APPENDIXES

Appendix I: The Ecology of Dune

> *Beyond a critical point within a finite space, freedom diminishes as numbers increase. This is as true of humans in the finite space of a planetary ecosystem as it is of gas molecules in a sealed flask. The human question is not how many can possibly survive within the system, but what kind of existence is possible for those who do survive.*
>
> ***—Pardot Kynes, First Planetologist of Arrakis***

THE EFFECT of Arrakis on the mind of the newcomer usually is that of overpowering barren land. The stranger might think nothing could live or grow in the open here, that this was the true wasteland that had never been fertile and never would be.

To Pardot Kynes, the planet was merely an expression of energy, a machine being driven by its sun. What it needed was reshaping to fit it to man's needs. His mind went directly to the free-moving human population, the Fremen. What a challenge! What a tool they could be! Fremen: an ecological and geological force of almost unlimited potential.

A direct and simple man in many ways, Pardot Kynes. One must evade Harkonnen restrictions? Excellent. Then one marries a Fremen woman. When she gives you a Fremen son, you begin with him, with Liet-Kynes, and the other children, teaching them ecological literacy, creating a new language with symbols that arm the mind to manipulate an entire landscape, its climate, seasonal limits, and finally to break through all ideas of force into the dazzling awareness of order.

"There's an internally recognized beauty of motion and balance on any man-healthy planet," Kynes said. "You see in this beauty a dynamic stabilizing effect essential to all life. Its aim is simple: to maintain and produce coordinated patterns of greater and greater diversity. Life improves the closed system's capacity to sustain life. Life—all life—is in the service of life. Necessary nutrients are made available to life by life in greater and greater richness as the diversity of life increases. The entire landscape comes alive, filled with relationships and relationships within relationships."

This was Pardot Kynes lecturing to a sietch warren class.

Before the lectures, though, he had to convince the Fremen. To understand how this came about, you must first understand the enormous single-mindedness, the innocence with which he approached any problem. He was not naive, he merely permitted himself no distractions.

He was exploring the Arrakis landscape in a one-man groundcar one hot afternoon when he stumbled onto a deplorably common scene. Six Harkonnen bravos, shielded and fully armed, had trapped three Fremen youths in the open behind the Shield Wall near the village of Windsack. To Kynes, it was a ding-dong battle, more slapstick then real, until he focused on the fact that the Harkonnens intended to kill the Fremen. By this time, one of the youths was down with a severed artery, two of the bravos were down as well, but it was still four armed men against two striplings.

Kynes wasn't brave; he merely had that single-mindedness and caution. The Harkonnens were killing Fremen. They were destroying the tools with which he intended to remake a planet! He triggered his own shield, waded in and had two of the Harkonnens dead with a slip-tip before they knew anyone was behind them. He dodged a sword thrust from one of the others, slit the man's throat with a neat *entrisseur,* and left the lone remaining bravo to the two Fremen youths, turning his full attention to saving the lad on the ground. And save the lad he did... while the sixth Harkonnen was being dispatched.

Now here was a pretty kettle of sandtrout! The Fremen didn't know what to make of Kynes. They knew who he was, of course. No man arrived on Arrakis without a full dossier finding its way into the Fremen strongholds. They knew him: he was an Imperial servant.

But he killed Harkonnens!

Adults might have shrugged and, with some regret, sent his shade to join those of the six dead men on the ground. But these Fremen were inexperienced youths and all they could see was that they owed this Imperial servant a mortal obligation.

Kynes wound up two days later in a sietch that looked down on Wind Pass. To him, it was all very natural. He talked to the Fremen about water, about dunes anchored by grass, about palmaries filled with date palms, about open qanats flowing across the desert. He talked and talked and talked.

All around him raged a debate that Kynes never saw. What to do with this madman? He knew the location of a major sietch. What to do? What of his words, this mad talk about a paradise on Arrakis? Just talk. He knows too much. But he killed Harkonnens! What of the water burden? When did we

owe the Imperium anything? He killed Harkonnens. Anyone can kill Harkonnens. I have done it myself.

But what of this talk about the flowering of Arrakis?

Very simple: Where is the water for this?

He says it is here! And he did save three of ours.

He saved three fools who had put themselves in the way of the Harkonnen fist! And he has seen crysknives!

The necessary decision was known for hours before it was voiced. The tau of a sietch tells its members what they must do; even the most brutal necessity is known. An experienced fighter was sent with a consecrated knife to do the job. Two watermen followed him to get the water from the body. Brutal necessity.

It's doubtful that Kynes even focused on his would-be executioner. He was talking to a group that spread around him at a cautious distance. He walked as he talked: a short circle, gesturing. Open water, Kynes said. Walk in the open without stillsuits. Water for dipping it out of a pond! Portyguls!

The knifeman confronted him.

"Remove yourself," Kynes said, and went on talking about secret windtraps. He brushed past the man. Kynes' back stood open for the ceremonial blow.

What went on in that would-be executioner's mind cannot be known now. Did he finally listen to Kynes and believe? Who knows? But what he did is a matter of record. Uliet was his name, Older Liet. Uliet walked three paces and deliberately fell on his own knife, thus "removing" himself. Suicide? Some say Shai-hulud moved him.

Talk about omens!

From that instant, Kynes had but to point, saying "Go there." Entire Fremen tribes went. Men died, women died, children died. But they went.

Kynes returned to his Imperial chores, directing the Biological Testing Stations. And now, Fremen began to appear among the Station personnel. The Fremen looked at each other. They were infiltrating the "system," a possibility they'd never considered. Station tools began finding their way into the sietch warrens—especially cutterays which were used to dig underground catchbasins and hidden windtraps.

Water began collecting in the basins.

It became apparent to the Fremen that Kynes was not a madman totally, just mad enough to be holy. He was one of the umma, the brotherhood of

prophets. The shade of Uliet was advanced to the sadus, the throng of heavenly judges.

Kynes—direct, savagely intent Kynes—knew that highly organized research is guaranteed to produce nothing new. He set up small-unit experiments with regular interchange of data for a swift Tansley effect, let each group find its own path. They must accumulate millions of tiny facts. He organized only isolated and rough run-through tests to put their difficulties into perspective.

Core samplings were made throughout the bled. Charts were developed on the long drifts of weather that are called climate. He found that in the wide belt contained by the 70-degree lines, north and south, temperatures for thousands of years hadn't gone outside the 254-332 degrees (absolute) range, and that this belt had long growing seasons where temperatures ranged from 284 to 302 degrees absolute: the "bonanza" range for terraform life ... once they solved the water problem.

When will we solve it? the Fremen asked. When will we see Arrakis as a paradise?

In the manner of a teacher answering a child who has asked the sum of 2 plus 2, Kynes told them: "From three hundred to five hundred years."

A lesser folk might have howled in dismay. But the Fremen had learned patience from men with whips. It was a bit longer than they had anticipated, but they all could see that the blessed day was coming. They tightened their sashes and went back to work. Somehow, the disappointment made the prospect of paradise more real.

The concern on Arrakis was not with water, but with moisture. Pets were almost unknown, stock animals rare. Some smugglers employed the domesticated desert ass, the kulon, but the water price was high even when the beasts were fitted with modified stillsuits.

Kynes thought of installing reduction plants to recover water from the hydrogen and oxygen locked in native rock, but the energy-cost factor was far too high. The polar caps (disregarding the false sense of water security they gave the pyons) held far too small an amount for his project ... and he already suspected where the water had to be. There was that consistent increase of moisture at median altitudes, and in certain winds. There was that primary clue in the air balance—23 per cent oxygen, 75.4 per cent nitrogen and .023 per cent carbon dioxide—with the trace gases taking up the rest.

There was a rare native root plant that grew above the 2,500-meter level in

the northern temperate zone. A tuber two meters long yielded half a liter of water. And there were the terraform desert plants: the tougher ones showed signs of thriving if planted in depressions lined with dew precipitators.

Then Kynes saw the salt pan.

His ’thopter, flying between stations far out on the bled, was blown off course by a storm. When the storm passed, there was the pan—a giant oval depression some three hundred kilometers on the long axis—a glaring white surprise in the open desert. Kynes landed, tasted the pan’s storm-cleaned surface.

Salt.

Now, he was certain.

There’d been open water on Arrakis—once. He began reexamining the evidence of the dry wells where trickles of water had appeared and vanished, never to return.

Kynes set his newly trained Fremen limnologist to work: their chief clue, leathery scraps of matter sometimes found with the spice-mass after a blow. This had been ascribed to a fictional “sandtrout” in Fremen folk stories. As facts grew into evidence, a creature emerged to explain these leathery scraps —a sandswimmer that blocked off water into fertile pockets within the porous lower strata below the 280° (absolute) line.

This “water-stealer” died by the millions in each spice-blow. A five-degree change in temperature could kill it. The few survivors entered a semidormant cyst-hibernation to emerge in six years as small (about three meters long) sandworms. Of these, only a few avoided their larger brothers and pre-spice water pockets to emerge into maturity as the giant shai-hulud. (Water is poisonous to shai-hulud as the Fremen had long known from drowning the rare “stunted worm” of the Minor Erg to produce the awareness-spectrum narcotic they call Water of Life. The “stunted worm” is a primitive form of shai-hulud that reaches a length of only about nine meters.)

Now they had the circular relationship: little maker to pre-spice mass; little maker to shai-hulud; shai-hulud to scatter the spice upon which fed microscopic creatures called sand plankton; the sand plankton, food for shai-hulud, growing, burrowing, becoming little makers.

Kynes and his people turned their attention from these great relationships and focused now on micro-ecology. First, the climate: the sand surface often reached temperatures of 344° to 350° (absolute). A foot below ground it might be 55° cooler; a foot above ground, 25° cooler. Leaves or black shade

could provide another 18° of cooling. Next, the nutrients: sand of Arrakis is mostly a product of worm digestion; dust (the truly omnipresent problem there) is produced by the constant surface creep, the “saltation” movement of sand. Coarse grains are found on the downwind sides of dunes. The windward side is packed smooth and hard. Old dunes are yellow (oxidized), young dunes are the color of the parent rock—usually gray.

Downwind sides of old dunes provided the first plantation areas. The Fremen aimed first for a cycle of poverty grass with peatlike hair cilia to intertwine, mat and fix the dunes by depriving the wind of its big weapon: movable grains.

Adaptive zones were laid out in the deep south far from Harkonnen watchers. The mutated poverty grasses were planted first along the downwind (slipface) of the chosen dunes that stood across the path of the prevailing westerlies. With the downwind face anchored, the windward face grew higher and higher and the grass was moved to keep pace. Giant sifs (long dunes with sinuous crest) of more than 1,500 meters height were produced this way.

When barrier dunes reached sufficient height, the windward faces were planted with tougher sword grasses. Each structure on a base about six times as thick as its height was anchored—“fixed.”

Now, they came in with deeper plantings—ephemerals (chenopods, pigweeds, and amaranth to begin), then scotch broom, low lupine, vine eucalyptus (the type adapted for Caladan’s northern reaches), dwarf tamarisk, shore pine—then the true desert growths: candelilla, saguaro, and bis-naga, the barrel cactus. Where it would grow, they introduced camel sage, onion grass, gobi feather grass, wild alfalfa, burrow bush, sand verbena, evening primrose, incense bush, smoke tree, creosote bush.

They turned then to the necessary animal life—burrowing creatures to open the soil and aerate it: kit fox, kangaroo mouse, desert hare, sand terrapin ... and the predators to keep them in check: desert hawk, dwarf owl, eagle and desert owl; and insects to fill the niches these couldn’t reach: scorpion, centipede, trapdoor spider, the biting wasp and the wormfly ... and the desert bat to keep watch on these.

Now came the crucial test: date palms, cotton, melons, coffee, medicinals—more than 200 selected food plant types to test and adapt.

“The thing the ecologically illiterate don’t realize about an ecosystem,” Kynes said, “is that it’s a system. A system! A system maintains a certain fluid stability that can be destroyed by a misstep in just one niche. A system

has order, a flowing from point to point. If something dams that flow, order collapses. The untrained might miss that collapse until it was too late. That's why the highest function of ecology is the understanding of consequences."

Had they achieved a system?

Kynes and his people watched and waited. The Fremen now knew what he meant by an open-end prediction to five hundred years.

A report came up from the palmaries:

At the desert edge of the plantings, the sand plankton is being poisoned through interaction with the new forms of life. The reason: protein incompatibility. Poisonous water was forming there which the Arrakis life would not touch. A barren zone surrounded the plantings and even shai-hulud would not invade it.

Kynes went down to the palmaries himself—a twenty-thumper trip (in a palanquin like a wounded man or Reverend Mother because he never became a sandrider). He tested the barren zone (it stank to heaven) and came up with a bonus, a gift from Arrakis.

The addition of sulfur and fixed nitrogen converted the barren zone to a rich plant bed for terraform life. The plantings could be advanced at will!

"Does this change the timing?" the Fremen asked.

Kynes went back to his planetary formulae. Windtrap figures were fairly secure by then. He was generous with his allowances, knowing he couldn't draw neat lines around ecological problems. A certain amount of plant cover had to be set aside to hold dunes in place; a certain amount for foodstuffs (both human and animal); a certain amount to lock moisture in root systems and to feed water out into surrounding parched areas. They'd mapped the roving cold spots on the open bled by this time. These had to be figured into the formulae. Even shai-hulud had a place in the charts. He must never be destroyed, else spice wealth would end. But his inner digestive "factory," with its enormous concentrations of aldehydes and acids, was a giant source of oxygen. A medium worm (about 200 meters long) discharged into the atmosphere as much oxygen as ten square kilometers of green-growing photosynthesis surface.

He had the Guild to consider. The spice bribe to the Guild for preventing weather satellites and other watchers in the skies of Arrakis already had reached major proportions.

Nor could the Fremen be ignored. Especially the Fremen, with their windtraps and irregular landholdings organized around water supply; the

Fremen with their new ecological literacy and their dream of cycling vast areas of Arrakis through a prairie phase into forest cover.

From the charts emerged a figure. Kynes reported it. Three per cent. If they could get three per cent of the green plant element on Arrakis involved in forming carbon compounds, they'd have their self-sustaining cycle.

"But how long?" the Fremen demanded.

"Oh, that: about three hundred and fifty years."

So it was true as this umma had said in the beginning: the thing would not come in the lifetime of any man now living, nor in the lifetime of their grandchildren eight times removed, but it would come.

The work continued: building, planting, digging, training the children.

Then Kynes-the-Umma was killed in the cave-in at Plaster Basin.

By this time his son, Liet-Kynes, was nineteen, a full Fremen and sandrider who had killed more than a hundred Harkonnens. The Imperial appointment for which the elder Kynes already had applied in the name of his son was delivered as a matter of course. The rigid class structure of the faufreluches had its well-ordered purpose here. The son had been trained to follow the father.

The course had been set by this time, the Ecological-Fremen were aimed along their way. Liet-Kynes had only to watch and nudge and spy upon the Harkonnens ... until the day his planet was afflicted by a Hero.