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NUTRITIONAL BIOENERGETICS IN FISHES AND SHELLFISHES

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Matter or energy can neither be created nor destroyed but can be converted thus says the second law of thermodynamics, which is the cardinal concept in bioenergetics. In nutritional bioenergetics also known as physiological bioenergetics we are concerned about energy entering into the organism as food and its partitioning into various forms of work. The quality of food consumed is also known as ration (C). It is possible to draw up a balance sheet or energy budget, which in a very simple form can be given as

$$C = P + R + U + F.$$

where C stands for consumption, ^{P for growth,} R for metabolism, U for non-faecal excretion, F for excreta as faeces. The partitioning can be well be explained in the form of a energy flow chart.

FORMULAE AND INDICES USED

Since we are not concerned at present with ecological bioenergetics let me summerise briefly indices useful in nutritional bioenergetics. For fuller list of formulae also take into consideration these given in the chapter on proteins.

1. Gross conversion efficiency (k_1) (%) = $\frac{P}{C} \times 100$

Herein we take the parameters in dry weight for the sake of uniformity. In the field this parameters is difficult to obtain. Therein we use FCR.

2. Food conversion ratio (FCR) = $\frac{\text{Food (fed) offered}}{\text{weight gain}}$

FCR is used in a highly arbitrary manner. Some use both in dry weight, while some one of the parameters in dry and the other in wet weight and still some authors use both in wet weight.

3. Assimilation efficiency = $\frac{C-F \times 100}{C} = \frac{A}{C} \cdot 100$
or

digestibility (%)

4. Net conversion efficiency = $\frac{P}{A} \times 100$

K_2 (%)

where $A = C-F$

5. True digestibility (%) = $\frac{C-(F-MFN)}{C} \cdot 100$

While MFN - Metabolic faecal nutrient (endogenous nutrient)

6. Digestibility of a nutrient % = $100 - \left\{ \frac{\text{(100% indicator in food)}}{\text{% indicator in faeces}} \times \right.$

$\left. \frac{\text{% nutrient in faeces}}{\text{% nutrient in food}} \right\}$

7. Total digestibility Assimilation = $100 - \left\{ \frac{\text{(100% indicator in food)}}{\text{% indicator in faeces}} \right\}$

8. Trophic coefficient = $\frac{C}{P}$

9. Partial growth efficiency (%) = $\frac{P}{C-m} - 100$

m = maintenance ration

$$10. \text{ Body weight gain (\%)} = \frac{W_t - W_o}{W_o} \times 100$$

W_o and W_t are live weight at the time of starting the experient and at the end of the experient for that duration of days for the size used.

$$11. \text{ Nutrient retention (\%)} = \frac{\text{Nutrient gained}}{\text{Nutrient consumed}} \times 100$$

$$12. \text{ Optimum ratio of dietary energy (DE) to protein (P)} \\ (\text{DE/P ratio}) = \frac{(\text{Kcal/Kg dry diet})}{\% \text{ dietary protein}}$$

$$13. \text{ Metabolizable energy} \\ (\text{Kcal/g of diet}) = \frac{A_e E - U_e (A_p P - G_p)}{C}$$

Where

A_e = apparent digestibility for energy (%)

E = Total energy for the quantity ^{of} consumed food (Kcal)

U_e = Energy loss of nitrogenous products per gram of protein deaminated (Kcal/g protein)

A_p = apparent digestibility for protein (%)

P = quantity of protein in the consumed diet (g)

(% protein diet X feeding rate in % live weight \div 100)

G_p = quantity of protein retained as growth (g)

(protein balance ie. assimilated protein -

(non-faecal (exogenously excreted nitrogen) X 6.25)

C = weight of food consumed (g)

$$14. \text{ Specific growth rate (SGR)} \\ (\% \text{ body weight per day}) = \frac{\ln W_t - \ln W_o}{t} \times 100$$

where t is duration in days.

15 In grown up organisms (Eg. large fishes) growth rate

(k) is constant ($\log W_t - \log W_o/t = k$)

in such cases mean daily growth per day in percentage body weight (\bar{P}) is calculated by the following formula

$$\bar{P} = \frac{2(W_t - W_o)}{t (W_t + W_o)} \times 100$$

15 b. When the growth changes in short intervals

$$\bar{P} = \left\{ 10^{\frac{1}{t} (\log W_t - \log W_o)} - 1 \right\} \times 100$$

16. Average food consumption per day in percentage body weight $\bar{C} = \frac{2C}{(W_t + W_o) t} \times 100$

17. In case of mortality occurring to the experimental organisms during the course of the experient food consumption ratio (r) is useful

$$r = \frac{C}{(\bar{W}_t + D) - \bar{W}_o}$$

Where D is the total weight (wet weight) of dead animals (g), C is the total quantity of food consumed (g) and \bar{W}_o , \bar{W}_t are average initial and final weight of fishes (g).

CONSUMPTION

The forms of feed used in nutritional studies can be classified roughly under the following heads.

- i. Live feed
 - i. Algal) Plain or enriched
 - ii. Animal)
 - iii. Algae & Animal mixed
- ii. Test diets
 - i. Purely plant origin (dried algae, single cell protein)
 - ii. Animal tissue meal (silk worm, pupae, etc.)

iii. Compounded (formulated) diet

- a. Dry - pelleted diet
- b. Semi - dry diet (crumbles)
- c. Moist diet (dough)
- d. Encapsulated diet
- e. Particulated (bound) diet

Consumption is the quantity of food eaten by the experimental organism during the unit time, usually per day. Though experimenters use weight, units in terms of calories or gram protein is preferred. Fin fishes and shell fishes use protein and lipid as the major energy sources rather than carbohydrate and lipids. Thus protein is used by the organism as a source of energy on being deaminated. Therefore by many in the budget protein units alone are used either as gram protein or as nitrogen units. Much of blood glucose is derived from gluconeogenesis rather than from carbohydrates. Optimum protein/calorie ratio for salmon has been worked out to be 100 mg protein/digestible Kcal in food, while in mammals it is only about 70 mg. For both carnivorous and omnivorous fish lipids are the principal non-pool energy source. In the chapter on protein-requirements a critical discussion was made on the importance of using protein over calories as a sole unit of measurement. Calorie is the amount of heat required to heat 1 g water by 1°C at 15°C. 1000 calories (also known as gram - calorie or small calorie) make ^{one} Kcal (large calorie). In older literatures small and large calories used to be written as calorie and Calorie. Now a days kilojoules is preferred over kilo calories. One kilojoule (KJ) is 4.184 Kcal, and similarly 1 calorie = 4.184 joules. Various methods of determination of calorie values is being dealt with else where in this manual. Calorie ~~or the~~ heat unit is the only unit which can be used as the single unit for protein, carbohydrate and fat put together and

independently.

Methods:

Consumption can be measured directly only for a few organisms, for example in the large carnivorous fishes and in the carnivorous squids from the number and weight of the whole fish eaten per day, consumption can be easily estimated. But for the organisms of other feeding types it is not so easy. The method being followed in fishes to estimate total consumption is by gastric evacuation, herein the average rate at which a fish passes food out of its fore gut is taken as the rate of consumption. For this purpose either the serial sacrifice method or radiographic method is followed. In the former from a batch of fishes after feeding, at time interval one fish is killed and the movement of food within the alimentary canal is watched. This involves killing of many test fishes. In the radiographic method either the fish is X'ray photographed at time intervals after feeding with plain food or feeding with food mixed with a radio opaque substance like iron powder of 100-200 μm at the rate of 4% W/W with 20% water or with barium sulphate at 20% W/W level.

In the third method the organism is fed with a radioactivity substance; either the loss of radio activity from the medium or percentage activity of the whole organism over that of the food offered gives the clue for the quantity of food consumed.

The most popular method is by the use food marker. The important criteria of a substance to be used as the marker is that it must be thoroughly resistant to digestive enzymes, non toxic, easily determinatable, should not overtake or undertake the feed through the passage and well acceptable by the organism. Usually acid and distilled

water washed fine power of Cr_2O_3 , a green substance is used. The marker is well mixed with the diet at about 2% level or less and the organism is feed at libitum level to satation. The faecal matter alone is carefully collected. The quantity of Cr_2O_3 is determined usually by calorimetric method. The determination is as follows.

$$\begin{array}{rcl} \text{Eg: } \text{Cr}_2\text{O}_3 \text{ in the feed} & - & 2\% \\ \text{Cr}_2\text{O}_3 \text{ in the faeces} & - & 180 \text{ mg} \\ \therefore \frac{100 \times 0.180}{2} & = & 9 \text{ g} \\ \text{Food consumed} & = & 9 \text{ g} \end{array}$$

Other makers used are ammonium molybdate, hydrolysis resistant organic matter (HROM), hydrolysis resistant ash (HRA), crude fibre (CF), titanium (IV)-oxide, mineral elements like iron powder, polyethylene, magnesium ferrite, $^{144}\text{CeCl}$, lignin and colourants.

Many times digestibility of the organisms in nature can be calculated by picking out an indicator substance present already in the diet. For example the ratio of silica and organic matter in the diet and in the faecal matter can be used in the determination of digestibility and even for the estimation of consumption if one can calculate the ratio in the surrounding, say in the surface film for a detritivore. The Silica : organic matter ratio in the consumed diet can be calculated by collecting a few well fed animals at random from the field and chemically estimating the stomach contents. Shorter the duration between feeding and removal from the stomach is ideal. To collect the stomach contents from the stomach free from contamination by the gut tissues, the fresh animals can be kept in the deep freezer for a duration allowing the gut contents to become solid (ice) and by

opening the stomach without thawing. Thus the stomach contents can be secured as a solid mass. Latter it can be dried for the sake of consistency of the value and the ratio of silica:organic matter expressed in terms of dry weight. Similarly the faecal matter is also collected, concentrated by centrifuging, dried and analysed.

Fifthly consumption can be calculated from the balanced equation where one has estimated all other parameters. This method is also known as physiological method, where,

$$P + R + U + F = C$$

For the filter feeders consumption can be calculated from the rate of filtration.

Pandian and Vivekanandan (1985) have worked out that in fishes, feeding rate in percentage body weight has a direct bearing on the latitude of the habitat. Thus fishes which live between 70°-27°N (temperate region) consume about 1.8 to 17.3% body weight per day with a mean of 5.9%, while tropical (21° - 7°N) fishes consume 4.1 to 36 % with a mean of 16.7% body weight per day. Thus the feeding rate of tropical fishes over that of the temperate is about 180% greater. It is been calculated that tropical fishes ... incur an energy expenditure of 2.1 KJ/kg/hr while temperate spend only 1.2 KJ/kg/hr.

Fisher et al. (1973) have calculated consumption for the grass carp in the form of a regression formula under laboratory conditions as follows:

For animal and vegetable - mixed diet

$$C = 1.06.W^{0.81}$$

For exclusive vegetable food

$$C = 0.30.W^{0.81}$$

Where weight is in grams and C in calories per day.

The time taken for an organism in foregoing and to stop its feeding is known as the time taken for the animal to get satiated or satiation time. Filter feeders usually have a prolonged satiation time, while the carnivorous a short^{er} one. In the bivalves it has been found that the feed particles need to be at an optimum concentration known as critical cell density (CCD). At higher concentration they take very little into the oesophages and more of the food particles are encased in the mucus and sent out as pseudofaeces.

The critical cell density (CCD) at which the ingestion system is saturated for bivalves varies with particle size. Thus for food particles of sizes of 5 μm ; 5-75 μm , 7.2-9.4 μm ; 7.5-10 μm , 40-50 μm and 60 μm CCD in terms of $\times 10^{-6}$ /litre works out to be in the order 450, 60, 35-40, 50, 20-30 and 2. Thus CCD decreases with larger food particles (Newell, 1979).

Crustaceans, esp., in copepods when food is supplied at above optimum levels they resort to superfluous feeding. The algae taken into the gut passes out unaltered.

The average ingestion rate per day for Crassostrea virginica works out to be 3.8% body weight per day while for Penaeus setiferus 9.3% and for Mugil cephalus 3.2%. The benthic molluscs have found to process the sediments at the rate of 0.7-200 $\text{g}/\text{m}^2/\text{yr}$. While for Clymenella torquata it is 3288 $\text{g}/\text{m}^2/\text{yr}$ (Newell, 1979).

In Metapenaeus monoceros juveniles of about 27 mm consumption is about 12 percentage body weight per day (Qasim and Easterson, 1974) for natural detritus. Consumption in $\frac{1}{2}$ body weight ^{is} high in fast growing animals ^{and in these} whose metabolic rate is high. Thus juveniles have higher rate over

that of the adult. Consumption rate also is bound to increase with increase in temperature upto an optimum. Consumption is also high in animals feeding on low nutritive substances. Thus largest values are met with ^{the} detritus feeders and ^{the} animals which live on ooze. These organisms practically feed continuously.

ASSIMILATION (A)

That portion of the nutrient not excreted as faeces out of the quantity consumed is known as assimilation. Other equivalent terms ^{used} are absorption and digestibility. In the earlier part of this chapter the formulae need to be used in estimating total digestibility and digestibility of a specific nutrient is given when an indicator is used in the diet. When the quantity of metabolic nutrient excreted along with the faeces is deducted from the faecal nutrient in the calculation the coefficient obtained is known as true digestibility. When no correction is made for release metabolic nutrient into the faeces the coefficient is called as apparent digestibility. Though Cr_2O_3 (Chromium oxide) is used commonly as the indicator substance the use of titanium oxide has the advantage in the protein studies, wherein TiO_2 can be determined directly in the kjeldahl digest (Njaa, 1961).

Removal of faecal matter is the subject of many authors. Still date there is no fool proof method available. The use of resin to trap liquid metabolic wastes is not useful while working in a saline medium as in the case of brackish and sea water ^{animals}.

^{followed}
The Practice ⁱⁿ our studies ^{is} for the collection of faeces is as follows. In order not to agitate the water

always the experimental tanks are not aerated heavily. When the water used is well aerated and in the room too whereⁿ enough of forced air is available during day time aeration can even be dispensed with. Aeration is critical at night usually after midnight. Usually around 3 A.M. it is at this time it has been found that oxygen exchange is minimum between air and water. The faecal matter is very carefully siphoned out using wide mouthed, pipettes having fine polished tip. Thus removed faecal matter is transferred on to a very fine meshed bolting silk which has been retained over the mouth of a wide mouth beaker using a rubber band. The sea water drops into the beaker. The faecal matter is always kept at the centre of the netting. After the collection is over little quantity of distilled water is poured drop-wise at the periphery of the beaker mouth. Thus dropped distilled water used to slide to the centre and after removing the salt from the adhering sea water drops into the beaker. Latter the netting is removed turned upside down keeping the central portion containing faeces over the mouth of the preweighed wide mouthed clean container. Just a drop or two of distilled water dropped from a little distance over is sufficient to remove the entire lot from the netting into the container. Then the faeces along with the container is dried on a hot air over at 55°C. Thus pooled faeces is used for analysis.

It is also possible that a little of liquid matter also ^{secreted} ~~comes~~ along with the faeces. Elliott (1976) has found out this quantity of organic matter to be of the order of 4% or less to the total faecal matter. Therefore the error arising out of this is small (Brafeld, 1985).

Winberg (1956) is of the opinion that total assimilation efficiency is around 80% (P+R). According to Phillips (1972) it is 90% for protein, 85% for lipid and

40% for starch. All for a normal diet. Carbohydrates of cellulose type are not digested well, except in some herbivorous fishes, wherein the cellulolytic microorganisms present in the gut does the job. Schaeperclaus (1933) is of the opinion that carbohydrates are digested 30-90% by the omnivorous carp. For grass carp total assimilation is less than 13%. For typical carnivorous organisms it can be over 70%. Usually animal proteins are assimilated well; beef heart 96%, white fish meal 92%, casein 99%, and fish protein concentrate over 90%. Assimilation of protein of vegetable origin ^{is} slightly lower, in silver carp (Hypophthalmichthys molitrix) ^{total} assimilation efficiency is 73-93%, while for gold fish (Carassius auratus) 54-63%. At some special situations and ^{for} feeds, value over 90% is possible. At optimal level assimilation efficiencies of 57-80% are highly likely. The assimilation efficiency ^{for a nutrient} varies with the concentration of the nutrient in the diet and feeding level. Physiologically also depends on the physiological status of the organism, feeding habit, temperature of the medium and special situation in the life history like, maturation, spawning, incubation period of the egg etc., when the particular nutrient is available at low level assimilation for that has been observed ^{to be} high. So also when limited feeding regimen is used assimilation is high. Therefore at ad libitum feeding only assimilation efficiencies should be calculated. When assimilation is generalised assimilation efficiency for test and experimental diets are to be taken into account ^{separately} with that of the organism's natural diet. Since A% is either bound to be high or low with test diets, which may or may not be of the organism's liking.

ENERGY - TOTAL, DIGESTIBLE AND METABOLIC

Total energy:

The total energy content of the biological matter (ash free) is measured by total combustion in the bomb calorimeter. Thus bomb calorimetric value for the total substance gives the total energy in it, when we need to know how much calories ^{out of} in the total is from protein, carbohydrate and fat we need to estimate using conversion factors for the available quantity of nutrients. The generalised conversion factors for carbohydrate, fat and protein for one gram of substance are 4.10 Kcal (17.2 KJ); 9.45 Kcal (39.5 KJ); and 5.65 Kcal (23.6 KJ) respectively. These values are biased towards mammalian tissue nutrients. The mammalian lipid is mainly saturated in nature, while that of marine/aquatic organisms are highly unsaturated. Therefore for the lipids of finfishes and shellfishes 8.50 Kcal (35.56 KJ) per gram is preferred, while specifically working with fish lipid 8.65 Kcal (36.2 KJ) per gram is more appropriate (Brafeld, 1985).

The above given value for protein is correct only when protein, free from non-protein nitrogen is used. Jobling (1983 b) quotes that non-protein nitrogen in the salmonid skeletal ^{muscle tissue} can be about 2% of total nitrogen while for elasmobranchs it is as high as 38%. Thus conversion of total kjeldahl nitrogen into protein will give erroneous caloric value.

Though between different purified carbohydrates the combustion values differ significantly -3.74 Kcal/g for glucose and 4.23 Kcal/g for starch - the values given above is generally acceptable while using for tissue carbohydrates.

Digestible energy:

The terminology used for the part of energy digested from the energy nutrients varies between different authors. Brett and Groves use the term physiological energy while others use the term metabolisable energy. I am the one who prefer the term digestible energy, since it is self-explanatory. Digestible calorie = heat of combustion value X % digestibility \div 100. Since digestibility is highly variably it is better that actual digestibility for each nutrient is used. The mean digestibility values for carbohydrate, fat and protein are 40%, 85% and 90% respectively (Philips, 1972). This is a highly generalised opinion.

Metabolic energy (ME):

Often ME is also termed physiologic energy. ME is calculated based on respiratory (oxygen consumption) studies - viz., Respiratory Quotient ($RQ = CO_2$ liberated/ O_2 utilised) and Oxycaloric (oxycalorific quotient) values ($Q_{ox} =$ calorie liberated/unit O_2 utilised). The type of physiological fuel used as energy source can be estimated from RQ and the quantity of non-faecal excretion.

Under total aerobic conditions RQ for carbohydrate and fat are 1.0 and 0.7 ⁱⁿ the order. For ureotelic organisms RQ for protein is around 0.82 and about 0.90 for ammonotelic organisms. Nitrogenous wastes are excreted either as ammonia, or as urea or as uric acid, alone or a mixture of the above and in many along with creatinine and amino acids. Marine teleosts excrete along with a little quantity of trimethylamine oxide (Brett and Groves, 1979). Further proteins contain sulphur at about 1% level. Since Q_{ox} varies with the end products of catabolism, all these varied excretory products of protein make

Table 1 - Energy equivalents used - bioenergetics (Brutt & Groves, 1979)

Nutrient		Energy of food and body resources			Respiratory energy equivalents		Respiratory quotient CO ₂ /O ₂ Ratio
		Food		body	OxyCalorific Values		
		Heat of combustion (kcal/g)	Digestible energy kcal/g	Metabolic energy kcal/g	Qox kcal/lit. O ₂	Qox cal/ mg O ₂	
Carbohydrate	Mammal	4.10	4.0-3.2	4.10	5.04	3.53	1.0
	Fish	4.10	3.3-1.6	4.10	5.04	3.53	1.0
Fat	Mammal	9.45	9.0	9.45	4.69	3.28	0.71
	Fish	8.66	8.0	9.45-8.66	4.69	3.28	0.70
Protein	Mammal	5.65	4.2-3.9	4.70	4.82	3.37	0.81
	Fish	5.65	4.5-3.9	4.80	4.58	3.20	0.90
Mixed	Mammal	5.95	-	-	4.86	3.40	0.83
	Fish	5.89	-	-	4.63	3.25	0.90

calculation of RQ and Q_{ox} for protein complicated.

Brafield and Llewellyn (1982) present the production of ammonia from 100 g of protein as follows: (4.42 C, 7.00 H, 1.44 O, 1.14 N) + 4.6 $O_2 \longrightarrow$ 1.14 NH_3 + 4.42 CO_2 + 1.79 H_2O .

RQ values of above 1.0 is obtainable during active fat synthesis and RQ 1-2 is possible when anaerobic respiration is resorted to (Kutty and Mohammed, 1975).

1 mole of glucose on complete combustion will liberate 677.1 Kcal (2833 KJ) of energy utilising 6 mole of oxygen (ie 192 g). Therefore Q_{ox} for glucose (carbohydrate) is 14.76 KJ/g or 3.53 Kcal/g oxygen consumed. Lipids differ in the order of saturation and the generally accepted Q_{ox} value is 4.63 Kcal/liter O_2 .

For mixed diet Brett and Groves (1979) suggest 4.63 Kcal/liter of O_2 while others are of the opinion that it is 4.8-5.0 Kcal/liter O_2 as Q_{ox} . (Table - 1 & 2).

Jobling (1983 b) suggest the following semi-direct method for the measurement of 'potential' metabolisable energy based on values of total energy, digestibility and incorporating the assumption that nitrogenous excretion is in the form of ammonia, wherein 0.95 Kcal is lost per gram of protein catabolised.

Thus ME (Kcal/g) = Digestibility coefficient of energy X
total energy content of the diet
(Kcal/g) - 0.95 X digestibility
coefficient for protein x dietary
protein content on a relative weight
basis (g/g).

He also is of the opinion that digestible energy for carbohydrates and fats are as good as ME. Therefore 'potential' ME for protein, carbohydrate and fat are as follows. Following Brody (1945) he has taken for protein energy lost in nitrogenous excretion as urea 1.3 Kcal/g.

$$\begin{aligned} \text{ME of protein (Kcal/g)} &= (5.65 - 1.3) \times 0.90 = 3.9 \\ \text{ME of lipid (Kcal/g)} &= 9.45 \times 0.85 = 8.0 \\ \text{ME of carbohydrate (Kcal/g)} &= 4.10 \times 0.40 = 1.6 \end{aligned}$$

METABOLISM (R)

Metabolic rate in fishes and crustaceans is distinguishable into 5 major categories. Basal metabolism that is the metabolic rate at physiological rest at optimum oxygen saturation is difficult ^{to measure} in aquatic organisms. The available dissolved oxygen in aquatic and terrestrial animals is in the order of 10 : 10,00,000 by weight (Priede, 1985). Therefore the term standard metabolism is used.

1. Standard metabolism (R_g) - metabolic rate at minimal maintenance or resting metabolism of an unfed fish below which physiological function would be affected someway. This value is arrived at from nos. 2 & 3 by curve fitting as intercept.
2. Routine metabolism or ordinary metabolism (R_r) - metabolic rate of the animal during its normal spontaneous activity.
3. Maximum sustained metabolism (R_{max}) - maximum metabolic rate for the animal for a sustained maximal activity. Usually obtained at maximum exercise speed.

4. Active metabolism (R_a) - metabolism related to swimming and to stress.
5. Internal heat increment (R_f) - use of energy for SDA. (Feeding metabolism)

Scope for activity or metabolic scope is the difference between R_{max} - R_s ; and varies with stage of development, environmental factors such as temperature and species. Always metabolic rate is calculated to a standard temperature and pressure, since it involves, physiology of the animal and gases viz., O_2 and CO_2 .

During short burst of muscular activity (glycolysis) fish can greatly exceed R_{max} . During this short burst of glycolysis, the glycogen reserve in the skeletal muscle is depleted and the level of lactate increases resulting in oxygen ^{debt}. Similarly R_s is not the absolute lowest limit of metabolism. During low oxygen tension in the medium metabolic rate may be depressed and tissues could function anaerobically for a short duration, which also results in oxygen debt.

As given above the aquatic cultivable organisms need to meet their metabolic demands over R_s within the scope for metabolism. Though the enhanced metabolism due to increased locomotor activity connected with chasing of prey, escape from enemies is ecological one. Physiological metabolic demands are specific dynamic action-(specific dynamic effect) also known as heat increment-and physiological stresses (for eg. osmotic stress). As in the beginning of this chapter it is pointed out energy is partitioned. When the organism spends energy in metabolism over that of routine metabolism, it needs to spend it from the metabolised energy. When this excess is not spent, this part of energy too would have gone for growth. Thus metabolic demand

and growth are competitive. The organism many times need to compromise ^{growth for its metabolic} energy needs.

SDA: Specific dynamic effect or heat increment is increase in heat production observed following a meal. This includes metabolism associated with gut motility, and general post feeding activity. It is difficult to measure by direct calorimetry and so is known ^{as} apparent SDA by Beamish (1974). SDA has been found to be greater if the diet is rich in protein. Therefore it is also thought SDA is energy of deamination. Estimates for SDA ^{are} reported to be 4-45% of the total energy of ingested food. Some are of the opinion it is 5-20% and most authorities feel it is 9-15% of the consumed energy (Brett and Groves, 1979). Jobling (1983 a) suggest that a close relationship exists between thyroid hormone secretion, protein synthesis and metabolic rates. Thus SDA is energy used in protein synthesis and directly associated with the activity of thyroid hormone, in otherwords ^{it is the} inescapable cost of growth.

SDA is usually calculated thus $SDA = M - (M_s + M_e)$ where M is metabolic rate of just fed ones, M_s - metabolic rate of starved animals and M_e - the elevated metabolic rate due to feeding.

Energy spent on activity

Oxygen consumption is always related to the body weight of the organism. In the regression equation $R = a \cdot W^b$, R is oxygen consumption per unit time at optimum oxygen tension, W is the live weight of the organism, 'a' is intercept which is equal to R of an organism of unit weight (ie. 1 g), and 'b' is the constant that indicate at which speed and in which direction R changes with increase in weight. As explained earlier in the respirometers routine

metabolism is measured rather than standard metabolism. In order to compare the regression formula oxygen consumed is standardised to standard temperature and pressure. Further 1 liter of O_2 consumed is equivalent to 4.63 Kcal. Thus R (where $R = R_r$) can be calculated for 24 Hrs. In nature ie. in the farm active animals like fishes are never in ^{any} ~~one~~ ^{metabolic} of the stage always. That is, they are neither at rest (R_s) nor at (R_r) nor very active (R_{max}) throughout. They are at all these rates at many times for different durations. Now our problem is how to estimate this actual metabolism per day. Winberg (1956) after pooling up all the available data on respiratory studies of his time proposed the following equation for routine metabolism.

$R = 0.56 \cdot W^{0.81}$	- Fish and crustaceans
$R = 0.297 \cdot W^{0.81}$	- Freshwater fishes
$R = 0.266 \cdot W^{0.87}$	- Marine fishes
$R = 0.3 \cdot W^{0.8}$	- for freshwater & marine fishes

These are also known as Winberg's basic equation. The interesting factor is that value for b is more static. According to Fry b varies between 0.5 - 1.0 and Kleiber is of the opinion it is around 0.75. Thus Winberg's basic equation stands for the average position. Winberg then proposed that the actual metabolism for fish per day is twice that of routine metabolism. Mann (1965) confirmed this preposition to be practically good in this studies on the fishes of Thames.

In this connection the following facts need to be pointed out. The metabolic rate of young ones are higher and that of the starved fishes is decreased. It is of interest to note that eels on starving for 3 months did keep respiratory (metabolic) level at the same level that

of fed ones (Inui and Ohshima, 1966). Fisher (1977) observed the similar fact in eel after starving for 400 days. It is proposed that they derive energy by gluconeogenesis.

URINARY LOSS (U)

Of all the parameters of the energy budget this is the only parameter which is least measured. The main reason is that quantitatively percentage loss of nutrients/energy on consumption by non-faecal loss is very little and ~~the~~ ^{due to the difficulty in its} estimation of ammonia, the main (60 to over 90%) excretory product. The estimation of ammonia—a highly volatile substance—accurately over a period is difficult. Ogino et al. (1973) devised a flow through system in which outgoing water was passed through a column of Amberlite IR-120 H to absorb liquid nitrogenous wastes and latter to retrieve them quantitatively. This system is not suitable for saline media and ^{further} urea and taurine are not retained by ~~the~~ ^{the} ~~gel~~ (Cowey and Sargent, 1979).

Gerking (1965) and Iwata (1970) have calculated that endogenous excretion of nitrogen is approximately $w^{0.54}$ and $w^{0.9}$ (where W is live weight in gram) for fish - for blue gill sunfish and crussian carp. The few studies available on exogenous (dietary origin) nitrogen indicate that about 22 - 11.4% of the consumption ^(N) is lost as U. At times about 27% of nitrogen consumed is excreted as non-faecal nitrogen (Brett and Groves, 1979). From Brafield (1985) it is calculated that 5.2 to 9.4% of energy intake is excreted as U. Thus it is evident that U is about 7% of C.

Table 2 - Oox values as quoted by Brafield (1985)

	After Brafield & Llwellyn (1982)	After Elliott & Davidson (1975)	After Gnaiger (1983)
Carbohydrate	- 3.53 cal 14.76 J	- 3.53 cal 14.77 J	- 3.52 cal 14.72 J
Fat	- 3.28 cal 13.72 J	- 3.28 cal 13.72 J	- 3.29 cal 13.75 J
Protein to ammonia	- 3.19 cal 13.36 J	- 3.20 cal 13.39 J	- 3.34 cal 13.97 J
Protein to urea	3.25 cal 13.60 J	3.25 cal 13.60 J	3.27 cal 13.69 J

Generalisation of K_1 and K_2

Winberg (1956) generalises that fishes in nature assimilate 85% of ration and 80% of ration is available as (net) physiologically useful energy. He considered urinary loss is negligible and metabolic loss is 3.7 of C. Therefore $P + T = A = 0.8 C$

$$C = 1.25 (P + T) \quad \text{where } K_1 = \frac{P \times 100}{C}$$

$$K_2 = 1.25 K_1$$

The energy the growing embryo utilises for development/growth is considered ^{to be} the maximum net conversion ^(K_2) efficiency possible for total nutrients. This works out to 65% at maximum and never over 70% (Vijayaraghavan et al.,). Whereby K_1 can be theoretically maximum of 44-55%.

GROWTH AND OVERALL BUDGET

Moulting is the feature of growth in crustaceans. Whereby their growth in terms of length are in the form of stanzas. There is little work on the quantity of energy lost by moulting. The study conducted by Thomas et al., (1984) show that 0.60% of ingested nitrogen is utilised as moult.

When the organism neither shows increase nor decrease in weight on feeding, then the quantity of nutrient uptake is said to be at maintenance level (C_m). At levels lower than C_m the organism will show reduction in weight and the meat becomes high in water content. Then it is said to be in degrowth. At degrowth it will be utilising the synthesised body nutrients for its metabolic needs by the process of autolysis. Thus in Penaeus indicus at 25-30 mm size, below 10-12% dietary protein level at the

consumption rate of 11.4% body weight per day, though carbohydrate, lipid and other nutrients being ^{present} at optimum show degrowth (unpub. data). Below this level the dietary protein is not sufficient for metabolic needs and such requirement need to be met by degradation of already formed tissues. Protein cannot be stored. The only little storage possible is by way of free amino acids. Thus when starved of protein the only way left for the fishes and shellfishes is to use its own tissue protein.

With the increase in ration the organism shows increased growth and with further increase in ration the growth does not show any increase. It becomes plateaued. From such a graph it is possible to identify as shown in the figure optimum and maximum ration size (Fig. 2).

Brett and Groves (1979) have come to the following energy budget for young fishes.

Carnivorous: $100 C = 29 P + 44 R + 7 U + 20 F$

Herbivorous: $100 C = 20 P + 37 R + 2 U + 41 F$

In the omnivorous shrimps the budget appears as follows for nitrogen.

Omnivore $100 C = 1432 P + 83 (R+U) + 2.2 F + 0.5 \text{ moult}$

Concluding it should be emphasised that as shown above the fish need to budget its energy. When metabolic demands are too high it should meet it at the cost of growth. At times it need to meet even at the cost of feeding whenever it becomes the question of high SDA and metabolism (Priede, 1985).

Table 2 - Qox values as quoted by Brafield (1985)

	After Brafield & Llwellyn (1982)	After Elliott & Davidson (1975)	After Gnaiger (1983)
Carbohydrate	- 3.53 cal 14.76 J	- 3.53 cal 14.77 J	- 3.52 cal 14.72 J
Fat	- 3.28 cal 13.72 J	- 3.28 cal 13.72 J	- 3.29 cal 13.75 J
Protein to ammonia	- 3.19 cal 13.36 J	- 3.20 cal 13.39 J	- 3.34 cal 13.97 J
Protein to urea	3.25 cal 13.60 J	3.25 cal 13.60 J	3.27 cal 13.69 J

When growth response to diet is low one or a few of the following could be the cause.

1. Nutritional

- a. Food not enough
- b. Food not assimilable
- c. Food not palatable
- d. Low in essential factors
- e. Leeching out of nutrients

2. Physiological

- a. Rapid gonadial development
- b. Infection, Disease

3. Management stress

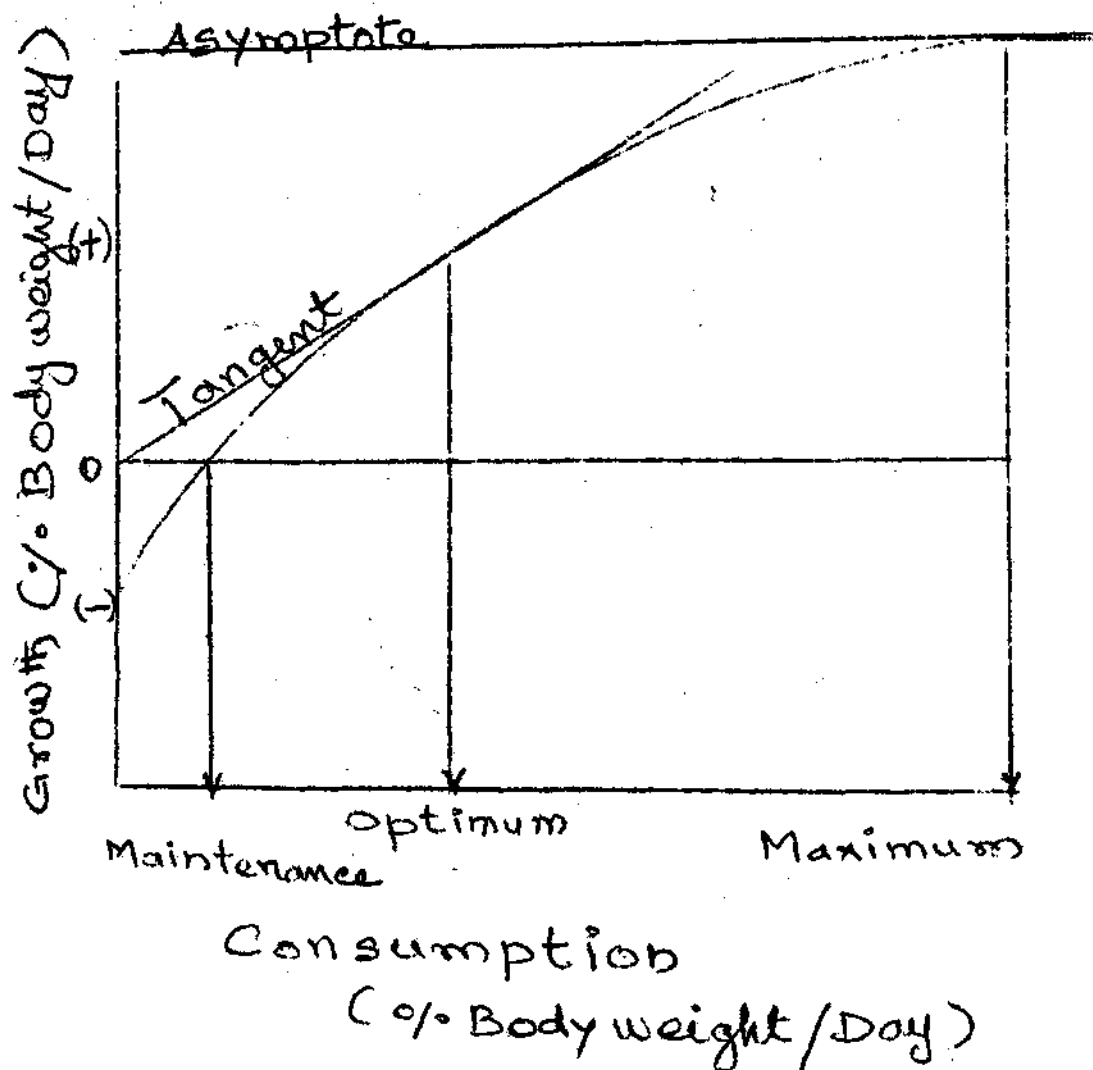
- a. Heavy stocking, competition
- b. Feeding schedule and strategy not suitable
- c. Improper form of diet and particle size
- d. Improper positioning of feed pellets
- e. Type and form of feed not suitable

4. Environmental stress

- a. O₂, temperature, pH, S ‰ and pollutants.
- b. Engineering - system & design

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No food	$C = 0$	$P = \text{negative}$
At maintenance level	$C = \text{small}$	$P = \text{zero}$
At optimum level	$C = \text{optimum}$	$P = \text{good}$
	$K_1 = \text{maximum}$	
At maximum level	$C \ \& \ P \ \text{are maximum}$	

Figure- 2. Showing the graphical method of finding out the levels of ration and meat production economics.

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