De Clariasis Gariepini Nutritione et Incremento

Feeding and Growth Parameters of the African Catfish (*Clarias Gariepinus*) in the body weight range from newly hatched larvae (about 0.003 grams) to about 1500 grams

An overview of Data from the Literature and the Internet

Composit et Scripsit

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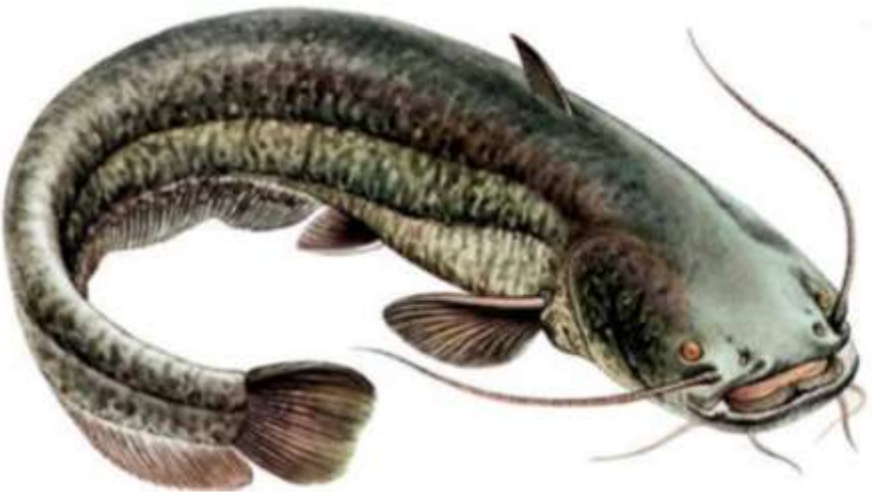

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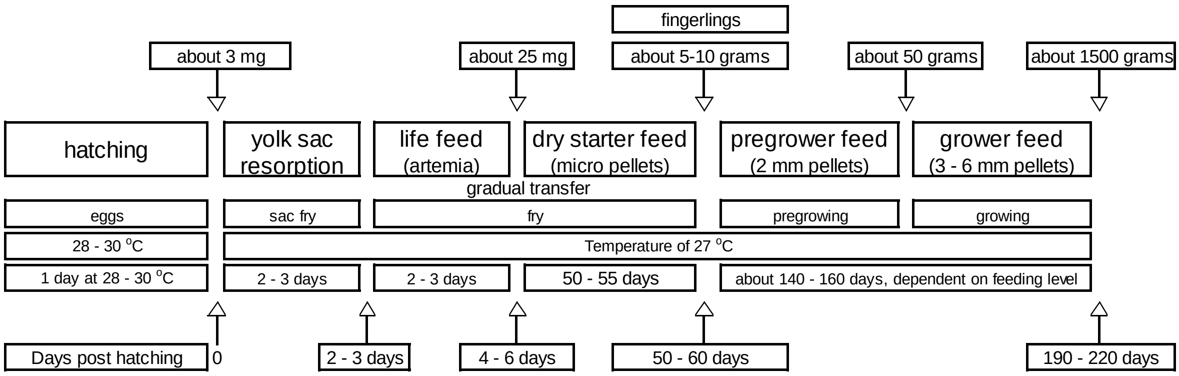
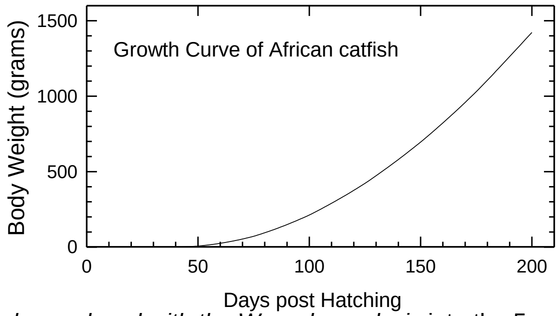
The Netherlands, Anno Domini MMXV (2015)

Summary

1. *The life cycle of the African catfish*.

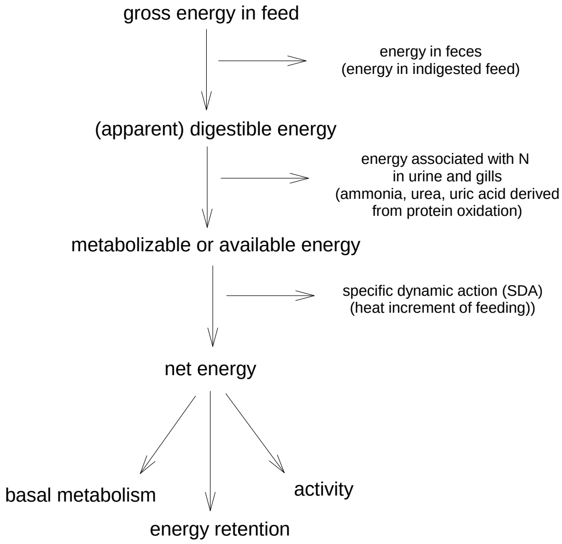


2. *A typical growth curve of the African catfish*.



3. *African catfish feeds can be analyzed with the Weende analysis* into the 5 major compounds, i.e. protein, fat, moisture, ash and fiber. The % protein and % fat are two major characteristics of African catfish feeds.

4. *The energy in an African catfish feed* can be described in terms of (1) gross energy, (2) digestible energy, (3) metabolizable energy and (4) net energy.



5. *The body composition of a catfish* can be described by allometric equations of the form: $y = a * BW(g)^b$:

Moisture (%) = $81.98\ BW(g)^{-0.0213}$
Protein (%) = $12.66\ BW(g)^{0.0545}$
Fat (%) = $2.70\ BW(g)^{0.1647}$
Ash (%) = $2.39\ BW(g)^{0.0482}$
Energy (kJ/gram) = $3.929\ BW^{0.0975}$

Moisture (g) = $0.8198\ BW(g)^{0.9787}$
Protein (g) = $0.1266\ BW(g)^{1.0545}$
Fat (g) = $0.027\ BW(g)^{1.1647}$
Ash (g) = $0.0239\ BW(g)^{1.0482}$
Energy (kJ) = $3.929\ BW^{1.0975}$

6. *The feed intake in African catfish* can be described by allometric scaling formulae of the general form: y = a*BW(kg) ^{b} in two different ways:

(a) as percentage of body weight (grams per 100 grams of fish per day) or
(b) in grams per kg metabolic weight (per BW(kg) $^{0.80}$) per day

The feed intake expressed in % of body weight can be converted into the feed intake expressed in grams per kg metabolic weight (per BW(kg)$^{0.80}$) with the formula:

Feed Intake in grams per kg metabolic weight = c = 10 *(% feed intake per day) / (BW(kg) $^{-0.20}$) **(1)**

and the feed intake expressed in grams per kg metabolic weight (c, per BW(kg)$^{0.80}$) can be converted in the feed intake expressed as % of body weight with the formula:

% feed intake = (c/10) * BW(kg) $^{-0.20}$ **(2)**

where c is the feed intake in grams per kg metabolic weight (per kg BW(kg)$^{0.80}$).

Both ways of expressing the feed intake can be described by allometric scaling formulas of the general form a*BW(kg)^{b} where the feed intake (either as % of body weight or as grams per kg metabolic weight (per BW(kg) $^{0.80}$) is a function of the body weight. The % feed intake can be described by the allometric scaling formula:

% feed intake = a * BW(kg) ^{b} **(3)**

And subsequently converting this formula into grams per kg metabolic weight (per (BW(kg) $^{0.80}$ with formula (1) gives:

feed intake in grams per kg metabolic weight = 10 * a * BW(kg) $^{(b + 0.20)}$ **(4)**

Typical value for b = - 0.350 and a typical value for "a" at a temperature of about 25 - 27 ^{o}C for African catfish is 1.5 (low feeding level) and 1.75 (high feeding level).

Thus, *low feeding level*:

% feed intake = 1.5 * BW(kg) $^{-0.350}$ **(5)**

and expressed in grams per kg metabolic weight with formula (1):

feed intake in grams per kg metabolic weight = 15 * BW(kg) $^{-0.150}$ **(6)**

At this low feeding level, the % feed intake ranges from 7.5% for a catfish of 10 grams to 1.3% for a catfish of 1500 grams and the feed intake per gram metabolic weight (per BW(kg) $^{0.80}$) ranges from 30 grams for a catfish of 10 grams to 14 grams for a catfish of 500 grams.

and, *high feeding level*:

% feed intake = 1.75 * BW(kg) $^{-0.350}$ **(7)**

and expressed in grams per kg metabolic weight with formula (1):

feed intake in grams per kg metabolic weight = 17.5 * BW(kg) $^{-0.150}$ **(8)**

At this high feeding level, the % feed intake ranges from 8.8% for a catfish of 10 grams to 1.5% for a catfish of 1500 grams and the feed intake per gram metabolic weight (per BW(kg) $^{0.80}$) ranges from 34.9 gram for a catfish of 10 grams to 16.46 grams for a catfish of 1500 grams.

These feeding curves involve that the feed intake per kg metabolic weight (per BW(kg) $^{0.80}$) and the ratio of metabolizable energy for production / metabolizable energy for maintenance (Mp/Mm) decrease when the body weight of the African catfish increases. These feeding levels (at 25 - 27 ^{o}C) are comparable with the feeding levels as recommended by various fish feed manufacturers. Lower or higher feeding levels can be obtained by decreasing or increasing the value of "a".

7. The criteria for a good performing catfish feed (or a good catfish feed ingredient) can be summarized with the 4 P 's concept:

1.	**P**alatability	Attractive feed to assure a high feed intake.
2.	**P**erformance	A good feed conversion ratio FCR or feed efficiency ratio (FER).
3.	**P**ollution	High digestibility and faeces that are compact and thus easily to collect.
4.	**P**rice	The price should be right and the feed should be cost effective.

Contents

Life Cycle of the African Catfish

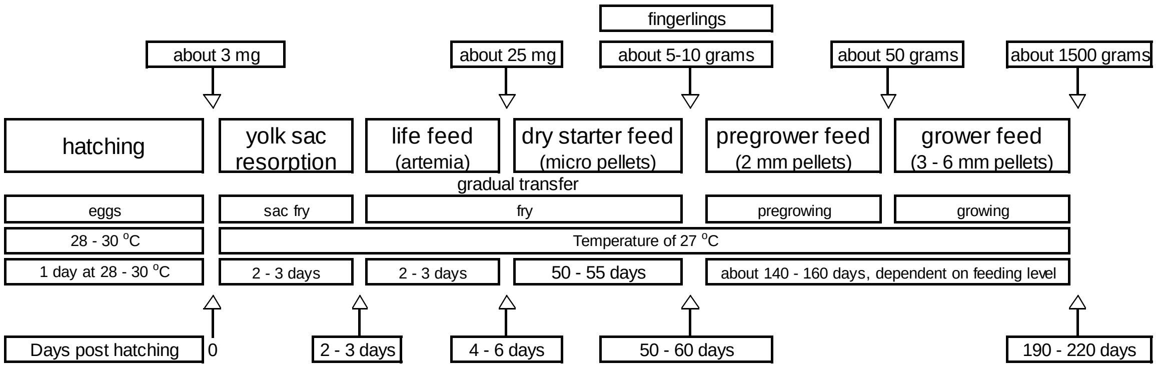
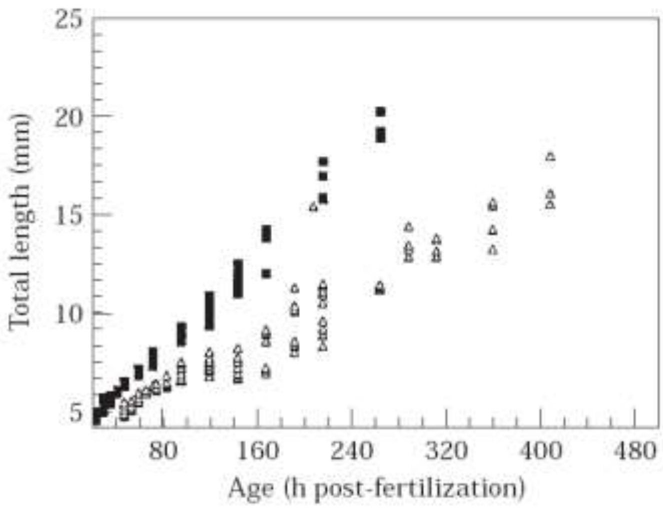


Figure 1
Life cycle of the African Catfish

Fertilized eggs of African catfish usually hatch in about one day at temperatures around 28 - 30 °C. Body weights of newly hatched larvae are about 1 - 3 mg and 5 – 7 mm (see also figure below). The yolk sac resorption takes about 2 – 3 days and the larvae are then fed with life food (artemia) for about 2 days, The larvae are subsequently transferred to dry feed and it takes about 50 – 60 days for the larvae to reach a body weight of 5 – 10 gram. They are now called fingerlings (the size of a finger) and the grow-out period starts. The length of the larvae as a function of time is given by Snik et al. (1997), see Figure 2 below:



Graph showing total length as a function of h post-fertilization. Note the faster growth of *Clarias* (■) reared at 28·5° C compared to *Cyprinus* (△) reared at 24° C. Only the first 420 h of *Cyprinus* are shown to facilitate comparison with *Clarias*.

Figure 2
Data from Snik et al. (1997)

It takes about 140 – 160 days for fingerlings of 5 – 10 grams to reach a body weight of 1500 grams and then they are suitable for consumption. Thus, the time period between a newly hatched larvae (1 – 3 mg) and the size suitable for consumption (1500 grams) is about 190 – 220 days, thus about 6 – 7 months or even shorter.

The African catfish is a fast growing fish, and the fast growth rate is also related to the large amounts of feed that the catfish can consume; the feeding level and feed intake is high compared with other fish species such as e.g. trout.

Catfish (male and female) are able to reproduce themselves when they are approximately 1 years old.

Figure 3
Length of the intestines of a catfish

2 The Composition of Catfish Feeds

Around the year 1860, the researchers Henneberg and Stohmann at the Agricultural Research Institute in Weende in Germany proposed to partition animal feeds into six major compounds, i.e. (1) moisture, (2) protein, (3) fat, (4) ash, (5) crude fibre and the so called (6) nitrogen free extract (NFE). The moisture, protein, ash and fibre were measured and the NFE was calculated as the difference between the total amount of the feed and these five measured compounds. This so-called Weende analysis is still being used for the analysis of (fish) feeds and foods.

Catfish feeds are mostly characterized by their protein and fat levels and the ratio of protein / energy (mg protein / kJ energy). The protein in the feed is primarily needed for the build-up of (muscle) tissues and the fat is a major source of energy and for accretion of fat tissue. Protein drives the growth but there is a maximum amount of protein that can be deposited per day. Thus, it is important that sufficient protein (and protein with the right amino acid composition) is taken up to achieve this maximum protein deposition and growth. On the other hand, the intake of excess of protein that exceeds the maximum capacity to deposit the protein, and also excess of energy will result in the deposition of fat and result in fatty fish. Thus, the right ratio of energy to protein and the right amount of feed is important for optimal growth and trout composition.

The digestible protein / digestible energy ratio is thus an important characteristic of a fish feed, and as a rule of thumb, this ratio in the trout feed (for growing fish) should be similar to the ratio of protein / energy of the fish itself. This way, a maximal retention of dietary protein, an expensive ingredient of trout feed, is achieved. When the fish grows larger, the protein / energy ratio of the fish becomes lower (the percentage fat of the fish increases whereas the percentage protein remains the same), and as a consequence, the ratio protein / energy in the diet should also decrease in order to maintain a maximum protein retention. This phenomenon is called phase feeding or the protein sparing effect of fat.

3 Energy in Catfish Feeds

Fats, carbohydrates and proteins are the major sources of energy in trout feeds. The energy density of these three compounds is different and the amount of energy in a trout feed is related to the amount of fat, carbohydrates and proteins in the feed. The energy in a trout feed can be expressed as gross, digestible and metabolizable energy (Figure 4).

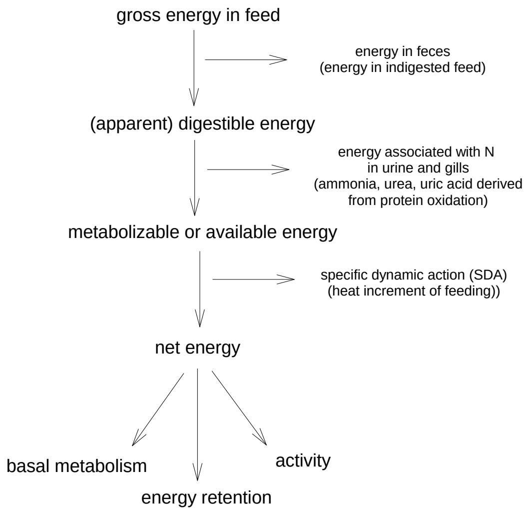


Figure 4
Gross, digestible, metabolizable, and net energy

Gross Energy

The gross energy is the energy or heat that is generated when the feed is completely oxidized. The law of Hess (1838) states that the heat produced in a chemical reaction is always the same regardless of whether it proceeds directly or via a number of intermediate steps (the law of constant heat summation). It means effectively that the heat of metabolizing a nutrient through a complex web of metabolic reactions in the body may be determined and duplicated by measuring the heat produced by burning the same nutrient in a bomb calorimeter. The gross energy can thus be determined by complete combustion of the feed in a so called bomb calorimeter and by measuring the amount of energy or heat that is released. This way, the amount of gross energy can be determined in a complete feed or in only fat, carbohydrates or proteins (Table 1 and 2).

Digestible Energy

The digestible energy is the amount of gross energy in the feed that is digested and is taken up by the fish. The digestibility of fat, carbohydrates and proteins is different and is dependent on various factors. Some raw materials are better digested than others and also the feeding level plays a role; a higher feed intake results usually in a lower digestion of the feed. The average digestibilities are given in Table 1 and are generally used to calculate the digestible energy in a fish feed.

Metabolizable Energy

The metabolizable energy is the energy in the feed that the Tilapia can actually utilize. Metabolizable energy is the digested energy that the body can use and is available to the body. The (gross) energy of the digested carbohydrates and fat are completely available for the body. The fish can completely oxidize the fat and carbohydrates to generate energy. The metabolizable energy of fat and carbohydrates would be equal to the gross energy when fat and carbohydrates would be completely digested. Proteins, on the other hand, contain nitrogen and the nitrogen that is released during the oxidation of proteins as ammonia can only be excreted by the fish in the form of ammonia and urea (Figure 4). About 85% of the released nitrogen is excreted as ammonia through the gills and about 15% as urea in the urine. Ammonia and urea contain substantial amounts of energy, i.e. ammonia has an energy density of 20.7 kilojoule (kJ) per gram and 1 gram urea an energy density of 10.8 kJ per gram. This means that the fish can not completely use the gross energy in the proteins. The energy excreted in ammonia (85%) and urea (15%) is 3.98 kJ per gram protein and the metabolizable or available energy is then 23.65 – 3.98 = 19.67 kJ per gram protein. Protein contains 23.65 kJ gross energy per gram and the fish can thus only use 19.67 kJ per gram protein (see paragraph 12, footnote 6 (g) for the calculations in the fish).

Net Energy

The processing of the nutrients after digestion (storage, deamination, synthesis, such as synthesis of urea and uric acid, etc.) requires energy and this energy is called the specific dynamic action (SDA) or the thermic effect of feed or food (TEF). The net energy is the metabolizable energy corrected for the energy of the SDA. Net energy is thus the energy that can eventually be used for the maintenance, activity and growth.

Table 1

Energy values of various dietary compounds as used in fish nutrition.

	Gross Energy in 1 gram nutrient (kJ/gram)	Metabolizable Energy in 1 gram nutrient (kJ/gram)	Digestibility (%)	Digestible energy In feed (kJ/gram nutrient)	Metabolizable energy In feed (kJ/gram nutrient)
Crude Fat	39.60	39.60	90 (90-95)	35.64	35.64
Crude Protein	23.65	19.67	95 (85-95)	22.50	18.69
NFE or Carbohydrates	17.50	17,50	70 (40-90)	12.25	12,25
Fiber and Cellulose	17.50	17,50	0	0	0

The metabolizable energy in 1 gram of fat or carbohydrate is similar to the gross energy in 1 gram of fat or carbohydrate. However, the metabolizable energy in 1 gram of protein is the gross energy (23.65 kJ) minus the energy that is excreted into the urine in the form of ammonia (85%) and urea (15%) (a total of 3.98 kJ, see paragraph 12, footnote 6 (g), thus 23.65 – 3.98 = 19.67 kJ). The values for gross energy and for the metabolizable energy in 1 gram nutrient can be used for all fish species. However, the values for the digestibilities (and thus the values for the digestible and metabolizable energy in the feed) may vary and are dependent on the type of the diet and the fish species.

Fish metabolize and oxydize predominantly fat and proteins and the average energy equivalent of oxygen (Eeq O_2) for fat (13.72 kJ per gram oxygen) and for protein (13.79 per gram oxygen in ammoniatelic fish) (see page 26, paragraph 12) is about 13.75 kJ per gram oxygen. Thus, the energy expenditure or heat production of the fish in kJ can be calculated by multiplying the oxygen uptake (grams) of a fish by 13.75.

Calculation of the energy in a Catfish feed

The amount of energy in a catfish feed can be easily calculated with the data in Table 1. The percentages of fat, protein, ash and fibre are usually declared on the label on the bag of the catfish feed and the percentage of moisture is usually about 4 - 8%. The percentage of carbohydrates (also called the nitrogen free extract, or NFE) is calculated as (100 - % protein - % fat - % ash - % fibre -% moisture). Table 2 gives as example of a catfish feed with 45% protein, 30% fat, 10% ash and 1% fibre. Thus the percentage of carbohydrates or NFE = (100 – 45% protein – 13% fat - 9% ash – 1.5% fibre – 5% moisture) = 26.5%. The composition of a typical sturgeon feed is given in Table 2.

Energy is usually expressed in joules (J) or kilojoules (kJ; 1 kJ = 1000 joules). Sometime, energy is also expressed in calories (cal) or kilocalories (kcal); 1 cal = 4.184 joule. In the metric system and in science only joules are used.

Table 2
Composition of a typical Catfish feed

Nutrient	% in diet	Gross Energy in 1 gram nutrient (kJ/g)	Metabolizable Energy in 1 gram nutrient (kJ/g)	Gross Energy in 1 gram feed (kJ/g)	Digestibility (%)	Digestible Energy in 1 gram feed	Metabolizable Energy in 1 gram feed
Protein	45,00	23,65	19.67	10,64	95,00	10,11	8,41
Fat	13,00	39,60	39,60	5,15	90,00	4,63	4,63
Ash	9,00						
Moisture	5,00						
Fiber	1,50	17,50	0,00	0,26	0,00		
NFE	26,50	17,50	17,50	4,64	60,00	2,78	2,78
Total	100,00			20,69		17,53	15.82

NFE, nitrogen free extract, the carbohydrate faction. DP/DE (digestible protein/digestible energy) = (450*0.95)/17.53 = 24.39 mg/kJ

4 Feed Sizes for Catfish

The size of the feed is dependent on the body weight and body length of the catfish. The feed sizes as recommended by the fish feed manufacturers Coppens International are given in Table 3.

Table 3
Feed sizes for Catfish

Body Weight (grams)	Feed size (mm)	Type feed
0.025 - 0.1	0.2 - 0.3	starter
0.1 - 0.3	0.3 - 0.5	starter
0.3 - 1.7	0.5 - 0.8	starter
1.7 - 3.3	0.8 - 1.2	starter
3.3 - 10	1.2 - 1.5	starter
10 - 50	2.0	pregrower
50 – 100	3.0	grower
100 - 250	4.5	grower
250 -	4.5 - 6.0	grower

Data from the website of Coppens International: www.coppens.eu (accessed in 2014)

5 Feed Intake and Feeding Levels

For details on the background and derivations of the formulas of feed intake and feeding level curves in general, the reader is referred to the article: "*feeding and growth parameters of the trout"* (Paragraph 6).

In summary:

The feed intake in catfish can be expressed in two different ways:

(1) as percentage of body weight (gram per 100 gram of fish) per day or
(2) in grams per kg metabolic weight (per $BW(kg)^{0.80}$) per day.

The feed intake expressed in % of body weight can be converted into the feed intake expressed in grams per kg metabolic weight (per $BW(kg)^{0.80}$) with the formula:

Feed Intake per kg metabolic weight = c = 10 *(% feed intake per day) / ($BW(kg)^{-0.20}$) (1)

and the feed intake expressed in grams per kg metabolic weight (c, per $BW(kg)^{0.80}$) can be converted in the feed intake expressed as % of body weight with the formula:

% feed intake per day (or feed intake per 100 gram of fish) = (c/10) * $BW(kg)^{-0.20}$ (2)

where c is the feed intake per kg metabolic weight (per kg $BW(kg)^{0.80}$).

Both ways of expressing the feed intake can be described by allometric scaling formulas of the general form $a*BW(kg)^b$ where the feed intake (either as % of body weight or as grams per kg metabolic weight (per $BW(kg)^{0.80}$) is a function of the body weight. The % feed intake can be described by the allometric scaling formula:

$$\textbf{\% feed intake} = a * BW(kg)^{b} \quad (3)$$

And subsequently converting this formula into grams per kg metabolic weight (per ($BW(kg)^{0.80}$ with formula (1) gives:

Feed Intake per kg metabolic weight = c = 10 *(a * $BW(kg)^{-b}$) / ($BW(kg)^{-0.20}$) or

feed intake per kg metabolic weight (per kg $BW(kg)^{0.80}$) = 10 * a * $BW(kg)^{(b + 0.20)}$ (4)

Example:
We have the following feeding curve expressed in % of body weight:
% feed intake = 1.5 * $BW(kg)^{-0.250}$
The % feed intake of a fish of 350 grams is: 1.5 * $(0.350)^{-0.250}$ = 1.95
The total feed intake for a fish of 350 grams is: 0.0195 * 350 = **6.83 grams**

The feed intake expressed in grams per kg metabolic weight (per $BW(kg)^{0.80}$) is:
Feed intake (grams) per $BW(kg)^{0.80}$ = 1.5 * 10 * $BW(kg)^{(-0.250 + 0.20)}$ or
Feed intake (grams) per $BW(kg)^{0.80}$ = 15.0 * $BW(kg)^{-0.050}$
The feed intake in grams per kg metabolic weight for a fish of 350 grams is: 15 * $(0.350)^{-0.050}$ = 15.81
The total feed intake for a fish of 350 grams is : 15.81 * $(0.350)^{0.80}$ = **6.82 grams**

6 Feed Intake and Feeding Levels from the Internet

Feeding levels and feeding tables for African catfish are given by the feed manufacturer Coppens International on the internet (www.coppens.eu) (Table 4). We plotted the feeding levels (% of body weight) vs the body weights of the catfish (Figure 5). A linear plot should arise when the data were plotted on a double logarithmic scale. The slope and the intercept of this plot can be calculated with linear regression and an allometric scaling equation can be constructed of the form:

$$\% \text{ feed intake} = a * BW(kg)^{b}$$

where a is the normalization constant and b is the scaling coefficient and the body weights BW(kg) are expressed in kilograms.

Table 4
Feeding levels for African catfish as recommended by Coppens

Body weight (grams)	Feeding Level % body weight	Feeding Level per $BW(kg)^{0.80}$	Feed Size (mm)
10	5,62	22,37	2.0
11	5,59	22,68	2.0
12	5,57	23,00	2.0
13	5,55	23,29	2.0
15	5,51	23,79	2.0
16	5,47	23,92	2.0
18	5,44	24,36	2.0
19	5,4	24,44	2.0
35	4,99	25,52	2.0
58	4,48	25,35	3.0
90	4,04	24,96	3.0
132	3,61	24,08	3.0
184	3,16	22,52	4.5
242	2,74	20,63	4.5
305	2,37	18,69	4.5
372	2,08	17,07	4.5
441	1,87	15,88	4.5/.6.0
514	1,70	14,88	4.5/.6.0
589	1,57	14,12	4.5/.6.0
669	1,50	13,84	4.5/.6.0
754	1,43	13,51	4.5/.6.0
845	1,36	13,15	4.5/.6.0
940	1,3	12,84	4.5/.6.0
1040	1,24	12,50	6.0
1144	1,18	12,12	6.0
1251	1,12	11,71	6.0
1361	1,06	11,27	6.0
1473	1,02	11,02	6.0
1589	0,97	10,64	6.0/8.0
1706	0,92	10,24	6.0/8.0
1826	0,89	10,04	6.0/8.0
1948	0,86	9,83	6.0/8.0
2000	0,84	9,65	6.0/8.0

From the website of Coppens International, www.coppens.eu (accessed in 2014). The feeding level expressed in % feed intake were converted into grams per kg metabolic weight (per $BW(g)^{0.80}$) with the formula: feed intake per kg metabolic weight (per $BW(kg)^{0.80}$) = 10 *(% feed intake per day) / ($BW(kg)^{-0.20}$).

The feeding levels of Coppens (Table 4) expressed in % of body weight were plotted vs the body weights in kilograms (Figure 5). The regression line describing this linear plot was calculated to be :

$$\log (\% \text{ feed intake}) = \text{intercept} + b * \log BW(kg)$$

$$\log (\% \text{ feed intake}) = 0.1067 - 0.3685 * \log BW(kg)$$

$$\text{anti-log of } 0.1067 = 1.2786$$

$$\log \% \text{ feed intake} = \log 1.2786 - 0.3685 * \log BW(kg)$$

$$\log \% \text{ feed intake} = \log 1.2786 + \log (BW(kg)^{-0.3685}$$

$$\log \% \text{ feed intake} = \log (1.2786 * BW(kg)^{-0.3685})$$

$$\% \text{ feed intake} = 1.2786 * BW(kg)^{-0.3685}$$

(for the properties of logarithms, see paragraph 12)

The feeding curves expressed in % of body weight can be converted into feeding curves expressed in grams per kg metabolic weight (per $BW(kg)^{0.80}$) as following (formula 1, page 10):

feed Intake per kg metabolic weight = c = 10 *(% feed intake per day) / (BW(kg) $^{-0.20}$) or

The formula for the feed intake expressed as % of body weight is:

% feed intake = 1.2786 * BW(kg) $^{-0.3685}$ (27 ^{o}C)

Substitution into the conversion formula gives:

feed intake per kg metabolic weight = c = 10 *(1.2786*BW(kg) $^{-0.3685}$) / (BW(kg) $^{-0.20}$) or

feed intake in grams per kg metabolic weight (per BW(kg) $^{0.80}$) = 12.786 * BW(kg) $^{(-0.1682)}$

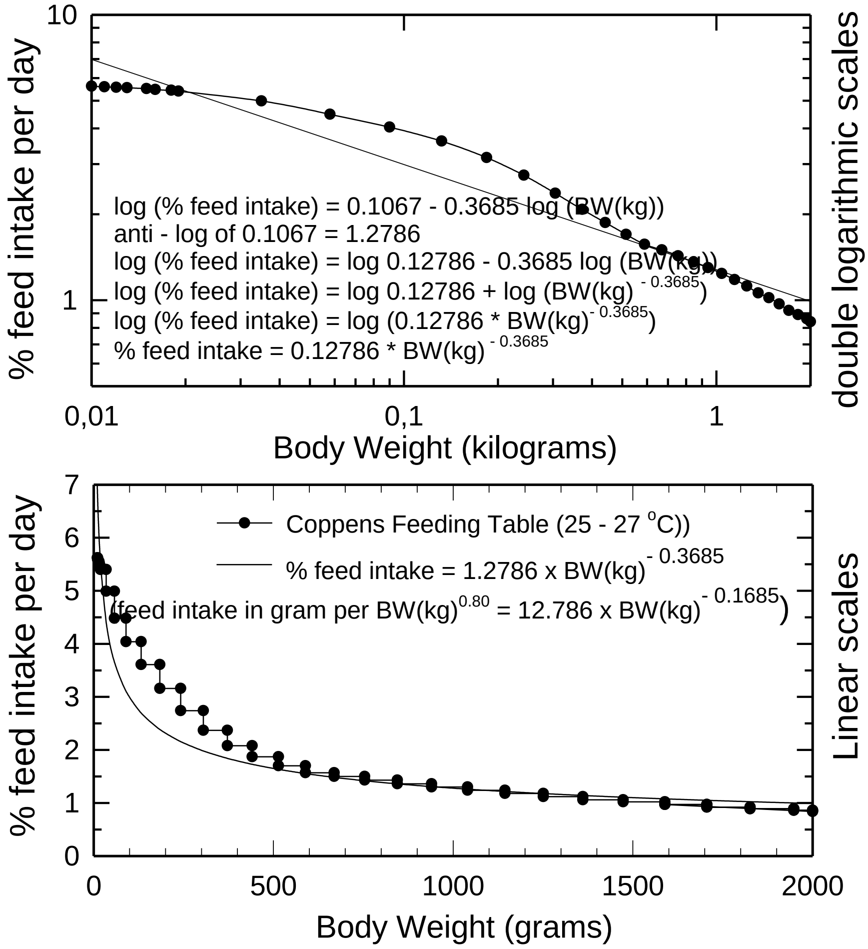


Figure 5
Feed intake levels for the African catfish (data from Table 4)

7 Construction of a General Feeding Curve for the African Catfish

We can construct two different types of feeding curves:

(a) where the ratio of metabolizable energy for production / metabolizable energy for maintenance (Mp/Mm) is the same for all different sizes of Catfish and independent of the body weights and the feed intake per kg metabolic weight (per BW(kg) $^{0.80}$) is then also the

same for all the various sizes of Catfish and is also independent of the body weights. In this situation, the scaling coefficient of the feeding curve or formula describing the feed intake as percentage of body weight (% feed intake = a * BW(kg) ^{b}) has to be b = – 0.2.

__(b) where the ratio of metabolizable energy for production / metabolizable energy for maintenance ratio (Mp/Mm) is different for all different sizes of Catfish__ and dependent of the body weights and thus relatively less energy is used for growth and relatively more for maintenance when the catfish grows larger. The feed intake per kg metabolic weight (per BW(kg) $^{0.80}$) is then also different for all the various sizes of trout and is dependent on the body weights. In this situation, the scaling coefficient of the feeding curve or formula describing the feed intake as percentage of body weight (% feed intake = a * BW(kg) ^{b}) has to be different from – 0.20 (or b ≠ – 0.20).

Details for the construction of these two types of feeding curves are given in the article: "*Feeding and growth parameters of trout*", paragraph 6 page 17).

We will construct here a feeding curve for Catfish where where the ratio of metabolizable energy for production / metabolizable energy for maintenance ratio (Mp/Mm) is different for all different sizes of Catfish. We can construct a general feeding formula where the feed intake is expressed as % of body weight with a allometric scaling formula:

% feed intake = a * BW(kg) ^{b}

Where "xa is the normalization constant and "b" is the scaling coefficient. We can choose a value for "a" and "b" depending on the feeding levels we are interested in. Note that increasing or decreasing the normalization "a" constant will linearly increase or decrease the feeding level. The scaling coefficient, however, determines the slope of the feeding curve and a change of the scaling coefficient will affect how fast the feeding level will decrease when the catfish grows larger.

The African catfish is a fast growing fish species and has a growth rate that is considerable higher than that of e.g. a trout. As a consequence, the feed intake is also high. We could use a value of – 0.350 as the scaling coefficient for feeding curves for catfish and a value of 1.50 (low) 1.75 (high) for the normalization constant and the feeding formula becomes then:

% feed intake = 1.50 * BW(kg) $^{-0.350}$

and expressed in gram per kg metabolic weight (formula 1, page 10):

gram per BW(kg) $^{0.80}$ = 15.0 * BW(kg) $^{-0.150}$

Thus, the feeding curves expressed as percentage of body weight are (Figure 6):

Low level % feed intake = 1.5 * BW(kg) $^{-0.350}$
High level % feed intake = 1.75 * BW(kg) $^{-0.350}$

The feeding curves expressed in % of body weight can be converted into feeding curves expressed in grams per kg metabolic weight (per BW(kg) $^{0.80}$) (formula 1, page 9):

Low level: feed intake in grams (per BW(kg) $^{0.80}$) = 15 * BW(kg) $^{(-0.150)}$
High level: feed intake in grams (per BW(kg) $^{0.80}$) = 17.5 * BW(kg) $^{(-0.150)}$

These feeding levels expressed in % of body weight decreases when the body weight of the African catfish increases. In addition, the feed intake as expressed in grams per kg metabolic weight (per BW(kg) $^{0.80}$) also decreases when the body weight of the catfish increases; as a consequence, the ratio of metabolizable energy for production / metabolizable energy for maintenance (Mp/Mm) also decreases when the body weight of the African Catfish increases (*see article* "*Feeding and growth parameters of trout*" for details, paragraph 6).

We can linearly decrease or increase the feeding level by decreasing or increasing the value for "a", the normalization constant of the feeding formula. This way, various feeding levels and curves for African Catfish can be generated.

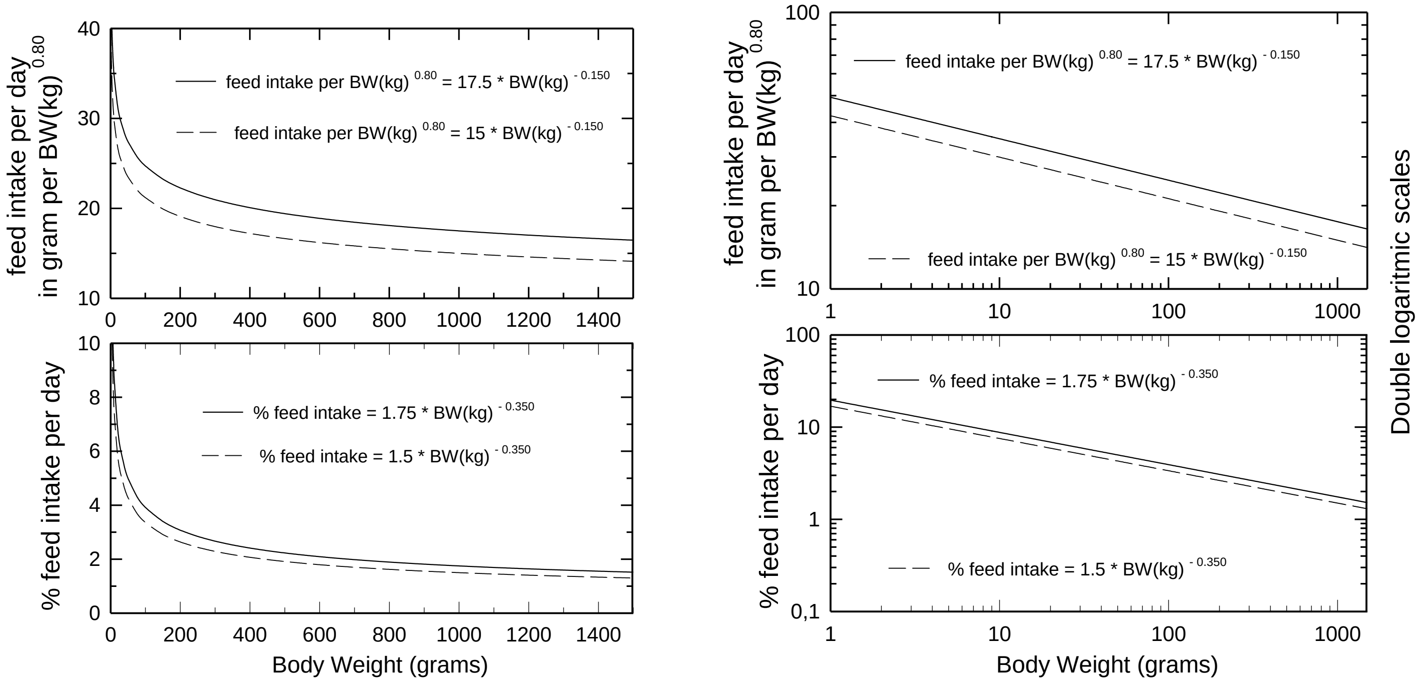


Figure 6

General feeding curves for African catfish at a water temperature of about 25 - 27 ^{o}C.

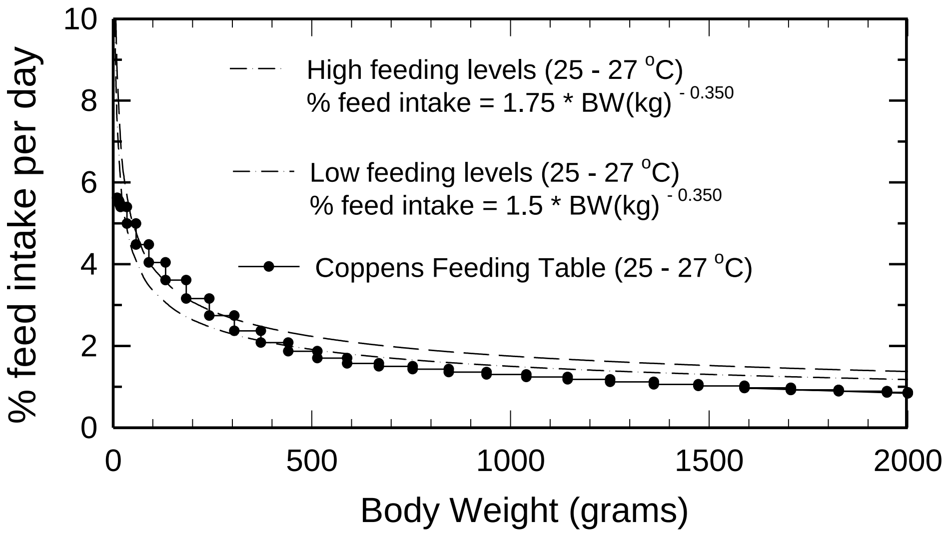


Figure 7

General low and high feeding curve for African catfish compared with feeding curves as recommended by Coppens.

Example: The feeding curve is:
(1) % feed intake = 1.5 * $BW(kg)^{-0.350}$ or
(2) feed intake (per $BW(kg)^{0.80}$) = 15 * $BW(kg)^{(-0.150)}$

We have for example a catfish of 150 grams:
(1) % feed intake = 1.5 * $BW(kg)^{-0.350}$ = 1.5 * $0.150^{(-0.350)}$ = 2.91
The feed intake is then 0.0291 * 150 = **4.37** grams of feed.

(2) feed intake (per $BW(kg)^{0.80}$) = 15 * $BW(kg)^{(-0.150)}$ = 15 *$0.150^{(-0.150)}$ = 19.94
The feed intake is then 19.94 * $BW(kg)^{0.80}$ = 19.94 * $0.15^{0.80}$ = **4.37** grams of feed.

8 Growth Curves for African Catfish

(for details, see the article: *Some aspects of energy metabolism in homeotherm animals and poikilotherm fish*)

Two major types of growth curves can be used for catfsih, the exponential growth curve and the power growth curve, also called the Daily Growth Coefficient (DGC) growth curve (Iwama, 1981, Kaufman, 1981). The exponential growth curve can be used to describe the growth of catfish larvae, up to about 10 - 30 grams, and the power growth curve to describe the growth of larger size catfish.

The exponential growth curve is described by the formula:

$$\mathbf{BW_1 = BW_o\ e^{\alpha t}}$$

which is an exponential function where t is the time in days and BW_0 is the body weight when t=0. The logarithmic and linear form is:

$$\ln (BW_1) = \ln (BW_o * e^{\alpha t}) = \ln BW_o + \alpha t \ln e = \ln BW_o + \alpha t$$

A growth curve fits an exponential growth curve when a linear plot arises when the ln values of the body weights are plotted vs the time. An example of the exponential growth curve is given in Figure 12. The ln values of the body weights are plotted vs the time (days). The slope α and the intercept (ln BW_0) of this linear plot can be calculated by linear regression and the slope α is the exponent of the function and the anti-ln of the intercept (ln BW_0) is BW_0 at t=0.

The slope α can also be estimated by taking two points of the graph and using the formula (shortened method):

$$\alpha = \ln BW_{t=t2} – \ln BW_{t=t1}$$

When we have calculated the value of α and BW_0 (the anti-ln of the intercept), then we can calculate the body weights at each time point with the formula: $BW_1 = BW_o\ e^{\alpha t}$ for any value of BW_0.

Example: The growth of African catfish larvae is for example described by the exponential function:
$BW_1 = BW_0 * e^{\alpha t} = 0.0224 * e^{0.1133*t}$ where BW_o is the BW at t = 0 and is in this example 0.0224 grams
The body weight at t = 60 days is:
$BW_1 = 0.0224 * e^{0.1133*60}$ = 20.07 grams.
The body weight after another 10 days is:

Method 1:
$BW_1 = BW_o * e^{\alpha t} = 20.07 * e^{0.1133*10} = 62.32$ grams
Method 2:
$BW_1 = BW_o * e^{\alpha t} = 0.0224 * e^{0.1133*70} = 62.32$ grams.

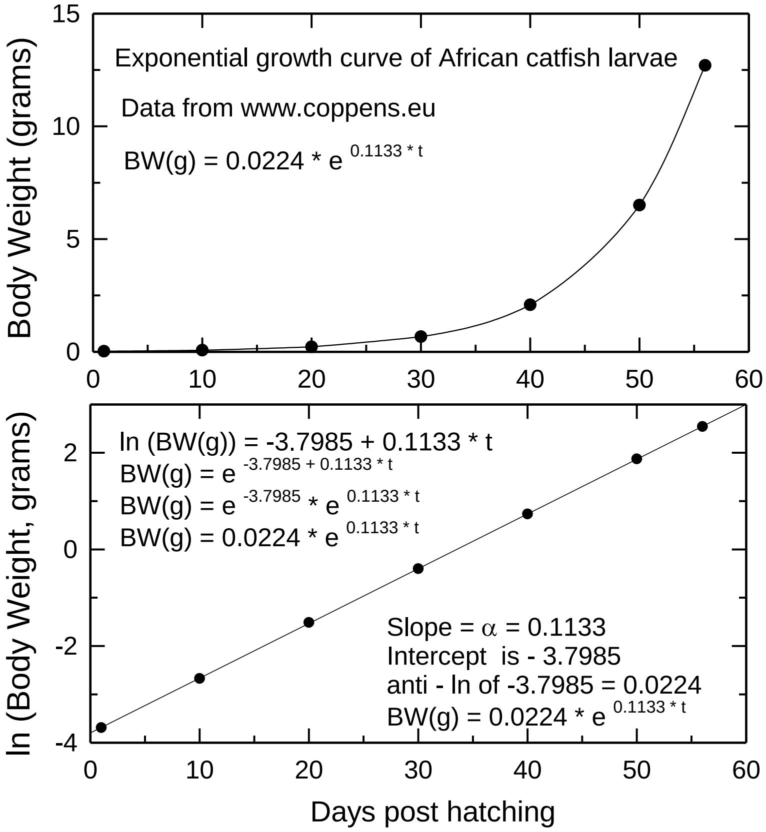


Figure 8

Exponential growth curve of African catfish larvae. Data from www.coppens.eu (accessed 2014)

Further, we can calculate the time that is needed to double the body weights:

$$t = t_2 - t_1 = \frac{\ln 2}{\alpha}$$

Similarly, the time needed to triple the body weights is:

$$t = t_2 - t_1 = \frac{\ln 3}{\alpha}$$

When α = 0.1135, then the time to double the body weights is: ln 2 / 0.1135 = 6.11 days.
Note that the time to double (or triple) the body weights is independent of the initial body weight.

Note that the time to double (or triple) the body weights is independent of the initial body weight.

In addition, we can calculate the % of growth per unit of time

$$\textbf{\% growth per time unit of } t_1\text{-}t_0 = 100\% * (e^{\alpha(t1-t0)} - 1)$$

And the % growth per day is

$$\textbf{\% growth per day} = 100\% * (e^{\alpha} - 1)$$

Note that the % growth per day is independent of the (initial) body weight.

Example: Suppose that we calculated from experimental data that α = 0.1133 and we want to calculate the % growth per day, thus t_1-t_0 = 1 day.

$$\text{\% growth per day} = 100\% * (e^{\alpha} - 1)$$

$$\text{\% growth per day} = 100\% * (e^{(0.1133 *1)} - 1) = 12.00 \text{ \% per day}$$

This result means that the body weights will increase every day with 12%, independently of the (initial) body weights. A similar phenomenon is seen with an amount of money on the bank with a so called compound interest rate per year; every year the amount of money will increase with the percentage of the interest rate, independent of the (initial) amount of money on the bank.

The percentage growth per day is usually called the specific growth rate (SGR). In financial terms it is called the interest rate per year. Mostly, the value of α is used as the SGR, but this is not really correct, although the differences between the value of α and the SGR as calculated above is not much different (11.33 vs 12.00% in the example above).
Similarly, we can calculate the % growth per 2 days, 3 days etc.

<u>The power growth curve is described by the formula:</u>

$$BW^{1/3}_{\ day=1} = BW^{1/3}_{\ day=0} + c\ t$$

which is a linear function where $BW^{1/3}$ is the body weight raised to the power 1/3, t is time (days), c is the slope of the graph, and $BW^{1/3}_{day=0}$ is the body weight raised to the power 1/3 when t=0. The slope c multiplied by 100 is called the Daily Growth Coëfficient (DGC, *Iwama 1981*). A growth curve fits a power growth curve when a linear graph arises when the values of the body weights raised to the power 1/3 are plotted vs the time. The slope c of this linear plot and the intercept $BW^{1/3}_{\ day=0}$ can be calculated with linear regression. Also a power coefficient (d) different from 1/3 has sometimes to be used to fit a power growth curve. The correct power coefficient (d) can be found by trial and error. A correct power coefficient means that the body weights raised to the power coefficient and plotted vs the time results in a linear curve. The value of the power coefficient (d) is 1 > d > 0.

The formula can also be written as:

$$BW_{\ day=1} = (BW^{1/3}_{\ day=0} + c\ t)^3$$

and, since the daily growth coefficient (DGC) is c * 100:

$$BW_{\ day=1} = (BW^{1/3}_{\ day=0} + (DGC/100)\ t)^3$$

When we know the DGC, we can calculate with this formula the body weights $BW_{\ day=1}$ at various time points for any value of $BW_{day=0}$.

<u>How to calculate the the DGC:</u>

<u>Method 1.</u>

When a set of growth data are given (various time points with various body weights), then all the (body weights)^d are plotted versus the time. Then, by means of a linear regression analysis, the intercept (intercept is BW^d when time = 0) and the slope (x 100 = DGC) can be calculated. The value for d has to be determined by trial and error. A correct value for d has been found when the graph of the values of the (body weights)^d vs the time is a linear graph. For African catfish of about 10 – 1500 grams a value for d of ½ = 0.5 appears to be suitable (see Figure 9 below, but may vary, depending on the growth conditions).

<u>Method 2.</u>
When only the body weights at two time points are known and one is confident that these two time points are the points of a linear curve describing the BW ^{d} vs time, then the slope can be calculated as follows:

$$BW^{d}_{\ day=1} = BW^{d}_{\ day=o} + c*days$$

$$c = (BW^{d}_{\ day=1} - BW^{d}_{\ day=o}) / days$$

This c is per definition the slope of the graph (c). The DGC is then c*100. The DGC is expressed as % (weight gain)^d per day.

$$\text{Daily Growth Coefficient} = DGC = 100\% * (BW^{d}_{\ day=1} - BW^{d}_{\ day=o}) / days$$

Figure 9 shows a power growth curve of the African catfish. We used a value of d = 1/3 = 0.33 in this graph (Figure 9). However, a better fit was obtained when we used a value of d = 1/2 = 0.5. This value was found by trial and error, i.e. a linear graph should be generated when the body weights raised to this power are plotted vs the time (see bottom panel of Figure 9).

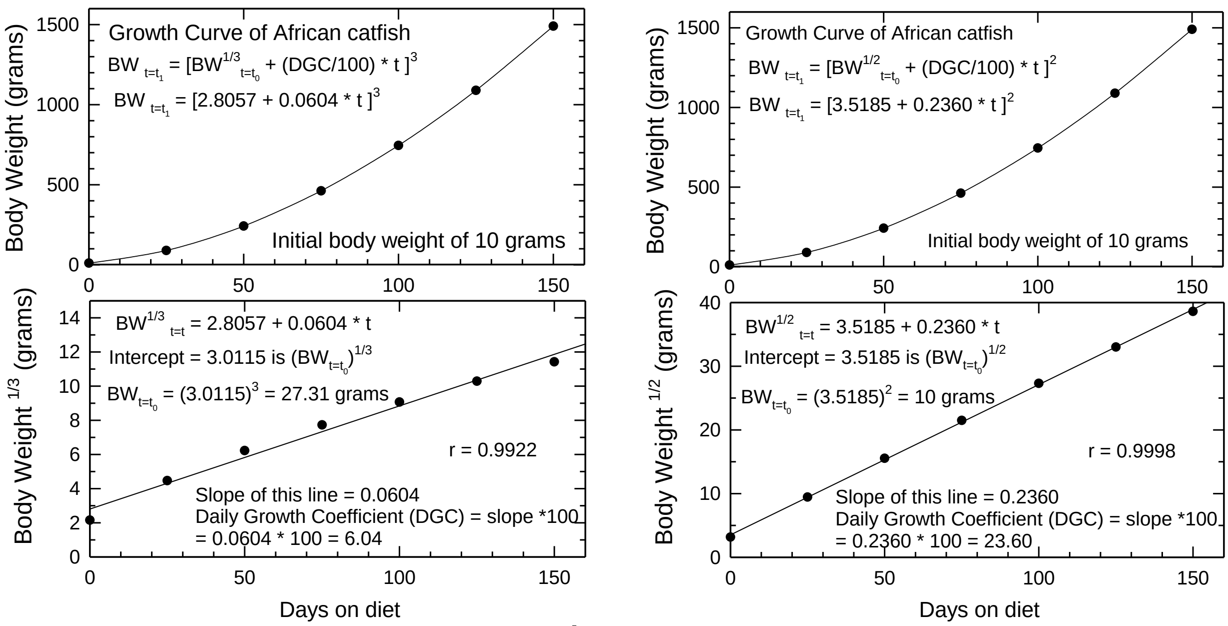


Figure 9

Power growth curves of African catfish. The curve was generated by using a growth model for the African catfish(see article: "Feeding and growth parameters of the trout", the paragraph on the energy budget of a trout). We used in these graphs a power coefficient of 1/3 and 1/2

The calculated DGC can be used to predict body weights after a defined number of days as:

$$\textbf{Final Body Weight} = [\, (\textbf{Initial Body Weight})^{d} + (\textbf{DGC}/100) * \textbf{days on diet} \,]^{1/d}$$

Further, when the final body weight is known, the number of days, and the DGC, then the initial body weight can be calculated:

$$\textbf{Initial Body Weight} = [\, (\textbf{Final Body Weight})^{d} - (\textbf{DGC}/100) * (\textbf{days on diet}) \,]^{1/d}$$

Similarly, when the initial body weight is known and the DGC, then it can be calculated after how many days a defined body weight has been reached:

$$\textbf{Days on Diet} = 100 * [\, (\textbf{Final Body Weight})^{d} - (\textbf{Initial Body Weight})^{d} \,) \,] / (\textbf{DGC})$$

Example: The body weight at day 0 is 10 grams and the body weight at day 100 is 745 grams and d = 1/2, thus number of days is 100 days (data from Figure 9, then the DGC is:

$$\text{DGC} = 100\% * (\text{BW}^{1/2}_{\text{day=1}} - \text{BW}^{1/2}_{\text{day=o}}) / \text{days}$$
$$\text{DGC} = 100 \times [(745)^{1/2} - (10)^{1/2}] / 100 = 24.13\ \%\ (\text{weight gain})^{1/2} \text{ per day (compare the value 23.60\% in Figure 9)}$$

Example: The initial body weight is 10 grams and d = 1/2 and the DGC is 24.13. Then the body weight after 100 days can be calculated as

$$\text{Final Body Weight} = [\, (\text{Initial Body Weight})^{1/2} + (\text{DGC}/100) * \text{days on diet} \,]^{2}$$
$$\text{Final Body Weight} = [\, (10)^{1/2} + (24.13 / 100)*100 \,]^{2} = 745 \text{ grams.}$$

Example: The final body weight is 745 grams at 100 days and the DGC is 24.13. Then the body weight at 0 days is (thus days on diet is 100 – 0 = 100 days):

$$\text{Initial Body Weight} = [\, (\text{Final Body Weight})^{1/2} - (\text{DGC}/100) * (\text{days on diet}) \,]^{3}$$
$$\text{Initial Body Weight at day 0} = [\, (745)^{1/2} - (24.13/100) * (100) \,]^{2} = 10 \text{ grams}$$

***Example*:** The initial body weight is 10 grams and d = 1/2 and the DGC is 24.13. How long does it take to double the body weight?

$$\text{Days on Diet} = 100 * [\, (\text{Final Body Weight})^{1/2} - (\text{Initial Body Weight})^{1/2} \,) \,] / (\text{DGC})$$
$$\text{Days on Diet} = 100 * [\, (20)^{1/2} - (10)^{1/2} \,) \,] / (24.13) = 5.4 \text{ days}$$

Note that the time to double the body weight is dependent on the initial body weight (see example below). The time to double the body weight for an exponential growth curve is independent of the initial body weight.

***Example*:** The initial body weight is 100 grams and d = 1/2 and the DGC is 24.13. How long does it take to double the body weight?

$$\text{Days on Diet} = 100 * [\, (\text{Final Body Weight})^{d} - (\text{Initial Body Weight})^{d} \,) \,] / (\text{DGC})$$
$$\text{Days on Diet} = 100 * [\, (200)^{1/2} - (100)^{1/2} \,) \,] / (24.13) = 17.2 \text{ days}$$

The exponential growth curve is mostly used to describe the growth of African catfish larvae up to about 10 - 15 grams whereas the power growth curve is used for larger size African catfish. However, the power growth curve can also be used to describe the growth rate of African catfish larvae, but a power coefficient smaller than ½ = 0.5 or 1/3 = 0.333 has to be used. The correct power coefficient has to be found by trial and error and we found that a power curve with a power coefficient of 0.10 can also describe the growth rate of African catfish larvae instead of an exponential growth curve. Dumas et al. (2007b) described that various power coefficients may be used dependent on the size of fish and the growth stanza. Figure 10 shows that the growth curve of African catfish larvae can also be described by a power growth curve instead of an exponential growth curve.

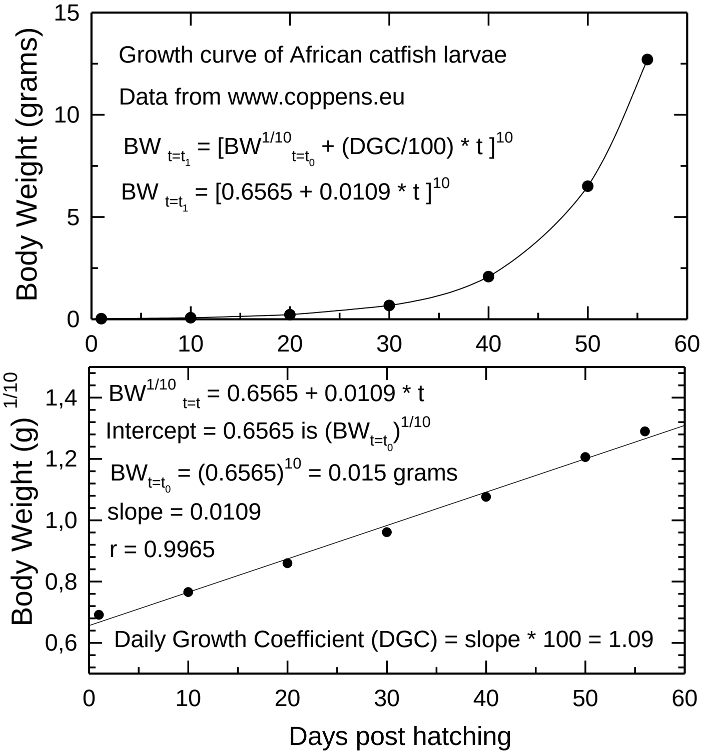


Figure 10

Power growth curve of African catfish larvae. We used a power coefficient of 1/10 = 0.10 to obtain the best fit. Data from www.coppens.eu. (accessed in 2014)

9 Body Composition of the African catfish

The major components of the African catfish are water, protein, fat and ash. The proportion of protein in the body is rather constant (about 15 - 20%) and the same is true for the ash content (about 2%). However, the fat and water content can vary strongly and is dependent on various factors such as e.g. the feeding level and the composition of the diets. Further, the fat and the water content are negatively correlated with each other, i.e. a high fat content is associated with a low water content. When the correlation between water content and fat content is known, then the proportion of fat in the body can be derived from the water content in the body. The water content of the body of experimental animals can be easily measured by drying in an oven.

The amount of protein, fat, water and ash in the body can be described by the allometric scaling equation:

$$\text{amount (\%)} = a * BW(g)^b$$

where a is the normalization constant, BW is the body weight in grams and b is the scaling coefficient.

For the body composition of the African Cafish (*Clarias gariepinus*), the compositional data of the following articles have been used:

Machiels, M.A.M. & Henken, A.M. (1986) A dynamic simulation model for growth of the African Catfish, *Clarias Gariepinus* (Burchell 1822). I Effect of feeding level on growth and energy metabolism. Aquaculture 56: 29-52

Machiels, M.A.M. (1987) A dynamic simulation model for growth of the African Catfish, *Clarias Gariepinus* (Burchell 1822). IV Effect of feed formulation on growth and feed utilization. Aquaculture 64: 305-323.

Hogendoorn, H.F. (1983) Growth and production of the African Catfish *Clarias lazera* (C&V). II Effects of body weight, temperature and feeding level in intensive tank culture. Aquaculture 34: 265-285.

Lim, P.-K., Boey, P.-L. and Ng, W.-K (2002) Dietary palm oil level affects growth performance, protein retention and tissue vitamin E concentration of African catfish, *Clarias gariepinus*. Aquaculture 202: 101-112.

Ali, M.Z. and Jauncey, K. (2005) Approaches to optimizing dietary protein to energy ratio for African catfish Clarias gariepinus (Burchell 1822). Aquaculture Nutrition 11: 95-101.

Ali, M.Z. and Jauncey, K. (2004) Optimal dietary carbohydrate to liid ratio in African catfish *Clarias gariepinus* (Burchell 1822) Aquaculture International 12: 169-180.

Ng, W.-K., Wang, Y., Ketchimenin, P. and Yuen, K.-H. (2004) Replacement of dietary fish oil with palm oil fatty acid distillate elevates tocopherol and tocotrienolconcentraions and inceases oxidative stability in the muscle of African catfish , *Clarias gariepinus*. Aquaculture 223: 423-437.

Ng, W.-K., Lim, P.-K. and Boey, P.-L. (2003) Dietary lipid and palm oil source affects growth, fatty acid composition and muscle α-tocopherol concentration of African catfish, *Clarias gariepinus.* Aquaculture 215: 229-243.

We combined the compositional data from the various African catfish studies in the literature and we derived the following formulae:

Moisture (%) = 81.98 BW(g) $^{-0.0213}$
Protein (%) = 12.66 BW(g) $^{0.0545}$
Fat (%) = 2.70 BW(g) $^{0.1647}$
Ash (%) = 2.39 BW(g) $^{0.0482}$
Energy (kJ/gram) = 3.929 BW $^{0.0975}$

mg protein / kJ = 32.22 BW $^{-0.0431}$

Moisture (g) = 0.8198 BW(g) $^{0.9787}$
Protein (g) = 0.1266 BW(g) $^{1.0545}$
Fat (g) = 0.027 BW(g) $^{1.1647}$
Ash (g) = 0.0239 BW(g) $^{1.0482}$
Energy (kJ) = 3.929 BW $^{1.0975}$

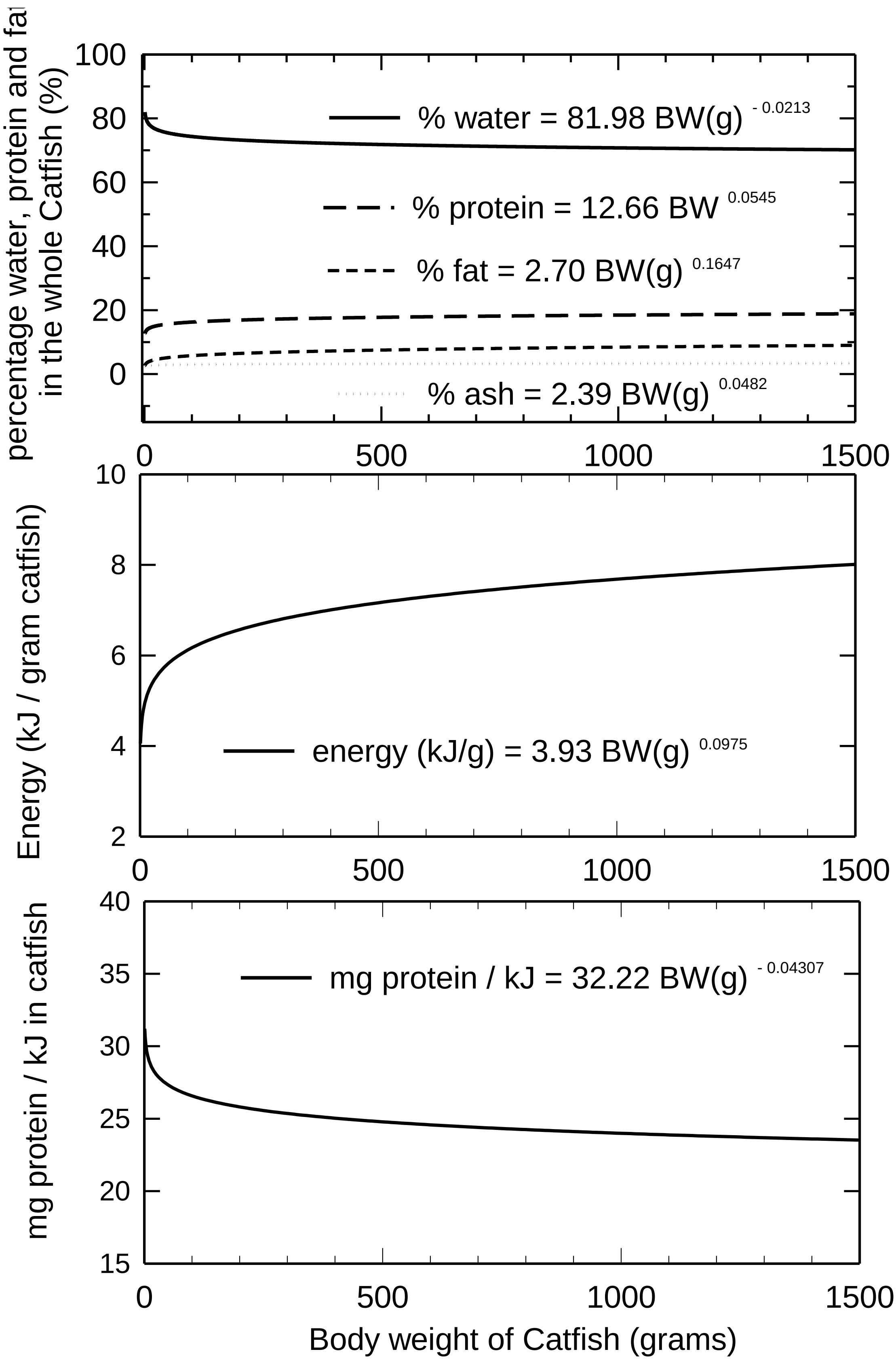


Figure 11
Body composition of African Catfsih

10 Factors that affect the Performance of an African catfish Feed: the 4 P's concept.

Protein drives the growth and the maximum growth of a trout is determined by the maximum capacity to deposit protein. Thus, it is important that sufficient protein (and protein with the right amino acid composition) can be taken up to achieve this maximum protein deposition and growth. On the other hand, the intake of excess of protein that exceeds the maximum capacity to deposit the protein, and also excess of energy will result in the deposition of fat and result in fatty fish. Thus, the right ratio of protein to energy and the right amount of feed is important for optimal growth. As a rule of thumb, the ratio mg digestible protein / kJ digestible energy in growing fish should be similar to this ratio of the fish itself see also: feeding manual for trout, paragraph on phase feeding).

A factor that determines the uptake of a feed is the *palatability* of the feed. A feed that is not attractive to the Tilapia will result in a low feed intake and thus in a low protein intake. A high feed intake results also in less energy for maintenance during the whole life span of the trout.

Further, the *performance* of a feed or the feed conversion ratio (FCR) is important. Factors that affect the performance are for example the digestibility of the protein, fat and carbohydrates in the diet and the amino composition of the protein.

An important issue in aquaculture is also the *pollution*. The feeds should have a high digestibility and generate little feces and the waste generated should not be loose but more compact in order to be able to collect easily the feces.

A final issue is the *price* of a Tilapia feed. The price should be right and the feeds should be cost effective.

Thus, the criteria for a good African catfish feed (or a good African catfish feed ingredient) can be summarized with the 4 P's concept:

5.	**P**alatability	Attractive feed to assure a high feed intake.
6.	**P**erformance	The FCR ratio should be as low as possible.
7.	**P**ollution	High digestibility and feces that are compact and thus easily to collect.
8.	**P**rice	The price should be right and the feed should be cost effective.

11 Literature

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(Volume 2: http://www.fao.org/docrep/field/003/AB468E/AB468E00.htm
(Volume 3: http://www.fao.org/docrep/field/003/AB467E/AB467E00.htm)

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USDA Food Tables on the Internet: (http://www.nal.usda.gov/fnic/foodcomp/search/) Gives the composition of food and food stuffs.

DTU Food Tables on the Internet (Danish Technical University):
http://www.foodcomp.dk/v7/fcdb_default.asp

FAO website: Food Composition Tables for International Use (1955):
http://www.fao.org/docrep/x5557e/x5557e00.htm#Contents

12. Energy values of fats, carbohydrtaes and proteins

The values for energy generated in the body, Respiratory Quotient (RQ) and the Energy Equivalents $EeqO_2$ and $EeqCO_2$ for carbohydrate, fat, protein and alcohol according to data from Elia and Livesey (1992).

	MW	Energy Generated in the Body[1] (kJ/mol)	Energy Generated in the Body[1] (kJ/g)	H_2O generated (mol/mol)	H_2O generated (g/g)	O_2 consumed (mol/mol)	O_2 consumed (g/g)	O_2 consumed (L/g)	$C0_2$ generated (mol/mol)	$C0_2$ generated (g/g)	$C0_2$ generated (L/g)	RQ (CO_2/O_2)	$EeqO_2$[4] (kJ/g)	$EeqO_2$[4] (kJ/L)	$EeqCO_2$[4] (kJ/g)	$EeqCO_2$[4] (kJ/L)	Atwater Digest.Coeffic (%)	. Metabol Energy (kJ/g)
Protein (combustion)[2]	2260,0	53448	23,65	79,50	0,63	125,2	1,77	1,24	100,0	1,95	0,99	0,799	13,35	19,06	12,14	23,85	92	21,76
Protein (in body)[3]	2260,0	45376	20,08	50,60	0,40	104,0	1,47	1,03	86,6	1,69	0,86	0,833	13,64	19,47	11,91	23,38	92	18,47
Fat (dioleylpalmitate)[3]	859,4	34022	39,59	51,00	1,07	77,5	2,89	2,02	55,0	2,82	1,43	0,710	13,72	19,59	14,06	27,61	95	37,61
Carbohydrate (glucan)[3]	162,1	2840	17,52	5,00	0,56	6,0	1,18	0,83	6,0	1,63	0,83	1,000	14,79	21,12	10,76	21,12	97	16,99
Sacharose ($C_{12}H_{22}O_{11}$)	342,3	5641	16,48	11,00	0,58	12,0	1,12	0,79	12,0	1,54	0,79	1,000	14,69	20,98	10,68	20,98	97	15,99
Glucose ($C_6H_{12}O_6$)	180,2	2803	15,56	6,00	0,60	6,0	1,07	0,75	6,0	1,47	0,75	1,000	14,60	20,85	10,62	20,85	97	15,09
Alcohol (C_2H_6O)	46,1	1367	29,67	3,00	1,17	3,0	2,08	1,46	2,0	1,91	0,97	0,667	14,24	20,34	15,53	30,50	97	28,78
Kleibers standard protein Data from Elia and Livesey[5]																		
Protein to mixture [3]	2260,0	45376	20,08	50,60	0,40	104,0	1,47	1,03	86,6	1,69	0,86	0,833	13,64	19,47	11,91	23,38	92	18,47
Protein to urea	2260,0	45950	20,33	52,80	0,42	105,3	1,49	1,04	87,0	1,69	0,86	0,826	13,64	19,47	12,00	23,57	92	18,71
Protein to uric acid	2260,0	41880	18,53	65,00	0,52	95,5	1,35	0,95	67,5	1,31	0,67	0,707	13,71	19,57	14,10	27,69	92	17,05
Protein to ammonia	2260,0	46450	20,55	13,80	0,11	105,3	1,49	1,04	100,0	1,95	0,99	0,950	13,79	19,69	10,55	20,73	92	18,91
Protein to creatinine	2260,0	33960	15,03	48,47	0,39	79,3	1,12	0,79	65,3	1,27	0,65	0,824	13,38	19,11	11,81	23,20	92	13,82
Protein to allantoin	2260,0	43254	19,14	59,30	0,47	98,8	1,40	0,98	74,0	1,44	0,73	0,749	13,68	19,54	13,28	26,09	92	17,61
Kleibers standard protein Calculated[6]																		
Protein to mixture[3]	2260,0	44415	19,68	50,60	0,40	104,0	1,47	1,03	86,6	1,69	0,86	0,833	13,35	19,06	11,65	22,89	92	18,08
Protein to urea	2260,0	45037	19,93	52,80	0,42	105,3	1,49	1,04	87,0	1,69	0,86	0,826	13,37	19,09	11,76	23,10	92	18,33
Protein to uric acid	2260,0	40962	18,12	65,00	0,52	95,5	1,35	0,95	67,5	1,31	0,67	0,707	13,40	19,14	13,79	27,08	92	16,67
Protein to ammonia	2260,0	44270	19,59	13,80	0,11	105,3	1,49	1,04	100,0	1,95	0,99	0,950	13,14	18,76	10,06	19,76	92	18,02
Protein to creatinine	2260,0	33193	14,69	48,47	0,39	79,3	1,12	0,79	65,3	1,27	0,65	0,824	13,08	18,68	11,54	22,67	92	13,51
Protein to allantoin	2260,0			59,30		98,8			74,0									

Data are from:

M. Elia and G. Livesey (1992) Energy expenditure and fuel selection in biological systems: the theory and practice of calculations based on indirect calorimetry and tracer methods, World Review of Nutrition and Dietetics, volume 70, page 68-131 (see pages 71 and 78 for the equations of the oxidations of the carbohydrtaes, fats and proteins).

1.The energy generated is the energy generated in the body. For the protein, a correction is made for the energy excreted in the urine in the form of form of urea, ammonia, uric acid, creatine, creatinine, and allantoin. The protein in this Table refers to the Kleiber's standard protein ($C_{100}H_{159}N_{26}O_{32}S_{0.7}$ (MW = 2260, contains 16.1% N). The energy generated from the carbohydrates and the fat and alcohol in the body is identical to the energy generated in a bomb calorimeter.

2. Complete combustion of the Kleiber's protein in a bomb calorimeter. The heat of complete combustion of protein in the bomb calorimeter is 23.65 kJ/g (gross energy). The equation of the complete combustion is: $C_{100}H_{159}N_{26}O_{32}S_{0.7} + 124.8\ O_2 = 100\ CO_2 + 78.8\ H_2O + 13\ N_2 = 0.7\ H_2SO_4 + 53448$ kJ.

3. The Kleibers standard protein is metabolized to urea, creatinine and ammonia in the nitrogen mass ratio of 90:5:5 (See Elia and Livesey 1992, page 71):

$C_{100}H_{159}N_{26}O_{32}S_{0.7}$ + 104 O_2 (= 22.414 x 104 = 2331.06 liters) = 86.6 CO_2 (= 22.414 x 86.6 = 1941.05 liters) + 50.6 H_2O + 11.7 N_2H_4CO (urea) + 1.3 NH_4OH (ammonia) + 0.43 $N_3C_4H_7O$ (creatinine) + 0.7 H_2SO_4
For the heat of combustion released from the oxidation of fat and carbohydrates, see Elia and Livesey 1992, page 71 and for the oxidation of saccharose and glucose and alcohol (ethanol): K. Blaxter 1989, page 296.(*K. Blaxter (1989)* Energy metabolism in animals and man, Cambridge University press).

4. Eeq, energy equivalent. All values for the volumes of O_2 and CO_2 are at 1 bar and a temperature of 0 ^oC (273.15 ^oK).
1 mg O_2 = 0.700 ml O_2 and 1 ml O_2 = 1.428 mg O_2. Further 1 mg CO_2 = 0.509 ml CO_2 and 1 ml CO_2 ° 1,963 mg CO_2

Data on energy equivalents of oxygen consumption for protein, fat and carbohydrates have also been given in earlier literature , see: J.M. Elliot and W. Davison (1975) Energy equivalents of oxygen consumption in animal energetics. Oecologia (Berlin) Volume 19, pages 195-201.

5. Data are from Elia and Livesey 1992 (page 71 and 78).

6.These data are calculated as following: The N in the protein can be excreted in the form of ammonia, urea, creatinine, creatin, or allantoin. These compounds contain a considerable amount of energy (See Appendix Table 4 and 5).

(a). <u>*Excretion of the nitrogen in the form of urea*</u>: the energy density of urea (in solution) is 647 kJ per mol (647 / 60.056 = 10.77 kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 13 mol urea (Elia and Livesey 1992, page 78). This amount of urea contains thus 13 x 647 = 8411 kJ of energy, which is excreted in the urine. The gross energy of protein is 23.65 x 2260 = 53448 kJ. Thus 53448 – 8411 = 45037 kJ is left. Thus, the available energy of the protein is then 45037 / 2260 = 19.93 kJ per gram protein.
Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein): $C_{100}H_{159}N_{26}O_{32}S_{0.7}$ + 105.3 O_2 = 87 CO_2 + 52.8 H_2O + 13 N_2H_4CO (urea) + 0.7 H_2SO_4

The complete combustion of Kleiber's protein is
(1) C_{100} H_{159} N_{26} O_{32} $S_{0.7}$ + 124.8 O_2 = 100 CO_2 + 78.8 H_2O + 13 N_2 + 0.7 H_2SO_4 + 53448 kJ and (complete combustion of protein)
(2) 13 N_2H_4CO (urea) +19.5 O_2 = 13 CO_2 + 26 H_2O + 13 N_2 + 13 * 647 kJ (= 8411 kJ) (complete combustion of urea)
Substract (2) from (1): (compare McLean and Tobin 1987, page 33, and Blaxter 1989, page 12, law of Hess, law of constant heat summation).
C_{100} H_{159} N_{26} O_{32} $S_{0.7}$ + 105.3 O_2 = 87 CO_2 + 52.8 H_2O + 13 N_2H_4CO (urea) + 0.7 H_2SO_4 + 45037 kJ or 45037 / 2260 = 19.93.

We can also assume that protein in general contains 16% nitrogen (The Kleiber's protein contains16.1% protein). Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Urea contains 46.6% nitrogen, thus the oxidation of 1 gram of protein results in the formation of 0.16 / 0.46 = 0.34 grams of urea. The energy density of 1 gram of urea is 10.77 kJ, thus the energy of 0.34 grams of urea is 0.34 x 10.77 = 3.66 kJ and the available energy in 1 gram protein is then 23.65 – 3.66 = 19.99 kJ.

(b) <u>*Excretion of the nitrogen in the form of uric acid*</u>: the energy density of uric acid is 1921 kJ per mol (1921 / 168.112 = 11.42 kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 6.5 mol uric acid (Elia and Livesey 1992, page 78). This amount of uric acid contains thus 6.5 x 1921 = 12487 kJ of energy, which is excreted in the urine. The gross energy of protein is 23.65 x 2260 = 53448 kJ. Thus 53448 – 12487 = 40961 kJ is left. Thus, the available energy of the protein is then 40961 / 2260 = 18.12 kJ per gram protein.
Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein: $C_{100}H_{159}N_{26}O_{32}S_{0.7}$ + 95.5 O_2 = 67.5 CO_2 + 65 H_2O + 6.5 $C_5H_4O_3N_4$ (uric acid) + 0.7 H_2SO_4

We can also assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Uric contains 33.3% nitrogen, thus the oxidation of 1 gram of protein results in the formation of 0.16 / 0.33 = 0.48 grams of urea. The energy density of 1 gram of uric is 11.40 kJ, thus the energy of 0.48 grams of uric acid is 0.48 x 11.40 = 5.47 kJ and the available energy in 1 gram protein is then 23.65 – 5.47 = 18.18 kJ.

(c) *Excretion of the nitrogen in the form of ammonia*: the energy density of ammonia (in solution) is 353 kJ per mol (353 / 17.031 = 20.73 kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 26 mol ammonia (Elia and Livesey 1992, page 78). This amount of ammonia contains thus 26 x 353 = 9178 kJ of energy, which is excreted in the urine. The gross energy of protein is 23.65 x 2260 = 53448 kJ. Thus 53448 – 9178 = 44270 kJ is left. Thus, the available energy of the protein is then 44270 / 2260 = 19.59 kJ per gram protein.
Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein): $C_{100}H_{159}N_{26}O_{32}S_{0.7}$ + 105.3 O_2 = 100 CO_2 + 13.8 H_2O + 26 NH_4OH (ammonia) + 0.7 H_2SO_4

We can also assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. ammonia contains 82.2% nitrogen, thus the oxidation of 1 gram of protein results in the formation of 0.16 / 0.822 = 0.195 grams of ammonia. The energy density of 1 gram of ammonia is 20.73 kJ, thus the energy of 0.13 grams of ammonia is 0.195 x 20.73 = 4.04 kJ and the available energy in 1 gram protein is then 23.65 – 4.04 = 19.61 kJ.

(d) *Excretion of the nitrogen in the form of creatinine*: the energy density of creatinine is 2337 kJ per mol (2337 / 113.120 = 20.66 kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 8.667 mol creatinine (Elia and Livesey 1992, page 78). This amount of creatinine contains thus 8.667 x 2337 = 20255 kJ of energy, which is excreted in the urine. The gross energy of protein is 23.65 x 2260 = 53448 kJ. Thus 53448 – 20255 = 33193 kJ is left. Thus, the available energy of the protein is then 33193 / 2260 = 14.69 kJ per gram protein.
Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein): $C_{100}H_{159}N_{26}O_{32}S_{0.7}$ + 79.3 O_2 = 65.332 CO_2 + 48.466 H_2O + 8.667 $N_3C_4H_7O$ (creatinine) + 0.7 H_2SO_4

We can also assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. creatinine contains 37.147% nitrogen, thus the oxidation of 1 gram of protein results in the formation of 0.16 / 0.371 = 0.43 grams of creatinine. The energy density of 1 gram of creatinine is 20.66 kJ, thus the energy of 0.43 grams of creatinine is 0.43 x 20.66 = 8.88 kJ and the available energy in 1 gram protein is then 23.65 – 8.88 = 14.77 kJ.

(e) *Excretion of the nitrogen in the form of creatine*: the energy density of creatine is 2324 kJ per mol (2324 / 115.136 = 20.18 kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 8.667 mol creatine (Elia and Livesey 1992, own calculation). This amount of creatine contains thus 8.667 x 2324 = 20142 kJ of energy, which is excreted in the urine. The gross energy of protein is 23.65 x 2260 = 53448 kJ. Thus 53448 – 20142 = 33306 kJ is left. Thus, the available energy of the protein is then 33306 / 2260 = 14.74 kJ per gram protein.
Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein): $C_{100}H_{159}N_{26}O_{32}S_{0.7}$ + 79.288 O_2 = 65.332 CO_2 + 39.779 H_2O + 8.667 $N_3C_4H_9O_2$ (creatine) + 0.7 H_2SO_4

We can also assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Creatine contains 36.497% nitrogen, thus the oxidation of 1 gram of protein results in the formation of 0.16 / 0.365 = 0.44 grams of creatine. The energy density of 1 gram of creatine is 20.18 kJ, thus the energy of 0.44 grams of creatine is 0.44 x 20.18 = 8.88 kJ and the available energy in 1 gram protein is then 23.65 – 8.88 = 14.77 kJ.

(f) *Excretion of nitrogen in the form of a mixture of urea (90%), creatinine (5%) and ammonia (5%).* We can assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Urea contains 46.6% N and 10.77 kJ per gram urea, creatinine contains 37.1%N and 20.66 kJ per gram creatinine and ammonia contains 82.2% N and 20.73 kJ per gram ammonia. Thus the loss of energy is ((0.16 x 0.90 / 0.466) x 10.77) + ((0.16 x 0.05) / 0.371) x 20.66) + ((0.16 x 0.05 / 0.822) x 20.73) = 3.975 kJ per gram protein. Thus the available energy of 1 gram of protein is 23.65 – 3.975 = 19.68 kJ per gram protein.

(g) *Excretion of nitrogen in the form of a mixture of ammonia (85%) and urea (15%) as in fish.* We can assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Ammonia contains 82.2% N and 20.73 kJ per gram ammonia and urea contains 46.6% N and 10.77 kJ per gram urea, Thus the loss of energy is ((0.16 x 0.85 / 0.822) x 20.73) + ((0.16 x 0.15 / 0.466) x 10.77) = 3.98 kJ per gram protein. Thus the available energy of 1 gram of protein is 23.65 – 3.98 = 19.67 kJ per gram protein in fish.

13 Properties of logarithms:

$\ln(a) + \ln(b) = \ln(ab)$

$\ln(a) - \ln(b) = \ln(a/b)$

$a \ln(b) = \ln(b)^a$

$\ln(a)$ means ${}^e\ln(a)$.

$g \wedge ({}^g\log a) = a$

<u>proof:</u> $^g\log a = {}^g\log a$*, and thus, per definition:* $g \wedge ({}^g\log a) = a)$

${}^a\log b = ({}^g\log b) / ({}^g\log a)$ or

$({}^a\log b) * ({}^g\log a) = ({}^g\log b)$

<u>proof:</u>

${}^a\log b = ({}^g\log b) / ({}^g\log a)$

${}^a\log b) * ({}^g\log a) = ({}^g\log b)$

$({}^g\log a \wedge ({}^a\log b) = ({}^g\log b)$

$a \wedge ({}^a\log b) = b$

or

${}^a\log b = {}^a\log b$ *(see above)*

${}^a\log b = 1/ ({}^b\log a)$

<u>proof:</u>

${}^a\log b = {}^b\log b / {}^b\log a = 1/ ({}^b\log a)$

when ${}^e\ln(a) = b$, then this means $e^b = a$,

thus the anti - ln of b is a and is e^b

e = 2.71828 (and with many more decimals !!) and can be calculated on a calculator as the anti - ln of 1.

<u>Note</u>

$10^1 = 10$

$10^0 = 1$

$1^a = 1$

$\frac{1}{\infty} = 0$

$\frac{0}{1} = 0$

$\frac{1}{0}$ does not exist

0^a does not exist, and log(0) does also not exist.

The logaritmes of 0 and negative numbers do not exist.

Anti - ln of 1 = e = 2.71828 (^{e}ln e = 1)

Further:

$10^5 * 10^3 = 10^{(5 + 3)} = 10^8$

$10^5 / 10^3 = 10^{(5 - 3)} = 10^2$

a/b = c/d then: a*d = b*c (cross-wise multiplication)

$\sqrt[2]{10} = 10^{(1/2)}$ root is the inverse of the power

10 / 2 = 10 * (1/2)

$^2\log 50 = a$, then $2^a = 50$

$^a\log a = 1$ ($a^1 = a$)

$^a\log 1 = 0$ ($a^o = 1$)

The number e = 2.71:

The derivative of y = $^a\log x = (1/x)\ ^a\log 2.71$

Thus, when a = 2.7, then the derivative of y = $^{2.71}\log 2.71$ 1/x) = 1/x

Thus , the derivative can be simplified by taking a = 2.71 (^{e}log = ln, or the natural logaritme)