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Food variety and biodiversity: Econutrition

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Both annual biomass production and biodiversity at any locality on earth are continually under threat as the population of *Homo sapiens* steadily increases, with the resultant pollution of atmosphere, soil and water. Today, environmental degradation and global warming (with its effect on evaporative aerodynamics and cellular respiration) have increased at an alarming rate. The ABP of all terrestrial plant communities (natural or cultivated) is slowly declining, thus reducing the energy supply of component plants and resident animals; in turn, the biodiversity of all the world's ecosystems, plant and animal, is threatened. The maintenance of biodiversity is important to human health for several reasons: (i) a varied food supply is essential to maintain the health of the omnivorous human species; (ii) a range of diverse food sources is necessary to safe-guard against climatic and pestilent disasters which may affect one or more of the food sources; (iii) a diversity of plants and animals may provide a rich source of medicinal material, essential for the extraction of undiscovered therapeutic compounds; (iv) intact ecosystems of indigenous plants and animals appear to act as a buffer to the spread of invasive plants and animals, and of pathogens and toxins, thus contributing to the health of populations nearby; and (v) the 'spiritual' values of exploring the diversity of plants, animals and ecosystems in an area appear to have a beneficial effect on mental health, strengthening the feeling of 'belonging to the landscape'. The variety of foods, their energy contents and food values, consumed throughout the year is amenable to scientific enquiry; as is the amount of energy expended in this collection or production. The control and management of food production and of water supplies, with attention to safety issues, has led to an improvement in life expectancy for a proportion of the world's population. The question is at what point might human health be disadvantaged by the present-day food-production systems. In order to achieve variety in food patterns is an agreed and internationally asserted Dietary Guideline, but the way in which, and the extent to which, this is or needs to be achieved is a pressing issue for biological science in general. It is a field of enquiry which may be identified as 'Eco-nutrition'.

Key words: eco-nutrition, food variety, food production, biodiversity, biomass production, global warming, pollution.

Biodiversity

At present, there are countless, possibly 10 million (excluding microbes), species of living things, microbial, plant and animal, both vertebrate and invertebrate, with an animal extinction measured in at least the thousands (approximately 10 000 invertebrates each year).[1] The biomass and its diversity depends principally on the evaporative power of the atmosphere, along with solar radiation, carbon dioxide level, ambient temperature, and the availability of water and inorganic nutrients.[2] The plant biomass in turn determines the animal biomass.

The human species, *Homo sapiens*, emerged in its present form as recently as approximately 200 000 years ago, by studies of mitochondrial genetics (S Marzuki, pers. comm. 1997), and ventured out of Africa as a group of about 500 individuals around 137 000 years ago.[3] It coevolved with other species, primates and large animals, until approximately 60 000 years ago. Technology, by way of traps, nets and spears, allowed it to be successfully competitive.[4] The ecological niches of the species broadened, and has continued to do so. Biodiversity was by this stage also particularly affected by the human species.

As discussed by Kellert,[1] Edward Wilson developed the concept of 'biophilia' for 'a deep biological need for affiliating with life and nature'. In turn, Kellert has propounded nine values of nature that have to do with human development (Table 1).

Although in America the humanistic value is dominant, the values are undergoing a temporal and demographic shift, with a decline in the utilitarian and a rise in the ecologistic-scientific values. This may provide some optimism for an arrest in the decline in biodiversity, although population pressures and political factors may supervene. It may represent a return to traditional ecological knowledge and wisdom.[5]

Determinants of ecosystem relationship and global warming

Atmospheric pollution and global warming present an increasing human impost on viable ecosystems as temperature increases firstly, evaporative aerodynamics (affecting the proportion of the land covered by foliage), and secondly, stem-root respiration (affecting the stature of vegetation).[2,6]

The aerodynamics of the wind flowing over and through a plant community influences the horizontal spread of foliage

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(foliage projective cover (FPC)) in both the overstorey and understorey strata, so that the sum of the two FPC remains a constant. Furthermore, as well, the structure, physiology and biochemistry of all developing leaves are determined by evaporative aerodynamics in the gradient from the arid to the perhumid climatic zone, and from the tropics to temperate zones.[2]

A small proportion of the solar radiation intercepted by overstorey FPC is fixed by photosynthesis, the amount depending on ambient temperature, water and nutrient stress; during a short period of the year, foliage shoot growth (and fruit production) is initiated in the canopy. Because the biomass (dry weight, kg) of a tree in a plant community depends on the area (FPC, m^2) of its canopy, an allometric relationship has been demonstrated between annual shoot growth (per hectare) and descriptors of the plant community: stand density (number of trees per hectare), stand height (m), basal area (m^2 of stems at breast-height). Species richness (per hectare) of both overstorey tree species and vertebrates (possibly invertebrates, as well) are also allometrically related to Annual Shoot Growth.[2]

Annual biomass production (ABP) reflects these ecosystem relationships. Biodiversity (BD) (per hectare) thus depends on: (i) the proportion of the ground covered by overstorey foliage (FPC); and (ii) the amount of growth (leaves and fruits) produced annually by this foliage canopy. Any perturbation which upsets either or both of these parameters will lead to a reduction in biodiversity (per hectare). Global warming will increase the evaporative aerodynamics of the atmosphere throughout the world and reduce the (horizontal) proportion of the ground covered by overstorey foliage.[2] Thus:

Closed-forests → Open-forests → Woodlands → Open-woodlands
FPC > 70% → 70–50% → 50–30% → < 30%

Water and nutrient stress, along with pollution and pests, may also affect the annual growth (vertical) of the foliage canopy, usually cancelling the small increase in photosynthesis due to increased carbon dioxide. The biodiversity of each of the world's ecosystems is in jeopardy.

Indigenous Australians

The biodiversity of rainforest remnants and wetland vegetation in monsoonal northern Australia ensured a wide variety of plant foods for the hunter-gatherers who arrived on the continent over 50 000 years ago.[7,7a]

Monsoonal rainforests

22 spp. fruit and 1 spp. yam (wet season – 8 spp.; dry season – 10 spp.)

Wetland vegetation

7 spp. fruit and 18 spp. yam (wet season – 4 spp.; dry season – 18 spp.)

The dryland eucalypt forest contained fewer plant foods

4 spp. fruit and 3 spp. yam (wet season – 4 spp.; dry season – 5 spp.)

Time and motion studies with Aboriginal tribal groups in Arnhem Land enabled food consumption of animal and plant foods (and their nutritional values) to be assessed during four seasons of the monsoonal year;[8,9] these data were compared with the food consumption of Aborigines residing in settlements.[10] The health and nutritional status of the two groups, when compared,[11] indicated the advantage for the hunter-gatherer of the diversity of 'bush-tucker', in comparison with the 'flour-sugar-tobacco-tea' available in the settlements at that time (i.e. 1948). After a few weeks of living on 'bush-tucker', a great improvement was noted in the health of the Aborigines.[11] However, the dearth of plant foods at the end of the dry season reduced ascorbic acid intake from over 100 mg to less than 30 mg per day.[8]

The techniques available to the nutrition unit on the American–Australian Scientific Expedition to Arnhem Land, Northern Territory of Australia in 1948 enabled only plant products, that is, protein, fat, carbohydrate, crude fibre, ash and ascorbic acid, to be assessed.[12,13] The survival of hunter-gatherers, who were stranded so long ago on the arid and nutrient-poor Australian continent, depended on the diversity of many phytochemicals in native plant foods and their availability throughout the whole year, not just for a few days.

In 1948, the change from hunter-gatherer culture to a simple form of agriculture was practised in the Umbakumba Settlement on Groote Eylandt, Arnhem Land.[10] The diversity of root vegetables was reduced from 20 to two (cassava and sweet potatoes); only watermelon and a few paw-paws were available as fruit. The nutrition of Aborigines on the Settlement was poorer than of those natives existing on 'bush-tucker'.[11] This diet was still far better than that of 'flour-sugar-tobacco-tea' which was provided in some other settlements in Arnhem Land.

Even in the arid centre of Australia, where plant and animal diversity is low, a range of plant products enabled the Aborigines to remain healthy throughout the year:[14] 3 spp. with tubers and corms; 9 spp. with edible fruits and seeds. Of

Table 1. Values of nature related to human development

Value	Definition	Function
Utilitarian	Practical and material exploitation of nature	Physical sustenance/security
Naturalistic	Direct experience and exploration of nature	Curiosity, discovery, recreation
Ecologistic-scientific	Systematic study of structure, function, and relationship in nature	Knowledge, understanding, observational skills
Aesthetic	Physical appeal and beauty of nature	Inspiration, harmony, security
Symbolic	Use of nature for language and thought	Communication, mental development
Dominionistic	Mastery, physical control, dominance of nature	Mechanical skills, physical prowess, ability to subdue
Humanistic	Strong emotional attachment and 'love' for aspects of nature	Bonding, sharing, cooperation, companionship
Moralistic	Spiritual reverence and ethical concern for nature	Order, meaning, kinship, altruism
Negativistic	Fear, aversion, alienation	Security, protection, safety, awe from nature

course, the gathering of plant foods in central Australia took much more time than was needed near the coast, especially during the driest time of the year.

Human diversity

The development of human diversity has been a wonderful, risky and troublesome journey for our species from its beginnings in Africa, where the human genome is still apparently more diverse than the offshoot which migrated and spread out to cover the globe.[15–20] Human diversity is unique among species for grafting on to genetic diversity non-genetically based behavioural, cultural, technological and residential diversities. With this has gone a remarkable range of eating patterns typified by the broad categories of: forager (until technological advances which facilitated hunting); hunter-gatherer; pastoralist; subsistence agriculturalist; agri-business-urban dweller; and the beginning of a new era of information technology directed eating, underpinned by biotechnology

The omnivorous capacity of the human species has been a biological advantage in withstanding climate change and its effects on the food supply, as well as in enabling migration[21,22] and re-settlement in vastly different ecological niches (e.g. water's edge, the littoral; plains and savannah; bushland; mountain; island; and desert with its oases). In turn, this has required environmental understanding, co-operation or management unless environmental degradation and forced migration were to be accepted; the latter undoubtedly happened at times and may have led to desertification, as with early and more recent pastoralists. Recovery from human-initiated fire, at least on the scale used by hunter-gatherers, was possible within a few years, depending on biomass determinants.[7]

One question is how obligatory human omnivorous behaviour has been, and how much is elective, convenient, economic, attractive or nutritionally advantageous. What is certain is that human life is not sustainable beyond days without water and beyond weeks without certain essential nutrients. However, they can be obtained from a range of foods (e.g. magnesium from seeds, chlorophyll containing plants, and milk; vitamin C from various fruits, vegetables and even from animal tissues; essential fatty acids from selected land plants, sea plants, structural lipids in animals and, especially, depot fat in fish, shellfish and crustaceans and in monogastric animals). Thus, human diversity, food diversity and cultural diversity are achievable despite the metabolic pathway limitations of the species.

Indeed, it may be argued that, because of an unusually large repertoire of essential nutrients (macronutrients, micronutrients, vitamins and minerals, and certain phytochemicals and zoo-chemicals whose essentiality is yet to be defined), the human species is peculiarly destined to be at once highly ecologically dependent and with a requirement to locate various ecological niches for its survival.

The completion of the Human Genome project in the near future and the advent of molecular, especially mitochondrial (maternal), genealogy as a companion to molecular evolutionary studies will allow these ideas to be rigorously tested from a genetic point of view.

It may be, however, that the cultural and technological pluralism we have achieved will override and/or enhance the genetic diversity disproportionately, at least from a global perspective. Noteworthy is the observation that intra-ethnic genetic diversity exceeds the inter-ethnic, but that the reverse is true for cultural (social habit and belief) diversity (perhaps because of the pressing locality need for ecological cohesion). Indeed, it is becoming clear that genetic contributions to health have often been over-rated and ecologically sensitive cultural determinants under-rated because they embrace family units and communities; it is the comparisons of twin and adoptive studies which have shed most light on this phenomenon.[22]

Human influences on biological diversity

It seems that at a critical point in the history of human social and technological evolution the species was able to gain ascendancy over other species with which it had coevolved.[4] It then made inroads on habitats and eco-systems, aided and abetted by the use, at times, of fire. With small numbers and nomadic propensity, eco-system recovery was high.

As interest in particular forms of food grew and the means to propagate and manage these food species grew, the impact on biodiversity increased. Of particular impact were the progressions to herds-people and pastoralists (where milk and meat were sought), to farmers and agriculturalists (where grains and root crops were used as staples), and to horticulture (where fruits and nuts were harvested and cultivated, as with plantain in Africa, coconuts for island communities, or tropical fruits, nuts and yams by indigenous Australians in the continental north). Major changes in world history resulted from these food-seeking practices.[24]

Because of the dependency on these increasingly monocultural practices, there came to be an assumption in human nutrition science that staples were desirable. In reality, they made sustainable food supplies and health more precarious as evidenced when climatic restraints and pestilence compromised production.

Only recently has there been a renewed interest in mixed farming, ecologically robust food production[25–28] and biological control of agriculture production (rather than high dependence on pesticides and herbicides). This ecological approach to farming has been referred to as 'permaculture'.[25,26]

Fortunately, the remaining available gene pool is providing new opportunities for biotechnology and genetically modified organisms to reduce some of these human initiated pressures on biodiversity. However, the management of these new technologies needs to acknowledge the value of maintained biodiversity.

Food determinants of human evolution

One of the stark realities becoming clearer is the extent to which the biosphere affects our own evolution. Mostly, we have thought about this in terms of natural selection, as though our survival was complementary to our biological fitness. But approximately 200 000 years of defined *Homo sapiens* is but a tiny fraction of the history of the earth's biosphere. Many species, dominant in their locality through size, numbers or predatory advantage have withered and disappeared. Some trees, such as the gymnosperms and the ancient Gondwanan angiosperms, and associated reptiles, rattite birds and insects are remarkably enduring.

We might well ask what confers biospherical longevity? Is it simple nutrient requirements, climatic adaptability, relative independence or limited interdependence, or some combination of these factors? Dependence on one or a few foods to the exclusion of others, as with the Australian koala which lives only on eucalyptus leaves, makes a species particularly vulnerable. If one can switch from one food to another as a nutrient source, as is the case with humans, perhaps the pressures of food supply on our biological evolution can be resisted – otherwise there may be some unpredictable changes afoot for humans!

One species defence mechanism humans have had is the ability to procreate in the face of famine, unless it be extreme to the point where female reproductive function ceases. The price, however, is high infant mortality, as high as 50% (or even more), by five years of age, which still obtains where food security is precarious and where proneness to infectious disease through malnutrition-related immunodeficiency is the prime cause of death. With increasing food security, fecundity, but usually not fertility, tends to decrease by quite complex, dominantly social means. This outcome of controlled population size may, however, occur with little or much cost to the biosphere. Where there is much cost (e.g. through monocultural agriculture), there is likely to have been a period of population instability (further increasing as the food supply quantitatively improves, which happened with the introduction of potatoes and maize crops into Europe from the Americas; in turn there was emigration of excess population) followed by reduced fecundity, but ongoing risk of recurrent food insecurity and further population instability.[24] One of the most troubling possibilities is that food crop biotechnology may produce a further population increase.

Somehow, we must regenerate ecological niches which allow annual biomass fixation and associated biodiversity to be optimized. Improved landcare is one of the most available strategies.[29] What are the critical levels to which a diverse human food chain can go before human survival, let alone optimal health, is threatened?

One interesting way of considering food and the successful, whilst vulnerable, aspects of human evolution is the dependency of the regulation of human physiology and metabolism on food components. Plant chemicals (phytochemicals) with hormonal activity were known to be present in human biological fluids like urine. In the late 1980s we demonstrated, in menopausal (oestrogen-deficient) women, that foods containing isoflavones (soy) and lignans (linseed) could partially reduce the impact of the menopause.[30,31] It was as though, for successful ageing in women, the body's own endocrine system needed a complementary biospherical hormonal input. Of course, on reflection, this is a broadening of the concept of essential nutrients to the ecosystem and optimal health — 'eco-nutrition'. There are bound to be many more examples of this in the human food and health experience; some examples may already have been lost through environmental degradation and affected irrevocably our biology. Other potential losses can be anticipated. For example, walking in the bush or forest exposes our olfactory system to multiple smells. The olfactory apparatus has countless receptors for countless molecules, many of which are in our food stuffs. The olfactory system is linked to memory and almost certainly facilitates it. Thus, the activity-food-memory linkage will be most operative with an intact ecosystem of significant biodiversity. Food memory itself is dependent on a host of inputs related to a food, such as tactility, smell, appearance, taste and texture.[32]

Not least is the realization that genetic expression can be nutritionally dependent: we may have genes potentially detrimental, as for diabetes, but their manifestation can be environmentally dependent, even to the extent of their own regulation by nutrients. There are now numerous examples of gene regulation by essential nutrients (such as iron and essential fatty acids) and phytochemicals (such as isoflavones).

It is a very interesting phenomenon that our physical appearance may also be affected by the food we eat. To take a simple example, with foods requiring greater mastication (e.g. foods high in dietary fibre), the muscles of mastication develop to a greater extent and jaw shape changes. Stature is clearly dependent on early life nutrition. It is likely that appearances associated with biological ageing, such as skin wrinkling, kyphosis, laryngeal function, cognitive function and reproductive function, will be progressively linked, in part, to food intake.

People also tend to smell like the food they eat, which accentuates the environmental niche.

Food variety and human health

The most internationally agreed upon dietary guidelines specify the promotion of breast feeding and the enjoyment of food variety. At the beginning of extra-uterine existence we can depend on one food alone, from one's mother, ideally eating a variety of foods herself, and, thereafter, we explore a widening array of foods, if they are available, and achieve food variety.

Simple ways of expressing food variety mathematically (number of biologically distinct foods eaten over a nominated time frame) are now current.[33–38] Greater food variety in the human diet predicts capacity for survival and reduced morbidity across ethnic groups.[39,40] More socially active people are more likely to achieve food variety.[41]

The combination of social activity, physical activity and food variety is the most likely lifestyle profile to optimize health, reflected in longevity and healthy ageing.[42] It is an approach which is also likely to reduce substance abuse. But it is predicated on biodiversity for food variety and environments in which it is a pleasure to be active, both socially and physical.

Biodiversity and human health

There are several ways in which biodiversity confers health:[6]

1. A varied food supply is essential to maintain the health of the omnivorous human species.
2. A range of diverse food sources is necessary to safe-guard against climatic and pestilent disasters which may affect one or more of the food sources.
3. A diversity of plants and animals may provide a rich source of medicinal material, essential for the extraction of undiscovered therapeutic compounds.
4. Intact ecosystems of indigenous plants and animals appear to act as a buffer to the spread of invasive plants and animals, and of pathogens and toxins, thus contributing to the health of populations nearby.

5. The 'spiritual' values of exploring the diversity of plants, animals and ecosystems in an area appear to have a beneficial effect on mental health, strengthening the feeling of 'belonging to the landscape'.

Seasons and the added diversity they bring also appear to confer vigour. Even where seasons have been regarded as simply 'dry' and 'wet', as in the tropics, the reality is great change through the solar and lunar years.[1,4]

Food variety and biodiversity

Food variety is indeed contingent on biodiversity.

It is a moot point whether key genetic material for human health can be located in a narrower range of organisms, equivalent to the more biodiverse biomass.

One factor determining the required biodiversity, from a food variety point of view, is obviously the extent of required food variety. Available evidence indicates that, with a week as a time frame, at least 20, and probably as many as 30 biologically distinct types of food, with the emphasis on plant food, are required.[37,38]

One of the more intriguing interfaces between biodiversity and food variety is human resistance to infections such as malaria, a parasite that crossed into the human species near its evolution 200 000 years ago, according to the mitochondrial genetic homology studies of Sangkot Marzuki at the Eijkman Institute in Jakarta. A number of genetic changes in red cell metabolism have featured in populations exposed to malaria, notably sickle cell anaemia and various haemoglobinopathies. Glucose 6-phosphate dehydrogenase deficiency limits use of a plant food, broad beans, and is known as favism, but partially protects against malaria. Here a food restriction is required for survival prospects.

Eco-nutrition

We are arguably at the point in human history where our food supply and health will be jeopardised by a further decline in biodiversity. Already desolate environs may yet be rehabilitated by phyto-remediation techniques coming out of the new plant biology of elite clones.[43] Gordon writes about the potential for perennial rather than animal grain crops, reducing intercrop top soil loss.[29]

There will be increasing value in the articulation of eco-nutrition as a field of scientific enquiry and health advocacy.[6,44] Arguably, it is the most critical conjunction of all the sciences for human survival, health and well-being.

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