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# Nutrient Flow in a Major Urban Settlement: Hong Kong

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*A nutrient balance is established for the contemporary urban ecosystem of Hong Kong. The flow of nutrients in the Hong Kong food system in particular is examined, including current and potential nutrient recycling patterns. Losses of nutrients in food for human consumption are found to be up to 20% for major nutrients. The flow of mineral phosphorus in the Hong Kong food system is examined in detail. About 3600 tonnes of phosphorus are lost from the Hong Kong food system each year. A comparison is made between the land-based forage area demand of the Hong Kong population and a similar-sized Western population, that of Sydney, Australia. It is estimated that the average Hong Kong person consumes a diet which requires only half the land area needed to produce the diet of the average Sydney person. However, Hong Kong relies on the ocean for 25% of its animal protein supply compared with 2.5% for Sydney. Patterns of food production and nutrient recycling are proposed, with the aim of optimizing resource utilization in close association with contemporary urban settlements.*

**KEY WORDS:** urban ecosystems; Hong Kong; nutrient flow; recycling; diet.

## INTRODUCTION

Urbanization has proceeded apace in the 20th century, and projections for the year 2000 indicate that 63% of the population of developed countries will reside in urban settlements (United Nations, 1969). Early in the 21st century urban settlements will constitute the most common environment for human habitation. The task of sustaining life-supporting systems in urban environments presents unique problems, not the least of which is to ensure a continued flow of essential nutrients to expanding urban populations. Until the 20th cen-

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tury most of mankind remained in close proximity to the sources of nutrients essential to its survival. Before long the great majority of the world's population will rely for nutrients on intricate and extensive networks of supply encompassing not only the local region but areas of high agricultural productivity in distant parts of the world. The situation already prevails for populations in the developed world.

Effectively, urban settlements are vast loci where the consumption of energy and key materials such as nutrients exceeds their production. Hence an understanding of the patterns of consumption and disposal of energy and materials in urban settlements is of obvious importance to modern man.

The work presented in this paper, as part of the Hong Kong Human Ecology Programme,[2] documents the supply of nutrients to the urban settlement of Hong Kong and discusses questions related to the origin and ultimate fate of nutrients entering the city ecosystem.[3] We have also examined the potential for nutrient conservation and recycling and have paid particular attention to the likely impact of Western influences on the forage area[4] requirement for nutrient production and the process of nutrient cycling in Hong Kong, a city whose system ecology is strongly influenced by Chinese cultural traditions. An examination of questions of nutrition in an urban population is a natural concomitant of a study dealing with overall patterns of nutrient flow and is presented elsewhere (Newcombe, 1976a).

## THE SETTING OF HONG KONG

Hong Kong (latitude 22°N) is located on the south coast of China, extending into the South China Sea. Its population in March 1971 was about 3.9 million people. Hong Kong's land area, including the new Territories, is 1046 $km^2$.

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[3] The original definition given by Tansley (1935) is adopted here, whereby an ecosystem is an open-ended, not necessarily self-sustaining portion of a larger system with which there may be a constant exchange of organic and inorganic materials, organisms, and so on.

[4] Forage area here refers to the surface area of the earth required to produce foodstuffs directly or after flowing through additional trophic levels for a specified human population. It refers to the total surface area utilized anywhere in the world to provide food for that human population. Although entirely appropriate, we have not in this paper included in forage area the surface area utilized in the production of other resources used for agricultural production, such as water, energy, and materials for machinery. Also, because of insufficient data, we have been unable to estimate meaningfully the sea-based forage area for marine produce.

There are 253 islands, the largest ones being Hong Kong Island, Lantau Island, and Lamma Island. The terrain is mountainous and rugged, with very little land available for settlement and agriculture. Only some 124 km$^2$ can be regarded as arable land. In fact, in 1971, only 12,103 hectares (ha) were used for agricultural production, including 3633 ha of fallow. It is important in the context of the present study to note that Hong Kong is a major fishing port. Hong Kong's fishing fleet is composed of 5200 vessels, ranging from junks to trawlers, which travel as far as the Paracel Islands, 640 km to the south, to maintain a regular input of fresh marine produce to the Hong Kong population.

## ANALYZING NUTRIENT FLOW

The British colony of Hong Kong is, in effect, a city state. Concurrently, therefore, a study of nutrient flow in Hong Kong is a study of nutrient flow in a contemporary urban settlement. Government records of trade, local production, and so on provide excellent basic data for determining overall patterns of nutrient flow and have been employed here to estimate an input-output balance of nutrients for Hong Kong in the calendar year 1971. This study of nutrient flow deals primarily with nutrients in the Hong Kong food system, although reference will be made to nutrient flow outside the food system.

The procedure adopted to analyze the flow of nutrients was straightforward. All food items listed as imports, exports, reexports, and those produced locally (Census and Statistics Department, 1971; Director, Department of Agriculture and Fisheries, 1972) were grouped into generally recognized categories of foodstuffs, and computations were made to represent their content in terms of the major food components, namely, animal and plant protein, fats, carbohydrates, somatic energy,[5] calcium, iron, thiamine, ascorbic acid, and food water. Food composition tables used to present Hong Kong foodstuffs in terms of their nutrient content were compiled from a wide range of tabulations useful for analyzing foodstuffs common in the region (McCance and Widdowson, 1960; Tung *et al.,* 1961; Platt, 1962; Watt and Merrill, 1963; Daftar Analisa Bahan Mokanan, 1967; Thomas and Corden, 1970; Anonymous, no date) or were estimated in consultation with members of the Commonwealth Department of Health, Australia (M. Corden and E. Hipsley, personal communication, 1974). In estimates of the loss of human food in the flow of nutrients, as many of the potentially important points of food wastage were taken into account as possible. For example, food wastes from marketing and processing operations

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[5] Somatic energy: that energy which is utilized, through the metabolic processes, within a living organism. Here the term most commonly applies to the energy in food. Extrasomatic energy: that energy which flows through or is utilized by a human community and and which is not utilized through metabolic processes within a living organism. In this research "extrasomatic energy" only includes fuels in current use.

and nutrients in domestic and commercial refuse were analyzed in considerable detail. Nutrients held in stocks of human food in Hong Kong were also included in the analysis. Here it was found that the amounts and kinds of foods held in reserves and storage, including those required by legislation, did not change significantly during the period. In addition they constituted a negligible proportion of the total flow of nutrients.

Through use of the above information a balance of nutrients retained in the Hong Kong food system as food for human consumption was derived from the sum of imports and local production, minus the sum of exports, reexports, and estimated or "known" losses. Nutrients in animal feedstuffs and fertilizers were not included in drawing up this balance. The balance of nutrients obtained in this manner is essentially the apparent consumption of food by the human population.

## NUTRIENT SUPPLY

Figure 1 is a schematic representation of nutrient flow in the Hong Kong food system. It shows that important sources of nutrients entering the Hong Kong ecosystem are imported human and animal food and fertilizers. From this input of nutrients are derived food stocks, human and animal feed and fertilizer exports, nutrient supplements to local agricultural production, and, of course, food wastes. The movement of nutrients in the Hong Kong ecosystem is complex, with some part of the initial input of nutrients being recycled as either animal feed or fertilizers. Needless to say, although the manner in which the data are presented gives the impression of a static balance, the flow of nutrients is dynamic.

The overall picture is that, while local production makes an important contribution to local nutrient consumption, Hong Kong nevertheless relies heavily on imported nutrients. There is little throughput of nutrients in the form of exports of human food, animal feed, or fertilizer. Losses within the food system are large and a portion of the losses from food formerly fit for human consumption is recycled as animal feed or fertilizers.

An important anomaly in the presentation of data is that local production statistics include marine products harvested from the South China Sea, well outside Hong Kong territorial waters. For the purpose of constructing a nutrient balance we treat such nutrients as being locally produced, but we refer, on occasion, to the more strict definition which encompasses only those nutrients produced within the territory of Hong Kong. Virtually none of the marine products included under local production are in fact produced within Hong Kong territory.

This broad perspective is confirmed in the detail of the tabulations presented here. Tables I to V present nutrients in the major sectors of nutrient flow

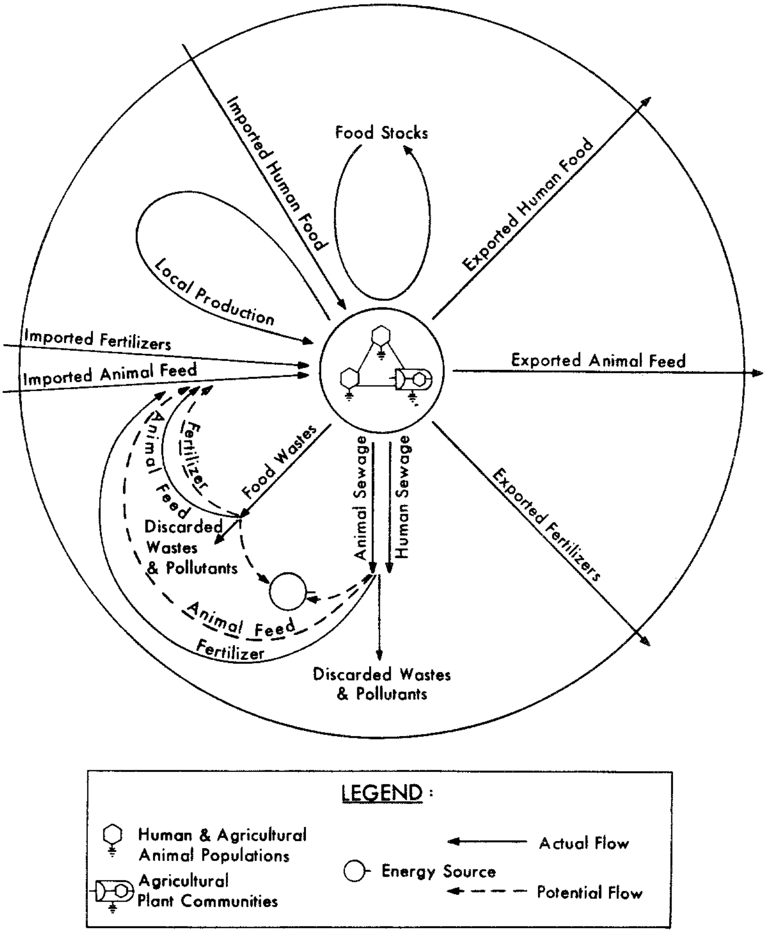

**Fig. 1.** A schematic representation of nutrient flow in the Hong Kong food system.

in Hong Kong, i.e., imports, local production, exports, reexports, and known losses respectively. Each of these contributes to the balance of nutrients available for human consumption, or apparent consumption, in Hong Kong in 1971, as shown in Table VI. Table VII presents retained local production, retained imports, and losses as a percentage of the retained input of particular nutrients and energy to Hong Kong. In addition to such major nutrients as protein, fats, and carbohydrates, calcium is considered here because we have shown elsewhere that it is in unusually short supply in the Hong Kong diet (Newcombe, 1976a). One gains the impression from these figures that fats and calcium produced in Hong Kong are a significant proportion of the total, and this is correct. However,

**Table I.** Imports of Nutrients in Food for Human Consumption[a]

| Category | Protein: Animal, kg × 10⁶ | Protein: Plant, kg × 10⁶ | Fat, kg × 10⁶ | Carbohydrates, kg × 10⁶ | Somatic energy, MJ × 10⁶ | Calcium, kg | Phosphorus, kg | Iron, kg | Thiamine, kg | Ascorbic acid, kg | Water, kg × 10⁶ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Milk and milk products | 4.03 | | 3.62 | 10.78 | 367.14 | 124,221 | 41,188 | 177 | 22 | 3898 | 15.28 |
| Meat and offal | 23.52 | | 60.11 | 2.39 | 3082.07 | 16,745 | 298,571 | 3464 | 920 | 3204 | 90.82 |
| Poultry and fish | 27.98 | | 5.65 | 1.96 | 1335.95 | 141,096 | 324,049 | 2790 | 150 | 6525 | 85.95 |
| Eggs and egg products | 6.88 | | 6.48 | 0.48 | 373.47 | 30,737 | 124,124 | 1321 | 58 | – | 40.22 |
| Oils and fats (inc. butter) | 0.03 | | 3.15 | 0.02 | 118.33 | 640 | 602 | 4 | 1 | – | 0.60 |
| Sugar and syrups | | 0.15 | – | 97.27 | 1588.81 | 21,028 | 3463 | 1806 | 15 | 1 | 41.94 |
| Pulse and nuts | | 2.75 | 5.59 | 4.00 | 401.03 | 7918 | 51,585 | 380 | 100 | 446 | 6.70 |
| Vegetables | | 14.93 | 1.72 | 78.41 | 1592.32 | 126,898 | 356,396 | 8322 | 509 | 44,437 | 228.37 |
| Fruit and fruit products | | 1.79 | 1.86 | 40.72 | 592.27 | 57,983 | 38,159 | 1157 | 138 | 32,409 | 231.15 |
| Grain products | | 53.45 | 8.42 | 627.43 | 11,728.26 | 159,479 | 640,059 | 11,213 | 549 | – | 94.22 |
| Beverages | | 4.33 | 3.73 | 11.16 | 501.45 | 34,798 | 88,875 | 2256 | 4 | 16,014 | 2.85 |
| Miscellaneous | | 1.11 | 3.42 | 2.86 | 307.72 | 27,168 | 17,190 | 176 | 18 | 914 | 11.24 |
| Totals | 62.44 | 78.51 | 103.75 | 877.48 | 21,988.82 | 748,711 | 1,984,261 | 33,066 | 2484 | 107,848 | 849.34 |

[a] Source: Census and Statistics Department (1971).

**Table II.** Local Production of Nutrients as Food for Human Consumption[a,b]

| Category | Protein: Animal, kg × $10^6$ | Protein: Plant, kg × $10^6$ | Fat, kg × $10^6$ | Carbohydrates, kg × $10^6$ | Somatic energy, MJ × $10^6$ | Calcium, kg | Phosphorus, kg | Iron, kg | Thiamine, kg | Ascorbic acid, kg | Water, kg × $10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Milk and milk products | 0.02 | | 0.03 | 0.03 | 1.89 | 772 | 644 | 1 | * | 7 | 0.59 |
| Meat and offal | 2.68 | | 9.89 | 0.01 | 424.64 | 1632 | 38,436 | 418 | 2 | 46 | 10.13 |
| Poultry and fish | 39.36 | | 3.94 | 0.30 | 859.77 | 204,400 | 386,395 | 3873 | 159 | 321 | 134.99 |
| Eggs and egg products | 0.96 | | 0.88 | 0.05 | 51.02 | 4112 | 16,599 | 183 | 8 | – | 5.61 |
| Vegetables | | 4.25 | 0.71 | 9.20 | 217.58 | 184,859 | 8597 | 2653 | 140 | 123,298 | 163.63 |
| Fruit and fruit products | | 0.02 | – | 0.36 | 5.01 | 735 | 491 | 10 | 2 | 1118 | 2.45 |
| Grain products | | 1.38 | 0.12 | 17.26 | 318.44 | 3621 | 23,643 | 149 | 17 | – | 2.66 |
| Totals | 43.02 | 5.65 | 15.57 | 27.21 | 1878.35 | 400,131 | 474,805 | 7287 | 328 | 124,790 | 320.06 |

[a] Source: Director, Agriculture and Fisheries Department (1972). Local production here includes marine products harvested outside Hong Kong territory.

[b] (*) Negligible.

**Table III.** Exports of Nutrients in Food for Human Consumption[a,b]

| Category | Protein | | Fat, kg × $10^6$ | Carbohydrates, kg × $10^6$ | Somatic energy, MJ × $10^6$ | Calcium, kg | Phosphorus, kg | Iron kg | Thiamine, kg | Ascorbic acid, kg | Water, kg × $10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Animal, kg × $10^6$ | Plant, kg × $10^6$ | | | | | | | | | |
| Meat and offal | 0.01 | – | 0.01 | – | 0.66 | 14 | 28 | 2 | * | – | 0.02 |
| Poultry and fish | 1.26 | – | 0.07 | 0.03 | 28.66 | 98,847 | 20,368 | 125 | 4 | 92 | 4.42 |
| Eggs and egg products | * | – | * | * | 0.30 | 32 | 124 | 1 | * | – | 0.02 |
| Vegetables | | 0.29 | 0.13 | 1.50 | 32.00 | 3367 | 11,883 | 368 | 5 | 237 | 1.82 |
| Fruits and fruit products | | 0.01 | 0.01 | 0.37 | 26.21 | 108 | 351 | 7 | * | 104 | 1.18 |
| Grain products | | 1.51 | 0.78 | 10.83 | 242.04 | 9142 | 48,791 | 183 | 29 | – | 1.53 |
| Beverages | | 0.09 | 0.02 | 0.38 | 10.05 | 216 | 1924 | 61 | * | 621 | 1.07 |
| Miscellaneous | | 0.36 | 0.13 | 1.11 | 209.60 | 13,568 | 8040 | 43 | 4 | 630 | 1.72 |
| Totals | 1.27 | 2.26 | 1.15 | 14.22 | 549.52 | 125,294 | 91,509 | 790 | 42 | 1684 | 11.78 |

[a] Source: Census and Statistics Department (1971).
[b] (*) Negligible.

Table IV. Reexport of Nutrients in Food for Human Consumption[a,b]

| Category | Protein | | Fat, kg × $10^6$ | Carbohydrates, kg × $10^6$ | Somatic energy, MJ × $10^6$ | Calcium, kg | Phosphorus, kg | Iron, kg | Thiamine, kg | Ascorbic acid, kg | Water, kg × $10^6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Animal, kg × $10^6$ | Plant, kg × $10^6$ | | | | | | | | | |
| Milk and milk products | 0.31 | | 0.30 | 0.79 | 32.16 | 11,970 | 5538 | 24 | 6 | 574 | 0.35 |
| Meat and offal | 0.24 | | 0.64 | 0.03 | 15.82 | 233 | 1382 | 35 | 1 | 43 | 0.93 |
| Poultry and fish | 0.93 | | 0.09 | 0.01 | 20.95 | 10,492 | 12,130 | 122 | 2 | 13 | 1.58 |
| Eggs and egg products | 0.08 | | 0.08 | 0.01 | 4.27 | 390 | 1569 | 17 | 1 | – | 0.49 |
| Oils and fats (inc. butter) | | | 0.05 | – | 2.06 | 11 | 11 | * | * | – | 0.01 |
| Sugar and syrups | | | – | 38.14 | 622.93 | 1515 | 354 | 114 | 1 | * | 2.22 |
| Pulse and nuts | | 0.99 | 1.74 | 0.93 | 103.11 | 2386 | 17,970 | 127 | 32 | 48 | 0.86 |
| Vegetables | | 4.64 | 0.35 | 21.59 | 299.62 | 26,801 | 93,149 | 1971 | 33 | 12,576 | 31.83 |
| Fruits and fruit products | | 0.13 | 0.08 | 4.99 | 83.72 | 3918 | 4196 | 115 | 11 | 2322 | 25.85 |
| Grain products | | 1.63 | 0.24 | 17.94 | 339.07 | 4562 | 24,448 | 216 | 24 | – | 2.78 |
| Beverages | | 3.00 | 3.31 | 6.71 | 288.82 | 28,476 | 42,648 | 1140 | * | 2894 | 1.03 |
| Miscellaneous | | 0.01 | 0.19 | 0.05 | 21.64 | 1898 | 463 | 5 | * | 46 | 0.33 |
| Totals | 1.56 | 10.40 | 7.07 | 91.19 | 1934.17 | 92,922 | 203,858 | 3886 | 111 | 18,515 | 68.26 |

[a] Source: Census and Statistics Department (1971). Reexports are exports of goods previously imported.

[b] (*) Negligible.

Table V. Known Nutrient Wastes in Hong Kong, 1971[a]

| Category | Protein: Animal, kg × 10⁶ | Protein: Plant, kg × 10⁶ | Fat, kg × 10⁶ | Carbohydrates, kg × 10⁶ | Somatic energy, MJ × 10⁶ | Calcium, kg | Phosphorus, kg | Iron, kg | Thiamine, vitamin B, kg | Ascorbic acid, vitamin C, kg | Water, kg × 10⁶ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Domestic refuse[b] | 4.6 | 5.23 | 7.08 | 50.65 | 1271.71 | 76,828 | 137,557 | 1778 | 194 | 40,956 | 79.20 |
| Condemned food[c] | 0.04 | – | 0.03 | 0.06 | 3.03 | 107 | 452 | 5 | * | – | 0.19 |
| Abattoir wastes[d] | 0.44 | – | 1.42 | – | 60.87 | 2319 | 55,417 | 598 | 195 | – | 1.44 |
| Market wastes[e] | 0.18 | 1.28 | 0.36 | 14.75 | 246.19 | 43,544 | 30,911 | 1032 | 96 | 44,246 | 118,18 |
| Restaurant and stall wastes for pig food[f] | 1.75 | 6.03 | 6.30 | 60.66 | 1373.86 | 25,859 | 130,222 | 1438 | 200 | 4750 | 51.09 |
| Total known waste | 7.01 | 12.54 | 15.19 | 126,12 | 2955.66 | 148,657 | 354,559 | 4851 | 685 | 89,953 | 250.10 |

[a] (*) Negligible.

[b] Personal communication, R. Grieve, Maunsell Consultants, Asia, Hong Kong, 1974. Analysis revealed approximately 0.22 lbs food matter per day, ranging from less than ½ in. to more than 1¼ in. in size, and approximately 20% as animal matter, 80% vegetable matter for which food composition formula was devised in accordance with main food types present.

[c] Personal communication, Un Wai-Kwok, Urban Services Department, Hong Kong, 1974. Detailed analysis of food destroyed following inspection in 1971.

[d] Personal communication, Chan Kin Wang, Kennedy Town Abattoir, and Ho Man Chan, Cheung Sha Wan Abattoir, 1974. Very small private abattoirs in the New Territories were assumed to have negligible wastes by comparison.

[e] Personal communication, Yu Hon Ping, Li King Hung and Yuen Wai-Keung, Urban Services Department, Hong Kong, 1974, regarding Kennedy Town Markets, regarding vegetable wastes. N. K. Lee, Agriculture and Fisheries Department, Hong Kong, 1974, and Ip Yuek-Lam, The Association of Dealers in Fruit, Vegetables, Beef, Mutton, Poultry, Pork and Fish, Hong Kong and Union Egg Corporation Ltd., 1974, regarding vegetable, poultry, fish, fruit, and egg wastes in Hong Kong.

[f] Estimated from "Pig Manure Treatment and Disposal" Bulletin No. 3, February, 1975, Agriculture and Fisheries Department, Hong Kong, and personal communication, J. E. J. Revell, Agriculture and Fisheries Department, Hong Kong, 1975.

**Table VI.** Nutrient Balance for Hong Kong, 1971[a]

| Category | Protein |  | Fat, kg × 10⁶ | Carbohydrates, kg × 10⁶ | Somatic energy, MJ × 10⁶ | Calcium, kg | Phosphorus, kg | Iron, kg | Thiamine, kg | Ascorbic acid, kg | Water, kg × 10⁶ |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Animal, kg × 10⁶ | Plant, kg × 10⁶ |  |  |  |  |  |  |  |  |  |
| Imports | 62.44 | 78.51 | 103.75 | 877.48 | 21,988.82 | 748,711 | 1,984,261 | 33,066 | 2484 | 107,848 | 849.34 |
| Local production | 43.02 | 5.65 | 15.57 | 27.21 | 1878.35 | 400,131 | 474,805 | 7287 | 328 | 124,790 | 320.06 |
| Total input | 105.46 | 84.16 | 119.32 | 904.69 | 23,867.17 | 1,148,842 | 2,459,066 | 40,353 | 2812 | 232,638 | 1169.40 |
| Export | 1.27 | 2.26 | 1.15 | 14.22 | 549.52 | 125,294 | 91,509 | 790 | 42 | 1684 | 11.78 |
| Reexport | 1.56 | 10.40 | 7.07 | 91.19 | 1834.17 | 92,922 | 203,858 | 3886 | 111 | 18,515 | 68.26 |
| Known wastes | 7.01 | 12.54 | 15.19 | 126.12 | 2955.66 | 148,657 | 354,559 | 4851 | 685 | 89,953 | 250.10 |
| Total output | 9.84 | 25.20 | 23.41 | 231.53 | 5339.35 | 366,873 | 649,926 | 9527 | 838 | 110,152 | 330.14 |
| Apparent consumption | 95.62 | 58.96 | 95.91 | 673.16 | 18,527.52 | 781,969 | 1,809,140 | 30,826 | 1974 | 122,486 | 839.26 |

[a] Source: Tables I-V.

67% of the animal protein listed under local production is in fact imported from the South China Sea. Thus, in effect only 13% ($14.07 \times 10^6$ kg) of animal protein is locally produced, while 28% is imported by the large commercial fishing fleet based in Hong Kong. Of this $14.07 \times 10^6$ kg of animal protein produced in Hong Kong territory, $6.33 \times 10^6$ kg is from fresh-water fish, $5.04 \times 10^6$ kg from poultry and eggs, $2.65 \times 10^6$ kg from pork, $0.03 \times 10^6$ kg from beef, and $0.02 \times 10^6$ kg from milk.

From the above data on the sources of animal protein produced within Hong Kong territory, we can see that $7.7 \times 10^6$ of animal protein are derived from pig and poultry products. In Hong Kong the pig and poultry populations are fed on both recycled feed and imported feed. Table V shows that $7.8 \times 10^6$ kg of plant and animal protein from commercial food refuse are recycled for animal feed, largely for pigs. Ten percent, or about $1.0 \times 10^6$ kg, of domestic refuse (see Table V) is also estimated to be recycled as animal feed (Binnie and Partners, 1974). Imported animal feedstuffs include cereal concentrates such as brans, oilcakes, and various meals. On the basis of trade information (Census and Statistics Department, 1971) and appropriate conversion factors to calculate digestible protein content (Morrison, 1958), it appears that imported animal feeds contain roughly $17.7 \times 10^6$ kg of digestible protein. Recycled and imported animal feed together provide $26.5 \times 10^6$ kg of digestible protein. The implication here is that the conversion efficiency of feedstuff protein to animal protein by the pig and poultry population is 29%. But, in reality, it is likely that the conversion efficiency is closer to 20% and that there are additional, unaccounted for sources of animal feed such as domestic refuse, wastes from crop production, and so on. These assumptions appear reasonable considering, first, that the conversion efficiency of feed protein to animal protein is generally accepted as being between 15 and 19% (Godden, 1948), and, second, that the Agriculture and Fisheries authorities in Hong Kong suggest that they have underestimated the amount of food wastes recycled as pig feed.

Feed protein for the local bovine population comes mainly from crop residue and free-range grazing over approximately 3600 ha (C. T. Wong, Department of Agriculture and Fisheries, personal communication, 1974). Milk cows in Hong Kong consume a tiny amount of imported feedstuffs and they graze over about 50 ha of pasture land.

The other major source of animal protein produced within Hong Kong territory is fresh-water fish. During the 5-year period 1970-1974 the land area occupied by fish ponds increased from 940 to 1370 ha (Director, Department of Agriculture and Fisheries, 1974). This expanding industry does not require imported feeds or a share of recycled food wastes. However, as will be discussed later, the nutrients required for local fish culture form a vital part of nutrient flow in the Hong Kong ecosystem.

Although some food wastes are recycled as animal feed, losses of food for human consumption are considerable and more detailed discussion of food losses is warranted.

## LOSSES OF NUTRIENTS

The losses of nutrients considered here are those from food available for human consumption. Table V contains data on these nutrients under the heading "known nutrient wastes." Clearly it is difficult to account for all losses of nutrients from human food. Nevertheless, the data shown in Table VII indicate that the nutrient losses we have been able to record form a considerable proportion of the nutrients in food available for consumption in Hong Kong. By these records, 18% of plant protein and 14-16% of other important nutrients retained in the Hong Kong ecosystem as human food are ultimately unavailable for human consumption. These losses, with the exception of animal protein, represent 16-22% of apparent consumption (see Table VII). In contrast to large losses of other nutrients, only about 7% of animal protein is lost from human food. This is all the more exceptional because, out of the total of animal and plant protein lost, animal protein makes up only 32%, whereas it comprises 64% of the total protein available for human consumption. Presumably there are strong economic incentives which ensure that the generally more expensive animal protein is subjected to greater care and supervision, aimed at preventing losses during the food preparation and marketing processes.

There are at least two reasons for concern about such large losses of nutrients in the Hong Kong food system. First, any large-scale loss of nutrients adds to the already considerable burden of world food production or, at least, negates part of that effort to produce enough food. Similarly, each unit of nutrient lost

**Table VII.** Net Local Production, Net Imports and Losses[a] as a Percentage of Net Input of Particular Nutrients and Energy to Hong Kong

| Food component | | Net local production, % | Net imports, % | Losses, % |
|---|---|---|---|---|
| Protein | Animal | 40.6 | 59.4 | 6.9 |
| | Plant | 4.6 | 95.4 | 17.5 |
| Fat | | 13 | 87.0 | 13.7 |
| Carbohydrates | | 1.6 | 98.4 | 15.8 |
| Energy | | 4.7 | 95.3 | 13.8 |
| Calcium | | 29.4 | 70.6 | 15.9 |

[a] Losses (see Table V) are calculated as a percentage of net inputs as the sum of net local production and net imports (see Table VIII).

**Table VIII.** Calculation of Retained Inputs of Particular Nutrients and Energy to Hong Kong (per Capita per Day)

| Food component | | Retained imports (i.e., imports minus reexports) | plus | Retained local production (i.e., local production-exports) | equals | Retained inputs |
|---|---|---|---|---|---|---|
| Protein | Animal | 42.3 g | + | 29.0 g | = | 71.3 g |
| | Plant | 47.4 g | + | 2.3 g | = | 49.7 g |
| Fat | | 67.3 g | + | 10.0 g | = | 77.3 g |
| Carbohydrates | | 546.9 g | + | 9.0 g | = | 555.9 g |
| Energy | | 14,017.8 kJ | + | 924.2 kJ | = | 14,942.0 kJ |
| Calcium | | 456.5 mg | + | 191.2 mg | = | 647.7 mg |

also represents the loss of the extrasomatic energy, water, labor, time, and so on invested in its production.

Second, the loss of nutrients already in short supply in the local diet may lead to, or further aggravate, problems of a nutritional health nature. Calcium, for which the recorded losses are 16% of the total retained input in human food, is in this category of nutrients in Hong Kong.

Our figures on nutrients lost in the Hong Kong food system are clearly underestimates. While these figures corroborate the prediction by the Presidents' Science Advisory Committee (1967) that 15% of foodstuffs are lost in contemporary urban food systems, the likelihood is that actual losses exceed 20% of the retained input of most nutrients.

More careful scrutiny of the points of major nutrient losses, as shown in Table V, gives further cause for concern. For example, in the case of protein, about 90% of the losses are in food wastes from domestic homes, restaurants, and hotels. In other words, so long as a state of reasonable affluence prevails, it will be difficult to encourage consumers to be more frugal in purchasing and preparing their nutrient requirements. However, by way of compensation, much of the food waste listed in Table V enters an unusual system of nutrient recycling of considerable importance to the functioning of the Hong Kong ecosystem.

## RECYCLING: PRACTICE AND POTENTIAL

At least 130 X $10^6$ kg of food wastes from restaurants and food processing plants are transported annually to the pig farms of the New Territories in Hong Kong. This recycling measure substantially maintains a pig population of about 400,000 and provides a source of income and employment for thousands of small farmers. At the same time it overcomes the potentially severely problem of disposing of $130 \times 10^6$ kg of swill, for, whereas most domestic and trade refuse in Hong Kong is incinerated, or used as landfill, wet food wastes are unsuitable for either of these disposal methods. No composting plant was in operation in 1971, although composting will become important in the near future. The Hong Kong Department of Agriculture and Fisheries has only recently experimented with bioconversion plants which produce methane and fertilizer. Therefore, if Hong Kong were without a large pig population, the disposal of $130 \times 16^6$ kg of swill would pose a difficult problem.

However, it takes careful management to maintain a large pig population in a confined area, such as Hong Kong, without generating a sewage pollution problem. Consultant engineers, hired by the Hong Kong government to examine the problem of animal wastes in water catchment zones, have recommended either pumping pig sewage out to sea or, preferably, eliminating pigs altogether (Binnie and Partners, 1974). In effect, they are suggesting either an expensive process to dispose of a highly valuable resource, or the replacement of the pig sewage disposal problem in the New Territories with a pig swill disposal problem in the urban center of Hong Kong. Disposing of pig swill would also mean the loss of the high-quality human food produced from the food waste.

Sewage production by pigs in 1971 was about 1280 tonnes per day (Director, Department of Agriculture and Fisheries, 1973). (The tonne of the metric system equals 1000 kg.) If handled properly, this so-called waste could generate up to $33 \times 10^8$ megajoules (MJ) of extrasomatic energy and more than 100,000 tonnes of valuable fertilizer per annum. The methane which could be generated from the 600 tonnes of poultry manure and 1280 tonnes of pig manure produced daily is equivalent to 4% of Hong Kong's total energy requirements (Newcombe, 1975). Similarly, if all the pig and poultry manure produced in Hong Kong were applied to crop land at the same rate as it was 15-20 years ago in Hong Kong, it would satisfy much of the demand for fertilizer (Newcome, 1976b).

Poultry manure is even more valuable as a resource than is pig manure. Poultry manure is easier to handle, it is a high-grade fertilizer for crop land and fish ponds, and it can be fed to pigs as a protein feedstuff. Because poultry manure is more a solid than a liquid waste, it does not present the same water pollution problems as pig manure, which, with the water used to flush it from production sites, readily flows into waterways.

Experiments by the Department of Agriculture and Fisheries in Hong Kong aimed at drying poultry manure quickly have met with some success (J. E. J. Revell, personal communication, 1975). The Department of Agriculture and Fisheries intends to make dried poultry manure available to farmers as an organic fertilizer and also to experiment with it as a pig food. In 1971 about 10% of poultry manure was used to fertilize vegetable crops and fishponds (Binnie and Partners, 1974). In 1975 fresh-water fish farmers were purchasing all available poultry manure as a result of the increasing expense and general shortage of the usual fertilizer. This use of poultry manure by fish farms is really an extension of an older tradition whereby ducks are reared in association with fish farming, their droppings directly fertilizing the fish ponds. Ducks are one-fifth of the Hong Kong poultry population and an association between duck and freshwater fish farming is common.

Table V shows that domestic refuse constitutes a significant point for nutrient loss in Hong Kong. Currently very few of the nutrients in refuse are recycled, either as foodstuffs or fertilizer. However, composting plants to process approximately 15%, or 600 tonnes, of urban refuse per day, will be in operation by 1979-1980 (H. S. Grewal, Colonial Secretariat, personal communication, 1975). Clearly, more than 80% of the nutrients from food refuse will still be lost, but, if composting proves successful as a disposal method in Hong Kong, the proportions may change in the future.

Finally, the most significant of nutrient flows currently regarded as waste is sewage. An estimated 5900 tonnes (suspended solids) of human sewage is produced daily, 80% of which drains into Victoria Harbour between Hong Kong Island and the mainland. To regard human sewage as no more than a waste that creates a disposal problem is a viewpoint commonly held by engineers, urban planners, and policy makers in the Western world. However, this attitude is relatively new to Hong Kong and quite alien to the Chinese in the Hong Kong population.

During the late 1950s human sewage was applied to agricultural land in Hong Kong at the rate of up to 77 tonnes per hectare (Blackie, 1957). By 1971 virtually no human sewage was applied to Hong Kong cropland (Newcombe, 1976b), whereas in the People's Republic of China all available sewage, human and animal, is recycled into agricultural production (Sebastion, 1972; Sprague, 1975). It is important to see this trend away from applying organic matter to cropland as motivated largely by a change in attitudes towards the practice of agriculture; actually the trend is completely reversible. In this case, as with other forms of nutrient waste, there is good potential for recycling and conservation. Obviously the task appears more difficult and complex the larger each particular urban settlement becomes. Indeed, Borgstorm (1973) has postulated that with urbanization there is an inevitable breach in the flow of mineral nutrients. His postulate can be examined in the context of the following brief analysis of the flow of phosphorus in the Hong Kong food system.

## The Example of Phosphorus

The flow of phosphorus in the Hong Kong food system is depicted in Fig. 2. The amounts of phosphorus involved in each part of the food system are marked on the flow chart in units of kilograms of elemental phosphorus per day. The total input of phosphorus is 12,803 kg/day. The major components

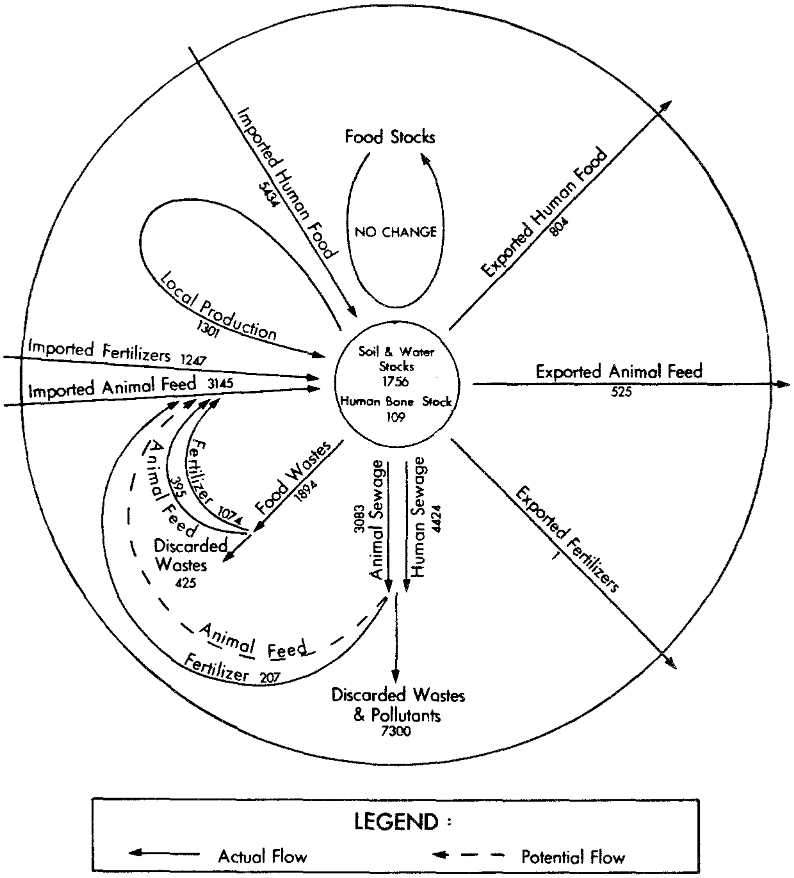

**Fig. 2.** A schematic representation of the flow of mineral phosphorus in the Hong Kong food system in 1971 (kg of P per day).

of this input are human food (42%), imported animal feed (25%), imported fertilizers (10%), and local production (10%). The fate of the phosphorus input is very largely to be lost in human and animal sewage. Thirty-five percent of the phosphorus is disposed of in human sewage and 24% in animal sewage. Fourteen percent is in soil and water reserves and 10% is exported as human and animal food. Only 13% of the total phosphorus input is recycled, 10% as fertilizer from waste food and sewage and 3% in waste human food fed to animals. In effect, some $3.6 \times 10^6$ kg of phosphorus are immobilized in, or discarded from, the Hong Kong ecosystem each year, often eutrophicating freshwater and marine ecosystems in the process. In addition, we have estimated that a further $1.6 \times 10^6$ kg of phosphorus contained in detergents, textile chemicals, and other industrial agents are discarded into Hong Kong marine environments each year.[6]

The data on phosphorus flow have been obtained from a number of sources. Imports, local production, exports, reexports, and food wastes data on phosphous in human food are derived from Tables I to V. Phosphorus in food wastes has been recycled as described for all nutrients in the previous section. A large proportion of the phosphorus recycled from food wastes comes from bone meal. The food waste, namely, bones and minimal scrap meat, was not included among the food wastes listed in Table V. Local fertilizer factories produce some 4000 tonnes of bone meal each year. The phosphorus contents of abattoir wastes which are listed in Table V are included in the estimate of 1074 kg P/day given in Fig. 2 as recycled food wastes.

Data on the import and export of fertilizers and animal feedstuffs (Census and Statistics Department, 1971; Director, Department of Agriculture and Fisheries, 1973) were converted to phosphorus content, with the use of appropriate conversion factors (Spector, 1956: 138-139, 191). The phosphorus content of animal sewage produced in 1971 (Director, Department of Agriculture and Fisheries, 1973) was calculated by using data from analyses of pig and poultry manure conducted by the Department of Agriculture and Fisheries (Y. C. Lim, personal communication, 1974) and of cattle manure conducted by Hart and Turner (1965).

The phosphorus content of human sewage in Hong Kong was obtained by taking the apparent consumption of phosphorus presented in Table VI and deducting an amount representing the phosphorus requirement of the increased human biomass resulting from population growth at given rates (after Aston *et al.*, 1972). The phosphorus content of "actual" sewage would be greater due to the input of detergents and other phosphorus-containing effluents from domestic and household sources. The increase in soil and water reserves of phosphorus is assumed to be the difference between the input and output of phosphorus after all other likely fates are examined.

Recycling of phosphorus occurs very much in the ways we have described for nutrients in general. There are some recent changes in Hong Kong which aid, specifically, the recycling of phosphorus. As mentioned, there has been a reversion to the practice of fertilizing fishponds with poultry manure. The incentive for this move was provided by the scarcity and increased cost of the alternative, superphosphate. In early 1976, 62% of poultry farmers and 36% of pig farmers were utilizing or making available for others at least part of their animal

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[6] 405 tonnes P/yr are discarded from textile wastes (calculated from data from Mr. Short, J. D. Watsons and D. M. Watsons, Consultant Engineers, personal communication, 1975), 430 tonnes P/yr from detergents (calculated from Census and Statistics Department, 1971, and Devey and Harkness, 1973), and 1125 tonnes from P-containing chemicals imported to Hong Kong (calculated from Census and Statistics Department, 1971).

manure. Although this reflects a considerable change compared with 1971 conditions, this is unlikely to have exceeded 20% of total annual sewage, or 750 kg P/day.

Similarly, the new capacity to produce compost from urban waste, and the potential use of sewage sludge rich in phosphorus from advanced treatment works for fertilizer (Watsons and Watsons, 1974), substantially improves the outlook for phosphorus re̊cycling. Phosphorus-rich sludge could also be retrieved from the methane digestors with which the Department of Agriculture and Fisheries is experimenting (J. E. J. Revell, personal communication, 1975). However, the use of these latter kinds of fertilizer is apparently unlikely in any substantial way in the near future (E. H. Nichols, Department of Agriculture and Fisheries, personal communication, 1975).

For the moment there are no proposals to recycle the bulk of human sewage, which we have observed to be the largest source of phosphorus currently lost from the Hong Kong food system. The potential for applying human sewage, at the stage of primary treatment, to agricultural land is much diminished by the lack of available land and the prospect that increasing population will generate even more sewage. This does not mean that human sewage reduced to ash or composted with urban refuse, and thus much reduced in volume, could not largely be recycled within Hong Kong. For this to happen, incentives must be developed to make investment in, and deployment of, suitable technology a feasible proposition. Such incentives might include taxing fertilizers imported for local primary production. The hidden costs of either cleaning up or disregarding pollution caused by human and animal sewage are not included when reckoning agricultural productivity. If they were, there is no doubt that proposals of direct economic tax or subsidy incentives to use organic waste would appear more attractive.

But the recycling which now occurs and which might increase in the future is as much fortuitous as it is related to the desire to conserve phosphorus itself.

There can be no doubt of the economic and ecological profitability of recycling nutirients, such as phosphorus, within the urban ecosystem. This is substantiated by recent in-depth analysis of the energetics of vegetable production in Hong Kong (Newcombe, 1976c). In that analysis it was shown that, in response to a 585% increase in the energy costs of production in the past 15 years, there had been only an 8% increase in yield. With some crops, subjected to the same changes in production methodology, the yield actually decreased. Even where yields increased, at least part of the increase must be attributed to improved plant husbandry and crop varieties. The switch from organic fertilizers to inorganic fertilizers was the largest single factor in this increased energy cost.

For Hong Kong as a whole this transition has meant a reduction in employment opportunities, dependence on an international (oil-based) fertilizer market, and a reduction in critically important water catchment zones and environmental amenity, coupled with an increased cost of treatment and disposal of sewage now regarded as waste. Similarly, recent soil analyses of agricultural land in Hong Kong have revealed severe toxification problems generated by excessive use of artificial fertilizers — another instance in which a breach in nutrient cycling has decreased the long-term economic productivity of man-managed ecosystems.

But there are also economic and cultural barriers to nutrient recycling. Once having used concentrated granulated inorganic fertilizer, organic manures are, by comparison, messy and obnoxious. To the individual farmer there is a gain in convenience and a perceived gain in amenity. Also, depending on the price of inorganic fertilizer in relation to the price of labor required to distribute bulky organic fertilizers, farmers may receive a marginal economic gain.

These barriers are not insuperable; they exist only to the extent that the individual, given adequate information, attaches importance to long-term vs short-term, and societal vs private gain. It is interesting to note that farmers in Kwantung Province in China, a country in which very different economic and social aspirations prevail, import 280 tonnes of nightsoil each week from Hong Kong.

There are other ways in which the conduct of the urban population has a considerable bearing on resource consumption and conservation. The basic composition of the average diet chosen by an urban population influences the size of the forage area of the urban settlement and the amount of resources devoted to feed each individual in the population.

## THE INFLUENCE OF DIET ON FORAGE AREA

Table IX provides a comparison between the daily supply of nutrients, including wastes, to the urban settlements of Hong Kong and Sydney, Australia. The Hong Kong data are derived from Tables I-V. Exports and reexports of nutrients have not been included in the total supply, since they have been regarded as a direct throughput for the Hong Kong ecosystem to other populations. The Australian data are calculated from apparent consumption data documented by the Australian Bureau of Statistics (1971) and related to a population the size of Hong Kong in 1971 (3,939,153). Sydney is given as the Australian city because estimated figures based on the Sydney population and information relating the actual supply of of various nutrient categories to Sydney had previously been shown to compare well (Aston *et al.*, 1972).

The purpose of Table IX, for this study, is twofold. First, it provides a comparison between the nutrient intake of a city in which the people have adopted a typical Western diet, and a city in which the people follow a tradi-

**Table IX.** Comparative Data on Estimated Daily Supply of Nutrients to Hong Kong and Sydney[a,b]

| Food commodity | Energy, MJ × $10^6$ | Protein, kg × $10^4$ | Fat, kg × $10^4$ | Carbo-hydrates, kg × $10^4$ | Calcium, kg × $10^2$ | Iron, kg | Phosphorus, kg × $10^2$ |
|---|---|---|---|---|---|---|---|
| Hong Kong, 1971 (population, 3,939,153) | | | | | | | |
| Milk and milk products | 0.92 | 1.03 | 0.92 | 2.76 | 3.09 | 0.42 | 0.99 |
| Meats and offal | 9.57 | 7.16 | 19.00 | 0.65 | 0.49 | 10.53 | 9.19 |
| Poultry and fish | 5.88 | 17.99 | 2.58 | 0.61 | 6.47 | 17.59 | 18.56 |
| Eggs and egg products | 1.16 | 2.15 | 2.00 | 0.14 | 0.95 | 4.07 | 3.85 |
| Oils and fats | 0.32 | 0.01 | 0.85 | 0.01 | 0.01 | 0.01 | 0.01 |
| Sugar and syrups | 2.65 | 0.04 | | 16.21 | 0.53 | 4.64 | 0.09 |
| Pulse and nuts | 0.82 | 0.47 | 1.06 | 0.84 | 0.14 | 1.89 | 0.92 |
| Vegetables | 4.05 | 3.91 | 0.53 | 17.69 | 7.71 | 23.67 | 7.12 |
| Fruit and fruit products | 1.32 | 0.46 | 0.48 | 9.52 | 1.49 | 2.86 | 0.93 |
| Grain products | 31.43 | 14.17 | 2.06 | 168.88 | 4.09 | 30.05 | 16.16 |
| Totals | 58.12 | 47.39 | 29.48 | 217.31 | 24.40 | 95.73 | 57.82 |
| Sydney (standardized to Hong Kong's population to allow comparison), 1970 | | | | | | | |
| Milk products | 6.50 | 8.74 | 8.22 | 10.95 | 30.21 | 2.36 | 8.55 |
| Meats and offal | 9.53 | 12.25 | 19.11 | 0.20 | 0.77 | 18.51 | 17.05 |
| Poultry, fish and rabbits | 0.91 | 2.99 | 0.90 | – | 0.42 | 2.75 | 4.97 |
| Eggs and egg products | 0.79 | 1.49 | 1.38 | 0.07 | 0.64 | 2.75 | 2.94 |
| Oils and fats | 5.52 | 0.07 | 14.80 | 0.12 | 0.26 | – | 0.16 |
| Sugars | 8.68 | – | – | 53.05 | 0.10 | 0.39 | 0.84 |
| Pulse and nuts | 1.21 | 0.99 | 2.16 | 1.57 | 0.33 | 3.15 | 1.59 |
| Vegetables | 2.67 | 2.12 | 0.16 | 14.69 | 2.20 | 8.26 | 8.29 |
| Fruit and fruit products | 1.40 | 0.39 | 0.04 | 8.95 | 1.17 | 2.75 | 1.96 |
| Grain products | 14.02 | 10.00 | 1.49 | 72.95 | 1.87 | 16.93 | 20.15 |
| Totals | 51.23 | 39.04 | 48.26 | 162.55 | 37.97 | 57.85 | 66.50 |

[a] Source: Hong Kong data, Table VI; Sydney data derived from Australian Bureau of Statistics (1971).

[b] Note: Beverages and miscellaneous categories have been excluded from the analysis, for the appropriate figures are unavailable for Sydney. They comprise about 1% of the Hong Kong daily nutrient supply.

tional non-Western pattern of food consumption, at least as far as major foods are concerned. The Asian diet as represented by the consumption patterns of comparatively affluent Chinese of Hong Kong is high in grain products, poultry, fish, and eggs, and low in milk and milk products, fats and oils (e.g., butter), and sugars when compared with the Western diet characteristic of Sydney. Other important differences between the Sydney and Hong Kong diets, not immediately evident from Table IX, are that in Sydney there is a dominance of beef and mutton rather than pork; wheat and flour rather than rice; potatoes and root crops rather than leafy greens; and apples, pears, and bananas rather than oranges and citrus fruits.

Second, Table IX provides data fundamental for the calculation of estimated forage areas of both Sydney and Hong Kong, as presented in Table X. Before discussing the results presented in Table X, we must stress the limita-

**Table X.** Crude Calculation of Forage Areas for Sydney and Hong Kong (Land Only)[a,b]

| | Sydney | | Hong Kong | | Difference in requirements | |
|---|---|---|---|---|---|---|
| Category | ha | ha/cap | ha | ha/cap | ha | ha/cap |
| Milk and milk products[c] | 486,163 | 0.12 | 68,811 | 0.02 | 417,352 | 0.10 |
| Meats and offal[d] | 2,406,565 | 0.61 | 941,003 | 0.24 | 1,465,562 | 0.37 |
| Poultry[e] | 254,028 | 0.06 | 554,770 | 0.14 | −300,742 | −0.08 |
| Eggs and egg products[f] | 199,495 | 0.05 | 293,300 | 0.07 | −93,805 | −0.02 |
| Oils and fats[g] | 812,960 | 0.21 | 47,128 | 0.01 | 765,832 | 0.20 |
| Sugar and syrups[h] | 17,642 | 0.004 | 5386 | 0.001 | 12,256 | 0.003 |
| Pulse and nuts[i] | 19,206 | 0.005 | 13,015 | 0.003 | 6191 | 0.002 |
| Vegetables[j] | 23,628 | 0.006 | 41,752 | 0.011 | −18,124 | −0.005 |
| Fruit and fruit products[k] | 16,455 | 0.004 | 18,262 | 0.005 | −1807 | −0.001 |
| Grain products[l] | 213,005 | 0.05 | 290,212 | 0.07 | −77,207 | −0.02 |
| Totals | 4,449,147 | 1.12 | 2,273,639 | 0.57 | 2,175,508 | 0.55 |

[a] Source: Table VIII.

[b] Fish products not included in forage area calculations; see text. Beverages and miscellaneous categories, together about 1% of total nutrients, have also been excluded from calculations.

[c] Using current forage area per capita for Australian milk and milk product production of 0.12 ha/caput (Aston *et al.*, 1972) or in energy terms, 13.37 MJ/ha/day.

[d] Hong Kong meat and offal consumption rounds off to 17% beef, 82% pork, and 1% mutton, compared with 42% beef, 12% pork, and 46% mutton for Sydney (Australian Bureau of Statistics, 1971, Census and Statistics Department, 1972). The arbitrary standard for the calculation of forage area is that all animals are fed grain. The yield of grain is taken as the equivalent of Australian wheat at 1330 kg/ha or 56.5 MJ/ha/day. Given the different efficiencies of converting gross energy in feed for the respective meat animals (Morrison, 1958), the weighted average conversion efficiency for Sydney is 7% and for Hong Kong is 18%. Hence productivity is 10.17 MJ/ha/day for Hong Kong and 3.96 MJ/ha/day for Sydney.

[e] Poultry products contribute $0.72 \times 10^6$ MJ/day in Sydney and $1.57 \times 10^6$ MJ/day in Hong Kong. If we assume they are fed grain as in (*d*) and given a 5% efficiency of conversion of gross energy (Morrison, 1958), their productivity is 2.83 MJ/ha/day.

[f] As for (*d*) and (*e*), given a conversion efficiency of 7% and an energy production of 3.96 MJ/ha/day.

[g] Oils and fats are very largely butter in both Sydney and Hong Kong, so the production efficiencies of butter have been used to calculate forage area. About 21.30 lbs of milk are required for 1 lb of butter with a 49% loss of energy in the process. From (*c*) infer a production 6.79 MJ/ha/day.

[h] Sugars and syrups are very largely refined sugar and have been taken as such. Data from the Commonwealth Sugar Refineries Ltd. Australia (P. E. Robinson, personal communication, 1975) on average yields of refined sugar per hectare in major producing countries allowed an estimate of 492 MJ/ha/day.

[i] Pulses and nuts are represented particularly by peanuts in both cities. An average Australian yield of peanuts (1.32 tonnes/ha in shell) has been adopted to estimate forage area (Australian Bureau of Statistics, 1974b). This results in production of 63 MJ/ha/day.

[j] The relative consumption of all major vegetables was calculated for each city (Australian Bureau of Statistics, 1971, Census and Statistics Department, 1972). More detailed information was used for calculations but in broad categories Hong Kong's consumption was roots and tubers 20%, leafy greens 60%, cucurbits 15%, and tomatoes 5%, compared with Sydney's roots and tubers 59%, leafy greens 23%, cucurbits 6%, and tomatoes 12%. Australian average yields and Hong Kong average yields (Australian Bureau of Statistics,

tions and qualifications which apply to the calculations performed to obtain those results. The bases of the calculations are presented in detailed footnotes attached to Table X. Energy of the foodstuffs in each category has been used to estimate the respective and total forage areas. Precise estimates of forage area would be very detailed and complex, requiring information on specific farming techniques, yields of various feedstuffs and concentrates, efficiencies of the various animal converters, losses of each category of foodstuffs prior to entering the urban settlement ecosystems, all for each country exporting food and for the particular year in which it was produced. Therefore, for the purposes of this study assumptions have been made about the yields per unit area for crops, the type of feedstuffs consumed by animals, and the efficiency with which they convert gross energy into somatic energy of the human food they produce. It is especially difficult to estimate the area utilized by grazing animals; so, for convenience, the assumption has been made that they are all grain-fed. Australia and China are major exporters of grain, meat, vegetables, and milk products to Hong Kong, and average yields for Australian and Chinese produce are used to calculate forage area wherever applicable.

Information that would allow the calculation of oceanic forage area is not readily available. Indeed, accurate data that might allow estimations of forage area per unit of marine food are not readily accessible for any oceanic region (except with respect to sedentary mollusks and the like). Thus, we have restricted our analysis to estimating the land area required to provide food for each urban population. This restriction is important insofar as the Hong Kong population consumes 20 times as much in marine products as does a Sydney population of equivalent size.

It is obvious, then, that notional, rather than actual, forage area size is the outcome of such calculations. So, with a knowledge of the factors which could

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1974b, C.T. Wrong, Agriculture and Fisheries, personal communication, 1975), given the proportion each vegetable made of the total, allowed the computation of productivity figures of 97 MJ/ha/day for Hong Kong and 113 MJ/ha/day for Sydney.

[k] Fruit and fruit products data were handled as for vegetables [see (*j*)]. Information on yields of various fruits came from the Australian Bureau of Agricultural Economies (A. Bolman, personal communication, 1975) and the Australian Bureau of Statistics (1974a). Broad categorization shows Hong Kong's consumption at about 49% citrus; apple, pear, and bananas, 39%; dried tree fruits 9%; and others 3%, compared with Sydney, 36% citrus, apple, pear, and bananas, 58% dried tree fruits and others, 6%. Production figures derived from these data gave Hong Kong as 72.28 MJ/ha/day and Sydney as 85.08 MJ/ha/day.

[l] By using the same approach as for (*j*) and (*k*), grain consumption patterns were calculated as Hong Kong, 26% maize and products, 25% wheat and like grains and products, and 49% rice and products and Sydney, wheat and products 90%, maize and other 7%, rice 3%. Yields adopted for calculation were wheat 1330 Kg/ha, maize 2400 Kg/ha, and rice 3250 Kg/ha for China (Sprague, 1975) and 6060 kg/ha for Australia. Production calculated for Sydney grain supply was 65.82 MJ/ha/day and for Hong Kong 108.29 ha/day.

not be considered, the likelihood is that the forage areas on land, cited for each category of nutrients, and particularly the total forage area for each settlement, are underestimated.

Whereas care has been taken to document all major identifiable points of nutrient loss in the Hong Kong ecosystem, and to include these data as part of the total daily supply of nutrients to the city, the same is not true for Sydney. According to the Australian data source, "in many cases, allowance is not made for wastage before the foodstuffs are consumed" (Australian Bureau of Statistics, 1971). To the extent that nutrient losses are not reported, the forage area of Sydney is underestimated.

Keeping in mind these qualifications, we can still see from Table X that the overall land forage area for Sydney, adjusted to Hong Kong's population size, is more than double that for Hong Kong. Each Hong Kong citizen requires an average of about 0.57 ha to provide nutrients, compared with 1.12 ha for the average Sydney resident. The larger forage area demands of Sydney residents result from a high consumption of butter, milk and milk products, and the use of ruminants to provide meat and offal requirements. There are also differences in grain and vegetable yields between Australia and China which must be considered when comparing forage area requirement (see footnotes, Table X). Here Hong Kong's reliance on rice rather than wheat as a staple causes a significant reduction in its forage area. Although we have not considered marine forage area in these calculations, even if the additional animal protein derived from marine products by the Hong Kong population compared with the Sydney population were obtained instead from meat and offal it would add only 0.11 ha,[7] or 19% more area to the average per capita forage area for Hong Kong citizens.

In the light of the discussion on recycling of nutrients in Hong Kong it becomes clear that feeding food wastes rather than grain to pigs and poultry considerably reduces the demand for forage area, and performs a vital nutrient recycling function. Currently such practices are more likely to be a feature of urban ecosystems in the developing world than in the developed world, where legislation aimed at preventing the transmission of disease frequently prevents the use of waste human foodstuffs for animal production.

## GENERAL DISCUSSION AND CONCLUSIONS

The discussion of forage area requirements of Hong Kong and Sydney highlights an important distinction between the kinds of plants and animals on which the two populations rely for their essential nutrients. In general terms,

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[7] This area is calculated using the energy content of the marine produce consumed in Hong Kong and the production efficiency, in MJ/ha, for meat and offal consumed in Hong Kong, in Table X, footnote (*d*).

Hong Kong depends on species that are more efficient converters of available energy into the somatic energy of food acceptable for human consumption than are the species which provide food for the Sydney population. It is likely that this difference is not merely coincidental but has arisen over thousands of years from pressures on available land resources exerted by an ever-increasing Chinese population. Whyte (1972) writes of two major changes in the Chinese diet in response to the pressure of increasing population and decreasing land resources: From the 4th to the 1st century B.C. beef and mutton were foregone in favor of pork, and, from the 3rd to the 6th century rice replaced wheat and pulses as staples in the south and vegetables and fish compensated for reduced mineral, vitamin, and protein content. After beef was replaced by pork, milk and milk products disappeared from the diet, and cattle were used only for draught. Any beef consumed by rural Chinese today comes mostly from draught animals which traditionally consume crop residue and forage in areas peripheral to cropland, road ways, etc. (Fei and Chang, 1945; Buck, 1956). Of course wheat continues to dominate grain production in northern China (Wortman, 1975).

The particular combination of food-producing animals maintained in Hong Kong also ensures good potential for recycling nutrients. There can be little doubt that pigs were an acceptable alternative to beef for the Chinese of 2000 years ago because they could convert all manner of foodstuffs, including food wastes, into high-quality human food and could easily cohabit with man. Indeed, pigs were frequently kept in the same room with an entire Chinese family, even in the extraordinarily crowded conditions of Hong Kong in the 1860s (Endacott, 1958). Poultry also require little space and are able to convert human food wastes, husks, and the like into high-quality food with reasonable efficiency. As outlined in the discussion of recycling, if there is appropriate technology to convert animal sewage into extrasomatic energy, fertilizers, and other products, then pig, poultry, and fresh-water fish farming can be integrated to provide a valuable resource-conserving system, closely associated with urban settlements. In Hong Kong such a system has clearly contributed to considerable food production, essentially within the urban settlement itself. The point is illustrated by again comparing Hong Kong with Sydney. The total land area of Hong Kong is one quarter the size of the Sydney Statistical Division and yet contains 35% more people and produces up to 10% of its total animal protein and 5% of its total plant protein requirements. There are other proposals, such as to locate market gardens on large building complexes (Page, 1973), which could contribute to the development of an integrated system to cycle essential nutrients and to conserve space, energy, and other valuable resources in the urban environment.

Nevertheless, as the example of phosphorus flow in Hong Kong shows, urbanization has had a seriously disruptive influence on nutrient cycling. It would be possible to decrease the rate of dissipation of mineral nutrients, but this would require careful planning for which few incentives currently exist. Urban settlements are essentially large feedlots for human beings, involving the same immense concentration of organics and mineral nutrients as feedlots for beef, pigs, dairy cattle, and sheep.

Western influences in the management of the Hong Kong ecosystem only tend to exacerbate the problem of nutrient loss. Animal and human sewage generated in Hong Kong have more often been regarded as wastes posing an engineering problem of disposal than as resources posing a biological problem of utilization (Binnie and Partners, 1974). Initiatives by engineers to recover fertilizer or potable water from human sewage have been largely ignored (E. Short, J. D. Watsons, and D. M. Watsons, personal communication, 1975). Human and animal sewage fertilizer has been replaced by chemical fertilizers in the past 15 years (Newcombe, 1975), whereas in China, Taiwan, and Japan organics are highly valued as fertilizers along with large inorganic fertilizer supplements (Buck *et al.,* 1966; Sprague, 1975). As we have documented, the breach in nutrient cycling resulting from these developments is considerable.

Throughout Asia, including Hong Kong, beef is being promoted as a prestige food, as opposed to pork and poultry. Any shift in meat consumption toward beef and away from traditional meats in Hong Kong will tend to increase forage area demand and eventually decrease the capacity of the existing food system to recycle food wastes back into human food.

The importance of milk products, frequently stressed by nutritionists (Kon, 1959), and exaggerated by multinational corporations (Muller, 1975), is questionable. Breast feeding is abandoned in favor of cow's milk, fresh or powdered, often leading to increased cost, malnutrition, and infection (Jelliffe and Jelliffe, 1975). According to Hong Kong pediatricians, there is evidence of malnutrition in children whose mothers consistently mismanage the preparation of mixtures of powdered milk and water (G. Kneebone, personal communication, 1975). Clearly the nutritional arguments in favor of increasing milk consumption are debatable. In addition, a considerably increased forage area would be required to support milk consumption at a level approaching that of Western populations. These criticisms apply equally well to milk products, including butter.

It should be noted here that food policy makers have recently attached less importance to land as an agricultural resource and have been placing emphasis instead on fertilizers, irrigation, and machinery as agents to increase yield (U.S. Department of Agriculture, 1975). But land saved by the use of high-yield technology is, to a certain extent, required elsewhere to provide the vastly increased extrasomatic energy, material, and water requirements of the new production techniques. The availability of land remains critical to agricultural production, and we must view with concern any change in the combination of plant and animal producers which cannot be justified on nutritional grounds and has the effect of increasing forage area and/or energy and key materials demand and disrupting established patterns of nutrient consumption.

Losses of nutrients, likely to exceed 20% of the retained input of particular nutrients to the Hong Kong ecosystem, add to the already considerable burden of losses at the point of production and en route to urban settlements. Borgstrom (1974) suggests that half of the rice crop is lost through weeds, diseases, and pests and that 30 to 50% is lost post-harvest and prior to consumption. It follows that as the urban population grows the forage area grows, and the distance over which fresh food must travel increases. Therefore, unless a conscious effort is made to concentrate the production of fresh foods near and within the urban settlement, losses of fresh food are likely to increase, and, in addition, greater extrasomatic energy costs will be incurred in transporting, packaging, processing, and refrigerating foodstuffs.

The apparent human consumption of major nutrients in Hong Kong, with the notable exceptions of fats and calcium, is the same as or higher than in the United States, United Kingdom, New Zealand, and Australia (Newcombe, 1976a). Therefore the marked difference between Hong Kong and Sydney in land required for forage area offers some guidelines for establishing food production policies for developing urban settlements. Perhaps because of pressure on land resources, Hong Kong has sought to obtain about 25% of its animal protein from the ocean, compared with 2.5% in the case of Sydney. Currently 5% of the world's food comes from the ocean (Pimentel *et al.,* 1975), but it is unlikely that this will substantially increase in the future (Ryther, 1969). Not only will we have to learn more about the ocean's productivity, and how to harvest it without irrevocable damage, but steps will have to be taken to protect the rights of those countries that have already come to depend on the ocean for a major portion of their essential food nutrients.

We must be wary of imposing our Western values regarding foods and nutrition. Any combination of plant and animal producers which has been selected by agriculturalists over thousands of years must have advantages both in providing an adequate diet and in nutrient conservation. For example, farmers in southern China have, for hundreds of years, recycled human food wastes as animal feeds, and human sewage as fertilizer. They have used small animals with high conversion efficiency to maximize the production of animal protein from feed protein. These kinds of resource-conserving measures are only now being stressed by Western authors (Borgstrom, 1973; Dwyer and Mayer, 1975).

In summary, at least two aspects can be stressed. First, there can be speculation about the competition that might arise between human settlements for forage areas. As a human settlement grows, its population demands an ever-increasing forage area. Inevitably the demands of one population must compete with those of others. It is likely not only that settlements in the developed world use a comparatively larger forage area, but also that they can compete successfully with settlements in poorer countries to maintain that forage area through time. It is also likely that competition for forage areas will lead to high-energy, high-technology production methods to enhance agricultural productivity. The "green revolution" illustrates this. It is wise to be wary of these trends both because of the uncertainty of maintaining increased energy and material input and because the impact of these new techniques and technologies on the long-term viability of the agricultural ecosystem is uncertain. In effect, increases in food production can sometimes be dangerous insofar as they carry with them the potential for a sudden collapse in the intricate network of food supply. This may well have occurred in advanced civilizations of the past (Gyuk and Harrison, 1975).

Second, and related to the above, we have a global obligation to structure a food production system that combines high-quality output with minimum resource input and maximum sustainability. In this paper, we have analyzed systems that show great diversity in food production methods and reveal many options whereby developing and industrializing countries can decrease the impact on resources and yet maintain the same quality of dietary input. Essentially we have referred to an ecosystem strategy for the management of urban environments. It is essential that the urban area and its peripheral agricultural land be considered as two parts of the same system, whereby the latter is used as an ecological buffer zone in relation to the first and is simultaneously the sink for organic nutrients, the biological filter for recovering potable water, and a major zone of food production for the human settlement.

There are many features of the Hong Kong ecosystem which offer important lessons in this respect. It is clear that agricultural administrators in Hong Kong are slowly adopting an integrated, ecological approach to food production which, in many ways, they owe to the long evolution of Chinese agricultural ecosystems.

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