionary divergence among adjacent plant populations. I. The evidence and its theoretical analysis. *Heredity* 21, 407-441.
- Brenchley, W. E. (1918). Buried weed seeds. *J. agric. Sci.* 9, 1-31.
- Brenchley, W. E. and Warington, K. (1930). The weed seed population of arable soil. I. Numerical estimation of viable seeds and observations on their natural dormancy. *J. Ecol.* 18, 235-272.
- Brenchley, W. E. and Warington, K. (1930). The weed seed population of arable soil. II. Influence of crop, soil, and methods of cultivation upon the relative abundance of viable seeds. *J. Ecol.* 21, 103-127.
- Brenchley, W. E. and Warington, K. (1936). The weed seed population of arable soil. III. The re-establishment of weed species after reduction by fallowing. *J. Ecol.* 24, 479-501.
- Brenchley, W. E. and Warington, K. (1945). The influence of periodic fallowing on the prevalence of viable weed seeds in arable soil. *Ann. appl. Biol.* 32, 285-296.
- Brierley, J. K. (1955). Seasonal fluctuations in the oxygen and carbon dioxide concentrations in beech litter with reference to the salt uptake of beech mycorrhizas. *J. Ecol.* 43, 404-408.
- Briese, D. T. (1974). "Ecological studies on an ant community in a semi-arid habitat (with emphasis on seed-harvesting species)". Ph.D. thesis, Australian National University.
- Broadbent, L. (1957). "Investigation of Virus Diseases of Brassica Crops". Cambridge University Press, London and New York.
- Brook, J. M. (1969). "Studies of pattern and succession in seed populations". Ph.D. thesis, University of Wales.
- Brougham, R. W. (1962). The leaf growth of *Trifolium repens* as influenced by seasonal changes in the light environment. *J. Ecol.* 44, 448-459.
- Brougham, R. W. and Harris, W. (1967). Rapidity and extent of changes in genotypic structure induced by grazing in a rye grass population. *N.Z. J. agric. Res.* 10, 56-65.
- Brown, R. H., Cooper, R. B. and Blaser, R. E. (1966). Effects of leaf age on efficiency. *Crop Science* 6, 206-209.
- Brussard, P. F., Levin, S. A., Miller, C. N. and Whitaker, R. H. (1971). Redwoods: a population model debunked. *Science, N.Y.* 174, 435-436.
- Buchholtz, K. P. (1971). The influence of allelopathy on mineral nutrition. In "Biochemical Interactions among Plants". (U.S. Nat. Comm. for I.B.P., eds.) 86-89. Natn. Acad. Sci. Washington, D.C.
- Budd, A. C., Chepil, W. S. and Doughty, J. L. (1954). Germination of weed seeds. III. The influence of crops and fallow on the weed seed population of the soil. *Can. J. agric. Sci.* 34, 18-27.
- Buechner, H. K. and Dawkins, C. H. (1961). Vegetation changes induced by elephants and fire in Murchison Falls National Park, Uganda. *Ecology* 42, 752-766.
- Buell, J. H. (1945). The prediction of growth in uneven-aged timber stands on

REFERENCES

- the basis of diameter distribution. *Duke Univ. Sch. Forest. Bull.* 11, 70 pp.
- Bullock, J. A. (1967). The insect factor in plant ecology. *J. Indian bot. Soc.* 46, 323–330.
- Bunting, A. H. (1959). Some reflections on the ecology of weeds. In "The Biology of Weeds" (J. L. Harper, ed.) *Symp. Br. ecol. Soc.* 1, 11–26. Blackwell, Oxford.
- Burdon, J. J. and Chilvers, G. A. (1974). Fungal and insect parasites contributing to niche differentiation in mixed species stands of Eucalypt saplings. *Aust. J. Bot.* 22, 103–114.
- Burdon, J. J. and Chilvers, G. A. (1975). Epidemiology of damping-off disease (*Pythium irregulare*) in relation to density of *Lepidium sativum* seedlings. *Ann. appl. Biol.* 81, 135–143.
- Burrows, F. M. (1973). Calculation of the primary trajectories of plumed seeds in steady winds with variable convection. *New Phytol.* 72, 647–664.
- Burrows, F. M. (1975a). Wind-borne seed and fruit movement. *New Phytol.* 75, 405–418.
- Burrows, F. M. (1975b). Calculation of the primary trajectories of dust seeds, spores and pollen in unsteady winds. *New Phytol.* 75, 389–403.
- Bush, G. L. (1969a). Mating behaviour, host specificity, and the ecological significance of sibling species in frugivorous flies of the genus *Rhagoletis* (Diptera, Tephritidae). *Am. Nat.* 103, 669–672.
- Bush, G. L. (1969b). Sympatric host race formation and speciation in frugivorous flies of the genus *Rhagoletis* (Diptera, Tephritidae). *Evolution* 23, 237–251.
- Buxton, J. (1950). "The Redstart". Collins, London.
- Buzatti-Traverso, A. A. (1955). Evolutionary changes in components of fitness and other polygenic traits in *Drosophila melanogaster*. *Heredity* 9, 153–86.
- Cahn, M. A. and Harper, J. L. (1976a). The biology of the leaf mark polymorphism in *Trifolium repens* L. I. Distribution of phenotypes at a local scale. *Heredity* 37, 309–325.
- Cahn, M. A. and Harper, J. L. (1976b). The biology of the leaf mark polymorphism in *Trifolium repens* L. II. Evidence for the selection of leaf marks by rumen fistulated sheep. *Heredity* 37, 327–333.
- Cain, A. J. (1969). In "Speciation in tropical environments". *Biol. J. Linn. Soc.* 1, 234.
- Cameron, E. (1935). A study of the natural control of ragwort (*Senecio jacobaea* L.). *J. Ecol.* 23, 265–322.
- Campbell, M. H. and Swain, F. G. (1973). Effect of strength, till and heterogeneity of the soil surface on radicle entry of surface-sown seeds. *J. Br. Grassl. Soc.* 28, 41–50.
- Canfield, R. H. (1957). Reproduction and life span of some perennial grasses of Southern Arizona. *J. Range Management* 10, 199–203.
- Cannon, J. R., Corbett, N. H., Haydock, K. P., Tracey, J. G. and Webb, L. J. (1962). An investigation of the effect of the dehydrangustione present in the leaf litter of *Baccharis angustifolia* on the germination of *Araucaria cunninghamii* etc. *Aust. J. Bot.* 10, 119–128.
- Causton, J. E. (1969). The stability of natural populations and their sensitivity to technology. In "Diversity and Stability in Ecological Systems". *Brookhaven Symp. Biol.* 22, 197–203.
- Carton, L. T. (1968). "An outline of forest mensuration, with special reference to Australia". Australian National University Press, Canberra.
- Caswell, H., Reed, F., Stephenson, S. N. and Werner, P. A. (1973). Photosynthetic pathways and selective herbivory: a hypothesis. *Am. Nat.* 107, 465–480.
- Cavers, P. B. (1963). "Comparative biology of *Rumex obtusifolius* L. and *R. crispus* L. including the variety *trigranulatus*". Ph.D. thesis, University of Wales.
- Cavers, P. B. and Harper, J. L. (1966). Germination polymorphism in *Rumex crispus* and *Rumex obtusifolius*. *J. Ecol.* 54, 367–382.
- Chalbi, N. (1967). Biométrie et analyse quantitative de la compétition entre génotypes chez la Luzerne. *Ann. Amélior. Plantes* 17, 119–159.
- Chapman, S. S. (1949). Notes on the buried seed populations beneath different types of ley in their seedling year. *J. Ecol.* 37, 51–56.
- Chapman, S. S. and Morris, K. (1948). The population of buried viable weed seeds in relation to contrasting pasture and soil types. *J. Ecol.* 36, 149–173.
- Chancellor, R. J. (1965). Weed seeds in the soil. *Rep. A.R.C. Weed Res. Org.* (1960–4), 15–19.
- Chapman, H. H. (1945). Effect of overhead shade on loblolly pine seedlings. *Ecology* 26, 274–282.
- Charles, A. H. (1968). Some selective effects operating upon white and red clover. *J. Br. Grassl. Soc.* 23, 20–25.
- Charlesworth, B. and Giesel, J. T. (1972). Selection in populations with overlapping generations. II Relations between gene frequency and demographic variables. *Am. Nat.* 106, 388–401.
- Charnov, E. L. and Schaffer, W. M. (1973). The life historical consequences of natural selection: Coles' result revisited. *Am. Nat.* 107, 791–793.
- Chattaway, M. M. (1958). The regenerative powers of certain eucalypts. *Victoria Nat.* 75, 45–46.
- Chettleburgh, M. R. (1952). Observations on the collection and burial of acorns by jays in Hainault Forest. *British Birds* 45, 359–364.
- Chew, R. M. and Chew, A. E. (1965). The primary productivity of a desert shrub (*Larrea tridentata*). *Ecol. Monogr.* 35, 355–375.
- Chew, R. M. and Chew, A. E. (1970). Energy relationships of the mammals of a desert shrub (*Larrea tridentata*) community. *Ecol. Monogr.* 40, 1–21.
- Chippindale, H. G. and Milton, W. E. J. (1934). On the viable seeds present in the soil beneath pastures. *J. Ecol.* 22, 508–531.
- Chitty, D., Pimentel, D. and Krebs, C. J. (1968). Food supply of overwintered voles. *J. anim. Ecol.* 37, 113–120.
- Christie, B. R. and Kalton, R. R. (1960). Recurrent selection for seed weight in Bromegrass, *Bromus inermis*, Leyss. *Agron. J.* 52, 575–578.
- Churchill, G. B., John, H. H., Duncan, D. P. and Hodson, A. G. (1964). Long-term effects of defoliation of Aspen by the forest tent caterpillar. *Ecology* 45, 630–633.
- Clapham, A. R., Tutin, T. and Warburg, E. F. (1952). "Flora of the British Isles". Cambridge University Press, London.
- Clarke, B. (1962). Balanced polymorphism and the diversity of sympatric species. In "Taxonomy and Geography" (D. Nicholls, ed.), pp. 47–70. Systematics Association, London.
- Clatworthy, J. N. (1960). "Studies on the nature of competition between closely related species". D.Phil. thesis, University of Oxford.

- Chatworthy, J. N. and Harper, J. L. (1962). The comparative biology of closely related species living in the same area. V. Inter- and intraspecific interference within cultures of *Lemna* spp. and *Salvinia natans*. *J. exp. Bot.* 13, 307-324.
- Clegg, M. T. and Allard, R. W. (1973). Viability versus fecundity selection in the slender Wild Oat, *Avena barbata* L. *Science, N.Y.* 181, 667-668.
- Clements, F. E. (1916). Plant succession: an analysis of the development of vegetation. *Carnegie Inst. Wash. Publ.* 242, 1-512.
- Clements, F. E. and Goldsmith, G. W. (1924). The phytometer method in ecology. *Carnegie Inst. Wash. Publ.* 356, 1-106.
- Clements, F. E. and Weaver, J. E. (1924). Experimental vegetation. *Carnegie Inst. Wash. Publ.* 355, 1-172.
- Clements, F. E., Weaver, J. E. and Hanson, H. C. (1929). Competition in cultivated crops. *Carnegie Inst. Wash. Publ.* 398, 202-233.
- Clements, J. R. (1964). The potential influence of soil splashing by raindrops on seedling survival. *For. Chron.* 40, 512-513.
- Cody, M. L. (1966). A general theory of clutch size. *Evolution* 20, 174-184.
- Cohen, D. (1966). Optimising reproduction in a randomly varying environment. *J. theor. Biol.* 12, 119-129.
- Cole, L. C. (1954). The population consequences of life history phenomena. *Q. Rev. Biol.* 29, 103-137.
- Collins, W. J. and Aitken, Y. (1970). The effect of leaf removal on flowering time in subterranean clover. *Aust. J. agric. Res.* 21, 893-903.
- Colewell, R. (1951). The use of radioactive isotopes in determining spore distribution patterns. *Am. J. Bot.* 38, 511-523.
- Coquilhat, M. (1951). Sur les plantes les plus communes a la surface du globe. *Bull. Men. Soc. Lyon* 20, 165-170.
- Corner, E. J. H. (1966). "The Natural History of Palms". Weidenfeld and Nicholson, London.
- Coulter, J. M. and Chamberlain, C. J. (1909). "Morphology of Angiosperms". D. Appleton & Co., New York.
- Cowlishaw, S. J. and Alder, F. E. (1960). The grazing preferences of cattle and sheep. *J. agric. Sci., Camb.* 54, 157-165.
- Crawford-Sidebotham, T. J. (1972). The role of slugs and snails in the maintenance of the cyanogenesis polymorphisms of *Lotus corniculatus* L. and *Trifolium repens* L. *Heredity* 28, 405-411.
- Creed, R., ed. (1971). "Ecological Genetics and Evolution: Essays in Honour of E. B. Ford". Blackwell, Oxford.
- Gremer, K. W. (1965). Dissemination of seed from *Eucalyptus regnans*. *Aust. For.* 33-37.
- Cumming, B. G. (1959). Extreme sensitivity of germination and photoperiodic reaction in the genus *Chenopodium* (Tourn.) L. *Nature, Lond.* 184, 1044-1045.
- Cumming, B. G. (1963). Germination, as influenced by light and temperature, particularly in *Chenopodium* spp. *Int. Symp. Physiol., Ecol. and Biochem. of Germination*. 1-6.
- Cunningham, T. M. (1960). "The natural regeneration of *E. regnans*". Bull. 1, School of Forestry, University of Melbourne, Australia.
- Curtin, R. A. (1964). Stand density and the relationship of crown width to diameter and height in *Eucalyptus obliqua*. *Aust. For.* 91-105.
- Curtin, R. A. (1970). Dynamics of tree and crown structure in *Eucalyptus obliqua*. *For. Sci.* 16, 321-328.
- Curtis, J. T. and Greene, H. C. (1953). Population changes in some native orchids of southern Wisconsin, especially in the University of Wisconsin Arboretum. *The Orchid Journal* 2, 152-155.
- Curtis, R. O. and Reukema, D. L. (1970). Crown development and site estimates in a Douglas fir plantation spacing test. *For. Sci.* 16, 287-301.
- Dahlgren, R. (1971). Multiple similarity of leaf between two genera of Cape plants, *Cliffortia* L. (Rosaceae) and *Aspalanthus* L. (Fabaceae). *Bot. Notiser* 124, 292-304.
- Danilow, D. (1953). Einfluss der Samenerzeugung auf die Struktur der Jähringe. *Allg. Forstz.* 8, 454-455.
- Darlington, C. D. and Janaki Ammal, E. K. (1945). Adaptive iso-chromosomes in *Nicandra*. *Ann. Bot.* 9, 267-281.
- Darlington, H. T. (1931). The 50-year period for Dr. Beal's seed viability experiment. *Am. J. Bot.* 18, 262-265.
- Darlington, H. T. (1951). The seventy-year period of Dr. W. J. Beal's seed viability experiment. *Am. J. Bot.* 38, 379-381.
- Darlington, H. T. and Steinbauer, G. P. (1961). The eighty-year period for Dr. Beal's seed viability experiment. *Am. J. Bot.* 48, 321-325.
- Darwin, C. (1859). "The Origin of Species". Harvard Facsimile 1st edn. 1964.
- Darwin, C. (1881). "The Formation of Vegetable Mould Through the Action of Worms". John Murray, New York.
- Darwin, C. and Wallace, A. R. (1858). On the tendency of species to form varieties: and on the perpetuation of varieties and species by natural selection. *J. Linn. Soc. (Zool.)* 3, 45.
- Daubenmire, R. F. (1952). Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. *Ecol. Monogr.* 22, 301-330.
- Daubenmire, R. F. (1960a). A seven year study of cone production as related to xylem layers in *Pinus ponderosa*. *Am. Midl. Nat.* 64, 187-193.
- Daubenmire, R. F. (1960b). An experimental study of variation in the *Agropyron spicatum*-*A. inerme* complex. *Bot. Gaz.* 122, 104-108.
- Davidson, J. L. and Donald, C. M. (1958). The growth of swards of subterranean clover with particular reference to leaf area. *Aust. J. agric. Res.* 9, 53-72.
- Davidson, J. L. and Mithorpe, F. L. (1966a). Leaf growth in *Dactylis glomerata* following defoliation. *Ann. Bot.* 30, 174-184.
- Davidson, J. L. and Mithorpe, F. L. (1966b). The effect of defoliation on the carbon balance in *Dactylis glomerata*. *Ann. Bot.* 30, 186-198.
- Davidson, J. L. and Quick, J. P. (1961). The influence of dissolved gypsum on pasture establishment on irrigated sodic clays. *Aust. J. agric. Sci.* 12, 100-110.
- Davies, H. (1966). Molehills and pasture reversion. *J. Br. Grassl. Soc.* 21, 148-149.
- Davis, R. B. (1966). Spruce-fir forests of the coast of Maine. *Ecol. Monogr.* 36, 79-94.
- Dawkins, H. C. (1963). Crown diameters: their relation to bole diameter in

- tropical forest trees. *Commonw. For. Rev.* 42, 318-333.
- Devey, E. S. (1947). Life tables for natural populations of animals. *Q. Rev. Biol.* 22, 283-314.
- Demetrius, L. I. (1975). Reproductive strategies and natural selection. *Am. Nat.* 109, 243-249.
- Dethier, V. G. (1959). Food plant distribution and density and larval dispersal as factors affecting insect populations. *Can. Ent.* 91, 581-596.
- Dewers, R. S. and Moehring, D. (1970). Effect of soil water stress on initiation of ovulate primordia in loblolly pine. *For. Sci.* 16, 219-221.
- Dickinson, A. G. and Jinks, J. L. (1956). A generalized analysis of diallel crosses. *Genetics* 41, 65-78.
- Dickson, J. G. (1923). Influence of soil temperature and moisture on the development of the seedling blight of wheat and corn caused by *Gibberella saubinetii*. *J. agric. Res.* 23, 837-870.
- Dickson, J. G. (1928). The relation of temperature to the development of disease in plants. *Am. Nat.* 62, 311-313.
- Diem, J. E. and McGregor, J. L. (1971). Redwoods: a population model debunked. *Science, N.Y.* 174, 436.
- Dixon, A. F. G. (1971a). The role of aphids in wood formation. I. The effect of the sycamore aphid, *Drepanosiphum platanoides* (Schr.) (Aphididae), on the growth of sycamore, *Acer pseudo-platanus* (L.). *J. appl. Ecol.* 8, 165-179.
- Dixon, A. F. G. (1971b). The role of aphids in wood formation. II. The effect of the lime aphid, *Eucallipterus tiliae* L. (Aphididae), on the growth of the lime, *Tilia x vulgaris* Hayne. *J. appl. Ecol.* 8, 393-409.
- Dobben, W. H. van (1951). Enkele beschouwingen naar aanleiding van mengcultuur. *Maanbl. Landb. Voorl.* 8, 89-100.
- Dobben, W. H. van (1952). Proefnemingen met mengcultuur van haver en gerst in 1951. *C.I.L.O. Gest. Versl. Interprov. Proeren* 39, 1-19.
- Dobben, W. H. van (1953). Proefnemingen met mengcultuur van haver en gerst in 1952. *C.I.L.O. Gest. Versl. Interprov. Proeren* 42, 1-24.
- Dobzhansky, Th. (1970). "Genetics of the Evolutionary Process". Columbia University Press, New York.
- Dobzhansky, Th. (1973). Nothing in biology makes sense except in the light of evolution. *Am. Biol. Teacher* March 1973, 125-129.
- Dodd, A. P. (1940). "The Biological Campaign Against Prickly Pear". Commonwealth Prickly Pear Board, Brisbane, Australia.
- Dollinger, P. M., Ehrlich, P. R., Fitch, W. L. and Breedlove, D. E. (1973). Alkaloid and predation patterns in colorado lupine populations. *Oecologia (Berl.)* 13, 191-204.
- Donald, C. M. (1946). Competition between pasture species, with reference to the hypothesis of harmful root interactions. *J. Coun. scient. ind. Res. Aust.* 19, 32-37.
- Donald, C. M. (1951). Competition among pasture plants. I. Intra-specific competition among annual pasture plants. *Aust. J. agric. Res.* 2, 355-376.
- Donald, C. M. (1958). The interaction of competition for light and for nutrients. *Aust. J. agric. Res.* 9, 421-435.
- Donald, C. M. (1959). The production and life span of seed of subterranean clover (*Trifolium subterraneum* L.). *Aust. J. agric. Res.* 10, 771-787.
- Donald, C. M. (1961). Competition for light in crops and pastures. In "Mechanisms in Biological Competition". (F. L. Milthorpe, ed.) *Symp. Soc. exp. Biol.* 15, 283-313.
- Donald, C. M. (1963). Competition among crop and pasture plants. *Adv. Agron.* 15, 1-118.
- Draper, A. D. and Wilsie, C. P. (1965). Recurrent selection for seed size in Birdsfoot Trefoil, *Lotus corniculatus* L. *Crop. Sci.* 5, 313-315.
- Duffey, E., Morris, M. G., Sheail, J., Ward, L. K., Wells, D. A. and Wells, T. C. E. (1974). "Grassland Ecology and Wildlife Management". Chapman and Hall, London.
- Duncan, D. P. and Hodson, A. C. (1958). Influence of the forest tent caterpillar upon the aspen forests of Minnesota. *For. Sci.* 4, 71-93.
- Durrant, A. (1965). Analysis of reciprocal differences in diallel crosses. *Heredity* 20, 573-607.
- Duvel, J. W. T. (1902). Seeds buried in soil. *Science, N.Y.* 17, 872-873.
- Eber, W. (1971). The characterisation of the woodland light climate. In "Integrated Experimental Ecology" (H. Ellenberg, ed.). Chapman and Hall, London. 143-152.
- Egli, D. B., Pendleton, J. W. and Peters, D. B. (1970). Photosynthetic rate of three soybean communities as related to carbon dioxide levels and solar radiation. *Agron. J.* 62, 411-414.
- Ehrlich, P. R. and Birch, L. C. (1967). The "Balance of Nature" and "Population Control". *Am. Nat.* 101, 97-108.
- Ehrlich, P. R. and Gilbert, L. E. (1973). Population structure and dynamics of the tropical butterfly *Heliconius ethilla*. *Biotropica* 5, 69-82.
- Ehrlich, P. R. and Raven, P. H. (1965). Butterflies and plants: a study in coevolution. *Evolution* 18, 586-608.
- Ekberg, L. (1970). Studies in the genus *Allium*. III. Wind dispersal of *Allium* bulbs. *Bot. Notiser* 123, 115-118.
- Elsen, S. J., Harper, J. L. and Sagar, G. R. (1970). A comparative study of the distribution of the roots of *Avena fatua* and *A. strigosa* in mixed stands using a ¹⁴C labelling technique. *J. Ecol.* 58, 865-868.
- Elison, L. (1960). Influence of grazing on plant succession of rangelands. *Bot. Rev.* 26, 1-78.
- Elton, C. (1958). "The Ecology of Invasions by Plants and Animals". Methuen, London.
- Emlen, J. M. (1966). The role of time and energy in food preference. *Am. Nat.* 100, 611-617.
- Emlen, J. M. (1968). Optimal choice in animals. *Am. Nat.* 102, 385-389.
- England, F. J. W. (1965). Interaction in mixtures of herbage grasses. *Scottish Plant Breeding Station Rec.* 1965, 125-149.
- England, F. J. W. (1968). Competition in mixtures of herbage grasses. *J. appl. Ecol.* 5, 227-242.
- Engik, G. C. (1960). De concurrentie tussen witte klaver en Engels raaigras bij

REFERENCES

- verschillen in lichtintensiteit en vochtvoorziening. *Inst. voor Biol. en Scheikundig. Onderz. Landbouw. Wageningen. Mededeling* 109, 37–50.
- Epling, C. and Lewis, H. (1952). Increase of the adaptive range of the genus *Delphinium*. *Evolution* 6, 253–267.
- Evans, D. W. and Canode, C. L. (1971). Influence of nitrogen fertilization, gapping and burning on seed production of Newport Kentucky Bluegrass. *Agron. J.* 63, 575–580.
- Evans, G. C. (1956). An area survey method of investigating the distribution of light intensity in woodlands, with particular reference to sunflecks, including an analysis of data from rainforest in Southern Nigeria. *J. Ecol.* 44, 391–428.
- Evans, J. M. (1974). "Population variability and its ecological significance in *Arabidopsis thaliana* (L.) Heynh." Ph.D. thesis, University of Leicester.
- Evans, L. T. (1971). Evolutionary, adaptive and environmental aspects of the photosynthetic pathway: assessment. In "Photosynthesis and Photorespiration" (M. D. Hatch, C. B. Osmond and R. O. Slatyer, eds.). Wiley, New York.
- Evenari, M. (1965). Germination inhibitors. *Bot. Rev.* 15, 153–194.
- Evenari, M. (1965). Light and seed dormancy. *Encyclopedia of Plant Physiology* 15 (2), 804–847.
- Exell, A. W. (1931). The longevity of seeds. *Gdnrs' Chron.* 89, 283.
- Fail, H. (1956). The effect of rotary cultivation on the rhizomatous weeds. *J. agric. Engng Res.* 1, 68–80.
- Falinska, K. (1972). Fenologiczna reakcja gatunkow na zroznicowanie gadow. *Phytocoenosis* 1, 5–35.
- Feeny, P. P. (1968). Effect of oak leaf tannins on larval growth of the winter moth *Operophtera brumata*. *J. Insect Physiol.* 14, 805–817.
- Feeny, P. P. (1969). Inhibitory effect of oak leaf tannins on the hydrolysis of proteins by trypsin. *Phytochemistry* 8, 2119–2126.
- Feeny, P. P. (1970). Seasonal changes in oak leaf tannins and nutrients as a cause of spring feeding by winter moth caterpillars. *Ecology* 51, 565–581.
- Feeny, P. P. and Bostock, H. (1968). Seasonal changes in the tannin content of oak leaves. *Phytochemistry* 7, 871–880.
- Fehr, W. R. and Weber, C. R. (1968). Mass selection by seed size and specific gravity in soybean populations. *Crop Sci.* 8, 551–554.
- Feldman, M. W. (1972). Selection for linkage modification: 1. Random mating populations. *Theor. Pop. Biol.* 3, 324–346.
- Feller, W. (1940). On the logistic law of growth and its empirical verifications in biology. *Acta biotheor.* A5, 51–66.
- Fery, R. L. and Janick, J. (1971). Response of corn (*Zea mays* L.) to population pressure. *Crop Sci.* 11, 220–224.
- Fielding, J. M. (1964). Seed dissemination in forests of *Pinus radiata*. *Aust. For. Res.* 1, 48–50.
- Fielding, J. M. (1965). The viability of the seed in cones on trees of *Pinus radiata*. *Aust. For. Res.* 1, 22–23.
- Finlay, K. W. and Wilkinson, G. N. (1963). The analysis of adaptation in a plant-breeding programme. *Aust. J. agric. Res.* 14, 742–754.
- Fisher, R. A. (1929, revised 1958). "The Genetical Theory of Natural Selection" (Revised edition). Dover Press, New York.
- flint, L. H. and MacAlister, E. D. (1935). Wavelengths of radiation in the visible spectrum inhibiting the germination of light sensitive lettuce seed. *Smithson. misc. Collns* 94, 1–11.
- Flower-Ellis, J. G. K. (1971). Age structure and dynamics in stands of bilberry (*Vaccinium myrtillus* L.). Avdel f. Skogsekol., Rapp. Upps. 9, 108 pp.
- Ford, E. B. (1971). "Ecological Genetics" (3rd edition). Chapman and Hall, London.
- fortanier, E. J. (1973). Reviewing the length of the generation period and its shortening particularly in tulips. *Scientia Hort.* 1, 107–116.
- Foster, J. (1964). "Studies on the population dynamics of the daisy, *Bellis perennis*". Ph.D. thesis, University of Wales.
- Frankton, C. and Bussell, I. J. (1968). The genus *Atriplex* (Chenopodiaceae) in Canada, Part I. Three introduced species: *A. heterosperma*, *A. oblongifolia*, and *A. hortensis*. *Can. J. Bot.* 46, 1309–1313.
- Fresco, L. F. M. (1973). A model for plant growth. Estimation of the parameters of the logistic formation. *Acta. bot. neerl.* 22, 486–489.
- Frick, K. E. and Holloway, J. K. (1964). Establishment of the cinnabar moth, *Tyria jacobaeae*, on tansy ragwort in the western United States. *J. econ. Entomol.* 57, 152–154.
- Friedman, J. (1971). The effect of competition by adult *Zygophyllum dumosum* Boiss. on seedlings of *Artemisia herba-alba* Asso. in the Negev desert of Israel. *J. Ecol.* 59, 775–782.
- Friz, E. (1929). Some popular fallacies concerning California redwood. *Madroño* 1, 221–223.
- Gadgil, M. (1971). Dispersal: population consequences and evolution. *Ecology* 52, 253–261.
- Gadgil, M. and Bossert, W. H. (1970). The life historical consequences of natural selection. *Am. Nat.* 104, 1–24.
- Gadgil, M. D. and Solbrig, O. T. (1972). The concept of *r*- and *K*-selection: evidence from wild flowers and some theoretical considerations. *Am. Nat.* 106, 14–31.
- Gale, J. S. (1964). Competition between three lines of *Drosophila melanogaster*. *Heredity* 19, 681–699.
- Galil, J. (1967). On the dispersal of the bulbs of *Oxalis cernua* Thunb. by mole rats (*Spalax ehrenbergi* Nehring). *J. Ecol.* 55, 787–792.
- Gallais, A. (1970). Modèle pour l'analyse des relations binaires. In "Biometrie-Praximetric", XI, 2–3, 51–80.
- Garrett, S. D. (1956). "Biology of Root-infecting Fungi". Cambridge University Press, London and New York.
- Garrett, S. D. (1960). Inoculum potential. In "Plant Pathology" (J. G. Horsfall and A. E. Dimond, eds), Vol. 3, pp. 23–56. Academic Press, New York and London.
- Garrett, S. D. (1970). "Pathogenic Root-infecting Fungi". Cambridge University Press, London.
- Cashwiler, J. S. (1967). Conifer seed survival in a western Oregon clearcut. *Ecology*

- Gashwiler, J. S. (1970). Further study of conifer seed survival in a western Oregon clearcut. *Ecology* 51, 849-854.
- Gäumann, E. (1946). "Pflanzliche Infektionslehre". Verlag Birkhäuser, Basel.
- Gause, G. F. (1934). "The Struggle for Existence". Waverly Press, Baltimore, U.S.A.
- Gerhold, H. D. (1966). Selection for precocious flowering in *Pinus sylvestris*. *U.S. Forest Serv. Res. Pap.* NC-6, 4-7.
- Ghent, A. W. (1958). Studies of regeneration in forest stands devastated by the spruce budworm. II. Age, height, growth and related studies of balsam fir seedlings. *For. Sci.* 4, 135-146.
- Giesel, J. T. (1972). Sex ratio, rate of evolution and environmental heterogeneity. *Am. Nat.* 106, 380-387.
- Gibson, I. A. S. (1956). Sowing density and damping-off in pine seedlings. *E. Afr. agric. J.* 21, 183-188.
- Gilbert, J. M. (1958). "Eucalypt-rainforest relationships and the regeneration of eucalypts". Ph.D. thesis, University of Tasmania.
- Gilbert, J. M. (1959). Forest succession in the Florentine Valley, Tasmania. *Pap. Proc. R. Soc. Tas.* 93, 129-151.
- Gilbert, L. E. (1971). Butterfly-plant coevolution: has *Passiflora adenopoda* won the selectional race with Heliconine butterflies? *Science, N.Y.* 172, 585-586.
- Gilbert, L. E. (1975). Ecological consequences of a coevolved mutualism between butterflies and plants. *1st Int. Cong. Syst. & Evoln. Biol.* Boulder, Colorado (1973) Symp. 5, 210-240.
- Gillett, J. B. (1962). Pest pressure, an underestimated factor in evolution. *Systematics Association Publications* No. 4, 37-46.
- Gilpin, M. E. and Ayala, F. J. (1973). Global models of growth and competition. *Proc. Nat. Acad. Sci.* 70, 3590-3593.
- Gimingham, C. H. (1971). *Calluna* heathlands: use and conservation in the light of some ecological effects of management. In "The Scientific Management of Animal and Plant Communities for Conservation" (E. Duffey and A. S. Watt, eds). *Symp. Br. Ecol. Soc.* 11, 91-103.
- Ginzo, H. D. and Lovell, P. H. (1973a). Aspects of the comparative physiology of *Ranunculus bulbosus* L. and *Ranunculus repens* L. I. Response to nitrogen. *Ann. Bot.* 37, 753-764.
- Ginzo, H. D. and Lovell, P. H. (1973b). Aspects of the comparative physiology of *Ranunculus bulbosus* L. and *Ranunculus repens* L. II. Carbon dioxide assimilation and distribution of photosynthates. *Ann. Bot.* 37, 765-776.
- Gleason, H. A. (1926). The individualistic concept of the plant association. *Bull. Torrey bot. Club.* 53, 7-26.
- Godwin, H. (1936). Studies in the ecology of Wicken Fen. III. The establishment and development of fen scrub. *J. Ecol.* 24, 82-116.
- Good, R. (1974). "Geography of Flowering Plants". Longman, London.
- Goodall, D. W. (1967). Computer simulation of changes in vegetation subject to grazing. *J. Indian bot. Soc.* 46, 356-362.
- Goodall, D. W. (1969). Simulating the grazing situation. In "Biomathematics. Vol. 1, Concepts and Models of Biomathematics" (F. Heinmets, ed.), pp. 211-236. Dekker, New York.

- Goode, J. E. (1956). In *Rep. East Malling Res. Stn* for 1955, 69.
- Goodman, G. T. and Perkins, D. F. (1959). Mineral uptake and retention in Cotton-grass (*Eriophorum vaginatum* L.). *Nature, Lond.* 184, 467-468.
- Goodrum, P. D., Reid, V. H. and Boyd, C. E. (1971). Acorn yields, characteristics, and management criteria of oaks for wildlife. *J. Wildl. Mgmt* 35, 520-532.
- Goss, W. L. (1924). The vitality of buried weed seeds. *J. agric. Res.* 29, 349-362.
- Govier, R. N. (1966). "The interrelationships of the hemiparasites and their hosts, with special reference to *Odontites verna* (Bell.) Dum.". Ph. D. thesis, University of Wales.
- Graber, R. E. (1970). Natural seed fall in white pine (*Pinus strobus* L.) stands of varying density. *U.S.D.A. Forest Service Res. Note.* NE-119, 1-6.
- Graham, B. F. (1959). "Root grafts in eastern white pine, *Pinus strobus* L.: Their occurrence and ecological implications". Ph.D. thesis, Duke University.
- Graham, S. A. (1929). "Principles of Forest Entomology". McGraw-Hill, New York and London.
- Gram, E. (1960). Quarantines. In "Plant Pathology" (J. G. Horsfall and A. E. Dimond, eds), Vol. 3, pp. 313-356. Academic Press, New York and London.
- Grant, S. A. and Hunter, R. F. (1966). The effects of frequency and season of clipping on the morphology, productivity and chemical composition of *Calluna vulgaris* (L.) Hall. *New Phytol.* 65, 125-133.
- Grant, V. (1963). "The Origin of Adaptations". Columbia University Press, New York.
- Gray, R. and Bonner, J. (1948). An inhibitor of plant growth from the leaves of *Encelia farinosa*. *Am. J. Bot.* 34, 52-57.
- Gray, R. and Bonner, J. (1948). Structure determination and synthesis of a plant growth inhibitor, 3-acetyl-6-methoxybenzaldehyde found in the leaves of *Encelia farinosa*. *J. Am. chem. Soc.* 70, 1249-1253.
- Greenwood, D. J. (1969). Effect of oxygen distribution in the soil on plant growth. In "Root Growth" (W. J. Whittingham, ed.), pp. 202-223. Proc. 15th Easter School Ag. Sci. Nottingham, 1968.
- Greig-Smith, P. (1957). "Quantitative Plant Ecology". Butterworths, London.
- Greig-Smith, P. (1961). The use of pattern analysis in ecological investigations. In "Mathematical Analysis of Plant Communities". *Recent Advances in Botany* 2, 1354-1358.
- Griffin, J. R. (1971). Oak regeneration in the upper Carmel valley, California. *Ecology* 52, 862-868.
- Griffiths, M. and Barker, R. (1966). The plants eaten by sheep and by kangaroos grazing together in a paddock in south-western Queensland. *C.S.I.R.O. Wildlife Res.* 11, 145-167.
- Grime, J. P. and Hunt, R. (1975). Relative growth-rate: its range and adaptive significance in a local flora. *J. Ecol.* 63, 393-422.
- Grime, J. P. and Jeffrey, D. W. (1965). Seedling establishment in vertical gradients of sunlight. *J. Ecol.* 53, 621-642.
- Grümmner, G. (1955). "Die gegenseitige Beeinflussung höherer Pflanzen-Allelopathie". Fischer, Jena.
- Grümmner, G. (1961). The role of toxic substances in the interrelationships between higher plants. In "Mechanisms in biological competition" (F. L. Milthorpe, ed.) *Symp. Soc. Exp. Biol.* 15, 219-228.

- Grummer, G. and Beyer, H. (1960). The influence exerted by species of *Camelina* on flax by means of toxic substances. In "The Biology of Weeds" (J. L. Harper, ed.) *Br. ecol. Soc. Symp.* 1, 153–157.
- Gunary, D. (1968). Discussion on mineral nutrient supply from soils. In "Ecological Aspects of the Mineral Nutrition of Plants" (I. H. Rorison, ed.) *Br. ecol. Soc. Symp.*, pp. 149–152. Blackwell, Oxford.
- Guterman, Y., Witzum, A. and Evenari, M. (1967). Seed dispersal and germination in *Blepharis perissa*. *Israel J. Bot.* 16, 213–234.
- Gysel, L. W. (1971). A 10-year analysis of beechnut production and use in Michigan. *J. Wildl. Mgmt* 35, 516–519.
- Haber, E. S. (1950). Longevity of the seed of sweet corn inbreds and hybrids. *Proc. Am. Soc. hort. Sci.* 55, 410–412.
- Haddad, S. Y. (1968). "Studies on clones of *Agropyron repens* (L.) Beauv. with particular reference to herbicide response". M.Sc. thesis, University of Wales.
- Hafez, E. S. E. and Schein, M. W. (1962). "The Behaviour of Domestic Animals" (E. S. E. Hafez, ed.), Bailliere, Tindall and Cox, London.
- Hagner, S. (1965). Cone crop fluctuations in Scots Pine and Norway Spruce. *Stud. For. suec. Skogshogsk.* Stockholm. 33, 1–21.
- Hairston, N. G., Smith, F. E. and Slobodkin, L. B. (1960). Community structure, population control, and competition. *Am. Nat.* 94, 421–425.
- Haizel, K. A. and Harper, J. L. (1973). The effects of density and the timing of removal on interference between barley, white mustard and wild oats. *J. appl. Ecol.* 10, 23–31.
- Halbach, K. (1971). Redwoods: a population model debunked. *Science, N.Y.* 174, 436.
- Haldane, J. B. S. (1932). "The Causes of Evolution". Longmans, Green, London.
- Haldane, J. B. S. (1953). Animal populations and their regulation. *New Biol.* (Penguin Books) 15, 9–24.
- Hall, R. L. (1974a). Analysis of the nature of interference between plants of different species. I. Concepts and extension of the De Wit analysis to examine effects. *Aust. J. agric. Res.* 25, 739–747.
- Hall, R. L. (1974b). Analysis of the nature of interference between plants of different species. II. Nutrient relations in a Nandi *Setaria* and Greenleaf *Desmodium* association with particular reference to potassium. *Aust. J. agric. Res.* 25, 749–756.
- Hallé, F. and Oldeman, R. A. A. (1970). "Essai sur l'Architecture et la Dynamique de Croissance des Arbres Tropicaux." Masson, Paris.
- Hamilton, B. A., Hutchinson, K. J., Annis, P. C. and Donnelly, J. B. (1973). Relationships between the diet selected by grazing sheep and the herbage on offer. *Aust. J. agric. Res.* 24, 271–277.
- Hamilton, R. A. (1956). Utilisation of grassland. *Outlook on Agriculture* 1, 5–11.
- Hamilton, W. D. (1966). The moulding of senescence by natural selection. *J. theor. Biol.* 12, 12–45.
- Hansen, K. (1911). Weeds and their vitality. *Ugeskr. Landm.* 56, 149.
- Harberd, D. J. (1961). Observations on population structure and longevity of *Festuca rubra* L. *New Phytol.* 60, 184–206.

- Harberd, D. J. (1963). Observations on natural clones of *Trifolium repens* L. *New Phytol.* 62, 198–204.
- Harberd, D. J. (1967). Observations on natural clones of *Holcus mollis*. *New Phytol.* 66, 401–408.
- Harberd, D. J. and Owen, M. (1969). Some experimental observations on the clone structure of a natural population of *Festuca rubra* L. *New Phytol.* 68, 93–104.
- Harper, J. L. (1955). The influence of the environment on seed and seedling mortality VI. Effects of the interaction of soil moisture content and temperature on the mortality of maize grains. *Ann. appl. Biol.* 43, 696–708.
- Harper, J. L. (1956). The evolution of weeds in relation to the resistance to herbicides. *Proc. 3rd Br. Weed Control Conf.* (Blackpool) 1, 179–188.
- Harper, J. L. (1957). Biological flora of the British Isles, *Ranunculus acris* L. *Ranunculus repens* L. *Ranunculus bulbosus* L. *J. Ecol.* 45, 289–342.
- Harper, J. L. (1958a). Famous plants – 8. The Buttercup. *New Biol.* 26, 30–46.
- Harper, J. L. (1958b). The ecology of ragwort (*Senecio jacobaea*) with especial reference to control. *Herbage Abstr.* 28, 152–157.
- Harper, J. L. (1959). The ecological significance of dormancy. *Proc. IV Int. Congr. Crop. Prot.* (Hamburg, 1957), pp. 415–420.
- Harper, J. L. (1961). Approaches to the study of plant competition. In "Mechanisms in Biological Competition" (F. L. Milthorpe, ed.) *Symp. Soc. exp. Biol.* 15, 1–39.
- Harper, J. L. (1964a). The nature and consequence of interference amongst plants. In "Genetics Today". *Proc. XI. Internat. Cong. Genet.* 2, 465–482.
- Harper, J. L. (1964b). The individual in the population. *J. Ecol.* 52, (Suppl.) 149–158.
- Harper, J. L. (1966). The reproductive biology of the British poppies. In "Reproductive Biology and Taxonomy of Vascular Plants" (J. G. Hawkes, ed.) pp. 26–39. Botanical Society of the British Isles, London.
- Harper, J. L. (1967). A Darwinian approach to plant ecology. *J. Ecol.* 55, 247–270.
- Harper, J. L. (1969). The role of predation in vegetational diversity. In "Diversity and Stability in Ecological Systems", *Brookhaven Symp. in Biology* 22, 48–62.
- Harper, J. L. (1970). Grazing, fertilizers and pesticides in the management of grasslands. In "The Scientific Management of Animal and Plant Communities for Conservation" (E. Duffey, and A. S. Watt, eds), pp. 15–31. 11th Symp. Br. ecol. Soc.
- Harper, J. L. (1974). A century in population biology. *Nature, Lond.* 252, 526–527.
- Harper, J. L. and Benton, R. A. (1966). The behaviour of seeds in soil, part 2. The germination of seeds on the surface of a water supplying substrate. *J. Ecol.* 54, 151–166.
- Harper, J. L. and Chancellor, A. P. (1959). The comparative biology of closely related species living in the same area. IV. *Rumex*: interference between individuals in populations of one and two species. *J. Ecol.* 47, 679–695.
- Harper, J. L. and Clatworthy, J. N. (1963). The comparative biology of closely related species. VI. Analysis of the growth of *Trifolium repens* and *T. fragiferum* in pure and mixed populations. *J. exp. Bot.* 14, 172–190.
- Harper, J. L. and Gajic, D. (1961). Experimental studies of the mortality and

- plasticity of a weed. *Weed Res.* 1, 91-104.
- Harper, J. L. and McNaughton, I. H. (1960). The inheritance of dormancy in inter- and intraspecific hybrids of *Papaver*. *Heredity* 15, 315-320.
- Harper, J. L. and McNaughton, I. H. (1962). The comparative biology of closely related species living in the same area. VII. Interference between individuals in pure and mixed populations of *Papaver* species. *New Phytol.* 61, 175-188.
- Harper, J. L. and Obeid, M. (1967). Influence of seed size and depth of sowing on the establishment and growth of varieties of fiber and oil seed flax. *Crop. Sci.* 7, 527-532.
- Harper, J. L. and Ogden, J. (1970). The reproductive strategy of higher plants. I. The concept of strategy with special reference to *Senecio vulgaris* L. *J. Ecol.* 58, 681-698.
- Harper, J. L. and Sagar, G. R. (1953). Some aspects of the ecology of buttercups in permanent grassland. *Proc. Br. Weed Control Conf.* 1, 256-265.
- Harper, J. L. and White, J. (1971). The dynamics of plant populations. *Proc. adv. Study Inst. Dynamics Numbers Popul. (Oosterbeek, 1970)* 41-63.
- Harper, J. L. and White, J. (1974). The demography of plants. *A. Rev. Ecol. Syst.* 5, 419-463.
- Harper, J. L. and Wood, W. A. (1957). *Senecio jacobaea* L. In "Biological Flora of the British Isles". *J. Ecol.* 45, 617-637.
- Harper, J. L., Landragn, P. A. and Ludwig, J. W. (1955). The influence of environment on seed and seedling mortality. II. The pathogenic potential of the soil. *New Phytol.* 54, 119-131.
- Harper, J. L., Clatworthy, J. N., McNaughton, I. H. and Sagar, G. R. (1961). The evolution and ecology of closely related species living in the same area. *Evolution* 15, 209-227.
- Harper, J. L., Williams, J. T. and Sagar, G. R. (1965). The behaviour of seeds in soil. Part 1. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. *J. Ecol.* 53, 273-286.
- Harper, J. L., Lovell, P. H. and Moore, K. G. (1970). The shapes and sizes of seeds. *Ann. Rev. ecol. Syst.* 1, 327-356.
- Harris, P. (1974). A possible explanation of plant yield increases following insect damage. *Agroecosystems* 1, 219-225.
- Hartig, R. (1889). Über den Einfluss der Samenproduktion auf Zuwachsgroße und Reservestoffvorrat der Bäume. *Allgem. Forst. und Jagdztg.* 65, 13-17.
- Hartley, P. H. T. (1953). An ecological study of the feeding habits of the English titmice. *J. Anim. Ecol.* 22, 261-288.
- Hartsema, A. M. (1961). Influence of temperatures on flower formation and flowering of bulbous and tuberous plants. *Encyclopedia of Plant Physiology* 16, 123-167.
- Hasan, S. and Wapshare, A. J. (1973). The biology of *Puccinia chondrillina* a potential biological control agent of skeleton weed. *Ann. appl. Biol.* 74, 325-332.
- Ilatto, J. and Harper, J. L. (1969). The control of slugs and snails in British cropping systems, specially grassland. *Int. Copper Res. Assn. Project 115A*, 1-25.

- Hawkes, R. B. (1968). The cinnabar moth, *Tyria jacobaeae*, for control of tansy ragwort. *J. econ. Entomol.* 61, 499-501.
- Hawthorn, W. R. (1973). "Population dynamics of two weedy perennials, *Plantago major* L. and *P. rugelii* Decne." Ph.D. thesis, University of Western Ontario, London, Ontario, Canada.
- Heimburger, C. C. (1945). Comment on the budworm outbreak in Ontario and Quebec. *For. Chron.* 21, 114-126.
- Heinzelman, M. L. (1971). The natural role of fire in northern conifer forest. In "Fire in the Northern Environment - a Symposium". U.S.D.A. Forest Service, Pacific Northwest Forest Range. Exp. Stn, 61-72.
- Henry, J. D. and Swan, J. M. A. (1974). Reconstructing forest history from live and dead plant material - an approach to the study of forest succession in southwestern New Hampshire. *Ecology* 55, 772-783.
- Hermann, R. K. and Chilcote, W. W. (1965). Effect of seedbeds on germination and survival of Douglas-Fir. *Res. Pap. (For. Mgmt. Res.) Ore. For. Res. Lab.* 4, 1-28.
- Hett, J. M. (1971). A dynamic analysis of age in sugar maple seedlings. *Ecology* 52, 1071-1074.
- Hett, J. M. and Loucks, O. L. (1968). Application of life-table analyses to tree seedlings in Quetico Provincial Park, Ontario. *For. Chron.* 44, 29-32.
- Hewett, D. G. (1971). The effects of the winter of 1962/3 on *Juncus acutus* at Branton Burrows, Devon. *Rep. & Trans. Devon. Assoc. Advan. Sci. Lit. & Ant.* 102, 193-201.
- Hewston, L. J. (1964). "Effect of seed size on germination, emergence and yield of some vegetable crops". M.Sc. thesis, University of Birmingham.
- Heydecker, W. (1956). Establishment of seedlings in the field. I. Influence of sowing depth on seedling emergence. *J. hort. Sci.* 31, 76-88.
- Ilgaz, M. K. M. T. (1962). Shortening the juvenile phase for flowering. *Meded. Landhooges. Wageningen* 62, 1-53.
- Hirano, S. and Kira, T. (1965). Influence of autotoxic root exudation on the growth of higher plants grown at different densities (Intraspecific Competition Among Higher Plants XII). *J. Biol. Osaka City Univ.* 16, 27-44.
- Hirano, S. and Morioka, S. (1964). On the interrelation of the growth retarding activity of the root-excretion among various kinds of fruit tree. *J. Jap. Soc. hort. Sci.* 33, 287-290.
- Hiroi, T. and Monsi, M. (1966). Dry-matter economy of *Helianthus annuus* communities grown at varying densities and light intensities. *J. Fac. Sci. Univ. of Tokyo* 9, 241-285.
- Hodgkinson, K. C. (1974). Influence of partial defoliation on photosynthesis, photorespiration and transpiration by lucerne leaves of different ages. *Aust. J. Pl. Physiol.* 1, 561-578.
- Hodgson, G. L. and Blackman, G. E. (1957a). An analysis of the influence of plant density on the growth of *Vicia faba*. Part 1. The influence of density on the pattern of development. *J. exp. Bot.* 7, 147-165.
- Hodgson, G. L. and Blackman, G. E. (1957b). An analysis of the influence of plant density on the growth of *Vicia faba*. Part 2. The significance of competition

- for light in relation to plant development at different densities. *J. exp. Bot.* 8, 195-219.
- Hodgson, J. (1966). The frequency of defoliation of individual tillers in a set stocked sward. *J. Br. Grassl. Soc.* 21, 258-263.
- Holland, A. A. and Moore, C. W. E. (1962). The vegetation and soils of the Bollon District in south-western Queensland. *C.S.I.R.O. Aust. Div. Plant Ind. Tech. Pap.* 17.
- Itoland, P. G. (1969). Weight dynamics of *Eucalyptus* in the mallee vegetation of southeast Australia. *Ecology* 50, 212-219.
- Holliday, R. J. (1960). Plant population and crop yield. *Fld Crop Abstr.* 13, 159-167.
- Holliday, R. J. and Putwain, P. D. (1974). Variation in the susceptibility to simazine in three species of annual weeds. *Proc. 12th Brit. Weed Cont. Conf.* 2, 649-654.
- Holloway, J. K. (1964). Projects in biological control of weeds. In "Biological Control of Pests and Weeds" (P. DeBach, ed.), pp. 650-670. Chapman and Hall, London.
- Holmgård, E. (1955). Tree ring analysis of Danish Forest Trees. *Det. Forsk. Forvågvaesen Danmark* 22, 1-246.
- Holt, B. R. (1972). Effect of arrival time on recruitment, mortality and reproduction in successional plant populations. *Ecology* 53, 668-673.
- Honing, J. A. (1930). Nucleus and plasma in the heredity of the need of light for germination in *Nicotiana* seeds. *Genetica* 12, 441-468.
- Hope-Simpson, J. (1940). Studies of the vegetation of the English chalk. VI. Late stages in succession leading to chalk grassland. *J. Ecol.* 28, 386-402.
- Hopkinson, J. M. (1964). Studies on the expansion of the leaf surface. IV. The carbon and phosphorus economy of a leaf. *J. exp. Bot.* 15, 125-137.
- Horn, H. S. (1976). Succession, in "Theoretical Ecology" (R. M. May, ed.), pp. 187-204. Blackwell Scientific Publications, Oxford.
- Horn, H. S. and MacArthur, R. H. (1972). Competition among fugitive species in a barlequin environment. *Ecology* 53, 749-752.
- Horne, F. R. (1953). The significance of weed seeds in relation to crop production. *Proc. 1st Brit. Weed Cont. Conf.* 372-398.
- Horton, K. W. (1964). Deer prefer Jack Pine. *J. For.* 62, 497-499.
- Hough, J. S. (1953). Studies on the common spangle gall of oak. III. The importance of the stage in laminar extension of the leaf. *New Phytol.* 52, 229-237.
- Howarth, S. E. and Williams, J. T., *Chrysanthemum segetum*, In Biological Flora of the British Isles". *J. Ecol.* 60, 573-584.
- Hozumi, K. and Shinozaki, K. (1970). Studies on the frequency distribution of the weight of individual trees in a forest stand. II. Exponential distribution. *Jap. J. Ecol.* 20, 1-9.
- Hozumi, K., Shinozaki, K. and Tadaki, Y. (1968). Studies on the frequency distribution of the weight of individual trees in a forest stand. I. A new approach toward the analysis of the distribution function and the $-3/2$ th. power distribution. *Jap. J. Ecol.* 18, 10-20.
- Hozumi, K. and Ueno, Y. (1954). Spacing experiments on the growth of root vegetables. *Mem. Col. Agric. Kyoto Univ.* 70 (Hort. Ser. No. 3), 1-20.
- Huffaker, C. B. (1958). Experimental studies on predation: dispersion factors and predator-prey oscillations. *Hilgardia* 27, 343-383.

- Huffaker, C. B. (1964). Fundamentals of Biological Weed Control. In "Biological Control of Insect Pests and Weeds" (P. DeBach and E. I. Schlinger, eds) Ch. 20, pp. 74-117. Chapman and Hall, London.
- Huffaker, C. B. (1971). "Biological Control". Plenum Press, New York.
- Huffaker, C. B. (1975). Biological control in the management of pests. *Agroecosystems* 2, 15-31.
- Hughes, E. G. (1974). Coolibah trees return to life after 68 years 'dead'. *Arid Zone Newsletter*, C.S.I.R.O., Perth 166.
- Hughes, R. D. (1975). Introduced dung beetles and Australian pasture ecosystems. *J. appl. Ecol.* 12, 819-837.
- Humphries, E. C. (1963). Dependence of net assimilation rate on root growth of isolated leaves. *Ann. Bot.* 27, 175-183.
- Hunter, R. F. (1964). Home range behaviour in hill sheep. "Grazing in Marine and Terrestrial Environments" (D. J. Crisp, ed.), pp. 155-171. 4th Symp. Brit. Ecol. Soc. Blackwell, Oxford. 155-171.
- Hurlbert, S. H. (1971). The nonconcept of species diversity: a critique and alternative parameters. *Ecology* 52, 577-586.
- Hutchinson, G. E. (1948). Circular causal systems in ecology. *Ann. N. Y. Acad. Sci.* 50, 221-246.
- Hutchinson, G. E. (1951). Copepodology for the ornithologist. *Ecology* 32, 571-577.
- Hutchinson, G. E. (1965). "The Ecological Theater and the Evolutionary Play". Yale University Press, New Haven, Conn.
- Hutchinson, G. E. and Deavey, E. S. (1949). Ecological studies on populations. *Surv. Biol. Progr.* 1, 325-359.
- Hyde, E. O. G. (1954). The function of the hilum in some Papilionaceae in relation to the ripening of the seed and the permeability of the testa. *Ann. Bot. N.S.* 18, 241-256.
- Isaak, L. A. (1943). "Reproduction habits of Douglas Fir". Charles Lathrop Park Forestry Foundation, Washington, D.C.
- Iseley, D. (1952). Employment of tetrazolium chloride for determining viability of small grain seed. *Proc. Assoc. Off. Seed Analysts* 42, 143-153.
- Isikawa, S. (1954). Light sensitivity against germination. I. Photoperiodism of seeds. *Bot. Mag. Tokyo* 67, 51-54.
- Ivins, J. D. (1952). The relative palatability of herbage plants. *J. Br. Grassl. Soc.* 7, 43-54.
- Ivins, J. D. (1955). The palatability of herbage. *Herbage Abstr.* 25, 75-79.
- Jack, W. H. (1971). The influence of tree spacing on Sitka spruce growth. *Irish Forestry* 28, 13-33.
- Jacquard, P. (1968). Manifestation et nature des relations sociales chez les végétaux supérieurs. *Oecol. Plant.* 3, 137-168.
- Jacquard, P. and Caputa, J. (1970). Comparaison de trois modèles d'analyse des relations sociales entre espèces végétales. *Ann. Amélior. Plantes* 20, 115-158.
- Jain, S. K. and Bradshaw, A. D. (1966). Evolutionary divergence among adjacent plant populations. I. The evidence and its theoretical analysis. *Heredity* 21, 407-441.
- Jameson, D. J. (1963). Response of individual plants to harvesting. *Bot. Rev.* 29, 532-594.
- Janzen, D. H. (1967). Synchronization of sexual reproduction of trees within

- the dry season in central America. *Evolution* 21, 620-637.
- Janzen, D. H. (1968). Host plants as islands in evolutionary and contemporary time. *Am. Nat.* 102, 592-594.
- Janzen, D. H. (1969). Seed eaters versus seed size, number, toxicity and dispersal. *Evolution* 23, 1-27.
- Janzen, D. H. (1970). Herbivores and the number of tree species in tropical forests. *Am. Nat.* 104, 501-528.
- Janzen, D. H. (1971). *Cassia grandis* L. beans and their escape from predators: a study in tropical predator satiation. *Ecology* 52, 964-979.
- Janzen, D. H. (1972). Escape in space of *Sterculia apetala* seeds from the bug *Dysdercus fuscatus* in a Costa Rican deciduous forest. *Ecology* 53, 350-361.
- Janzen, D. H. (1976). Why bamboos wait so long to flower. *A Rev. Ecol. Syst.* 7, 347-91.
- Jayakar, S. D. (1970). A mathematical model for interaction of gene frequencies in a parasite and its host. *Theor. Pop. Biol.* 1, 140-164.
- Jelkowska, A. (1967). Investigations on the influence of barley-cover crop on undersown lucerne (in Polish) *Pamiętnik Pulauski-Prace Inst. Zesztyt* 26, 119-179.
- Johnston, T. J., Pendleton, J. W., Peters, D. B. and Hicks, D. R. (1969). Influence of supplemental light on apparent photosynthesis, yield and yield components of soybeans (*Glycine max* L.) *Crop Sci.* 9, 577-581.
- Jones, D. A. (1962). Selection of the acyanogenic form of the plant *Lotus corniculatus* L. by various animals. *Nature* 193, 1109-1110.
- Jones, D. A. (1966). On the polymorphism of cyanogenesis in *Trifolium repens* L. I. Selection by animals. *Can. J. Genet. Cytol.* 8, 556-567.
- Jones, D. A. (1972). On the polymorphism of cyanogenesis in *Lotus corniculatus* L. IV. The Netherlands. *Genetica* 43, 394-406.
- Jones, D. A. (1973). On the polymorphism of cyanogenesis in *Lotus corniculatus* L. Denmark. *Hereditas* 30, 381-386.
- Jones, D. A. (1967). Studies on hill land in Wales. *Tech. Bull. Welsh Pl. Breed. Stn* 2, 1-179.
- Jones, M. E. (1971a). The population genetics of *Arabidopsis thaliana* L. The breeding system. *Hereditas* 27, 39-50.
- Jones, M. E. (1971b). The population genetics of *Arabidopsis thaliana* L. Population structure. *Hereditas* 27, 51-58.
- Jones, M. G. (1933a). Grassland management and its influence on the sward. *Emp. J. exp. Agric.* 1, 43-57.
- Jones, M. G. (1933b). Grassland management and its influence on the sward. II. The management of a clover sward and its effects. *Emp. J. exp. Agric.* 1, 122-128.
- Jones, M. G. (1933c). Grassland management and its influence on the sward. III. The management of a "grassy" sward and its effects. *Emp. J. exp. Agric.* 1, 224-234.
- Jones, M. G. (1933d). Grassland management and its influence on the sward. IV. The management of poor pastures. V. Edaphic and biotic influences on pastures. *Emp. J. exp. Agric.* 1, 362-367.
- Jones, M. G. (1933e). Grassland management and its influence on the sward. *Jl R. agric. Soc.* 94, 21-41.

- Jones, M. G. and Jones, L. I. (1930). The effect of varying the periods of rest in rotational grazing. *Bull. Welsh Pl. Breed. Stn* 11, 38-59.
- Kannenberg, L. W. and Allard, R. W. (1967). Population studies in predominantly self-pollinated species. VIII. Genetic variability in the *Festuca microstachys* complex. *Evolution* 21, 227-240.
- Kappert, H. (1954). Experimentelle Untersuchungen über die Variabilität eines Totalapomiketen. *Ber. dt. Bot. Ges.* 67, 325-334.
- Kasanaga, H. and Monsi, M. (1954). On the light-transmission of leaves and its meaning for production of dry matter in plant communities. *Jap. J. Bot.* 14, 304-324.
- Kaufman, J. H. (1962). Ecological and social behaviour of the coat *Nasau nasau* on Barro Colorado Island, Panama. *Univ. Calif. Publ. Zool.* 60, 95-222.
- Kays, S. and Harper, J. L. (1974). The regulation of plant and tiller density in a grass sward. *J. Ecol.* 62, 97-105.
- Kershaw, K. A. (1962). Quantitative ecological studies from Landmannahellir, Iceland. II. The rhizome behaviour of *Carex bigelowii* and *Calamagrostis neglecta*. *J. Ecol.* 50, 171-179.
- Kershaw, K. A. (1964). "Quantitative and Dynamic Ecology". Arnold, London.
- Kerster, H. W. (1968). Population age structure in the prairie forb *Liatris aspera*. *BioScience* 18, 430-432.
- Khan, A. A. and Sagar, G. R. (1969). Alteration of the pattern of distribution of photosynthetic products in the tomato by manipulation of the plant. *Ann. Bot.* 33, 753-762.
- Khan, M. I. (1967). "The genetic control of canalisation of seed size in plants". Ph.D. thesis, University of Wales.
- Kidd, F. (1914). The controlling influence of carbon dioxide in the maturation, dormancy, and germination of seeds. *Proc. R. Soc. B* 87, 408-421, 609-625.
- Kidd, F. and West, C. (1917). The controlling influence of carbon dioxide. IV. On the production of secondary dormancy in seeds of *Brassica alba* following treatment with carbon dioxide, and the relation of this phenomenon to the question of stimuli in growth processes. *Ann. Bot.* 31, 457-487.
- Kira, T., Ogawa, H. and Shinozaki, K. (1953). Intraspecific competition among higher plants. I. Competition-density-yield inter-relationships in regularly dispersed populations. *J. Inst. Polytech. Osaka Cy. Univ. D.* 4, 1-16.
- Kitredge, J. (1944). Estimation of the amount of foliage of trees and shrubs. *J. For.* 42, 905-912.
- Klopfner, P. H. (1962). "Behavioural Aspects of Ecology". Prentice-Hall, London.
- Knapp, R. (1954). "Experimentelle Soziologie der höheren Pflanzen." Eugen Ulmer, Stuttgart.
- Knight, W. E. and Hofferwell, E. A. (1962). Response of crimson clover to different defoliation intensities. *Crop Sci.* 2, 124-127.
- Knipe, D. and Herbel, C. H. (1966). Germination and growth of some semi-desert grassland species treated with aqueous extract from creosotebush. *Ecology* 47, 775-781.
- Knuchel, H. (1953). "Planning and Control in the Managed Forest". Oliver and Boyd, Edinburgh.
- Koch, R. Complete Works. George Thieme, Leipzig, 1912, 1, 650-660. (10th International Medical Congress, Berlin, 1890).

- Koller, D. and Roth, N. (1963). Germination regulating mechanisms in some desert seeds. Part 7. *Panicum turgidum* (Gramineae). *Israel J. Bot.* 12, 64-73.
- Koller, D. and Roth, N. (1964). Studies on the ecological and physiological significance of amphicarp in *Gymnarrhena micrantha* (Compositae). *Am. J. Bot.* 51, 26-35.
- Koyama, H. and Kira, T. (1956). Intraspecific competition among higher plants. VIII. Frequency distribution of individual plant weight as affected by the interaction between plants. *J. Inst. Polytech. Osaka Cy. Univ.* 7, 73-94.
- Krajicek, J. E., Brinkman, K. A. and Gingrich, S. F. (1961). Crown competition - a measure of density. *For. Sci.* 7, 35-42.
- Krebs, C. J., Gaines, M. S., Keller, B. L., Myers, J. H. and Tamarin, R. H. (1973). Population cycles in small rodents. *Science, N.Y.* 179, 35-41.
- Kropáč, Z. (1966). Estimation of weed seeds in arable soil. *Pedobiologia* 6, 105-128.
- Kufman, H. M. (1971). Effect of insect defoliation on growth and mortality of trees. *A. Rev. Entom.* 16, 289-324.
- Kuroiwa, S. (1960). Ecological and physiological studies on the vegetation of Mt. Shimogure. V. Intraspecific competition and productivity difference among tree classes in the *Abies* stand. *Bot. Mag., Tokyo* 73, 165-174.
- Lacey, W. S. (1957). A comparison of the spread of *Galinsoga parviflora* and *G. ciliata* in Britain. In "Progress in the Study of the British Flora" (J. E. Lousley, ed.), pp. 109-115. (B.S.B.I. Conference Reports 5) Airbroath.
- Lack, D. (1947). "Darwin's Finches". Cambridge University Press.
- Lack, D. (1954). "The Natural Regulation of Animal Numbers". Clarendon Press, Oxford.
- Lack, D. (1964). "The Life of the Robin". Witherby, London.
- Lack, D. (1966). "Population Studies of Birds". Oxford University Press, London.
- Lang, A. (1965). Effect of some internal and external conditions on seed germination. *Encyclopedia of Plant Physiol.* 15, 848-893.
- Lang, A. L., Pendleton, J. W. and Dungan, G. H. (1956). Influence of population and nitrogen level on yield and protein contents of nine corn hybrids. *Agron. J.* 48, 284-289.
- Langer, R. H. M. (1972). "How Grasses Grow". Arnold, London.
- Large, E. C. (1940). "The Advance of the Fungi". Cape, London.
- Larson, M. M. and Schubert, G. H. (1970). Cone crops of ponderosa pine in central Arizona, including the influence of Albert squirrels. *U.S.D.A. Forest Service Res. Pap. RM-58*, 15 pp.
- Leach, L. D. (1947). Growth rates of host and pathogen as factors determining the severity of pre-emergence damping-off. *J. agric. Res.* 75, 161-179.
- Leak, W. B. (1964). An expression of diameter distribution for unbalanced, uneven aged stands and forests. *Forest Sci.* 10, 39-50.
- Lemon, E. R. and Wiegand, C. L. (1962). Soil aeration and plant root relations. II. Root respiration. *Agron. J.* 54, 171-175.
- Lerner, I. M. and Dempster, E. K. (1962). Indeterminism in interspecific competition. *Proc. Natn. Acad. Sci. U.S.A.* 48, 821-826.
- Lerner, I. M. and Flo, F. K. (1961). Genotype and competitive ability in *Tribolium* species. *Am. Nat.* 95, 329-343.

- Leslie, P. H. (1945). On the use of matrices in certain population mathematics. *Biometrika* 33, 183-212.
- Lester, D. T. (1967). Variation in cone production of red pine in relation to weather. *Can. J. Bot.* 45, 1683-1691.
- Levin, D. A. (1973). The age structure of a hybrid swarm in *Liatris* (Compositae). *Evolution* 27, 532-535.
- Levin, D. A. (1975). Pest pressure and recombination systems in plants. *Am. Nat.* 109, 437-451.
- Levins, R. (1968). "Evolution in Changing Environments". Princeton University Press, Princeton, N.J.
- Levins, R. (1969). Dormancy as an adaptive strategy. In "Dormancy and Survival" (H. W. Woolfhouse, ed.) *Symp. Soc. exp. Biol.* 23, 1-10.
- Lewis, H. (1962). Catastrophic selection as a factor in speciation. *Evolution* 16, 257-271.
- Lewis, H. (1966). Speciation in flowering plants. *Science, N.Y.* 152, 167-172.
- Lewontin, R. C. (1965). Selection for colonizing ability. In "The Genetics of Colonizing Species" (H. G. Baker and G. L. Stebbins, eds), pp. 77-91. Academic Press, New York and London.
- Lewontin, R. C. (1971). The effect of genetic linkage on the mean fitness of a population. *Proc. Natn. Acad. Sci. U.S.A.* 68, 984-986.
- Libby, W. F. (1951). Radiocarbon dates, II. *Science, N.Y.* 114, 291-296.
- Lindstrom, E. W. (1942). Inheritance of seed longevity in maize inbreds and hybrids. *Genetics* 27, 154.
- Linkola, K. (1935). Über die Dauer und Jahresklassenverhältnisse des Jungens Stadiums bei einigen Wiesenstaude. *Acta forest. fenn.* 42, 1-56.
- Linnaeus, C. (1762). *Amoenitates Academica* 2, 203-240 and in *Pan Suecicus* 30 submittit N.L. Hesselgren (Upsaliae, 1749).
- Lippert, R. D. and Hopkins, H. H. (1950). Study of viable seeds in various habitats in mixed prairies. *Trans. Kansas Acad. Sci.* 53, 355-364.
- Litav, M. and Harper, J. L. (1967). A method for studying the spatial relationship between the root systems of two neighbouring plants. *Plant and Soil* 26, 389-392.
- Livingstone, R. B. (1972). Influence of birds, stones and soil on the establishment of pasture juniper, *Juniperus communis*, and red cedar *J. virginiana* in New England pastures. *Ecology* 53, 1141-1147.
- Livingstone, R. B. and Alessio, M. L. (1968). Bunted viable seed in successional field and forest stands, Harvard Forest, Mass. *Bull. Torrey bot. Club* 95, 58-69.
- Lock, J. M. (1972). The effects of hippopotamus grazing on grasslands. *J. Ecol.* 60, 445-467.
- Lougman, K. A. (1969). The dormancy and survival of plants in the humid tropics. In "Dormancy and Survival" (H. W. Woolfhouse, ed.) *Symp. Soc. exp. Biol.* 23, 471-488.
- Lotka, A. J. (1925). "Principles of Physical Biology". Waverly Press, Baltimore.
- Ludwig, J. W., Bunting, E. S. and Harper, J. L. (1957). The influence of environment on seed and seedling mortality. III. The influence of aspect on maize germination. *J. Ecol.* 45, 205-224.

- Ludwig, J. W. and Harper, J. L. (1958). The influence of the environment on seed and seedling mortality. VIII. The influence of soil colour. *J. Ecol.* 46, 381–389.
- Ludwig, W. (1959). Die Selektionstheorie. In "Die Evolutionen der Organismen". (C. Herberer, ed.), pp. 662–712. Fischer, Stuttgart.
- Luxmoore, R. J., Stolzy, L. H. and Letey, J. (1970a). Oxygen diffusion in the soil-plant system. I. A model. *Agron. J.* 62, 317–322.
- Luxmoore, R. J., Stolzy, L. H. and Letey, J. (1970b). Oxygen diffusion in the soil-plant system. II. Respiration rate, permeability, and porosity of consecutive excised segments of maize and rice roots. *Agron. J.* 62, 322–324.
- Luxmoore, R. J., Stolzy, L. H. and Letey, J. (1970c). Oxygen diffusion in the soil-plant system. III. Oxygen concentration profiles, respiration rates, and significance of plant aeration predicted for maize roots. *Agron. J.* 62, 325–329.
- Luxmoore, R. J., Stolzy, L. H. and Letey, J. (1970d). Oxygen diffusion in the soil-plant system. IV. Oxygen concentration profiles, respiration rates, and radial oxygen losses predicted for rice roots. *Agron. J.* 62, 329–332.
- Lykke, J. (1965). Elk and forest. *Norsk Skogbr.* 11, 151–153.
- MacArthur, R. H. (1958). Population ecology of some warblers of northeastern coniferous forests. *Ecology* 39, 599–619.
- MacArthur, R. H. (1971). Patterns of terrestrial bird communities. In "Avian Biology" (D. S. Farner and J. R. King, eds), Vol. 1, pp. 189–221. Academic Press, New York and London.
- MacArthur, R. H. (1972). "Geographical Ecology: Patterns in the Distribution of Species". Harper and Row, New York.
- MacArthur, R. H. and Connell, J. H. (1956). "The Biology of Populations". Wiley, New York.
- MacArthur, R. H. and Levins, R. (1964). Competition, habitat selection, and character displacement in a patchy environment. *Proc. Natn. Acad. Sci.* 51, 1207–1210.
- MacArthur, R. H. and Pianka, E. R. (1966). On optimal use of a patchy environment. *Am. Nat.* 100, 603–609.
- MacArthur, R. H. and Wilson, E. O. (1967). "The Theory of Island Biogeography". Princeton University Press, Princeton, N.J.
- McClure, F. A. (1967). "The Bamboos – a Fresh Perspective". Harvard University Press, Cambridge, Mass.
- McClure, H. E. (1966). Flowering, fruiting and animals in the canopy of a tropical rain forest. *Malay. Forester* 29, 192–203.
- Macfadyen, A. (1957). "Animal Ecology – Aims and Methods". Pitman, London.
- McGee, C. E. and Della-Bianca, L. (1967). Diameter distributions in natural yellow-poplar stands. *U.S. Forest Service Res. Pap. SE-25*, 7 pp.
- McGilchrist, C. A. (1965). Analysis of competition experiments. *Biometrics* 21, 975–985.
- McGilchrist, C. A. and Trenbath, B. R. (1971). A revised analysis of competition experiments. *Biometrics* 27, 659–671.
- MacLusky, D. S. (1960). Some estimates of the areas of pasture fouled by the
- excreta of dairy cows. *J. Br. Grassl. Soc.* 15, 181–188.
- McNaughton, I. H. (1960). "The comparative biology of closely related species living in the same area, with special reference to the genus *Papaver*". D.Phil. thesis, University of Oxford.
- McQuilkin, W. E. (1940). The natural establishment of pine in abandoned fields in the Piedmont Plateau region. *Ecology* 21, 135–147.
- McQuilkin, M. J. (1974). Influence of plant husbandry on rice plant hoppers (Hemiptera: Delphacidae) in the Solomon Islands. *Agroecosystems* 1, 339–358.
- McRill, M. and Sagar, G. R. (1973). Earthworms and seeds. *Nature, Lond.* 243, 482.
- McRill, M. (1974). "Some botanical aspects of earthworm activity". Ph.D. thesis, University of Wales.
- Mack, R. (1976). Survivorship of *Cerastium altrovirens* at Aberffraw, Anglesey. *J. Ecol.* 64, 309–312.
- Mack, R. and Harper, J. L. (1977). Interference in dune annuals: spatial pattern and neighbourhood effects. *J. Ecol.* 65, 345–363.
- Maggis, D. H. (1964). Growth rates in relation to assimilate supply and demand. I. Leaves and roots as limiting regions. *J. exp. Bot.* 15, 574–583.
- Maguire, W. P. (1965). Are ponderosa pine cone crops predictable? *J. Forest.* 54, 778–779.
- Major, J. and Pyott, W. T. (1966). Buried viable seeds in California bunchgrass sites and their bearing on the definition of a flora. *Vegetatio Acta Geobotanica* 13, 253–282.
- Malone, C. R. (1967). A rapid method for the enumeration of viable seeds in the soil. *Weeds* 15, 381–382.
- Malthus, T. R. (1798). "An Essay on the Principle of Population". London.
- Mansfield, T. A. (1968). Carbon dioxide compensation points in maize and *Pelargonium*. *Physiol. Pl.* 21, 1159–1162.
- Marshall, C. and Sagar, G. R. (1965). The influence of defoliation on the distribution of assimilates in *Lolium multiflorum* Lam. *Ann. Bot.* 29, 365–372.
- Marshall, C. and Sagar, G. R. (1968). The distribution of assimilates in *Lolium multiflorum* Lam. following differential defoliation. *Ann. Bot.* 32, 715–719.
- Marshall, D. R. and Jain, S. K. (1967). Cohabitation and relative abundance of two species of wild oats. *Ecology* 48, 656–659.
- Martin, D. J. (1964). Analysis of sheep diet utilizing plant epidermal fragments in faeces samples. In "Grazing in Marine and Terrestrial Environments". (D. J. Crisp, ed.) *Symp. Br. Ecol. Soc.* 4, pp. 173–188 Blackwell, Oxford.
- Martin, P. and Rademacher, B. (1960). Untersuchungen zur Frage der Wurzelallopathie von Kulturpflanzen und Unkräutern. *Beiträge Biol. Pflanz.* 35, 213–237.
- Massey, A. B. (1925). Antagonism of the walnuts (*Juglans nigra* and *J. cinerea*) in certain plant associations. *Phytopathology* 15, 773–784.
- Mather, K. (1953). The genetical structure of populations. In "Evolution" (R. Brown and J. F. Danielli, eds) *Symp. Soc. exp. Biol.* 7, 66–95.
- Mather, K. (1973). "Genetical Structure of Populations". Chapman and Hall, London.

- Mather, K. and Cooke, P. (1962). Differences in competitive ability between genotypes of *Drosophila. Heredity* 17, 381-407.
- Mathews, J. D. (1963). Factors affecting the production of seed by forest trees. *Forest. Abstr.* 24, 1-13.
- Maun, M. A. and Cavers, P. B. (1971). Seed production and dormancy in *Rumex crispus*. I. The effects of removal of cauline leaves at anthesis. *Can. J. Bot.* 49, 1123-1130.
- May, R. M. (1973). "Stability and Complexity in Model Ecosystems". Princeton University Press, Princeton, N.J.
- Mayer, A. M. and Poljakoff-Meyber, A. (1963). "The Germination of Seeds". Pergamon, Oxford.
- Maynard Smith, J. (1964). Group selection and kin selection. *Nature, Lond.* 201, 1145-1147.
- Maynard Smith, J. (1976). A comment on the Red Queen. *Am. Nat.* 110, 325-330.
- Mayr, E. (1963). "Animal Species and Evolution". Harvard University Press, Cambridge, Mass.
- Mead, R. (1966). A relationship between individual plant spacing and yield. *Ann. Bot.* 30, 301-309.
- Medawar, P. B. (1952). "An Unsolved Problem in Biology". H. K. Lewis, London.
- Medawar, P. B. (1955). *CIBA Fdn. Colloq. Ageing* 1, 4.
- Medway, L. (1972). Phenology of a tropical rain forest in Malaya. *Biol. J. Linn. Soc.* 4, 117-146.
- Mellorby, K. (1968). The effects of some mammals and birds on regeneration of oak. *J. appl. Ecol.* 5, 359-366.
- Merz, E. (1959). Pflanzen und Raupen. Über einige Prinzipien der Futterwahl bei Grossschmetterlingsraupen. *Biol. Zbl.* 78, 152-188.
- Meyer, H. A. (1952). Structure, growth and grain in balanced uneven aged forests. *J. Forest.* 50, 85-92.
- Meyer, J. A. and Stevenson, D. D. (1949). The structure and growth of virgin beech-birch-maple-hemlock forests in northern Pennsylvania. *J. agric. Res.* 67, 465-484.
- Müller, J. H., Lofgreen, G. P. and Hull, J. L. (1957). Selective grazing by sheep and cattle. *J. Anim. Sci.* 16, 766-772.
- Miall, L. C. (1912). "The Early Naturalists, Their Lives and Work (1530-1789)". Macmillan, London.
- Miller, G. R., Nicholson, I. A., McCowan, D., Peterson, I. S., Parish, T., Badenoch, C. O., Cummins, R. P., Miles, A. M. and Moyer, S. M. (1970). Grazing and the regeneration of shrubs and trees. *Nat. Conservancy Research in Scotland, Rept.* 1968-70, pp. 33-35.
- Milne, A. (1961). Definition of competition among animals. In "Mechanisms in Biological Competition" (F. L. Milthorpe, ed.) *Symp. Soc. exp. Biol.* 15, 40-61.
- Milthorpe, F. L. (1961). The nature and analysis of competition between plants of different species. In "Mechanisms in Biological Competition" (F. L. Milthorpe, ed.) *Symp. Soc. exp. Biol.* 15, 330-355.
- Milthorpe, F. L. and Moorby, J. (1974). "An Introduction to Crop Physiology". Cambridge University Press, London.
- Milton, W. E. J. (1936). The buried viable seeds of enclosed and unenclosed

- hill land. *W.P.B.S. Bull. Series H* 14, 58-84.
- Milton, W. E. J. (1939). The occurrence of buried viable seeds in soils at different elevations and on a salt marsh. *J. Ecol.* 27, 149-159.
- Milton, W. E. J. (1940). The effect of manuring, grazing and liming on the yield, botanical and chemical composition of natural hill pastures. *J. Ecol.* 28, 326-356.
- Milton, W. E. J. (1947). The composition of natural hill pasture, under controlled and free grazing cutting and manuring. *Welsh J. Agric.* 14, 182-195.
- Mirov, N. T. (1936). Germination behaviour of some California plants. *Ecology* 17, 667-672.
- Mohamed, B. F. and Gimingham, C. H. (1970). The morphology of vegetative regeneration in *Calluna vulgaris*. *New Phytol.* 69, 743-750.
- Molisch, H. (1938). "The Longevity of Plants". Transl. E. H. Fulling, New York.
- Monshi, M. and Saeki, T. (1953). Über den Lichtfaktor in den Pflanzengesellschaften und seine Bedeutung für die Stoffproduktion. *Jap. J. Bot.* 14, 22-52.
- Moore, J. A. (1952). Competition between *Drosophila melanogaster* and *Drosophila simulans*. II. The improvement of competitive ability through selection. *Proc. Natn. Acad. Sci. U.S.A.* 38, 381-407.
- Morris, R. F. (1959). Single-factor analysis in population dynamics. *Ecology* 40, 580-588.
- Morris, R. F. (1963a). The dynamics of epidemic spruce budworm populations. *Mem. ent. Soc. Can.* 31, 1-332.
- Morris, R. F. (1963b). Predictive population equations based on key factors. *Mem. ent. Soc. Can.* 32, 16-21.
- Morris, R. M. (1969). The pattern of grazing in "continuously" grazed swards. *J. Br. Grassl. Soc.* 24, 65-70.
- Mortimer, A. M. (1974). "Studies of germination and establishment of selected species with special reference to the fates of seeds". Ph.D. thesis, University of Wales.
- Morton, E. S. (1973). On the evolutionary advantages and disadvantages of fruit eating in tropical birds. *Am. Nat.* 107, 3-22.
- Moss, R., Miller, G. R. and Allen, S. E. (1972). Selection of heather by captive red grouse in relation to the age of the plant. *J. appl. Ecol.* 9, 771-782.
- Mount, A. B. (1964). The interdependence of the Eucalypts and forest fires in Southern Australia. *Aust. Forestry* 28, 166-172.
- Mounfort, G. (1957). "The Hawfinch". Collins, London.
- Muckerji, S. K. (1936). Contributions to the autecology of *Mercurialis perennis* L. *J. Ecol.* 24, 38-81.
- Muller, C. H. (1953). The association of desert annuals with shrubs. *Am. J. Bot.* 40, 53-60.
- Muller, C. H. (1965). Inhibitory terpenes volatilised from *Salvia* shrubs. *Bull. Torrey Bot. Club.* 93, 332-351.
- Muller, C. H. and del Moral, R. (1966). Soil toxicity induced by terpenes from *Salvia leucophylla*. *Bull. Torrey bot. Club.* 93, 130-137.
- Muller, C. H., Muller, W. H. and Haines, B. L. (1964). Volatile growth inhibitors produced by aromatic shrubs. *Science, N.Y.* 143, 471-473.
- Muller, W. H. (1965). Volatile materials produced by *Salvia leucophylla*: effects

- on seedling growth and soil bacteria. *Bot. Gaz.* 126, 195–200.
- Muller, W. H. and Muller, C. H. (1956). Association patterns involving desert plants that contain toxic products. *Am. J. Bot.* 43, 354–361.
- Müllverstedt, R. (1963). Untersuchungen über die Keimung von Unkrautsamen in Abhängigkeit vom Sauerstoffpartialdruck. *Weed Res.* 3, 154–163.
- Murphy, G. I. (1968). Pattern in life history and the environment. *Am. Nat.* 102, 391–403.
- Murton, R. K. (1965). "The Woodpigeon". Collins, London.
- Murton, R. K., Isaacson, A. J. and Westwood, N. J. (1963). The use of baits treated with α -chloralose to catch wood pigeons. *Ann. appl. Biol.* 52, 271–293.
- Murton, R. K., Isaacson, A. J. and Westwood, N. J. (1966). The relationships between wood pigeons and their clover food supply and the mechanism of population control. *J. appl. Ecol.* 3, 55–93.
- Murton, R. K., Westwood, N. J. and Isaacson, A. J. (1964). The feeding habits of the wood pigeon *Columba palumbus*, stock dove. *C. oenas* and turtle dove *Streptopelia turtur*. *Ibis* 106, 174–188.
- Nägeli, C. (1874). Verdrängung der Pflanzenformen durch ihre Mitbewerber. *Sitzb. Akad. Wiss. München* 11, 109–164.
- Naylor, R. E. L. (1970a). Weed predictive indices. *Proc. Br. Weed Control Conf.* 10, 26–29.
- Naylor, R. E. L. (1970b). The prediction of blackgrass infestations. *Weed Res.* 10, 296–299.
- Naylor, R. E. L. (1972a). Aspects of the population dynamics of the weed *Alopecurus myosuroides* Huds. in winter cereal crops. *J. appl. Ecol.* 9, 127–139.
- Naylor, R. E. L. (1972b). Biological Flora of the British Isles. 129. *Alopecurus myosuroides* Huds. (*A. agrestis* L.). *J. Ecol.* 60, 611–622.
- Neales, T. F. and Incoll, L. D. (1968). The control of leaf photosynthesis rate by the level of assimilate concentration in the leaf: a review of the hypothesis. *Bot. Rev.* 34, 107–125.
- Neilson, J. A. (1964). Autoradiography for studying individual root systems in mixed herbaceous stands. *Ecology* 45, 644–646.
- New, J. K. (1958). A population study of *Spergula arvensis*. Part 1. Two clones and their significance. *Ann. Bot.* 22, 457–477.
- New, J. K. (1959). A population study of *Spergula arvensis*. Part 2. Genetics and breeding behaviour. *Ann. Bot.* 23, 23–33.
- New, J. K. (1961). Biological flora of the British Isles. No. 76. *Spergula arvensis*. *J. Ecol.* 49, 205–215.
- Newton, I. (1967). The feeding ecology of the bullfinch (*Pyrrhula pyrrhula* L.) in southern England. *J. Anim. Ecol.* 36, 721–744.
- Nicholson, A. J. (1933). The balance of animal populations. *J. Anim. Ecol.* 2 (Suppl.) 132–178.
- Nicholson, A. J. (1958). Dynamics of insect populations. *A. Rev. Ent.* 3, 107–136.
- Nicholson, A. J. and Bailey, V. A. (1935). The balance of animal populations. *Proc. zool. Soc. Lond. Part 1*, 551–598.
- Nilsson, H. (1947). Totale Inventiering der Mikrotypen eines Minimal areals von *Taraxacum officinale*. *Hereditas* 33, 119–142.

- Noble, J. C. (1975). The effects of *Emus (Dromaius novaehollandica)* Latham) on the distribution of the Nitre bush (*Nitraria billardieri* DC.) *J. Ecol.* 63, 979–984.
- Norrington-Davies, J. (1967). Application of diallel analysis to experiments in plant competition. *Euphytica* 16, 391–406.
- Norrington-Davies, J. (1968). Diallel analysis of competition between grass species. *J. agric. Sci., Camb.* 71, 223–231.
- Norrington-Davies, J. and Hutto, J. M. (1972). Diallel analysis of competition between diploid and tetraploid genotypes of *Secale cereale* grown at two densities. *J. agric. Sci., Camb.* 78, 251–256.
- Numata, M., Hayashi, K., Komura, T. and Oki, K. (1964). Ecological studies on the buried-seed population in the soil as related to plant succession. I. *Jap. J. Ecol.* 14, 207–215.
- Nye, P. H. (1968). The soil model and its application to plant nutrition. In "Ecological Aspects of the Mineral Nutrition of Plants" (I. H. Rorison, ed.), 9th Symp. Br. Ecol. Soc., pp. 105–114. Blackwell, Oxford.
- Obeid, M. (1965). "Experimental models in the study of interference in plant populations". Ph.D. thesis, University of Wales.
- Obeid, M., Machin, D. and Harper, J. L. (1967). Influence of density on plant to plant variations in Fiber Flax, *Linum usitatissimum*. *Crop Sci.* 7, 471–473.
- Ødum, S. (1965). Germination of ancient seeds; floristical observation and experiments with archaeologically dated soil samples. *Dansk Botanisk Arkiv.* 24, 1–70.
- Ogden, J. (1968). "Studies on reproductive strategy with particular reference to selected composites". Ph.D. thesis, University of Wales.
- Ogden, J. (1970). Plant population structure and productivity. *Proc. N.Z. ecol. Soc.* 17, 1–9.
- Oinonen, E. (1967a). Sporal regeneration of bracken in Finland in the light of the dimensions and age of its clones. *Acta forest. fenn.* 83, 3–96.
- Oinonen, E. (1967b). The correlation between the size of Finnish bracken (*Pteridium aquilinum* (L.) Kuhn) clones and certain periods of site history. *Acta forest. fenn.* 83, 1–51.
- Oldeman, R. A. A. (1972). "L'Architecture de la Forêt Guyanaise". Thèse, Université des Sciences et Techniques du Languedoc.
- Olinsted, N. W. and Curtis, J. D. (1947). Seeds of the forest floor. *Ecology* 28, 49–52.
- Olson, J. S. (1958). Rates of succession and soil changes on southern Lake Michigan sand dunes. *Bot. Gaz.* 119, 125–170.
- Oosting, H. J. (1956). "The Study of Plant Communities". W. H. Freeman, San Francisco.
- Oosting, H. J. and Billings, W. D. (1951). A comparison of virgin spruce-fir forest in the Northern and Southern Appalachian systems. *Ecology* 32, 84–103.
- Oosting, H. J. and Humphreys, M. E. (1940). Buried viable seed in a successional series of old fields and forest soils. *Bull. Torrey bot. Club.* 67, 253–273.
- Opie, J. (1968). Predictability of individual tree growth using various definitions of competing basal area. *For. Sci.* 14, 314–323.
- Orians, G. H. and Janzen, D. H. (1974). Why are embryos so tasty? *Am. Nat.* 108, 581–592.

- Orshan, G. (1954). Surface reduction and its significance as a hydroecological factor. *J. Ecol.* 42, 443-444.
- Orshan, G. (1963). Seasonal dimorphism of desert and mediterranean chamaephytes and its significance as a factor in their water economy. In "The Water Relations of Plants" (A. J. Rutter and F. H. Whitehead, eds.), pp. 207-222. 3rd Symp. Br. ecol. Soc. Blackwell, Oxford.
- Oswald, H. (1923). "Die Vegetation des Hochmoores Komosse". Akad. Abhandlungen, Uppsala.
- Oswald, H. (1947). Equipment of plants in the struggle for space. (In Swedish) *Växtodling* 2, 288-303.
- Ovington, J. D. (1957). Dry matter production by *Pinus sylvestris* L. *Ann. Bot.* 21, 287-314.
- Owen, M. (1971). The selection of feeding site by white-fronted geese in winter. *J. appl. Ecol.* 8, 905-919.
- Oxley, E. R. H. (1977). "The population dynamics of the foxglove, *Digitalis purpurea* L." (in prep.)
- Paine, R. T. (1966). Food web complexity and species diversity. *Am. Nat.* 100, 65-75.
- Paine, R. T. and Vadas, R. L. (1969). The effects of grazing by sea urchins *Strongylocentrotus* spp., on benthic algal populations. *Limnol. Oceanogr.* 14, 710-719.
- Palmblad, I. G. (1968). Competition in experimental studies on populations of weeds with emphasis on the regulation of population size. *Ecology* 49, 26-34.
- Park, T. (1955). Experimental competition in beetles, with some general implications. In "The Numbers of Man and Animals", pp. 69-84. Institute of Biology, Oliver and Boyd, Edinburgh.
- Parnell, J. R. (1966). Observations on the population fluctuations and life histories of the beetles *Bruchidius ater* (Bruchidae) and *Apion fuscirostre* (Curculionidae) on broom (*Sarothamnus scoparius*). *J. Anim. Ecol.* 35, 157-188.
- Passet, J. (1971). "Thymus vulgaris L. Chemotaxonomie et biogénèse monoterpénique". Thèse, Faculté de Pharmacie, Université de Montpellier.
- Passioura, J. B. (1972). The effect of root geometry on the yield of wheat growing on stored water. *Aust. J. agric. Res.* 23, 745-752.
- Pawsey, C. K. (1960). Cone production reduced, apparently by drought in the south-east of south Australia. *Aust. Forest.* 24, 74-75.
- Pearl, R. and Reed, L. J. (1920). On the rate of growth of the population of the United States since 1790 and its mathematical representation. *Proc. Natn. Acad. Sci., U.S.A.* 6, 275-288.
- Pearsall, W. H. and Bengry, R. P. (1940). The growth of *Chlorella* in darkness and in nutrient solution. *Ann. Bot.* 4, 365-377.
- Pelton, J. (1953). Studies on the life history of *Symphoricarpos occidentalis* Hook. in Minnesota. *Ecol. Monogr.* 23, 17-39.
- Pelton, J. (1956). A study of seed dormancy in eighteen species of high altitude Colorado plants. *Butler Univ. bot. Studies* 13, 74-84.
- Pemadasa, M. A. and Lovell, P. H. (1974). Factors affecting the distribution of

- annuals in the dune system at Aberffraw, Anglesey. *J. Ecol.* 62, 379-402.
- Penman, H. L. (1956). Evaporation: an introductory survey. *Neth. J. agric. Sci.* 4, 9-29.
- Peterken, G. F. (1966). Mortality of holly (*Ilex aquifolium*) seedlings in relation to natural regeneration in the New Forest. *J. Ecol.* 54, 259-269.
- Peterken, G. F. and Tubbs, C. R. (1965). Woodland regeneration in the New Forest, Hampshire, since 1650. *J. appl. Ecol.* 2, 159-170.
- Pharis, R. P. and Morf, W. (1969). Precocious flowering of Coastal and Giant Redwood with gibberellins A₃, A₄ and A₁₃. *BioScience* 19, 719-720.
- Pianka, E. R. (1974). "Evolutionary Ecology". Harper and Row, New York.
- Pickering, S. U. and the Duke of Bedford (1919). "Science and the Fruit Grower". Macmillan, London.
- Pijl, L. van der (1969). "Principles of Dispersal in Higher Plants". Berlin, Springer Verlag, Berlin.
- Pimentel, D. (1964). Population ecology and the genetic feedback mechanism. In "Genetics Today" *Proc. XIth Int. Cong. Genet.* The Hague, Netherlands (1963). Pergamon Press, Oxford, pp. 483-488.
- Pimentel, D. and Al-Hajidh, R. (1965). Ecological control of a parasite population by genetic evolution in the parasite-host system. *Ann. Ent. Soc. Am.* 58, 1-6.
- Pimentel, D., Feinburg, E. H., Wood, P. W. and Hayes, J. T. (1965). Selection, spatial distribution and the coexistence of competing fly species. *Am. Nat.* 99, 97-109.
- Pimentel, D., Nagel, W. P. and Madden, J. L. (1963). Space-time structure of the environment and the survival of parasite-host systems. *Am. Nat.* 97, 141-167.
- Plank, J. E. van der (1960). Analysis of epidemics. In "Plant Pathology" (J. G. Horsfall and A. E. Dimond, eds), Vol. 3, pp. 229-289. Academic Press, New York and London.
- Plank, J. E. van der (1963). "Epidemics and Control". Academic Press, New York and London.
- Poole, A. L. and Cairns, D. (1940). Botanical aspects of ragwort (*Senecio jacobaea* L.) control. *Bull. N.Z. Dep. sci. industr. Res.* 82, 1-66.
- Porter, J. W. (1972). Predation by *Acanthaster* and its effect on coral diversity. *Am. Nat.* 106, 487-492.
- Powell, J. R. (1971). Genetic polymorphism in varied environments. *Science*, N.Y. 174, 1035-1036.
- Pozzera, G. (1959). Relations between cone production by *P. pinea* and certain meteorological factors. *Ital. Forest. Mont.* 14, 196-206. (Cited from *Forest. Abstr.* 21, 1963.)
- Priestley, J. H. and Pearsall, W. H. (1922). An interpretation of some growth curves. *Ann. Bot.* 36, 239-249.
- Proebsting, F. L. and Gilmour, A. E. (1941). The relation of peach root toxicity to the re-establishment of peach orchards. *Proc. Am. Soc. hort. Sci.* 38, 21-26.
- Prokopy, R. J., Moericke, V. and Bush, G. L. (1973). Attraction of apple maggot flies to odor of apples. *Env. Ent.* 2, 743-749.
- Pryor, L. D. (1959). Species distribution and association in Eucalyptus. In

- "Biogeography and Ecology in Australia" (A. Keast, R. L. Crocker and C. S. Christian, eds), W. Junk, The Hague.
- Puckridge, D. W. and Donald, C. M. (1967). Competition among wheat plants sown at a wide range of densities. *Aust. J. agric. Res.* 18, 193-211.
- Purseglove, J. W. (1972). "Tropical Crops: Monocotyledons". Longmans, London.
- Putwain, P. D. and Harper, J. L. (1970). Studies in the dynamics of plant populations. III. The influence of associated species on populations of *Rumex acetosa* L. and *R. acetosella* L. in grassland. *J. Ecol.* 58, 251-264.
- Putwain, P. D. and Harper, J. L. (1972). Studies in the dynamics of plant populations. V. Mechanisms governing the sex ratio in *Rumex acetosa* and *R. acetosella*. *J. Ecol.* 60, 113-129.
- Putwain, P. D., Machin, D. and Harper, J. L. (1968). Studies in the dynamics of plant populations. II. Components and regulation of a natural population of *Rumex acetosella* L. *J. Ecol.* 56, 421-431.
- Rabotnov, T. A. (1956). Some data on the content of living seeds in soils of meadow communities. In "Akademika V.N. Sukacheva k 75-letiyu so dnia rozhdeniya". Akad Nauk SSSR, Moskva-Leningrad, 481-499. (In Russian.)
- Rabotnov, T. A. (1956). The life cycle of *Heracleum sibiricum* L. *Bull. Moscow Soc. Natur.* 61, 73-81. (In Russian.)
- Rabotnov, T. A. (1958). The life cycle of *Ranunculus acer* L. and *R. auricomus* L. *Bull. Moscow Soc. Natur.* 63, 77-86. (In Russian.)
- Rabotnov, T. A. (1960). Some problems in increasing the proportion of leguminous species in permanent meadows. *Proc. 8th Int. Grassl. Congr.* 260-264.
- Rabotnov, T. A. (1969). On coenopopulations of perennial herbaceous plants in natural coenoses. *Vegetatio* 19, 87-95.
- Rabotnov, T. A. and Saurina, N. I. (1971). The density and age composition of certain populations of *Ranunculus acris* L. and *R. auricomus* L. *Bot. Zh.* 56, 476-484. (In Russian.)
- Radford, P. J. (1967). Growth analysis formulae - their use and abuse. *Crop Sci.* 7, 171-175.
- Raup, H. M. (1957). Vegetational adjustment to the instability of site. *Proc. Pap. Union Conserv. Nature Nat. Resour.* 36-48.
- Rehfeldt, G. E., Stage, A. R. and Bingham, R. T. (1971). Strobili development in Western White pine; periodicity, prediction and association with weather. *Forest Sci.* 17, 454-461.
- Reineke, L. H. (1933). Perfecting a stand-density index for even-aged forests. *J. agric. Res.* 46, 627-638.
- Reynoldson, T. B. and Davies, R. W. (1970). Food niche and coexistence in lake-dwelling tritids. *J. Anim. Ecol.* 39, 599-617.
- Reynoldson, T. B. and Bellamy, L. S. (1973). Interspecific competition in lake-dwelling tritids; a laboratory study. *Oikos* 24, 301-313.
- Reynoldson, T. B. and Young, J. O. (1965). The food of four species of lake-dwelling tritids. *J. Anim. Ecol.* 32, 175-191.
- Rhodes, I. (1968). Yield of contrasting ryegrass varieties in monoculture and mixed culture. *J. Br. Grassl. Soc.* 23, 156-158.

- Rhodes, I. (1970). The production of contrasting genotypes of perennial ryegrass (*Lolium perenne* L.) in monocultures and mixed cultures of varying complexity. *J. Br. Grassl. Soc.* 25, 285-288.
- Rice, E. L. (1974). "Allelopathy". Academic Press, New York and London.
- Richards, P. W. (1952). "The Tropical Rainforest". Cambridge University Press, London.
- Ridley, H. N. (1930). "The Dispersal of Plants Throughout the World". L. Reeve & Co., Ashford, Kent.
- Righter, F. I. (1939). Early flower production among the pines. *J. Forest.* 37, 935-938.
- Roach, B. M. B. (1928). On the influence of light and of glucose on the growth of a soil alga. *Ann. Bot.* 42, 317-345.
- Roberts, E. H. (1960). The viability of cereal seed in relation to temperature and moisture. *Ann. Bot.* 24, 12-30.
- Roberts, E. H. (1961). The viability of rice seed in relation to temperature, moisture content, and gaseous environment. *Ann. Bot.* 25, 381-390.
- Roberts, H. A. (1958). Studies on the weeds of vegetable crops. 1. Initial effects of cropping on the weed seeds in the soil. *J. Ecol.* 46, 759-768.
- Roberts, H. A. (1964). Emergence and longevity in cultivated soil of seeds of some annual weeds. *Weed Res.* 4, 296-307.
- Roberts, H. A. (1968). The changing population of viable weed seeds in an arable soil. *Weed. Res.* 8, 253-256.
- Roberts, H. A. (1970). Viable weed seeds in cultivated soils. *Rep. natn. Veg. Res. Sin* (1969) 25-38.
- Roberts, H. A. and Feast, P. M. (1972). Fate of seeds of some annual weeds in different depths of cultivated and undisturbed soil. *Weed Res.* 12, 316-324.
- Roberts, H. A. and Feast, P. M. (1973). Emergence and longevity of seeds of annual weeds in cultivated and undisturbed soil. *J. appl. Ecol.* 10, 133-143.
- Roberts, H. A. and Stokes, F. G. (1966). Studies on the weeds of vegetable crops. VI. Seed populations of soil under commercial cropping. *J. appl. Ecol.* 3, 181-190.
- Robinson, E. L. and Kust, C. A. (1962). Distribution of Witchweed seeds in soil. *Weeds* 10, 335.
- Rockwood, L. L. (1973). The effect of defoliation on seed production of six Costa Rican tree species. *Ecology* 54, 1363-1369.
- Roe, A. L. (1967). Seed dispersal in a bumper spruce seed year. *U.S. Forest Service Res. Pap. (Int.)* 39, 1-10.
- Rohmeder, E. (1967). Beziehungen zwischen Frucht-bzw. Samenerzeugung und Holzzerzeugung der Waldbäume. *Allg. Forstwirtschaft.* 22, 33-39.
- Rollin, S. F. and Johnston, F. A. (1961). Our laws that pertain to seeds. In "Seeds. Yearbook of Agriculture, 1961". U.S.D.A. Washington, D.C. 482-492.
- Rorison, I. H. (1967). A seedling bioassay on some soils in the Sheffield area. *J. Ecol.* 55, 725-741.
- Rosensweig, M. L. and Sterner, P. W. (1970). Population ecology of desert rodent communities: body size and seed husking as bases for heteromyid coexistence. *Ecology* 51, 217-224.

- Ross, M. A. (1968). "The establishment of seedlings and the development of patterns in grassland". Ph.D. thesis, University of Wales.
- Ross, M. A. and Harper, J. L. (1972). Occupation of biological space during seedling establishment. *J. Ecol.* 60, 77-88.
- Roughgarden, J. (1972). Evolution of niche width. *Am. Nat.* 106, 683-718.
- Rousvoal, D. and Gallais, A. (1973). Comportement en association binaire de cinq espèces d'une prairie permanente. *Oecol. Plant.* 8, 279-300.
- Roy, D. F. (1966). Silvical characteristics of Redwood. *U.S. Forest Service Res. Pap. PSW-28*, 20 pp.
- Rudolph, T. D. (1966). Stimulation of earlier flowering and seed production in jack pine seedlings through greenhouse and nursery culture. *U.S. Forest Service Res. Pap. NC-6*, 80-83.
- Ruiter, L. de (1952). Some experiments on the camouflage in stick caterpillars. *Behaviour* 4, 222-232.
- Runge, M. (1971). Investigations of the content and the production of mineral nitrogen in soils. In "Integrated Experimental Ecology" (H. Ellenberg, ed.) pp. 191-202. Chapman and Hall, London.
- Russell, E. W. (1966). "Soil Conditions and Plant Growth". Longmans, London.
- Sacher, G. A. (1967). The complementarity between development and aging - experimental and theoretical considerations. In "Interdisciplinary Perspectives of Time" (E. M. Weyer, ed.). *Ann. N.Y. Acad. Sci.* 138, 680-712.
- Saeki, T. (1960). Interrelationships between leaf amount, light distribution and total photosynthesis in a plant community. *Bot. Mag. Tokyo* 73, 55-63.
- Saeki, T. and Kuroiwa, S. (1959). On the establishment of a vertical distribution of photosynthetic systems in a plant community. *Bot. Mag. Tokyo* 72, 27-35.
- Sagar, G. R. (1959). "The biology of some sympatric species of grassland". D.Phil. thesis, University of Oxford.
- Sagar, G. R. and Harper, J. L. (1960). Factors affecting the germination and early establishment of Plantains (*Plantago lanceolata*, *P. media* and *P. major*). In "The Biology of Weeds" (J. L. Harper, ed.). *Br. Ecol. Soc. Symp.* 1, 236-245.
- Sagar, G. R. and Harper, J. L. (1961). Controlled interference with natural populations of *Plantago lanceolata*, *P. major* and *P. media*. *Weed Res.* 1, 163-176.
- Sakai, K-I (1953). Studies on competition in plants. I. Analysis of the competition variance in mixed plant populations. *Jap. J. Bot.* 14, 161-168.
- Sakai, K-I (1955). Competition in plants and its relation to selection. *Cold Spring Harbor Symp. Quant. Biol.* 20, 137-157.
- Sakai, K-I. (1957). Studies on competition in plants. VII. Effect on competition of a varying number of competing and non-competing individuals. *J. Genet.* 55, 227-234.
- Sakai, K-I. (1958). Studies on competitions in plants and animals. IX. Experimental studies on migration in *Drosophila melanogaster*. *Evolution* 12, 98-103.
- Sakai, K-I. (1961). Competitive ability in plants: its inheritance and some

- related problems. *Symp. Soc. exp. Biol.* 15, 245-263.
- Sakai, K-I and Gotoh, K. (1955). Studies on competition in plants. IV. Competitive ability of F_1 hybrids in barley. *J. Hered.* 46, 139-143.
- Salisbury, E. J. (1916). The Oak-Hornbeam woods of Hertfordshire I & II. *J. Ecol.* 4, 83-120.
- Salisbury, E. J. (1918). The Oak-Hornbeam woods of Hertfordshire III & IV. *J. Ecol.* 6, 14-52.
- Salisbury, E. J. (1942). "The Reproductive Capacity of Plants". Bell, London.
- Salisbury, E. J. (1952). "Downs and Dunes". Bell, London.
- Salisbury, E. J. (1958). *Spergularia salina* and *Spergularia marginata* and their heteromorphic seeds. *New Bull.* 1, 41-51.
- Salisbury, E. J. (1961). "Weeds and Aliens". Collins, London.
- Sandfaer, J. (1968). Induced sterility as a factor in the competition between barley varieties. *Nature, Lond.* 218, 241-243.
- Sandfaer, J. (1970a). Barley stripe mosaic virus as the cause of the sterility interaction between barley varieties. *Hereditas* 64, 150-152.
- Sandfaer, J. (1970b). An analysis of the competition between some barley varieties. *Danish Atomic Energy Commission, Risø Report*, 230, Roskilde.
- Sang, J. H. (1950). Population growth in *Drosophila* cultures. *Biol. Rev.* 25, 188-219.
- Sarukhán, J. (1971). "Studies on plant demography". Ph.D. thesis, University of Wales.
- Sarukhán, J. (1974). Studies on plant demography: *Ranunculus repens* L., *R. bulbosus* L. and *R. acris* L. II. Reproductive strategies and seed population dynamics. *J. Ecol.* 62, 151-177.
- Sarukhán, J. and Gadgil, M. (1974). Studies on plant demography: *Ranunculus repens* L., *R. bulbosus* L. and *R. acris* L. III. A mathematical model incorporating multiple modes of reproduction. *J. Ecol.* 62, 921-936.
- Sarukhán, J. and Harper, J. L. (1973). Studies on plant demography: *Ranunculus repens* L., *R. bulbosus* L. and *R. acris* L. I. Population flux and survivorship. *J. Ecol.* 61, 675-716.
- Saurina, N. I. (1972). Dynamics of numbers of individuals and age spectrum in some populations of *Ranunculus acris* and *Ranunculus auricomus*. *Bull. Moscow Soc. Natur.* 77, 115-120. (In Russian.)
- Savage, Z. (1966). Citrus yield per tree by age. *Fla. Agr. Exp. Sta. Agr. Exten. Serv. Econ. Ser.* 66, 9 pp.
- Schaffer, W. M. (1974). Optimal reproductive effort in fluctuating environments. *Am. Nat.* 108, 783-790.
- Schmidtting, R. C. (1969). Reproductive maturity related to height of loblolly pine. *U.S.D.A. Forest Service Res. Note* SO-94.
- Schoener, T. W. (1969a). Models of optimal size for solitary predators. *Am. Nat.* 103, 277-312.
- Schoener, T. W. (1969b). Optimal size and specialisation in constant and fluctuating environments: an energy-time approach. In "Diversity and Stability in Ecological Systems". *Brookhaven Symp. Biol.* 22, 103-114.
- Schorger, A. W. (1966). "The Wild Turkey, its History and Domestication".

- University of Oklahoma Press.
- Schwanitz, F. (1957). "Die Entstehung der Kulturpflanzen". Berlin. (Published by Harvard University Press, Cambridge, Massachusetts.)
- Seaton, A. J. P. and Antonovics, J. (1967). Population interrelationships. I. Evolution in mixtures of *Drosophila* mutants. *Hereditas* (Lond.) 22, 19–33.
- Selman, M. (1970). The population dynamics of *Avena fatua* (Wild Oats) in continuous spring barley. *Proc. Br. Weed Control Conf.* 10, 1176–1188.
- Sen, D. N., Chawan, D. D. and Chatterji, U. N. (1968). Diversity in germination of seeds in *Calotropis procera* R. Br. population. *Österr. Bot. Z.* 115, 6–17.
- Sharitz, R. R. and McCormick, J. F. (1972). Population dynamics of two competing annual plant species. *Ecology* 54, 723–740.
- Sharp, W. M. (1958). Evaluating mast yields in the oaks. *Pennsylvania State Univ. agric. Exp. Stn Bull.* 635, 1–22.
- Sharp, W. M. and Sprague, V. G. (1967). Flowering and fruiting in the white oaks. Pistillate flowering, acorn development, weather and yields. *Ecology* 48, 243–251.
- Shaw, M. W. (1968a). Factors affecting the natural regeneration of sessile oak (*Quercus petraea*) in North Wales. I. A preliminary study of acorn production, viability and losses. *J. Ecol.* 56, 565–583.
- Shaw, M. W. (1968b). Factors affecting the natural regeneration of sessile Oak (*Quercus petraea*) in North Wales. II. Acorn losses and germination under field conditions. *J. Ecol.* 56, 647–660.
- Sheail, J. (1971). "Rabbits and Their History". David and Charles, Newton Abbot.
- Sheldon, J. C. (1974). The behaviour of seeds in soil. III. The influence of seed morphology and the behaviour of seedlings on the establishment of plants from surface lying seeds. *J. Ecol.* 62, 47–66.
- Sheldon, J. C. and Burrows, F. M. (1973). The dispersal effectiveness of the achenepappus units of selected Compositae in steady winds with convection. *New Phytol.* 72, 665–675.
- Shibles, R. M. and Weber, C. R. (1965). Leaf area, solar radiation interception and dry matter production by soybeans. *Crop Sci.* 5, 575–577.
- Shinozaki, K. and Kira, T. (1956). Intraspecific competition among higher plants. VII. Logistic theory of the C-D. Effect. *J. Inst. Polytech, Osaka Cy. Univ.* 7, 35–72.
- Shinozaki, K. and Kira, T. (1961). The C-D Rule, its theory and practical uses (Intraspecific competition among higher plants. X.) *J. Biol., Osaka Cy. Univ.* 12, 69–82.
- Shinozaki, K., Yoda, K., Hozumi, K. and Kira, T. (1964). A quantitative analysis of plant form – the pipe model theory. I. Basis analyses. II. Further evidence of the theory and its application in forest ecology. *Jap. J. Ecol.* 14, 97–105, 133–139.
- Sibma, L., Kort, J. and de Wit, C. T. (1964). Experiments on competition as a means of detecting possible damage by nematodes. *Jaarb. I.B.S.* 1964, 119–124.
- Singh, L. B. (1960). "The Mango". Leonard Hill, London.
- Skellam, J. G. (1951). Random dispersal in theoretical populations. *Biometrika* 38, 196–218.
- Slatyer, R. O. (1970). Comparative photosynthesis, growth and transpiration of two species of *Atriplex*. *Planta* 93, 175–189.
- Slobodkin, L. B. (1964a). "Growth and Regulation of Animal Populations". Holt, Rinehart and Winston, New York.
- Slobodkin, L. B. (1964b). Experimental populations of hydrida. *J. Ecol.* (Suppl.) 52, 131–148.
- Slobodkin, L. B. (1964c). The strategy of evolution. *Am. Sci.* 52, 342–357.
- Slobodkin, L. B. (1968). Toward a predictive theory of evolution. In "Population Biology and Evolution" (R. C. Lewontin, ed.), pp. 187–205. Syracuse University Press, N.Y.
- Slobodkin, L. B. and Rapoport, A. (1974). An optimal strategy of evolution. *Q. Rev. Biol.* 49, 181–199.
- Slobodkin, L. B., Smith, F. E. and Hairston, N. G. (1967). Regulation in terrestrial ecosystems, and the implied balance of nature. *Am. Nat.* 101, 109–124.
- Small, J. (1918). The origin and development of the Compositae. IX. Fruit dispersal. *New Phytol.* 17, 200–230.
- Sminova, O. V. and Toropova, N. H. (1972). The great life cycle of *Galeobdolon luteum* Huds. *Bull. Moscow Soc. Natur.* 77, 76–87. (In Russian.)
- Smith, C. C. (1968). The adaptive nature of social organisation in the genus of tree squirrels, *Tamiasciurus*. *Ecol. Monogr.* 38, 31–63.
- Smith, C. C. (1970). The coevolution of pine squirrels (*Tamiasciurus*) and conifers. *Ecol. Monogr.* 40, 349–371.
- Smith, H. S. (1935). The role of biotic factors in the determination of population densities. *J. econ. Ent.* 28, 873–898.
- Snaydon, R. W. (1970). Rapid population differentiation in a mosaic environment. I. The response of *Anthoxanthum odoratum* populations to soils. *Evolution* 24, 257–269.
- Snaydon, R. W. (1971). An analysis of competition between plants of *Trifolium repens* L. populations collected from contrasting soils. *J. appl. Ecol.* 8, 687–697.
- Snow, D. W. (1964). A possible selective factor in the evolution of fruit seasons in tropical forest. *Oikos* 15, 274–281.
- Soane, I. D. and Clarke, B. (1973). Evidence for apostatic selection by predators using olfactory clues. *Nature, Lond.* 241, 62–64.
- Solbrig, O. T. and Simpson, B. B. (1974). Components of regulation of a population of dandelions in Michigan. *J. Ecol.* 62, 473–486.
- Southwood, T. R. E. (1973). The insect/plant relationship – an evolutionary perspective. In "Insect/Plant Relationships" (H. F. van Emden, ed.). *Symp. R. ent. Soc.* 6, 3–30.
- Spedding, C. R. W. (1971). "Grassland Ecology". Clarendon Press, Oxford.
- Spencer, D. A. (1964). Porcupine population fluctuations in past centuries revealed by dendrochronology. *J. appl. Ecol.* 1, 127–149.

- Spring, P. E., Brewer, M. L., Brown, J. R. and Fanning, M. E. (1974). Population ecology of loblolly pine *Pinus taeda* in an old field community. *Oikos* 25, 1–6.
- Spurr, S. H. (1964). "Forest Ecology". The Ronald Press, New York.
- Stalter, R. (1971). Age of a mature pine (*Pinus taeda*) stand in South Carolina. *Ecology* 52, 532–533.
- Stapp, C. (1961). "Bacterial Plant Pathogens". (Translated by A. Schoenfeld). Oxford University Press.
- Stark, R. H., Ilafenrichter, A. L. and Klages, K. H. (1949). The production of seed and forage by mountain brome as influenced by nitrogen and age of stand. *Agron. J.* 63, 575–580.
- Stebbins, G. L. (1950). "Variation and Evolution in Plants". Columbia University Press, New York.
- Stebbins, G. L. (1958). Longevity, habitat and release of genetic variability in the higher plants. *Cold Spring Harb. Symp. quant. Biol.* 23, 365–378.
- Stebbins, G. L. (1974). "Flowering Plants – Evolution above the Species Level". Harvard University Press, Cambridge, Mass.
- Sterk, A. A. (1969). Biosystematic studies of *Spergularia media* and *Spergularia marina* in the Netherlands. Part 1. The morphological variability of *S. media*. *Acta bot. neerl.* 18, 325–338.
- Sterk, A. A. and Duijkhuisen, L. (1972). The relation between the genetic determination and the ecological significance of the seed wing in *Spergularia media* and *S. marina*. *Acta bot. neerl.* 21, 481–490.
- Stern, W. R. (1965). The effect of density on the performance of individual plants in subterranean clover swards. *Aust. J. agric. Res.* 16, 541–555.
- Stern, W. R. and Donald, C. M. (1962). Light relationships in grass-clover swards. *Aust. J. agric. Res.* 13, 599–614.
- Steveninck, R. F. M. van (1957). Factors affecting the abscission of reproductive organs in yellow lupins (*Lupinus luteus* L.) Part 1. The effect of different patterns of flower removal. *J. exp. Bot.* 8, 373–381.
- Stevens, O. A. (1932). The number and weight of seeds produced by weeds. *Am. J. Bot.* 19, 784–794.
- Stevens, O. A. (1957). Weights of seeds and numbers per plant. *Weeds* 5, 46–55.
- Stolzy, L. H. and Barley, K. P. (1968). Mechanical resistance encountered by roots entering compact soil. *Soil Sci.* 105, 297–301.
- Streeter, D. T. (1970). The effects of public pressure on the vegetation of chalk downland at Box Hill, Surrey. In "The Scientific Management of Animal and Plant Communities for Conservation" (E. Duffey and A. S. Watt, eds). 11th Symp. Br. ecol. Soc. Blackwell, Oxford.
- Studhalter, R. A. (1955). Tree growth: some historical chapters. *Bot. Rev.* 21, 1–72.
- Sukatschew, W. (1928). Einige experimentelle Untersuchungen über den Kampf ums Dasein zwischen Biotypen derselben Art. *Z. indukt. Abstamm.-u. VererbLehre* 45, 54–74.
- Sukatschew, W. N. (1928). "Plant Communities". Nauk, Moscow. (In Russian.)
- Summerfield, R. J. (1972). Biological inertia – an example. *J. Ecol.* 60, 793–798.

- Summerfield, R. J. (1973). Factors affecting the germination and establishment of seedlings of *Narthecium ossifragum* in mire ecosystems. *J. Ecol.* 61, 387–398.
- Summerhayes, V. S. (1951). "Wild Orchids of Britain". Collins, London.
- Sunderland, N. (1960). Germination of the seeds of angiospermous root parasites. In "The Biology of Weeds" (J. L. Harper, ed.) Symp. Br. ecol. Soc. 1, 83–93.
- Swarberg, P. O. (1951). Food storage, territory and song in the thick billed nutcracker. *Proc. Xth Internat. Ornith. Congr. Uppsala*, June 1950. 545–554.
- Sweeney, J. R. (1956). Responses of vegetation to fire: a study of the herbaceous vegetation following chaparral fires. *Univ. Calif. Publ. Bot.* 28, 143–250.
- Sweet, G. B. and Wareing, P. F. (1966). Role of plant growth in regulating photosynthesis. *Nature, Lond.* 210, 77–79.
- Sylvén, N. (1906). On de svenska dikotyledonernas första förstärkningsstadium eller utveckling från frö till blomning. 1. K. Sv. Vet.-Akad. *Handl.* 40
- Symonides, E. (1974). Populations of *Spergula vernalis* Willd. on dunes in the Torun basin. *Ekol. pol.* 22, 379–416.
- Tadros, T. M. (1957). Evidence of the presence of an edaphobiotic factor in the problem of serpentine tolerance. *Ecology* 38, 14–23.
- Takeda, T. (1961). Studies on the photosynthesis and production of dry matter in the community of rice plants. *Jap. J. Bot.* 17, 402–437.
- Tamm, C. O. (1948). Observations on reproduction and survival of some perennial herbs. *Bot. Notiser* 3, 305–321.
- Tamm, C. O. (1956a). Composition of vegetation in grazed and mown sections of a former hay meadow. *Oikos* 7, 144–157.
- Tamm, C. O. (1956b). Further observations on the survival and flowering of some perennial herbs. 1. *Oikos* 7, 274–292.
- Tamm, C. O. (1972a). Survival and flowering of some perennial herbs. II. The behaviour of some orchids on permanent plots. *Oikos* 23, 23–28.
- Tamm, C. O. (1972b). Survival and flowering of perennial herbs. III. The behaviour of *Primula veris* on permanent plots. *Oikos* 23, 159–166.
- Tansley, A. G. (1917). On competition between *Galium saxatile* L. (*G. hercynicum* Weig.) and *Galium sylvestre* Poll. (*G. asperum* Schreb.) on different types of soil. *J. Ecol.* 5, 173–179.
- Tansley, A. G. (1949). "The British Isles and their Vegetation". Cambridge University Press, Cambridge.
- Tansley, A. G. and Adamson, R. S. (1925). Studies of the vegetation of the English chalk. III. The chalk grasslands of the Hampshire-Sussex border. *J. Ecol.* 13, 177–223.
- Taylorson, R. B. and Borthwick, H. A. (1969). Light filtration by foliar canopies: significance for light-controlled weed seed germination. *Weed Sci.* 17, 48–51.
- Thoday, J. M. (1953). Components of fitness. In "Evolution" (R. Brown and J. F. Danielli, eds) Symp. Soc. exp. Biol. 7, 96–113.

- Thoday, J. M. (1972). Disruptive selection. *Proc. R. Soc. B* 182, 109–143.
- Thoday, J. M. (1975). Non-Darwinian evolution and biological programs. *Nature, Lond.* 255, 675–677.
- Thomas, A. S. (1960). The trampling animal. *J. Br. Grassl. Soc.* 15, 89–93.
- Thomson, A. J. (1969). Yields and tiller numbers of four perennial ryegrass varieties grown as monocultures and certain mixtures in microplots. *J. agric. Sci., Camb.* 73, 321–328.
- Thorsteinson, A. J. (1960). Host selection in phytophagous insects. *A. Rev. Ent.* 5, 193–218.
- Thurston, J. M. (1957). Morphological and physiological variation in wild oats (*Avena fatua* L. and *A. ludoviciana* Dur.) and in hybrids between wild and cultivated oats. *J. agric. Sci., Camb.* 49, 260–274.
- Timbergen, L. (1960). The natural control of insects in pine woods. 1. Factors influencing the intensity of predation by songbirds. *Archs néerl. Zool.* 13, 265–343.
- Tinker, P. B. (1968). The transport of ions in the soil around plant roots. In "Ecological Aspects of the Mineral Nutrition of Plants" (I. H. Rorison, ed.). 9th Symp. Br. ecol. Soc., 135–147. Blackwell, Oxford.
- Toole, E. H. and Brown, E. (1946). Final results of the Duvel buried seed experiment. *J. agric. Res.* 72, 201–210.
- Tothill, J. D. (1958). Some reflections on the cause of insect outbreaks. *Proc. 10th Internat. Congr. Ent.* (1956) 4, 525–531.
- Trenbath, B. R. (1974a). Neighbour effects in the genus *Avena* II. Comparison of weed species. *J. appl. Ecol.* 11, 111–125.
- Trenbath, B. R. (1974b). Biomass productivity of mixtures. *Adv. Agron.* 26, 177–210.
- Trenbath, B. R. (1975). Neighbour effects in the genus *Avena* III. A diallel approach. *J. appl. Ecol.* 12, 189–200.
- Trenbath, B. R. (1976). Application of a growth model to problems of the productivity and stability of mixed stands. *Proc. XII int. Grassl. Cong., Moscow* (1974), Vol. 1, Part 2, pp. 546–558.
- Trenbath, B. R. and Harper, J. L. (1973). Neighbour effects in the genus *Avena*. I. Comparison of crop species. *J. appl. Ecol.* 10, 379–400.
- Trevis, L. (1958). Interrelations between the harvester ant *Veromessor pergandei* (Mayr) and some desert ephemerals. *Ecology* 39, 695–704.
- Tripathi, R. S. and Harper, J. L. (1973). The comparative biology of *Agropyron repens* L. (Beauv.) and *A. caninum* L. (Beauv.) 1. The growth of mixed populations established from tillers and from seeds. *J. Ecol.* 61, 353–368.
- Triplett, G. B. and Tesar Jr. M. B. (1960). Effects of compaction, depth of planting, and soil moisture tension on seedling emergence of alfalfa. *Agron. J.* 52, 681–684.
- Troughton, A. (1960). Growth correlation between the root and shoots of grass plants. *Proc. 8th Int. Grassl. Cong.* 280–283.
- Tukey, H. B. Jr. (1971). Leaching of substances from plants. In "Biochemical

- Interactions Among Plants" (U.S. Nat. Comm. for IBP, eds, pp. 25–32). Natn. Acad. Sci. Washington, D.C.
- Turcek, F. J. (1966). Rediscovery of seeds cached by *Carrulus glandarius* and *Nucifraga caryocatactes*. *Waldhygiene* 6, 215–217.
- Turkington, R. A. (1975). "Relationships between neighbours among species of permanent grassland". Ph.D. thesis, University of Wales.
- Turner, J. R. (1967). Why does the genotype not congeal? *Evolution* 21, 645–656.
- Turner, R. G. (1969). Heavy metal tolerance in plants. In "Ecological Aspects of Mineral Nutrition in Plants". (I. H. Rorison, ed.) 9th Symp. Br. ecol. Soc., 399–410.
- Twamley, B. E. (1967). Seed size and seedling vigour in birdsfoot trefoil. *Can. J. Plant Sci.* 47, 603–609.
- Uranov, A. A., Grigorjeva, V. M., Egorova, V. N., Ermakova, I. M. and Matveev, A. R. (1970). The variability and dynamics of age spectra in some meadow plants. In "Theoretical Problems of Phytocenology and Biogenocenology" (to the 90th birthday of V. N. Sukachev), pp. 194–214. Nauk, Moscow. (In Russian.)
- Uranov, A. A. and Smirnova, O. V. (1969). Classification and basic features of the development of perennial plant populations. *Bull. Moscow Soc. Natur.* 74, 119–134. (In Russian.)
- Usher, M. B. (1966). A matrix approach to the management of renewable resources, with special reference to selection forests. *J. appl. Ecol.* 3, 355–367.
- Usher, M. B. (1973). "Biological Management and Conservation". Chapman and Hall, London.
- Utiada, S. (1957). Population fluctuation, an experimental and theoretical approach. *Cold Spring Harb. Symp. quant. Biol.* 22, 139–151.
- Van Valen, L. (1965). Morphological variation and width of ecological niche. *Am. Nat.* 99, 377–390.
- Van Valen, L. (1970). Variation and niche width re-examined. *Am. Nat.* 104, 587–590.
- Van Valen, L. (1973). A new evolutionary law. *Evolut. Theory* 1, 1–30.
- Van Valen, L. (1974). Predation and species diversity. *J. theor. Biol.* 44, 19–21.
- Vallis, I., Haydock, K. P., Ross, P. J. and Henzel, E. F. (1967). Isotopic studies on the uptake of nitrogen by pasture plants. III. The uptake of small additions of ¹⁵N-labelled fertiliser by Rhodes grass and Townsville Lucerne. *Aust. J. agric. Res.* 18, 865–877.
- Vandermeer, J. H. (1975). A graphical model of insect seed predation. *Am. Nat.* 109, 147–160.
- Varley, G. C. (1967). Estimation of secondary production in species with an annual life cycle. In "Secondary Production of Terrestrial Ecosystems" (K. Petrusewicz, ed.), pp. 447–457. Warsaw.
- Varley, G. C. and Gradwell, G. R. (1962). The effect of partial defoliation by caterpillars on the timber production of oak trees in England. *XI Int. Cong. Ent.* Wien, 1960, 2, 211–214.
- Vegis, A. (1961). Samenkeimung und vegetative Entwicklung der Knospen.

- Encyclopaedia of Plant Physiology* 16, 168–298.
- Vegis, A. (1964). Dormancy in higher plants. *A. Rev. Pl. Physiol.* 15, 185–224.
- Verhagen, A. M. W., Wilson, J. H. and Britten, E. J. (1963). Plant production in relation to foliage illumination. *Ann. Bot.* 27, 627–640.
- Verheij, E. W. M. (1968). Yield-density relationships in apple: Results of a planting system experiment in Hungary. *Instituut Voor Tuinbouwtechniek – Wageningen* 37, 1–31.
- Verhulst, P. F. (1844). Recherches mathématiques sur la loi d'accroissement de la population. *Mem. Acad. r. Bruxelles* 18, 1–58.
- Verhulst, P. F. (1846). Deuxième mémoire sur la loi d'accroissement de la population. *Mem. Acad. Roy. Bruxelles* 20, 1–52.
- Verschaaffelt, E. (1910). The cause determining the selection of food in some herbivorous insects. *Proc. Acad. Sci., Amsterdam* 13, 536–542.
- Vezina, P. E. and Boulter, D. W. K. (1966). The spectral composition of near ultraviolet and visible radiation beneath forest canopies. *Can. J. Bot.* 44, 1267–1284.
- Visser, T. (1964). Juvenile phase and growth of apple and pear seedlings. *Euphytica* 13, 119–129.
- Visser, T. (1965). On the inheritance of the juvenile period in apple. *Euphytica* 14, 125–134.
- Visser, T. (1967). Juvenile period and precocity of apple and pear seedlings. *Euphytica* 16, 319–320.
- Visser, T. (1970). The relation between growth, juvenile period and fruiting of apple seedlings, and its use to improve breeding efficiency. *Euphytica* 19, 293–302.
- Volterra, V. (1926). Variazioni e fluttuazioni del numero d'individui in specie animali conviventi. *Mem. Acad. Lincei* 2, 31–113.
- Vollterra, V. (1931). "Leçons sur la Théorie mathématique de la Lutte pour la Vie". Cahiers Scientifiques No. 7 Gauthiers-Villars, Paris.
- Wager, H. G. (1938). Growth and survival of plants in the Arctic. *J. Ecol.* 26, 390–410.
- Wapshere, A. J. (1970). The effect of human intervention on the distribution and abundance of *Chondrilla juncea* L. *Proc. Adv. Study Inst. Dynamics Popul. (Oosterbeek)* 469–477.
- Wapshere, A. J. (1971). Selection and biological control organisms of weeds. *Commonwealth Inst. of Biological Control, Misc. Pub. No.* 6, 56–61.
- Wapshere, A. J., Hasan, S., Waliba, W. K. and Caresche, L. (1974). The ecology of *Chondrilla juncea* in the Western Mediterranean. *J. appl. Ecol.* 11, 783–800.
- Waring, P. F., Khalifa, M. M. and Treharre, K. J. (1968). Rate-limiting processes in photosynthesis at saturating light intensities. *Nature, Lond.* 220, 453–457.
- Watkinson, A. R. (1975). "The population biology of a dune annual, *Vulpia membranacea*". Ph.D. thesis, University of Wales.
- Watson, D. J. (1958). The dependence of net assimilation rate on leaf area index. *Ann. Bot.* 22, 37–54.

- Watson, P. (1969). Evolution in closely adjacent populations. VI. An entomophilous species, *Potentilla erecta* in two contrasting habitats. *Heredity* 24, 407–422.
- Watt, A. S. (1919). On the causes of failure of natural regeneration in British oakwoods. *J. Ecol.* 7, 173–203.
- Watt, A. S. (1940). Contributions to the ecology of bracken (*Pteridium aquilinum*). I. The rhizome. *New Phytol.* 39, 401–422.
- Watt, A. S. (1943). Contributions to the ecology of bracken (*Pteridium aquilinum*). II. The frond and the plant. *New Phytol.* 42, 103–126.
- Watt, A. S. (1945). Contributions to the ecology of bracken (*Pteridium aquilinum*). III. Frond types and the make-up of the populations. *New Phytol.* 44, 156–178.
- Watt, A. S. (1947a). Contributions to the ecology of bracken (*Pteridium aquilinum*). IV. The structure of the community. *New Phytol.* 46, 97–121.
- Watt, A. S. (1947b). Pattern and process in the plant community. *J. Ecol.* 35, 1–22.
- Watt, A. S. (1970). Contributions to the ecology of bracken (*Pteridium aquilinum*). VII. Bracken and Litter. The cycle of change. *New Phytol.* 69, 431–449.
- Watt, K. E. F. (1968). "Ecology and Resource Management". McGraw-Hill, New York.
- Watts, C. H. S. (1968). The foods eaten by wood mice (*Apodemus sylvaticus*) and bank voles (*Clethrionomys glareolus*) in Wytham Woods, Berks. *J. Anim. Ecol.* 37, 25–41.
- Way, M. J. and Cammell, M. (1970). Aggregation behaviour in relation to food utilization by aphids. In "Animal Populations in Relation to their Food Resources" (A. Watson, ed.), pp. 229–247. 10th Symp. Br. ecol. Soc. Blackwell, Oxford.
- Weaver, J. E. (1919). The ecological relations of roots. *Carneg. Inst. Wash. Publ.* 286, 1–128.
- Webb, D. A. (1954). Notes on four Irish heaths. Part 1. *Irish Nat.* 11, 187.
- Webb, D. A. (1958). Notes on four Irish heaths. Part 2. *Proc. bot. Soc. Br. Isl.* 3, 105.
- Webb, L. J., Tracey, J. G. and Haydock, K. P. (1961). The toxicity of *Ermophila mitchellii* Benth. leaves in relation to the establishment of adjacent herbs. *Aust. J. Sci.* 24, 244–245.
- Webb, L. J., Tracey, J. G. and Haydock, K. P. (1967). A factor toxic to seedlings of the same species associated with living roots of the non-gregarious subtropical rain forest tree *Grevillea robusta*. *J. appl. Ecol.* 4, 13–25.
- Welbank, P. J. (1960). Toxin production from *Agropyron repens*. In "The Biology of Weeds" (J. L. Harper, ed.), pp. 158–164. 10th Symp. Br. ecol. Soc. Blackwell, Oxford.
- Welbank, P. J. (1961). A study of the nitrogen and water factors in competition with *Agropyron repens* (L.) Beauv. *Ann. Bot.* 25, 116–137.
- Welbank, P. J. (1962). The effects of competition with *Agropyron repens*

- and of nitrogen and water-supply on the nitrogen content of *Impatiens parviflora*. *Ann. Bot.* 26, 361–373.
- Welbank, P. J. (1963). Toxin production during decay of *Agropyron repens* (couch grass) and other species. *Weed Res.* 3, 205–214.
- Welbank, P. J. (1963). A comparison of competitive effects of some common weed species. *Ann. appl. Biol.* 51, 107–125.
- Welbank, P. J. (1964). Competition for nitrogen and potassium in *Agropyron repens*. *Ann. Bot.* 28, 1–15.
- Wells, T. C. E. (1967). Changes in a population of *Spiranthes spiralis* (L.) Chevall. at Knocking Hoe National Nature Reserve, Bedfordshire, 1962–5. *J. Ecol.* 55, 83–99.
- Wells, T. C. E. (1972). Ecological studies on calcareous grasslands. *Monks Wood exp. Sm. Rep.* (1969–71), 44–46.
- Went, F. W. (1942). The dependence of certain annual plants on shrubs in Southern Californian deserts. *Bull. Torrey bot. Club* 69, 100–114.
- Went, F. W. (1955). The ecology of desert plants. *Scient. Am.* 192, 68–75.
- Went, F. W. (1957). "The Experimental Control of Plant Growth". Chronica Botanica, Waltham, Mass.
- Went, F. W. (1973). Competition among plants. *Proc. Natn. Acad. Sci., U.S.A.* 70, 585–590.
- Werner, P. A. (1975a). Predictions of fate from rosette size in Teasel (*Dipsacus fullonum* L.). *Oecologia* 20, 197–201.
- Werner, P. A. (1975b). A seed trap for determining patterns of seed deposition in terrestrial plants. *Can. J. Bot.* 53, 810–813.
- Werner, P. A. and Platt, W. J. (1976). Ecological relationships of co-occurring golden rods (*Solidago*: Compositae). *Am. Nat.* 110, 959–971.
- Wesson, G. and Wareing, P. F. (1967). Light requirements of buried seeds. *Nature, Lond.* 213, 600–601.
- Wesson, G. and Wareing, P. F. (1969). The induction of light sensitivity in weed seeds by burial. *J. exp. Bot.* 20, 413–425.
- West, N. E. (1968). Rodent-influenced establishment of ponderosa pine and bitterbrush seedlings in central Oregon. *Ecology* 49, 1009–1011.
- White, J. (1968). "Studies on the behaviour of plant populations in model systems". M.Sc. thesis, University of Wales.
- White, J. and Harper, J. L. (1970). Correlated changes in plant size and number in plant populations. *J. Ecol.* 58, 467–485.
- White, J. H. and French, N. (1968). Leather jacket damage to grassland. *J. Br. Grassl. Soc.* 23, 326–329.
- Whittaker, R. H. (1969). Evolution of diversity in plant communities. In "Diversity and Stability in Ecological Systems". *Brookhaven Symp. Biol.* 22, 178–196. Springfield, Va. National Bureau of Standards, U.S. Dept. of Commerce.
- Whittaker, R. H. (1972). Evolution and measurement of species diversity. *Taxon* 21, 213–251.
- Whittaker, R. H. (1974). "The design and stability of plant communities". 1st *Int. Cong. Ecol. The Hague, Sept. 1974*. PUDDOC, Wageningen.
- Whittington, W. J. and O'Brien, T. A. (1968). A comparison of yields from plots sown with a single species or a mixture of grass species. *J. appl. Ecol.* 5, 209–213.
- Wilcott, J. C. (1973). "A seed demography model for finding optimal strategies for desert annuals". Ph.D. thesis, Utah State University, Logan, Utah.
- Williams, C. B. (1967). Spruce budworm damage symptoms related to radial growth of Grand Fir, Douglas Fir, and Engelmann Spruce. *For. Sci.* 13, 274–285.
- Williams, E. J. (1962). The analysis of competition experiments. *Aust. J. biol. Sci.* 15, 509–525.
- Williams, G. C. (1966). "Adaptation and Natural Selection". Princeton University Press, Princeton, N.J.
- Williams, J. T. and Harper, J. L. (1965). Seed polymorphism and germination. I. The influence of nitrates and low temperatures on the germination of *Chenopodium album*. *Weed Res.* 5, 141–150.
- Williams, O. B. (1970). Population dynamics of two perennial grasses in Australian semi-arid grassland. *J. Ecol.* 58, 869–875.
- Williams, O. B. and Roe, R. (1975). Management of arid grasslands for sheep: plant demography of six grasses in relation to climate and grazing. *Proc. ecol. Soc. Aust.* 9, 142–156.
- Williams, R. F. (1955). Redistribution of mineral elements during development. *A. Rev. Pl. Physiol.* 6, 25–42.
- Williams, W. A. (1963). Competition for light between annual species of *Trifolium* during the vegetative phase. *Ecology* 44, 475–485.
- Williams, W. A. (1967). Seedling growth of a hypogeal legume, *Vicia lasycarpa*, in relation to seed weight. *Crop Sci.* 7, 163–164.
- Williamson, M. H. (1957). An elementary theory of interspecific competition. *Nature, Lond.* 180, 422–425 and 181, 1415.
- Williamson, M. H. (1972). "The Analysis of Biological Populations". Arnold, London.
- Willson, M. F. (1971). Seed selection in some north American finches. *Condor* 73, 415–429.
- Wilson, B. F. (1968). Red Maple stump sprouts: development in the first year. *Harvard Forest Paper* 18, 1–10.
- Wilson, D. E. and Janzen, D. H. (1972). Predation on *Scheelea* palm seeds by Bruchid beetles: seed density and distance from the parent palm. *Ecology* 53, 954–959.
- Wilson, E. O. and Bossert, W. H. (1971). "A Primer of Population Biology". Sinauer Ass. Inc., Stamford, Conn.
- Wilson, R. E. and Rice, E. L. (1968). Allelopathy as expressed by *Helianthus annuus* and its role in old-field succession. *Bull. Torrey bot. Club* 95, 432–448.
- Winkworth, R. E. (1970). Soil water regime of an arid grassland community, Australia. *Agric. Meteorol.* 7, 387–399.
- Wit, C. T. de (1960). On competition. *Versl. Landbouwk. Onderz.* 66, 1–82.

- Wit, C. T. de (1965). Photosynthesis of leaf canopies. *Versl. Landbouwk. Onderz.* 663, 1-57.
- Wit, C. T. de, Tow, P. G. and Ennik, G. C. (1966). Competition between legumes and grasses. *Versl. Landbouwk. Onderz.* 687, 3-30.
- Witkamp, H. (1925). De ifzehaut als geologische indikator. *Trop. Natuur.* 14, 97-103.
- Womark, D. and Thurman, R. L. (1962). Effect of leaf removal on the grain yield of wheat and oats. *Crop Sci.* 2, 423-426.
- Woodell, S. R. J., Mooney, H. A. and Hill, A. J. (1969). The behaviour of *Larrea divaricata* (Creosote bush) in response to rainfall in California. *J. Ecol.* 57, 37-44.
- Woolhouse, H. W. ed. (1969). Dormancy and Survival. *Symp. Soc. exp. Biol.* 23, 1-598.
- Wright, J. L. and Lemon, E. R. (1966a). Photosynthesis under field conditions. VIII. Analysis of windspeed fluctuation data to evaluate turbulent exchange within a corn crop. *Agron. J.* 58, 255-261.
- Wright, J. L. and Lemon, E. R. (1966b). Photosynthesis under field conditions. IX. Vertical distribution of photosynthesis within a corn crop. *Agron. J.* 58, 265-268.
- Yelverton, C. S. and Quay, T. L. (1959). Food habits of the Canada goose. *Game Division, N. Carolina Wildlife Resources Commission. Raleigh, N. Carolina.* 1-44.
- Yocom, H. A. (1968). Short leaf pine seed dispersal. *J. Forest.* 66, 422.
- Yoda, K., Kira, T. and Hozimu, K. (1957). Intraspecific competition among higher plants. IX. Further analysis of the competitive interaction between adjacent individuals. *J. Inst. polytech., Osaka Cy Univ.* 8, 161-178.
- Yoda, K., Kira, T., Ogawa, H. and Hozumi, K. (1963). Self thinning in overcrowded pure stands under cultivated and natural conditions. *J. Biol. Osaka Cy Univ.* 14, 107-129.
- Zentmyer, G. A., Wallace, P. P. and Horsfall, J. G. (1944). Distance as a dosage factor in the spread of Dutch elm disease. *Phytopathology* 34, 1025-1033.
- Zimmermann, M. H. (1973). Transport problems in arborescent monocotyledons. *Q. Rev. Biol.* 48, 314-321.
- Zohary, M. (1962). "Plant Life of Palestine, Israel and Jordan". Ronald Press, New York.

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