# Fish Feeding:
# 9 - Digestibility

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## Fecal Energy and Digestible Energy

Values for DE and values for the digestibility of individual nutrients should be used to estimate levels of available energy and nutrients (as opposed to GE or crude nutrients) in feed ingredients for diet formulation . Formulation on a GE or crude nutrients (e.g., crude protein) is still very common in fish nutrition, but sufficient information on DE values of common fish feed ingredients is

now available to allow feeds to be formulated on a DE or a digestible nutrient basis. It is, however, important to emphasize that DE is only an indication of the potential contribution of the energy from nutrients in the ingredient.

These values do not serve as measures of the utilizable energy or of the

productivity of the diet.

# Digestibility

**Several techniques have been used to collect fecal material from fish. The suitability of these various techniques has been a subject of discussion and disagreement among fish nutritionists for many years.**

**Some early, yet still widely used techniques are**

**the collection of feces from the lower part of the intestine**

**by 1- stripping , 2- by suctioning fecal material, or 3- by dissecting**

**the fish .**

**It is generally agreed that forced evacuation of fecal material from the rectum results in the contamination of the samples with physiological fluids and intestinal epithelium that would otherwise have been reabsorbed by the fish before natural defecation. This affects the reliability of this type of approach and, in general, leads to underestimation of digestibility.**

# Digestibility

**Techniques involving the collection of feces voided naturally by the fish are, therefore, preferable. Smith (1971) developed a metabolic chamber to collect feces samples voided naturally into the water by fish. With this method, the fish need to be force-fed, and they frequently regurgitate and may not be in a positive nitrogen balance status. This technique clearly imposes an unacceptable level of stress on the fish and produces estimates of digestibility of questionable reliability .**

**Other techniques, such as the periodical collection of feces by siphoning from the bottom of a tank, are also likely to yield inaccurate estimates of digestibility since the breakup of feces by fish movement may lead to leaching of nutrients and, therefore, overestimation of digestibility of nutrients.**

# Digestibility

To prevent these problems, specific devices were developed to collect fecal material passively.

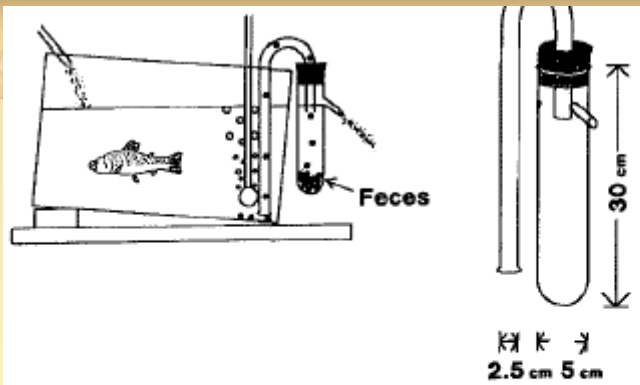
1-Collected feces by passing the effluent water from fish tanks through a filtration column (TUF column).

2- A settling column to separate the feces from the effluent water (Guelph system)

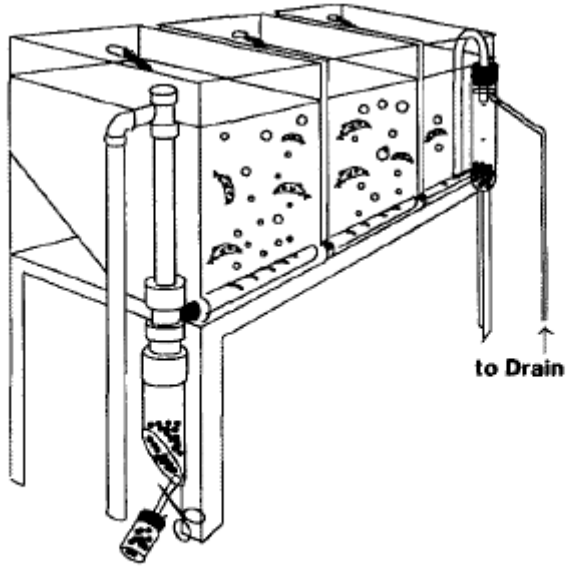
3- A mechanically rotating screen to filter out fecal material (St. P´ee system). These systems are convenient and have been adopted in many laboratories around the world.

They are widely recognized as producing meaningful estimates of digestibility of nutrients if used correctly, despite the fact that differences of opinion about the accuracy of these systems remain. In a study comparing the TUF column and the Guelph system, very similar apparent digestibility coefficients (ADC) of dry matter, protein, lipid, and energy were obtained with both methods for two reference diets .

Guelph

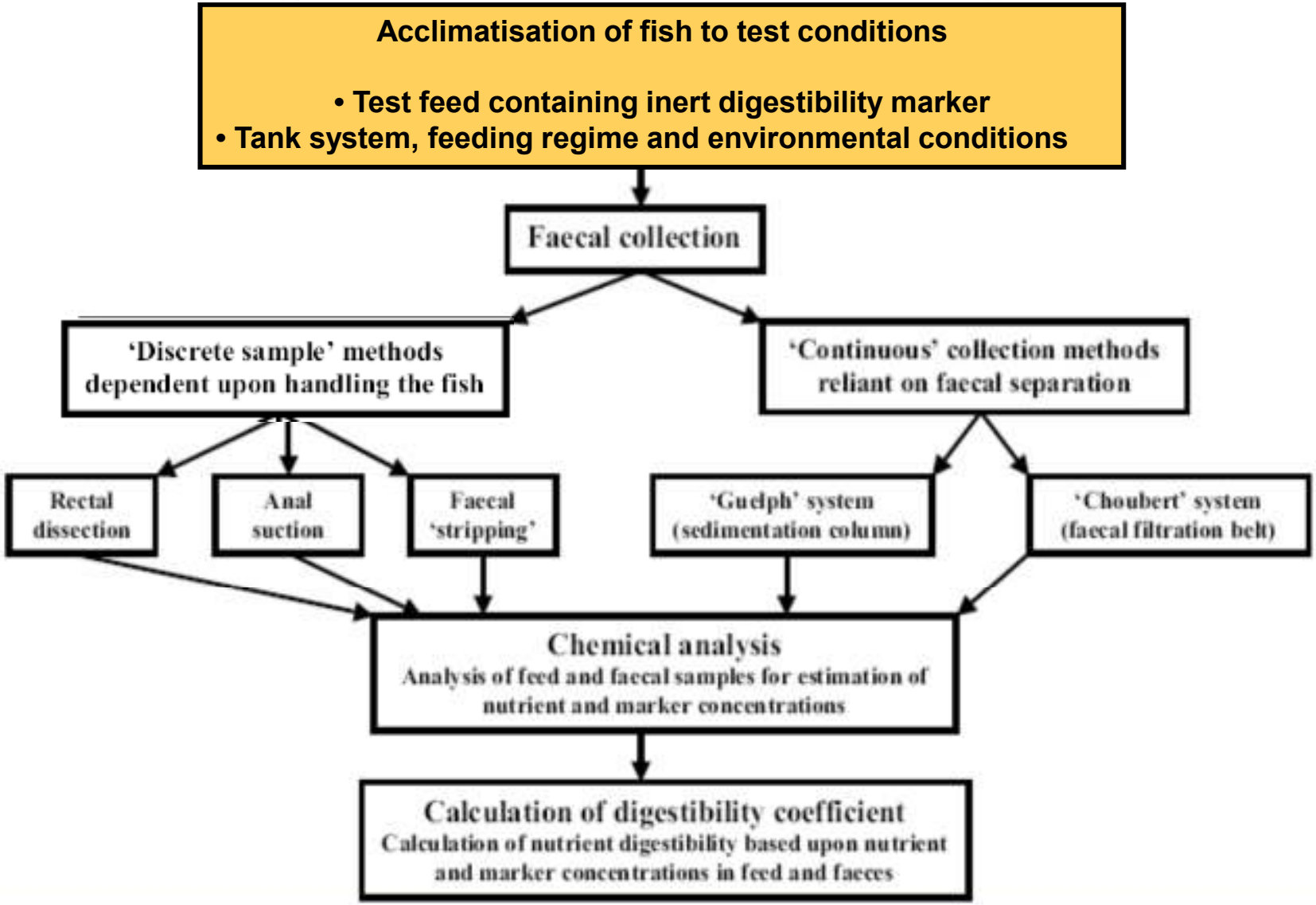



ig. 2. The "TUF Column System" for feces collection.




ig. 3. TUF Column attached to the first tank of the Guelph System.

# Digestibility



# Apparent versus True Digestibility

**Feces are composed of the undigested food components and the unreabsorbed residues of body origin. These residues are the remains of mucosal cells, digestive enzymes, mucoproteins, and other secretions released into the digestive tract by the animal, together with the residues of the microflora which inhabit the digestive tract**

**The combustion of these materials represents a loss of energy which is not derived from the food. This energy loss is designated Fecal Energy of Metabolic origin (FmE) and is influenced by the characteristics of the food and the level of feed intake.**

**Estimates of FmE allow the description of "true" digestible energy values, which are greater than "apparent" digestible energy values. The term "true" digestibility may be misleading since, to the animal, FmE losses are real and inevitable. The term "standardized digestibility" is slowly replacing "true digestibility" in the vocabulary of animal nutritionists**

**Apparent digestible energy (ADE) = IE − FE**

**True (or standardized) digestible energy = IE − (FE − FmE)**

**Measurement of FmE of fish has received little attention. The FmE that has been mostly studied in fish and other animals (swine and poultry) has been associated with endogenous protein/nitrogen losses. The most common approach for measuring Metabolic Fecal Nitrogen (MFN) representing endogenous nitrogenous losses is by determining the fecal nitrogen output of fish fed a protein-free (nitrogen-free) diet. The MFN of fish fed a protein free diet has been estimated as about**

**2.7–3.3 mg/100 g live body weight per day or 123–144 mg/100 g dry diet consumed in common carp at 20◦C.FmE as protein (probably contributing the most to FmE) can, therefore, be estimated to be about 0.4 kJ/100 g live body weight per day or 20 kJ/100 g dry matter intake. This is relatively small, being equivalent to about 1% of the IE or about 10–20% of the FE of animals fed good-quality practical diets.**

**1 Cal = 4.184 J, or 1 kcal = 4.184 kJ**

**GE values of carbohydrates, proteins, and lipids are 17.2, 23.6, and 39.5 kJ/g,**

# Apparent versus True Digestibility

**Fish will generally eat very little of a protein-free diet, making it very difficult to calculate meaningful estimates of MFN. Moreover, there is evidence that the amount of MFN produced by animals receiving a semi-purified protein-free diet can differ significantly from that of animals fed practical diets containing protein . Several other dietary constituents (fiber, anti-nutritional factors) can enhance MFN .**

**In fish maintaining a high feed intake, the contribution of MFN to the total fecal nitrogen is probably small. Under these conditions, the difference between the "true" and the apparent digestibility of protein is probably negligible.**

**If poor feed intake or poor growth is observed in a digestibility trial, it is preferable to discard the fecal samples collected since these samples may contain a high proportion of MFN and could produce unreliable estimates of apparent digestibility**

# Total collection calculations

- **Digestibility (g/kg) =**

$$\frac{\text{Nutrient in feed - Nutrient in feces}}{\text{Nutrient in feed}} \times 1000$$

- **Dry matter digestibility (DMD, g/kg) =**

$$\frac{\text{DM in feed - DM in feces}}{\text{DM in feed}} \times 1000$$

- **Organic matter digestibility (OMD, g/kg) =**

$$\frac{\text{OM in feed - OM in feces}}{\text{OM in feed}} \times 1000$$

Can be expressed as a proportion, % or g/kg

# Digestibility

**Talbot (1985)**

**Total Apparent Digestibility Coefficient (TADC)**

**% TADC = 100- [100x(%marker in diet / marker in faeces)]**

**Nutrient Apparent Digestibility Coefficient (NADC)**

**% NADC =**
**100- [100x(%marker in diet / marker in faeces)/(nutr.in faeces/nutr.in diet)]**

- E.g. if a feed contains 1% $Cr_2O_3$ & feces contains 2% $Cr_2O3$, diet digestibility = 50%
  - Since $Cr_3O_2$ conc. has doubled, 50% of DM must have been digested

Nitrogen content of a feed is 2%. If the animal eats 400g then the total N consumed is 400 X .02 = 8g. If the amount of N in the feces was 3% and the animal excreted 50g of feces the total N excreted in feces would be 50 X .03 = 1.5g.

APPARENT nitrogen digestibility:(8 - 1.5) / 8 X 100 = 81.25%

If the endogenous portion in the example above was 0.5% N (in the 50 g of feces)

$$\text{True N Digestibility} = \frac{\text{Nfeed} - (\text{NFeces} - \text{endogenous N})}{\text{Nfeed}} \times 100$$

or for the example above (8 - (1.5 - 0.25)) / 8 = 84.375% = 84.4%

# Factors that Affect Digestibility

- Physiological stage of the animal
- Particle size/processing
- Disease state (parasites, antibiotic treatment, etc…)
- Feed source and composition
- Level of intake
- Rate of passage
  - Too slow = high fermentation compounds
  - Too fast = incomplete digestion
- Nutrient imbalance (excess or deficiency)

# Digestibility

The marker must be non-toxic. It should not interfere with feeding, digestion and absorption, nor should it be absorbed or metabolised. The marker should also pass through the gut at the same rate as the other digesta, i.e. there should not be any separation of marker and other feed components during passage through the gut. Accurate analysis of the marker in both the feed and faeces must be possible, and it is advantageous if analyses can be performed cheaply and effectively. Finally, the feed containing the marker must be fed over a sufficiently long time period to enable representative sampling of faeces to be made, i.e. samples collected should be free of contamination by faeces produced during consumption of previously unmarked feed.

# Digestibility

Several marker substances have been used in digestibility trials with livestock, the markers, e.g. chromic oxide, titanium oxide, rare earth elements, celite or acid-insoluble ash, lignin and chromogens, being added to the feed at low concentration .Chromic oxide has been commonly used in digestibility studies with fish, but it is suspected of violating some of the prerequisites of an inert marker:
it may cause disturbance to digestive function, it has carcinogenic properties, and it may separate from the other digesta during passage through the gut. Acid-insoluble ash (AIA), barium carbonate, yttrium and ytterbium oxides, and ferro-nickel microtracers have all been suggested as being viable alternatives to chromic oxide . AIA is a natural component of feeds, but is usually present in too low a concentration to be used as a natural internal marker, so the concentration of AIA is increased by the addition of celite during feed manufacture.

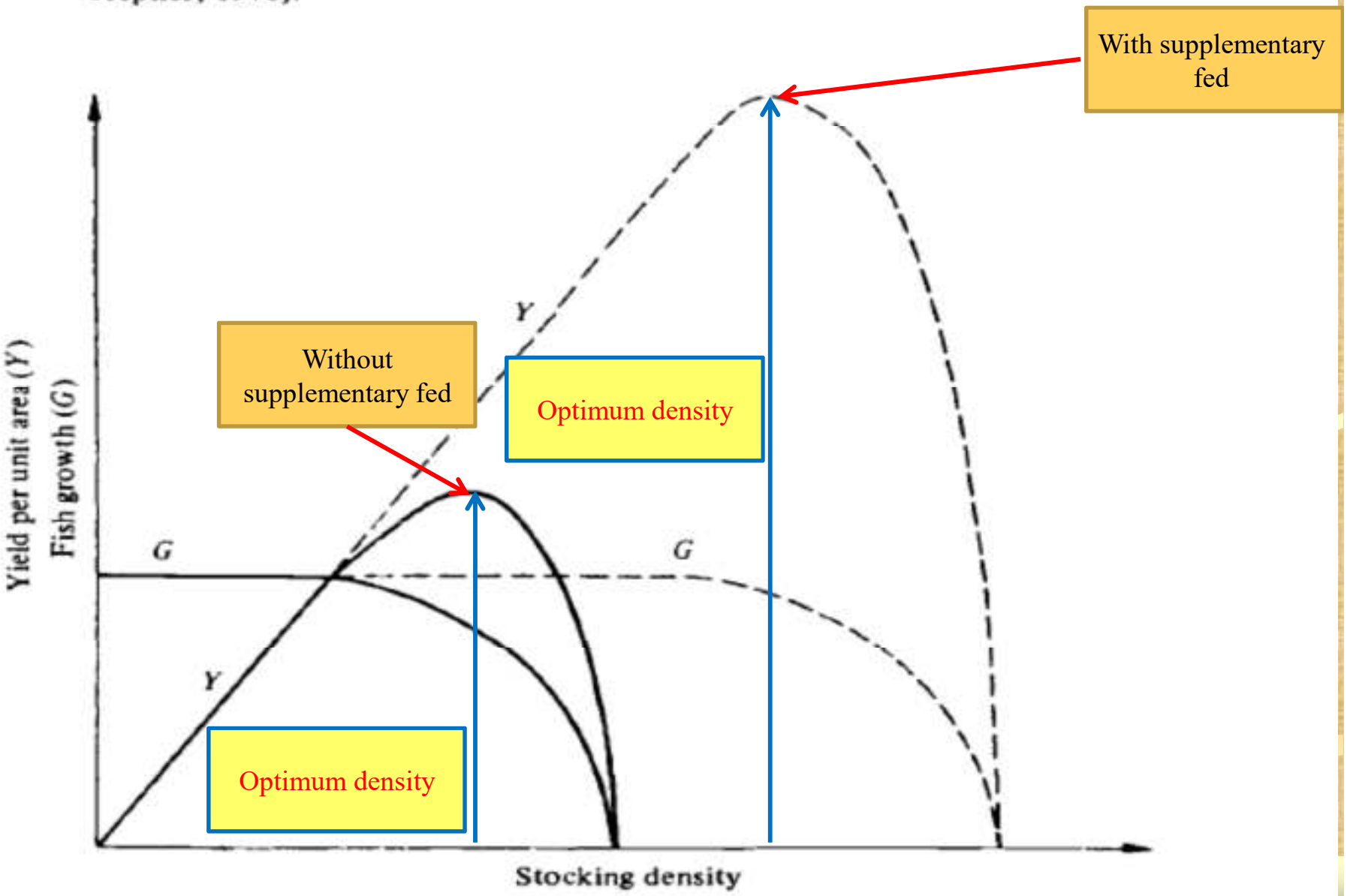
Apparent Digestibility Coefficients and Digestible Energy Values of Feed Ingredients[a]

| Ingredient | Apparent digestibility coefficient (%) | | | |
|---|---|---|---|---|
| | Dry matter | Crude protein | Lipid | Energy |
| Alfalfa meal | 39 | 87 | 71 | 43 |
| Blood meal | | | | |
| Ring-dried | 87 | 85 | — | 86 |
| Spray-dried | 91 | 96 | — | 92 |
| Flame-dried | 55 | 16 | — | 50 |
| Brewer's dried yeast | 76 | 91 | — | 77 |
| Corn yellow | 23 | 95 | — | 39 |
| Corn gluten feed | 23 | 92 | — | 29 |
| Corn gluten meal | 80 | 96 | — | 83 |
| Corn distiller, dried, soluble | 46 | 85 | 71 | 51 |
| Feather meal | 77 | 77 | — | 77 |
| Fish meal, herring | 85 | 92 | 97 | 91 |
| Meat and bone meal | 70 | 85 | — | 80 |
| Poultry by-products meal | 76 | 89 | — | 82 |
| Rapeseed meal | 35 | 77 | — | 45 |
| Soybean, full-fat, cooked | 78 | 96 | 94 | 85 |
| Soybean meal, dehulled | 74 | 96 | — | 75 |
| Wheat middlings | 35 | 92 | — | 46 |
| Whey, dehydrated | 97 | 96 | — | 94 |
| Fish protein concentrate | 90 | 95 | — | 94 |
| Soy protein concentrate | 77 | 97 | — | 84 |

## *Natural food*

**The relationship between the density and the individual growth rate is not linear but rather a curved regression. Since yield per unit area is a product of the average individual growth rate and the number of fish per unit area (density), the effect of density on yield is also not a simple one. As long as the rate of increase in fish density is higher than the rate of decrease in individual growth rate, yield increases. When, however, the decrease in growth rate exceeds the increase in fish density, yield decreases (Figure 31). The optimum density is therefore that in which the fish utilize the natural food to give the highest possible yield per unit area. The determination of the optimum fish density in these cases requires a better knowledge of the amounts of available natural food in the pond, on the one hand, and the relationships between 1- the amount of food, 2-fish density,**
**3-individual growth rate and 4-yield, on the other.**

Figure 31. Schematic presentation of the relationships between the stocking density, the short interval growth rate and the short interval yield per unit area, with (broken line) and without (solid line) supplementary feeding (from Hepher, 1978).

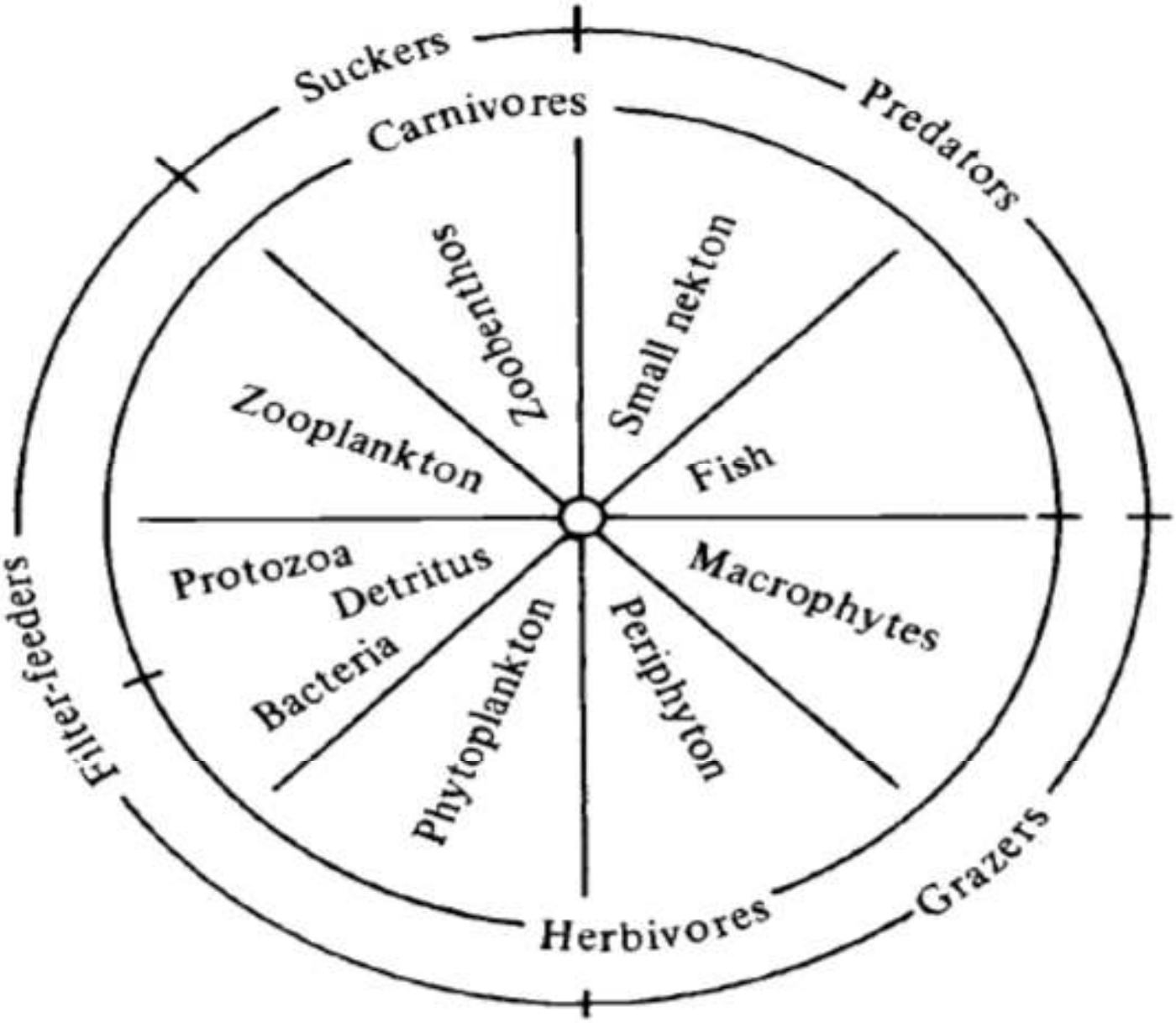


The amount of natural food available to fish in ponds (or any other water body) can be estimated in three ways: (a) estimating the natural food stock in the pond; (b) estimating the amount of food consumed by the fish; and (c) estimating the food intake indirectly through a bioenergetic balance analysis, taking into account fish weight, fish growth rate and energy expenditure for maintenance.

The first method seems to be the most direct one. However, difficulties involved become immediately apparent. The first question to resolve is: what is the natural food of a particular fish species?

All organisms, plants and animals, in the pond (or any other biotope) form the 'biocenose' of the pond and can serve as food for various fishes. These organisms interact with each other, mainly through predator-prey relationships, but also through others, such as competition for food, space, etc. These relationships have been described in many papers in various ways such as 'food chains', trophic levels creating a 'food pyramid' (in which the biomass of the lower trophic levels, especially primary producers, is much larger than that of the upper trophic levels, the consumers), as having intricate interrelationships of a 'food web', or otherwise.

Figure 32. The division of the biocenose to food organism groups according to their nature and size.



The biomass of each of the groups mentioned above can be determined and the 'biocenose profile' of the particular aquatic biotope thus obtained. However, from the nutritional point of view of the fish it is the production rate of these groups which counts, rather than the biomass at any given moment. When the production rates of each group of the biocenose is determined, the 'biocenose production profile' can be obtained. This is a long and tedious work and only very few studies gave the full biocenose profile, let alone biocenose production profile.

The most noticeable differences are between the larval stage, fry, and larger fish. Most fish feed in their young (late larval and fry stages) on zooplankton, even when the larger fish becomes herbivorous.Grass carp *(Ctenopharyngodon idella),* for instance, change from almost exclusively carnivorous to herbivorous feeding at a length of 25-30 mm. The same size was also found to mark the change in diet in gilthead bream, *Sparus aurata,* sea bass, *Dicentrarchus labrax* and the mullets *Liza ramada, L. aurata* and *L. saliens*. Also the diet of Indian carp *(Labeo rohita)* changes from zooplankton in the fry stage to phytoplankton in the adult stage. At a later stage, however, the trophic basis becomes more defined.

# *Food fish growth and fish yield relationships*

**Yield per unit area is a product of the individual growth rate and the number of fish per unit area (density). Since the individual growth rate is physiologically limited, the only way to increase yield per unit area is through increasing the density. As long as the amount of natural food exceeds requirements for maintenance and maximum growth, an increase in fish density (and thus also in standing crop) should not affect the individual growth rate of the fish. However, with the increase in standing crop the food requirement of the population also increases, until at a certain density/ standing crop food resources will be overtaxed and will not suffice for both maintenance and growth. Since maintenance is vital, less food will be diverted for growth, and individual growth rate will decrease. Hepher (1978) defined this standing crop as 'critical standing crop' *(CSC).* When standing crop reaches a level at which natural food is sufficient only for maintenance and no food is left for growth, growth ceases entirely. This is the 'carrying capacity' of the pond for the particular species. The rate of decrease in individual growth rate as the standing crop increases over the *CSC* is at first smaller than the increase in fish density.**

Yield therefore continues to increase, although not in proportion to the increase in density. At a certain standing crop, food demand for maintenance becomes so high that the decrease in individual fish growth rate becomes faster than the increase in density, and yield falls to reach zero at carrying capacity. If at standing crops above *CSC* the fish are fed supplementary feed of adequate nutritional quality, maximum growth rate will be maintained up to a point where some limiting factor in the feed will inhibit growth. Yield per unit area will thus continue to increase linearly with increasing density until the new *CSC* is reached (Figure 31). The larger the individual weight of the stocked fish, the higher the absolute food requirement for maintenance and growth. Therefore, while the instantaneous growth rate of large fish below the *CSC* is higher than that of small fish, a given amount of food will suffice for a smaller number Of fish and with increasing body weight *CSC* and carrying capacity will be reached at lower densities. The relationships between *CSC,* carrying capacity and body weight are, however, quite obscure. One may expect that since the *relative* requirement of food for maintenance and growth decreases with increasing body weight, the available food will suffice for a larger standing crop (kg/ha) of large fish than of small fish.

**However, farmers' experience does not support this. It has been noticed in practical fish farming that growth of fish ceases at a carrying capacity characteristic to the pond and method of its management irrespective of the average weight of the fish. Thus, for instance, if the carrying capacity of a pond is 150 kg/ha, at a density of 1500/ha fish will cease growing when they reach an average weight of 100 g, but 15 000 fish/ha will cease growing when they reach 10 g. In many cases it has even been observed that the smaller fish reach a higher carrying capacity than do large fish. This discrepancy may perhaps be explained by the higher efficiency of grazing and predation as the density increases . Using the above example, 15 000 fish each of 10 g have a greater capacity to graze or seek and catch prey than 1500 fish/ha of 100 g. From the above discussion it is clear that the main factor determining the *CSC* and the carrying capacity is the productivity of the pond, the treatment it gets (fertilization and manuring) and supplementary feeding. It should be noted that supplementary feeding has no effect below the *CSC* since fish receive all their nutritional needs from the natural food. The amount of food to be supplemented above the *CSC* depends on the available natural food on the one hand and the standing crop of fish on the other. The higher the standing crop, the less natural food can satisfy the fish nutritional requirement, and more supplementary food is needed to bridge the gap. It is obvious that for calculating the amount of supplementary feed required one must first estimate the amount of available natural food.**

| Treatment | *CSC* (kg/ha) | Carrying capacity (kg/ha) |
|---|---|---|
| No fertilization, no feeding | 65 | 130 |
| Fertilization but no feeding | 140 | 480 |
| Fertilized and fed sorghum | 550 | 2500 (estimated) |
| Fertilized and fed protein-rich pellets | 2400 | — |

Figure 36. The relationship between standing crop and yield per unit area for fish receiving sorghum in ponds stocked at two fish densities: (*a*) 2000/ha; (*b*) 4000/ha. Solid line gives calculated values based on actual average growth rates (Figure 22). Broken line gives extrapolated possible growth when food is not limiting according to equation (37) (from Hepher, 1978).

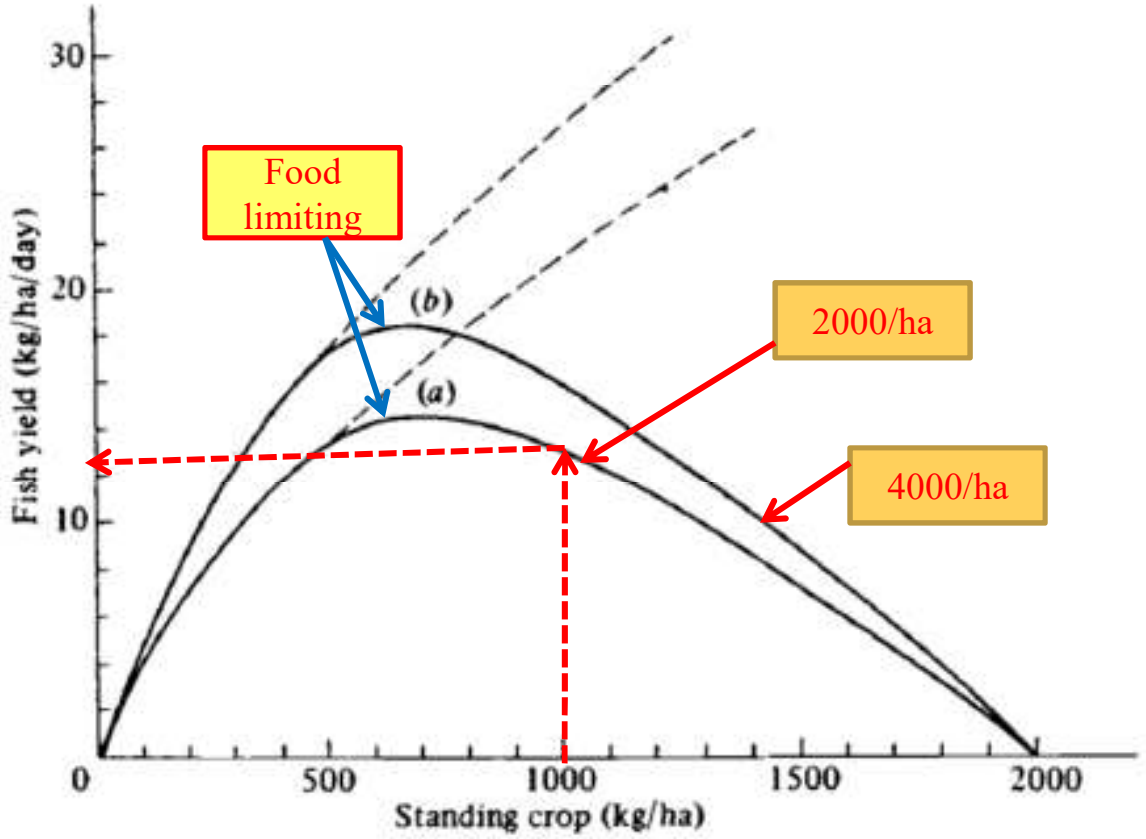


Figure 23. The relationship between growth rate (g/day) and the average weight (g) of common carp, as determined by two week interval sample weighings for four treatments: (1) no fertilization and no feeding (black triangles); (2) fertilization but no feeding (empty triangles) (3) feeding on sorghum (black circles); (4) feeding on protein-rich diet (empty circles). Each point is an average value determined from four replicated ponds.