

Chapter 3

We now turn directly to the Sparseness Adaptation Theory promised in the Introduction. The bias toward catalysis just predicted is quite general. Can we predict anything more specific about life's unfolding? We can.

Our general strategy, announced in the last chapter, was to "look for what changes very slowly and therefore is in a position to channel life's direction." In that chapter we began with the induced constraint that all organisms depend on various resources in order to survive and reproduce. Now we turn to a more specific physical constraint on life's unfolding – the constraint of limited resources accessible to each organism. We shall see that the effect of this inevitable constraint is the geographical separation of genetic types.

Our chief tool in the present investigation is a thought experiment styled the *Sparse Box* thought experiment. This is a *thought* experiment: Please do not perform it on the sentient.

The Sparse Box

Suppose that a hypothetical creature can survive on one food pellet a day, but not on less food. The pellet contains any needed water. The creature lives in an impervious box, and is fed its requisite one pellet per day so that all is well. Now suppose a second creature with identical needs is also put into the box. What happens? There is not food enough in the box for both of the inhabitants to survive. Only two outcomes are possible: Either one creature dies or both die. The only way life can persist in the sparse environment of the box is if one of the creatures prevents the other from eating. The one can do this in two ways: by grabbing food pellets more quickly than does the other or by slaying the other creature outright – and murder is the surer choice. Either way one creature kills the other. In the *Sparse Box* at least one creature *must* die, and generosity and camaraderie are exactly suicide.



Wherever creatures in a sparse area must move about in order to gather widely scattered food they can move only so far in a given time.¹ This makes a sufficiently large sparse area like a box to them. Once any carried food runs out they must find food within a short distance or perish. The limited range acts like the walls of a box and the inhabitants are forced into deadly competition for the few resources there. **Where there is food enough for one but not two no cooperative strategy can reliably transmit genes, but the genes of the deadliest competitor endure.**

¹ Replace *food* with *life-sustaining resources* as needed.

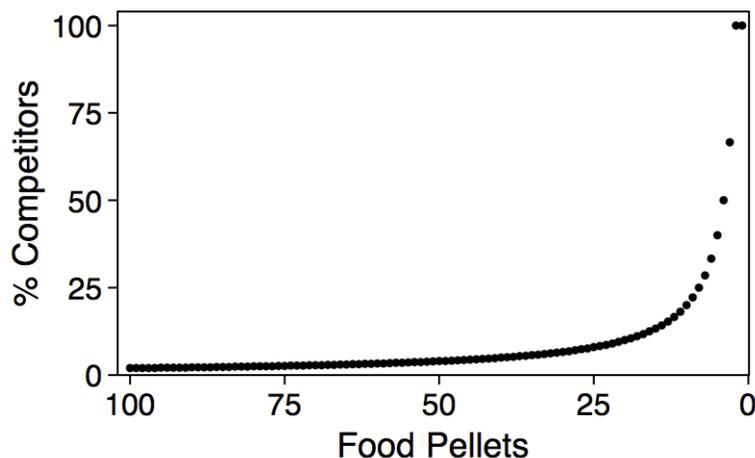
The impact of the forgoing sparseness constraint cannot be overstated. It shows that every region whose inhabitants must move to gather scarce food is an incubator of deadly genes. The genes that survive in extremely sparse areas *differ* on average from genes in lush areas: **Sparse regions foster a geographic separation of genetic types**, with genes in sparse areas more likely to cause the death of neighbors than genes in lush areas.

The Competition Gradient

The effects of resource sparseness do not end where there is food enough for only one. In general there is a *competition gradient* – and a corresponding gradient of expected competitive traits – increasing from the less competitive in lush areas toward the extremely competitive at sparse frontiers.

In nature populations often expand quickly to the level that resources and abilities can sustain, resulting in conditions like those in a box with a fixed number of food pellets. Suppose therefore that there is a *Variably Sparse Box* holding a variable number of food pellets, such that it can model either a lush or a sparse region. Consider now the following case.

Suppose that in a Variably Sparse Box there is, among many ordinary organisms, a single organism so competitive that it never loses a contest for a pellet with an ordinary organism. If at the outset there is food for 100 organisms then the lone competitor comprises 1% of the box's population. If the daily number of pellets drops to 10 then the competitor survives to make up 10% of the population, and in the case of extreme food sparseness, where there is food for only one (the condition in the original thought experiment) the competitor then forms 100% of the box's population. In this simple scenario the fraction of the population represented by the competitor is inversely proportional to the resource level, or $f = 1/r$. The following graph shows this fraction as the percentage of a population expected to be competitors, as food levels decline.



The fraction (as %) of a surviving population expected to be competitors, with increasing food scarcity

The expected fraction of competitors in the forgoing is lower if the competitor does not win all contests, but nevertheless rises with falling resource levels and is greater than the fraction expected if all the creatures are equally competitive.²

The effect of competition is that some creatures starve to death. When food levels decline, if one creature certainly does get food then another creature certainly does not. Thus in sparse conditions **competitors kill non-competitors** whether they happen to do so indirectly through efficient food-grabbing, or directly through outright murder. The graph of competitor survival is thus also a graph of killing prevalence, and it shows that killing happens not only at the most extreme frontier, but well within it.

The fraction f is a **measure of the average competitive ability** of organisms in a geographic region. Given large-scale geographic variation in food levels (compare for example rainforest and tundra) it follows that sparseness-caused selection for competition yields a geographic separation of average competitive abilities, verifying that **geographic variation in resource levels yields a geographic separation of types**. This is not a mere possibility, but a mathematical and logical necessity.

Please do note that the forgoing conclusions are unavoidable both in a Sparse Box and, barring the improbable, in the natural world. Unavoidable large-scale variations in food distribution guarantee the geographic separation of genetically-determined competitive types. At the deepest level competition can no more be learned than a heartbeat can be learned. Furthermore, the conclusions are *general* and do not depend on the exact mechanism of competition. For example, it does not matter to the argument whether a creature gains food through brain or through brawn. It does not even matter if the life-sustaining resource is food. What matters is that by some means the creature gains a life-sustaining resource, and the list of ways an organism can gain such a competitive edge is very long.

Nature and Nurture

At this point someone may ask, “Can differences in competitive tendency simply be *learned*, and not genetic?” This is the familiar *nature/nurture* question.

A simple look at the Sparse Box and the curves plotted above answers the question. The *minimum* probability of death for equally-competitive creatures arriving together at a

² This can be seen from the following: If 100 creatures in the box are uniformly competitive then the probability that any one creature survives when food levels have dropped to r pellets is $r/100$. That one creature then constitutes $1/r$ of the remaining population. Thus if all the creatures are uniformly competitive then any of the original 100 creatures is expected to constitute $r/100 \times 1/r = 1/100$ of the final population regardless of resource level. If a creature is only slightly more competitive than the others and its probability of surviving when the food level has dropped to r pellets is $(r+a)/100$ then the expected fraction of competitors is $(r+a)/100 \times 1/r = (1/100) \times (1 + a/r)$, which is both greater than $1/100$ and rises with falling r .

sparse extreme is 50%, and that death occurs far too rapidly (within a single day in the opening scenario) for a creature to learn the competitive skills needed to favor survival. In the Sparse Box the race is to the swift and deadly. Near the extreme frontier organisms don't have the time to learn what they must know always and immediately in order to survive. The situation is analogous to proposing that the instinct to breathe is learned rather than genetic:

"Today, class, we learn that in order to survive we must breathe."

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Such a Breathing Class is absurd: The newborn that doesn't know how to breathe at birth won't make it to the first class! In the same way the extreme-frontier organism that does not instinctively grab food first, and waste none of it, quickly succumbs to a rival with this instinct. Note also these further observations:

- The competitive genes described here need no "teleological foreknowledge" of what genetic variations will be favored. Genes that merely *happen* to favor murderous competition, by any avenue among millions, prevail simply because they are the ones that get the food enabling their reproduction. Genes are, after all, autocatalysts, and central ones. This assures that the tendency to murderous competition in sparse regions is strongly genetic.
- Given large-scale geographic variations in resource distribution the only way variations in competitive ability could *not* be gene-influenced is if not even one gene affecting competitive ability could ever be expressed. But where is there *any* gene or gene combination that has absolutely no influence on competitive ability in any context? It is arguable that *all* genes influence competitive ability.
- Learning itself depends on genes. Lacking the needed genes, a stone cannot learn to speak, nor a dog learn to prove theorems of calculus. Even if competitive ability were purely learned the creatures in a sparse region demonstrate more certainly than others the ability and the genes needed to *learn* competition. I detail the implications of such demonstrated ability later.
- A trait that is learned may *fail* to be learned, but a gene transmitted is a gene transmitted. Thus a critical trait passed on through genes is favored over one learned.
- Some competitive behaviors will of course be learned, and organisms may later learn to inhibit murderous instincts, but one can be sure that in the sparsest regions the primary and genetically-based instinct is murderous competition.

I say more about genes later, but for now we return from the digression on genes to a summary of what preceded it.

We have seen that both at the frontier and near it, the greater the probability of death due to starvation, the greater the probability that genes favoring murderous competition prevail. In many times and places on Earth it cannot realistically have been otherwise. The selection for murderous competition is strong not only at an extreme frontier, but at the near-frontier, and is much stronger in sparse than in lush areas. This yields the following:

Competition Prediction: Where per capita resource levels decrease in space and/or time genomes will increasingly direct resources away from others and toward themselves, and nearing the extremes of sparseness increasingly will kill others directly. The competitive tendency will exhibit adaptive inertia: Where per capita resource levels are declining organisms that have long dwelt among sparse life-sustaining resources will be genetically more inclined to kill neighbors than will cousins that have long dwelt in lush areas. Genetic tendencies to compete for resources will correlate with geographic variations in resource levels where the spatial scale of resource variations is larger than the range of genome migration over many generations.

To test this prediction do the following, again only where ethically possible: Take two strains of an organism that are cousins with long genetic histories in sparse and lush areas respectively. These areas are geographically separate on the face of it. Stable DNA differences that are only weakly related to competition can serve as markers of the time the two groups have been separated. Raise the two in similar conditions to control for learned differences. Then place equal numbers of lush and sparse genetic varieties in a shared environment, gradually lower the prevailing food (or other resource) level and then count how many of each kind actively kills a neighbor in a given period of time, or simply acquires resources faster or more effectively than neighbors of the other kind. If on average the killing rate is not measurably higher in the sparse-heritage group then the main part of the prediction is falsified.

There may be no way to both rigorously and ethically test the Competition Prediction in all species.³ Even subterfuges like leaving apparently potent but actually impotent means of killing lying about, and then recording the rates at which their use is *attempted*, is both risky and ethically suspect. Nevertheless, the fact that a decisive test is possible in principle shows that the Competition Prediction is scientifically rigorous.

We now turn from competition to cooperation.

Cooperation

Any two autocatalysts that share a sustaining causal loop are *cooperating*. If the causal

³ A possible indicator of the ethical in this case is uncoerced consent by participants, where this is possible.

loops that put game in two wolves' mouths contain both wolves, i.e. their mutual feeding depends on both of them participating in the hunt, then the wolves are cooperating.

As noted, genes themselves are autocatalysts, and their self-sustaining causal loops typically pass through almost all other elements of their containing organism, including not least any other genes in a genome. Genes function like animals in a pack, and their main pack is the genome. How do we know this? How can a human gene for green eyes persist if there are no genes for eyes, nor for a heart to send eyes blood, nor a mouth to feed the heart, or a brain to find dinner and keep the lot out of trouble? These are only a few examples among myriads that may be attested. In all of these relationships within organisms the causal loops contain multiple interconnected autocatalytic elements and so the relationships are cooperative.

The cooperation of elements in a living autocatalyst is generally as obvious as the causal interdependence of heart and lung, or of DNA and enzymes. However, outside the arbitrary boundary of an autocatalyst – in the world external to an organism or its group – matters are different. It is here that nature's red tooth and claw, and the struggle for existence – in a word, competition – most asserts itself. In competition one autocatalytic loop cuts or blocks another. We have already encountered an acme of this competition in the Sparse Box of the extreme frontier. How is it then that a world so marked by bloody competition gives rise to the relatively serene cooperation found inside living things and in tightly-knit social groups?

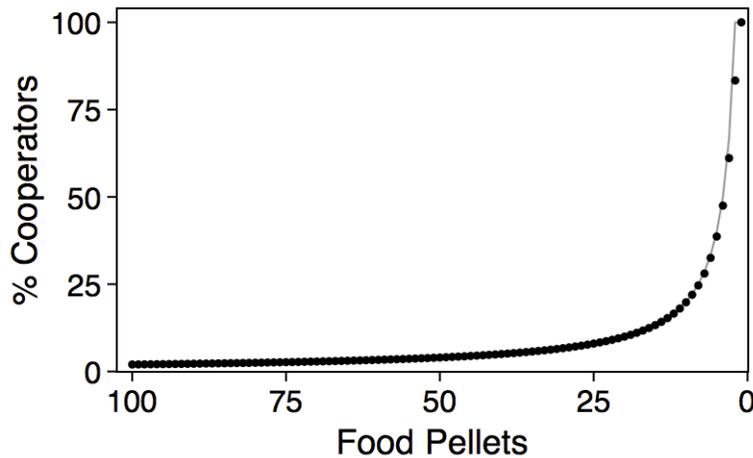
Coopetition

We have seen that sparseness favors competition. Now we encounter a great enigma of evolution: **The very near-frontier that favors fierce competition also favors a fundamental form of cooperation more strongly than do lush areas.** This is consistent with the instinct that teamwork is a good strategy near an extreme frontier. But how can this be? How can sparseness favor both competition and cooperation?

Suppose that a Variably Sparse Box is filled to its carrying capacity with creatures that are identical but for a pair of identical twins with a novel trait: When one grabs a food pellet for itself it guards a second pellet from all but its twin. This constitutes a simple form of cooperation between the twins. In all other respects the twins remain like their neighbors: As *individuals* the twins are assumed to be no more competitive than the others. Now suppose that the food pellet ration is decreased by one pellet per day. We trace how the cooperators fare relative to the non-cooperators in lush versus sparse boxes.

Because no two creatures grab food pellets at precisely the same time it follows that creatures grab pellets in a particular order. In the present scenario, when the first of the two twins grabs a pellet it guards a second for use by its twin. This means that the only way a twin can starve is if the first twin has grabbed the last available pellet, leaving no pellet to guard for its twin. This happens only when the twins are the last two to try grabbing pellets. (Given the ration decline there is of course no last pellet for the second twin to grab.)

Recall that in this model the twins individually are not more competitive than any of the other creatures in the box. Thus the probability is $2/n$ that one of two twins is in any position in the "food line", including the next-to-last position, and $1/(n-1)$ that the remaining twin is then in any other position, including the deadly last position. This yields a joint probability of $\frac{2}{n} * \frac{1}{n-1} = \frac{2}{n(n-1)}$ that the fatal condition arises in which one twin cannot save the other from starvation. This means that there is a probability of $1 - \frac{2}{n(n-1)}$ that two twins survive the cut, and a probability of $\frac{2}{n(n-1)}$ that only one lives. The expected number of surviving twins is thus $2 * \left(1 - \frac{2}{n(n-1)}\right) + 1 * \frac{2}{n(n-1)} = 2 \left(1 - \frac{1}{n(n-1)}\right)$. The expected fraction of the surviving population that is formed of cooperators is therefore this expected number of cooperators divided by $n-1$, the daily number of food pellets after the ration is cut by one pellet per day. Setting $r = n-1$ gives $f = \frac{2}{r} \left(1 - \frac{1}{r(r+1)}\right)$ for the fraction of creatures expected to be cooperators for each post-cut number of food pellets. This graph shows f as a percentage:



The grey line shows the curve expected if the twins had not been cooperators but, rather, individual *competitors* as described earlier.⁴ The curves for cooperator and competitor are nearly identical.⁵ **Cooperation here thus confers a significant competitive advantage.** The twins are not by themselves unusually competitive, but cooperation makes them so. This illustrates **coopetition**, cooperation that specifically aids competition. Note that this form of cooperation is not purely altruistic: The twins help only their genetic kind and no others, and they help themselves before helping even a twin. Note from the graph that this form of cooperation is strongly selected only in sparse conditions.

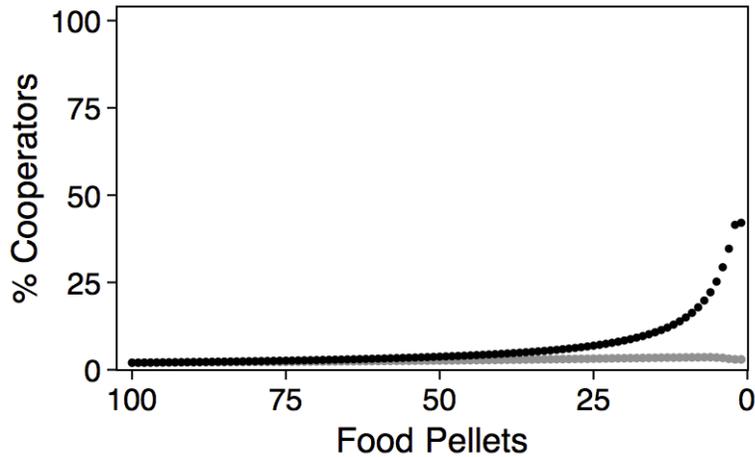
⁴ The plots show the expected population fraction after a one-pellet food reduction, for each given starting number of pellets. Expected fractions given *cumulative* pellet reduction are unchanged for the competitors and about half the plotted (black dot) values for the cooperators.

⁵ This is expected from the fact that the expected cooperator fraction differs from the pure competitor fraction $f = \frac{2}{r}$ by the factor $\frac{1}{r(r+1)}$, which exceeds 10% only for two or fewer remaining food pellets.

Coopetition, like pure competition, starves other creatures to death. Particularly in sparse regions **competitors and cooperators alike kill** other creatures – *any* others in the case of the purely competitive, and the genetically less-related in the case of the cooperators.

Cooperators in the Sparse Box are very particular about the genetic makeup of the ones they help. But must they be so? Couldn't the cooperators be more generous, more *altruistic*? Consider a creature that guards a pellet for its own twin half the time, but then one quarter of the time generously guards the pellet for an ordinary non-cooperator and another quarter of the time guards a pellet for a "selfish" relative that guards pellets only for its own kind exactly. At first the less discriminating but more generous behavior seems likely enough to thrive. But what actually happens? Because half the beneficiaries of the generous creature do not in turn help the generous creature survive, the result of generous cooperation in a sparse region is more probable death for the generous one.

The following graph shows what happens when two selfish cooperators and two generous cooperators are housed with 96 otherwise non-cooperating creatures – and the starting 100-pellet food ration is then decreased by a pellet a day each day. The graph shows the cumulative effects of continuous ration reduction over successive days. The black dots represent the population share of the selfish cooperators, and the grey of the generous cooperators. When food becomes sparse the selfish cooperators overwhelmingly dominate the generous ones. This simply shows that, as in the extreme Sparse Box that opened this chapter, both at an extreme frontier and well within it “generosity and camaraderie [*beyond one's genetic kind*] are exactly suicide.” There is no benevolent, purely altruistic strategy that can long succeed in a very sparse region: If such a strategy ever succeeded it would simply prove that the region actually was not very sparse.



The population share of selfish (black) and generous (grey) twins among 96 non-cooperators, as the food ration is cut by one pellet per day each day.⁶

⁶ The graph shows the averages for 10000 runs of a Monte Carlo simulation.

The fact that life is made of autocatalytic loops explains the failure of generous cooperation in sparse conditions. An autocatalytic loop may be compared to the shrill feedback one hears when a microphone is placed near a speaker amplifying the microphone's signal. A selfish cooperater is like a microphone and speaker held close together, feeding all of the speaker's sound back into the microphone. A generous cooperater is like a microphone and speaker held far apart, scattering sound away from the mic: With less sound returning to the microphone the feedback oscillations more easily die. In the case of generous cooperators it is their life cycle that dies.

Overall the forgoing leads to the following:

Coopetition Prediction

Where per capita resource levels are decreasing in space or time organism genes will increasingly direct resources away from genetically distant relatives and toward closer relatives and themselves. In the case of radical or radically-declining sparseness this shift will extend to active killing of more distant relatives – and finally at the extreme of sparseness to killing of all relatives nearby.

Testing of the Coopetition Prediction has two parts: The first, testing the predicted greater incidence of murderous competition among the sparse-adapted, was discussed above. The testing is the same for any mix of individual competition and coopetition. The second test is of the following specific prediction: Except in sparse extremes, and given comparable rates of neighbor-killing, sparse-adapted genomes will be less likely than lush-adapted to kill genetically-close relatives. If this is not observed on average then the second part of the prediction is falsified.

Which is the more effective behavior, competition or cooperation? Coopetition *is* a form of competition, of course, but the simple models here do not fully decide the question. They do, however, give these general guides:

- Competition and coopetition are equally but only weakly advantageous in lush conditions.
- Both competition and coopetition become strongly advantageous when food supports no more than a few dozen creatures.
- Individual competition surpasses coopetition where food supports only a handful of creatures.
- Individual competition is fully dominant in extreme sparseness.

In general both coopetitive and purely competitive behaviors are expected to predominate in sparse regions. Furthermore, creatures with long ancestral histories in sparse regions with fluctuating resource levels are very likely to have a **strongly bivalent nature** – that is, to be able to switch between competition and cooperation as the levels fluctuate: In sparse areas genomes will predominate that happen to cause their host organisms to sense per capita resource levels, to switch from intense, strong bonds with team members when food levels allow it, to murderous competition with the same team members when food levels plunge.

Bivalence is an example of the context-dependence promised in the last chapter. Bivalence, and context-dependence generally, complicate testing of the competition and cooptation predictions: A genome may have a long history in lush areas, and thus appear to be a perfect representative of lush-adaptation, but if it has a much longer history encompassing both lush and sparse areas it may be bivalent. In that case when placed in a sparse environment it may perform indistinguishably from a sparse-adapted cousin. There are ways to control for this confound.⁷

Fluctuations

Fluctuations in resource levels powerfully drive competitive adaptations. This is particularly the case where resources are generally sparse but fluctuate, as at northern latitudes on Earth. Resource fluctuations also occur when an organism moves through varied environments, as an organism is likely to do when traveling about.

In the lush phase of a resource fluctuation genomes have the materiel to reproduce and recombine, multiplying surviving genomes and creating variations. In the sparse phase all the forces of competition described earlier come to bear, and the most effective competitors, whether individual or cooptative, prevail. A recurring cycle of boom and bust thus refines competitive genomes. By contrast, constantly lush conditions do little to spur the development of competitive and cooptative genomes. Constantly sparse conditions do foster competition, but without the lush phase of a fluctuation there is no amplification and variation of surviving genomes, and so there is limited growth of competition.

Resource fluctuation also strongly drives the bivalent ability to switch between competitive and cooperative modes, because any genome that can thrive in both lush and sparse conditions thereby has more opportunities to persist.



The opening Sparse Box thought experiment concluded that in the Box “the genes of the deadliest competitor endure.” They endure for the lifetime of the competitor, that is, unless it reproduces – and sexual reproduction requires the participation of a second creature. This means that the genetic rudiments of cooperation must be in place in even the most vicious competitor if that competitor’s genes are to endure by non-artificial means. There must be one creature even the most murderously violent survivor of sparseness does not kill.

Tragically, rape is one way a competitor’s genes can persist, and indeed systematic rape has been a significant phenomenon in some times and places on Earth. Note, though, that even a rapist must be able at least to recognize a genetic relative, because a duck raping a

⁷ For example by limiting study to novel sparse areas entered recently enough to have no deep history, but occupied long enough that some genetic adaptation has been possible in it.

tree does not propagate duck genes. A duck raping and then killing a duck also does not propagate duck genes. Not-killing is the first act of cooperation. The point of these observations is that there are no surviving truly pure competitors. No genome is an island, and every enduring genome carries seeds of cooperation.

Taking Stock

In the last chapter we set out to augment Darwin's theory of life's evolution with a more predictive scientific theory, one that did not rely on hidden and ad hoc assumptions. This chapter gave a brief tour of primary expected biological adaptations to resource sparseness – a tour of what I call Sparseness Adaptation Theory. Does this theory meet our requirements? Is it more predictive than Darwin's theory alone, and does it depend on hidden and ad hoc assumptions?

As noted, the Competition and Coopetition Predictions are predictive, testable, and falsifiable in ways Darwin's theory is not. The predictions succeed where the earlier examples of antibiotic resistance, beak change and industrial melanism fail, because the predictions are *general*: They do not specify exactly how organisms in sparse regions will become more competitive, only that by whatever gene-catalyzed causal path they will. Their success lies in being general but falsifiable.

Like every theory the Sparseness Adaptation Theory makes assumptions. It assumes, for example, that most if not all of an organism's genes affect the likelihood an organism will win contests for limited resources. This is quite different from assuming that a bacterium has the genetic potential to resist a particular antibiotic, or that finch genes can make viable new beaks, or that a moth has the specific genetic capacity to darken and to do so without harm to its health. The key to making the present assumptions *not* ad hoc is again generality: No specific genes are assumed, only general properties (e.g. affecting competitiveness in some way) that inspection shows all genes must to some degree possess. This is not so much even an assumption as it is an appeal to reason and experience-verified insight. Assumptions surround and undergird every theory. The Sparseness Adaptation Theory welcomes their exposure to light.

The least that can be said of the Sparseness Adaptation Theory is that it shifts prediction and the dependence on assumptions to a new domain. That said, it does appear to meet our formal requirements.

The key expectations of Sparseness Adaptation to this point are these:

- Large-scale variations in life-sustaining resources force geographic separation of types within organism families on Earth.
- Organisms with ancestral histories in sparse areas will be more inclined and able to compete murderously than cousins with ancestral histories in lush areas.
- The same organisms will also be more able to form murderously competitive teams than cousins from lush areas.
- Exposure to fluctuating resource levels in sparser areas hastens the development of competitive and coopetitive abilities, and of the bivalent ability to switch between the two.

- The competitive abilities expected from long histories in sparse areas will be strongly genetic.

In short, organisms with ancestral histories in sparse areas will be genetically more inclined to murderous competition, both as individuals and in teams, than cousins from lush areas, and will compete most fiercely with genetically distant relatives.

Doubtless the predictions as stated here are flawed and can be made more formally rigorous, but they point clearly nevertheless. The Sparse Box thought experiment and the bit of algebra given may distract from what is intuitively very obvious, that there is less need to compete for survival when there is plenty of food about, with more coming, and there is more competition and benefit from teamwork when food is sparse and becoming sparser. The models serve to demonstrate that the intuition is grounded to the point of being incontrovertible. The Sparse Box encompasses vast swaths of the wet and dusty world.

This book's introduction makes little secret of where this reasoning is headed, but before tracing the impact of adaptive competition on human affairs we turn from the competitive to other abilities – to abilities favored when moving into new and uninhabited places, and to abilities that the fiercely sparse-adapted *lack*.