De Acipenseris Nutritione et Incremento

Feeding and Growth Parameters of the Sturgeon (*Acipenser*) during a Time Span of 1200 days (body weights range from 1 to 15000 grams)

An overview of Data from the Literature and the Internet

Composit et Scripsit

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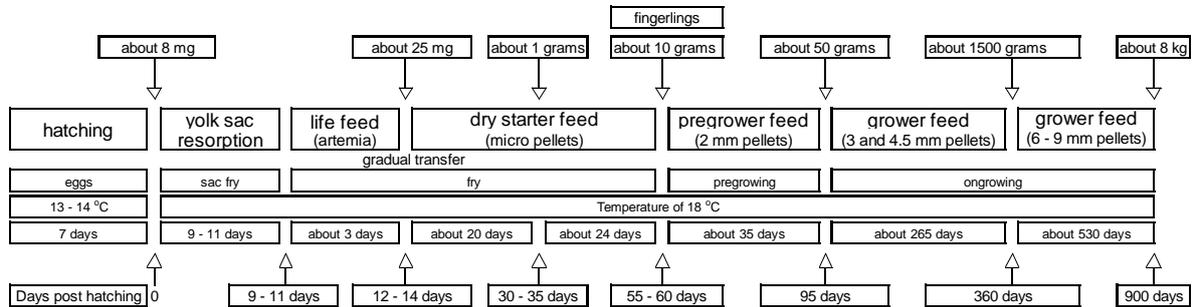

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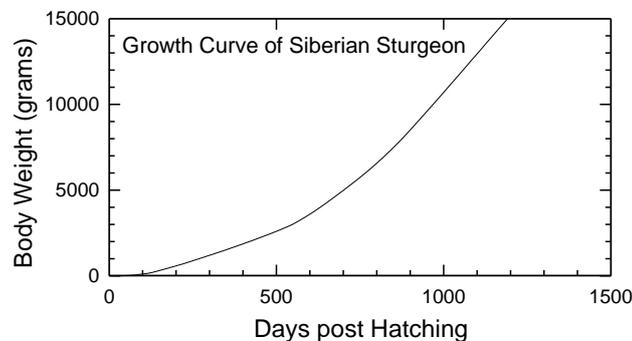
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The Netherlands, Anno Domini MMXV (2015).

Summary

1. *The life cycle of the sturgeon*.

2. *A typical growth curve of the Siberian sturgeon*.

3. *Sturgeon 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 trout feeds.

4. *The energy in a sturgeon feed* can be described in terms of (1) gross energy, (2) digestible energy, (3) metabolizable energy and (4) net energy.
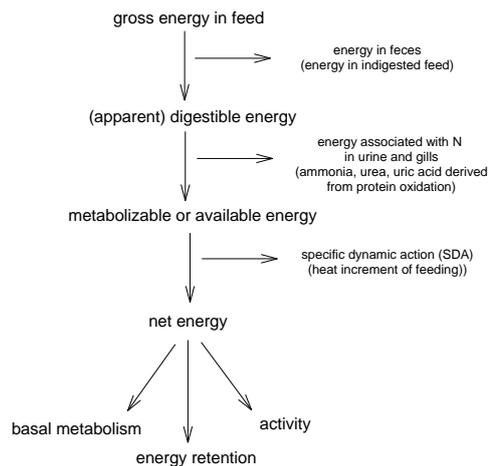
5. The body composition of a sturgeon (*Acipenser transmontanus*) can be described by allometric scaling equations of the general form: $y = a * BW(g)^b$:

Moisture (%) = 88.56 BW(g)$^{-0.0232}$
Protein (%) = 10.14 BW(g)$^{0.0706}$
Fat (%) = 1.62 BW(g)$^{0.1641}$
Ash (%) = 3.77 BW(g)$^{-0.0479}$
Energy (kJ/gram) = 2.942 BW$^{0.1011}$

Moisture (g) = 0.8856 BW(g)$^{0.9768}$
Protein (g) = 0.1014 BW(g)$^{1.0706}$
Fat (g) = 0.0162 BW(g)$^{1.1641}$
Ash (g) = 0.0377 BW(g)$^{0.952}$
Energy (kJ) = 2.942 BW$^{1.1011}$

6. The feed intake in sturgeon 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 (gram per 100 gram of fish) per day
(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:

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

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:

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

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 $BW(kg)^{0.80}$) per day is a function of the body weight. The % feed intake can be described by the allometric scaling formula:

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

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

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

Typical value for b = - 0.350 and a typical value for "a" at a temperature of 18 - 20 ^{o}C for sturgeon is 0.75. Thus:

$$\text{% feed intake} = 0.75 * BW(kg)^{-0.350} \qquad (6)$$

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

$$\text{feed intake in gram per } BW(kg)^{0.80} = 7.5 * BW(kg)^{-0.150} \qquad (7)$$

At this feeding level, the % feed intake ranges from 3.7% for a sturgeon of 10 grams to 0.4% for a sturgeon of 5000 grams and the feed intake per gram metabolic weight (per $BW(kg)^{0.80}$) ranges from 15 grams for a sturgeon of 10 grams to 6 grams for a sturgeon of 5000 grams.

These feeding curves take into account 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) decreases when the body weight of the sturgeon increases. Lower or higher feeding levels can be obtained by decreasing or increasing the value of "a".

The effect of the temperature T (^{o}C) on the feed intake is exponential and the feed intake of a sturgeon at a temperature of $T = T_2$ is:

$$\text{Feed intake at } T_2 = \text{Feed intake at } T_1 * e^{0.095(T2 - T1)} \qquad (5)$$

7. The criteria for a good performing sturgeon feed (or a good sturgeon 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

1. Introduction

Sturgeon are chondrostei (chondros means cartilage), i.e. cartiliginous fish with some ossification (teleostei are bony fish). They belong to the family of the Acipenseridae. The sturgeon and the related paddlefish appear in the fossil record approximately 200 million years ago. In that time, they have undergone remarkable little morphological changes and can be considered as living fossils; this is explained by the long intergeneration time (they have a long life span), their tolerance to a wide range of temperatures and salinity, the lack of predators due to their large size, and the abundance of prey items in the benthic environment. They are teethless, have 4 barbels and are benthic feeders (bottom feeders) and are anadromous (greek "ana" means upward and greek "dramema" is walking, this means that the spawn upstream in the rivers and feed in river deltas). Sturgeon is a fast growing fish species and the fat level in sturgeon diets is relatively low (about 10 – 15%). Further, sturgeon are able to synthesize vitamin C and are thus not dependent on the vitamin C in the diet, like most other fish species. Sturgeon can become very old, up to a 100 years and reach weights of more than 100 kg.

There are various types of sturgeons, such as:

(1) Acipenser Baeri (Siberian Sturgeon),
(2) Acipenser Gueldenstaedtii (Russian sturgeon),
(3) Acipenser Ruthenus (sterlet sturgeon of Euroaziatic sturgeon)
(4) Acipenser Beluga (European sturgeon or Huso Huso)
(5) Acipenser Transmontanus (White sturgeon or Pacific sturgeon in the coastal waters of California and North America)

2. Life cycle of the sturgeon
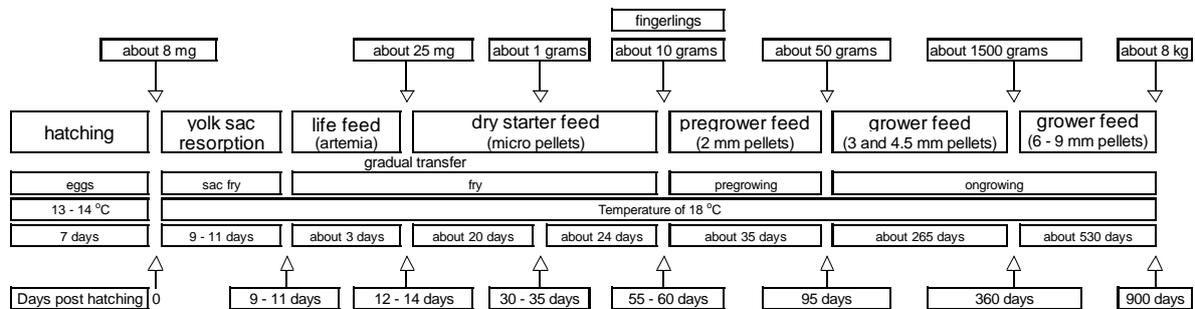
Figure 1
Life cycle of the sturgeon

An comprehensive overview of the rearing of the Siberian sturgeon (*Acipenser Baeri*) larvae has been published by Gisbert and Johnston (2002). They described that the first artificial spawning of the Siberian Sturgeon was achieved in the early 1980s. Fertilized eggs hatch after about 7 days at a temperature of 13 – 14 °C, and the hatching time is dependent of the temperature (see Figure 2 below that is copied from the review article of Gisbert and Johnston, 2002). The body weights of newly hatched larvae are about 8 mg and the length is about 12.5 mm.
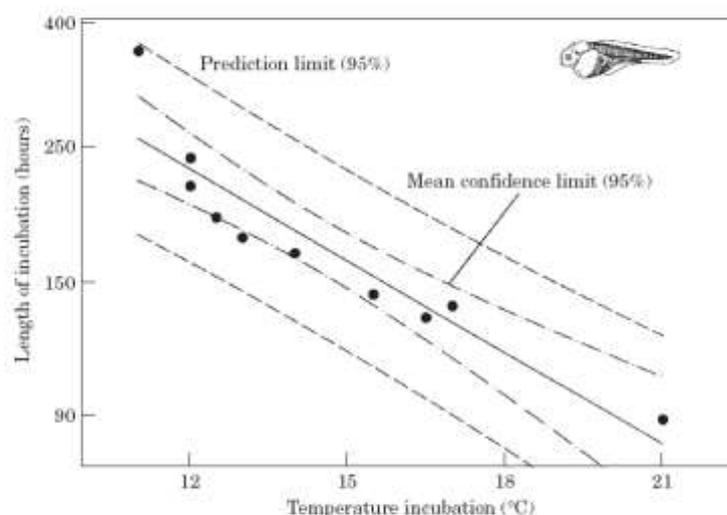
: Relationship between incubation water temperature (° C) and length of incubation (hours) in Siberian sturgeon using semi-logarithmic co-ordinates (right). Log Incubation length (hours)=2·96–0·05·Temperature (°C) (*n*=10; *r²*=0·86; *P*<0·001). (Data redrawn from Williot *et al.*, 1991; Gisbert & Williot, unpublished data.)

Figure 2
Growth in length and weight of sturgeon larvae (Gisbert and Williot 2002)

The yolk sac resorption takes place up to about 9 – 11 days post hatching, Then, artemia is fed for about 3 days i.e. from day 12 – 15 post hatching and subsequently, the larvae are gradually transferred to dry feed. A growth curve of the larvae at 18 °C is shown below in Figure 3 (from Gisbert and Johnston, 2002). Growth curves and length curves of fast and slow growing Russian sturgeon larvae and feeding protocols are also described by Nathanailides et al. (2002).
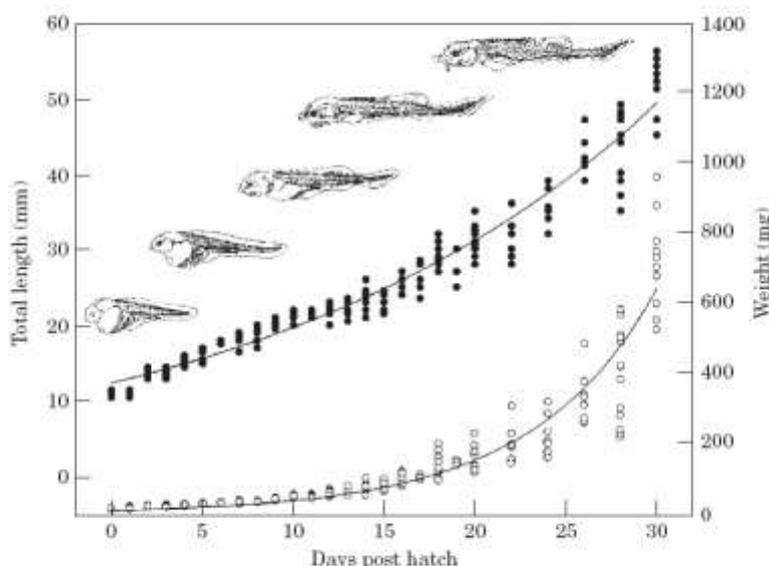

FIG. 5. Growth in length (●) (mm) and weight (○) (mg) of Siberian sturgeon larvae from hatching to 30 days post-hatch. Data were obtained from different females (*n*=21) and conducted under similar experimental rearing conditions (Gisbert, 1999; Gisbert *et al.*, 2000).

Figure 3
Growth in length and weight of sturgeon larvae (Gisbert and Johnston 2002)

The larvae growth rate according to an exponential curve (Gisbert and Johnston, 2002) is described by the following formula (18 $^{\circ}$C) (Figure 3):

$$BW(mg) = 8.08 * e^{days * 0.15}$$

where BW is in mg and days is days post hatching. When days = 0, then the BW is 8.08 mg (BW after hatching). The Specific Growth Rate (SGR) is about = 100 * 0.15 = 15%.

We can now calculate with this formula how long it will take for the larvae to reach e.g. a body weight of 1 gram (1000 mg):

$$1000 = 8.08 * e^{days * 0.15}$$

$$e^{days * 0.15} = (1000 / 8.08)$$

$$days * 0.15 = (1000 / 8.08)$$

$$days = [\ ln(1000 / 8.08)\ ] / 0.15 = 32.12\ days$$

Thus the larvae have reached a body weight of about 1 grams at day 32 after hatching (see also the graph of the life cycle of the sturgeon above) (see also Figure 5) .

Gisbert (1999) reported the relationship between body weight and length of the Siberian sturgeon (see Figure 4 below).
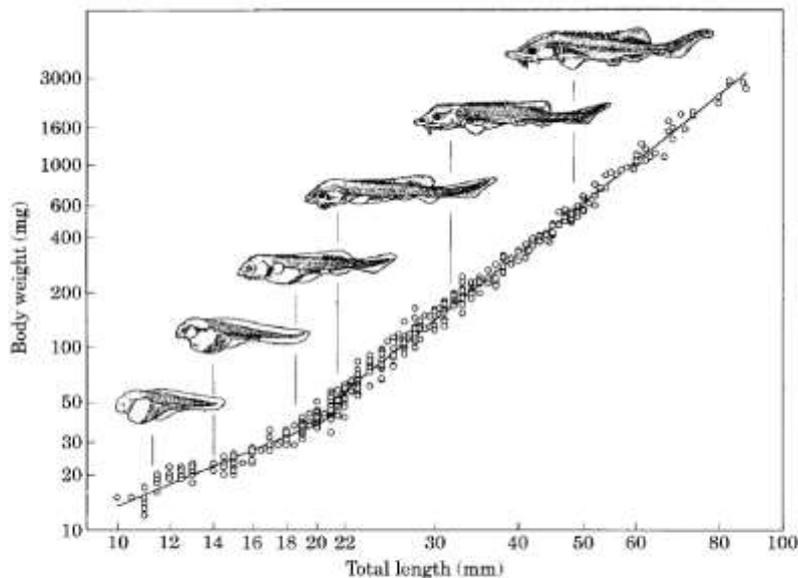
. 1. Allometric growth equations and relationship between body weight and total length in *A. baeri* during early stages of development (from hatching up to day 40). During the endogenous feeding stage, allometric growth in weight was negative ($y=0.436\ x^{1.46}$; $r=0.90$; $n=143$), while from the inflexion point at 20.0 mm L_T (day 9, first feeding), growth increased and became nearly isometric ($y=0.008\ x^{2.87}$; $r=0.99$; $n=107$).

Figure 4
Allometric relationship between length and body weight of sturgeon larvae (Gisbert 1999)

The feeding protocol and growth curves of Russian Sturgeon (Acipenser Gueldenstaedtii) is given by Memis et al. (2009), see Figure 5 below:

Figure 1. Feeding regime of the Russian sturgeon larvae.

Figure 2. Growth in length (cm) and weight (g) of Russian sturgeon larvae.

Figure 5
Feeding regimen and allometric relationship between length and body weight of the Russian sturgeon larvae (Memis et al. 2009)

Sturgeon (male and female) are able to reproduce themselves when they are approximately 20 years or older. They spawn about every 2 – 5 years.

The life cycle of the Siberian Sturgeon (data from Gisbert 1999 and Billund-Aqua in Denmark) is given in Figure 1.

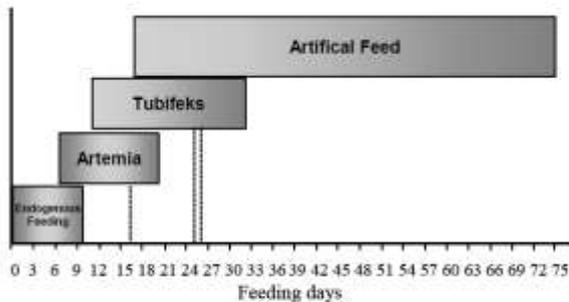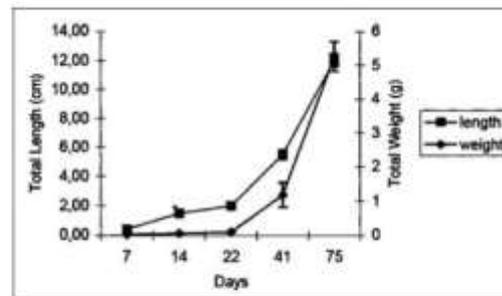## 3   The Composition of Sturgeon Feeds

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.

Fish 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 the intake of 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 sturgeon 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 trout) 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 fish feed, is achieved. When the sturgeon grows larger, the protein / energy ratio of the sturgeon 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.

The sturgeon is not a teleost and has a skeleton of predominantly cartilage. Vitamin C plays a role in the conversion of proline into hydroxyproline and hydroxyproline is a component of collagen, the matrix for the calcium and phosphor in the form of hydroxyapetite ($Ca_{10}(PO_4)_6(OH)_2$)) in the skeleton. Sturgeon are in contrast to e.g. trout and salmon able to synthesize vitamin C from glucose, and do essentially not need vitamin C in the diet. However, the capacity for the the synthesis of vitamin C may not meet the requirement for the fast growing sturgeon (sturgeon is a fast growing fish species). Therefore, the diets of sturgeon are usually supplemented with vitamin C at a level of about 150 - 200 mg per kg feed.

4   Energy in Sturgeon Feeds

Fats, carbohydrates and proteins are the major sources of energy in fish 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 fish feed can be expressed as gross, digestible, metabolizable, and net energy (Figure 6).
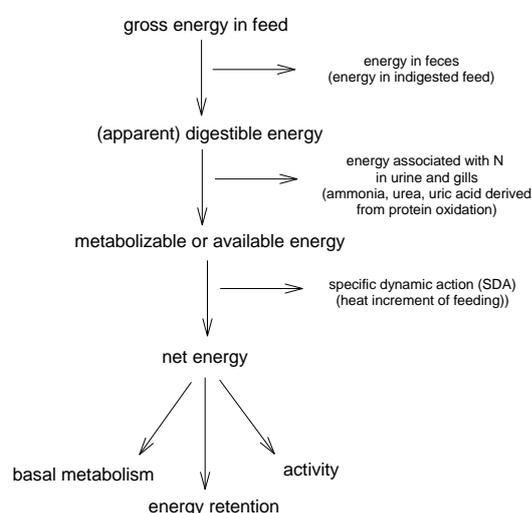
Figure 6
Gross, digestible, metabolizable, and net energy

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 sturgeon 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 8). 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 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 14, footnote 6 (g) for the calculations in the fish).

<u>*Net Energy*</u>

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 14, 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 is dependent on the type of the diet and the fish species.

Fish metabolize and oxidize 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 37, paragraph 14) 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 Sturgeon feed

The amount of energy in a Sturgeon 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 sturgeon 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 sturgeon feed with 30% protein, 8% fat, 7% ash and 8.5 % fibre. Thus the percentage of carbohydrates or NFE = (100 – 45% protein – 15% fat - 10% ash – 3.5% fibre – 6% moisture) = 20.5%. 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 Sturgeon feed

Nutrient	% in diet	Gross Energy in 1 gram nutrient (kJ/gram)	Metabolizable Energy in 1 gram nutrient (kJ/gram)	Gross Energy in 1 gram feed (kJ/gram)	Digestibility (%)	Digestible Energy in 1 gram feed (kJ/gram)	Metabolizable Energy in 1 gram feed (kJ/gram)
Protein	45	23,65	19.67	10,62	95	10,09	8,41
Fat	15	39,6	39,6	5,94	90	5,35	5,35
Ash	10						
Moisture	6						
Fiber	3,5	17,5	0	0,61	0		
NFE	20,5	17,5	17,5	3,58	60	2,15	2,15
Total	100			20,8		17,6	16,3

NFE, nitrogen free extract, the carbohydrate faction. DP/DE (digestible protein/digestible energy) = (450*0.95)/17.6 = 24.28 mg/kJ.

5 Feed Sizes for Sturgeon

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

Table 3
Feed Sizes for Sturgeon

Biomar (2014)			Coppens (2014)		
Body Weight grams	Body Length cm	Pellet Size mm	Body Weight grams	Pellet Size mm	Type Feed
0.3 - 0.5	3 - 4	0.5			starter
0.5 - 1	4 - 5	0.8			starter
1 - 3	5 - 7	1.1			starter
3 - 15	7 - 11	1.5			starter
15 - 50	11 - 16	2	10 - 50	1.5	pregrower
			50 - 100	2	pregrower
50 - 200	16 - 26	3	100 - 200	3	grower
200 - 1500	26 -49	4.5	200 - 1500	4.5	grower
1500 - 3000	49 - 61	6.5	1500 - 5000	6	grower
3000 - 10000	61 - 90	9	> 5000	8	grower

Websites: www.Biomar.com and www.Coppens.eu (accessed in 2014)

6   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 of a sturgeon 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 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 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**

7 Feed Intake and Feeding Levels from the Internet

Feeding levels and feeding tables for sturgeon are given by various feed manufacturers such as Coppens and Biomar and other companies such as Billund-Aqua. These feeding tables are given in Tables 4 (Biomar) and 5 (Billund-Aqua). We plotted the feeding levels vs the body weights of the sturgeon at the various temperatures (Figures 7 and 8, bottom panels). Linear plots arise when the data were plotted on a double logarithmic scale (Figure 7 middle panel and Figure 8 top panel). The slope and the intercept of these plots can be calculated with linear regression and allometric equations 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 4a

Feeding levels for sturgeon as recommended by Biomar

Feeding levels expressed in % of body weight.

Feed Sizes (mm)	Body Length (cm)	Feed Type	Body Weight (grams) (range)	(average)	Feeding Level (% of body weight) Temperature (°C) 14	16	18	20	22	24	26	28
1,1	5 - 7	Inicio plus	1 - 3	2	2,43	3,65	4,85	5,43	5,82	5,86	5,25	3,52
15	7 - 9	Inicio plus	3 - 8	5,5	1,89	2,84	3,79	4,23	4,54	4,58	4,09	2,75
1,5	9 - 11	Inicio plus	8 - 15	11,5	1,53	2,3	3,06	3,43	3,68	3,7	3,32	2,23
2	11 - 12	Inicio plus	15 - 20	17,5	1,29	1,94	2,59	2,89	3,11	3,13	2,8	1,88
2	12 - 16	Inicio plus	20 - 50	35	1,1	1,65	2,2	2,46	2,64	2,66	2,38	1,6
3	16 - 21	Effico Sigma 841	50 - 100	75	0,86	1,01	1,15	1,34	1,39	1,29	1,15	0,96
3	21 - 26	Effico Sigma 841	100 - 200	150	0,77	0,96	1,05	1,15	1,2	1,1	0,96	0,77
4,5	26 - 40	Effico Sigma 841	200 - 800	500	0,69	0,84	0,94	1,03	1,03	0,94	0,84	0,69
4,5	40 - 49	Effico Sigma 841	800 - 1500	1150	0,54	0,64	0,74	0,84	0,84	0,74	0,59	0,39
6,5	49 - 61	Effico Sigma 841	1500 - 3000	2250	0,34	0,43	0,53	0,62	0,62	0,53	0,43	0,29
9	61 - 72	Effico Sigma 841	3000 - 5000	4000	0,24	0,34	0,38	0,43	0,48	0,43	0,34	0,19
9	72 - 90	Effico Sigma 841	5000 - 10000	7500	0,19	0,27	0,31	0,35	0,38	0,35	0,27	0,15

The data were retrieved from the website of Biomar (www.biomar.com, accessed 2014)

Table 4b

Feeding levels for sturgeon as recommended by Biomar

Feeding levels expressed in grams per kg metabolic weight (per BW(kg) $^{0.80}$.)

Feed Sizes (mm)	Body Length (cm)	Feed Type	Body Weight (grams) (range)	Body Weight (grams) (average)	Feeding Level (gram per kg BW(kg) ^{0,80}) Temperature (oC) 14	16	18	20	22	24	26	28
1,1	5 - 7	Inicio plus	1 - 3	2	7,01	10,53	13,99	15,67	16,79	16,91	15,15	10,16
15	7 - 9	Inicio plus	3 - 8	5,5	6,68	10,03	13,39	14,94	16,04	16,18	14,45	9,71
1,5	9 - 11	Inicio plus	8 - 15	11,5	6,26	9,42	12,53	14,04	15,07	15,15	13,59	9,13
2	11 - 12	Inicio plus	15 - 20	17,5	5,74	8,64	11,53	12,87	13,85	13,94	12,47	8,37
2	12 - 16	Inicio plus	20 - 50	35	5,63	8,44	11,25	12,58	13,50	13,60	12,17	8,18
3	16 - 21	Effico Sigma 841	50 - 100	75	5,12	6,02	6,85	7,98	8,28	7,68	6,85	5,72
3	21 - 26	Effico Sigma 841	100 - 200	150	5,27	6,57	7,18	7,87	8,21	7,53	6,57	5,27
4,5	26 - 40	Effico Sigma 841	200 - 800	500	6,01	7,31	8,18	8,97	8,97	8,18	7,31	6,01
4,5	40 - 49	Effico Sigma 841	800 - 1500	1150	5,55	6,58	7,61	8,64	8,64	7,61	6,07	4,01
6,5	49 - 61	Effico Sigma 841	1500 - 3000	2250	4,00	5,06	6,23	7,29	7,29	6,23	5,06	3,41
9	61 - 72	Effico Sigma 841	3000 - 5000	4000	3,17	4,49	5,01	5,67	6,33	5,67	4,49	2,51
9	72 - 90	Effico Sigma 841	5000 - 10000	7500	2,84	4,04	4,64	5,24	5,69	5,24	4,04	2,24

The feeding level expressed in % feed intake (Table 4a) 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) $^{-0.20}$) (see formula 1, page 12).

For example, the feeding level of a sturgeon with an average body weight of 75 grams is 1.01% at a temperature of 16 ^{o}C.
Feed intake per kg metabolic weight (per BW(kg)$^{0.80}$ = 10 * 1.01 / 0.075 $^{-0.20}$ = 6.02 grams per kg metabolic weight (per BW(kg) $^{0.80}$.

Table 5

Some growth data for Acipenser baeri (Siberian Sturgeon)

Temperature is not given, but we assume a temperature of about 18 - 20 $^{\circ}$C

Size (grams)			Feeding rate		FCR	Daily growth	Time	Time cumulated
Average	Start	End	%	g / BW(kg)^{0,80}		%	days	days
5	1	10	8	27,73	0,8	10	24	24
15	10	30	6	25,90	0,9	6,67	17	41
45	30	60	4	21,51	1	4	18	59
80	60	100	3,5	21,12	1	3,5	15	74
150	100	200	2,5	17,11	1,1	2,27	31	105
450	200	700	1,5	12,79	1,1	1,36	92	197
1100	700	1.500	0,7	7,13	1,15	0,61	126	323
2250	1.500	3.000	0,5	5,88	1,2	0,42	201	524
4000	3.000	5.000	0,4	5,28	1,2	0,33	154	677
6500	5.000	8.000	0,35	5,09	1,3	0,27	175	852
12500	8.000	15.000	0,3	4,97	1,5	0,2	315	1167

Data from Billund Aquacultuur (www.billund-aqua.dk), Denmark.

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) $^{-0.20}$) (see text).

For example, the feeding level of a sturgeon with an average body weight of 450 grams is 1.5 %.
Feed intake per kg metabolic weight (per BW(kg)$^{0.80}$ = 10 * 1.5 / 0.455 $^{-0.20}$ = 12.79 grams per kg metabolic weight (per BW(kg) $^{0.80}$).
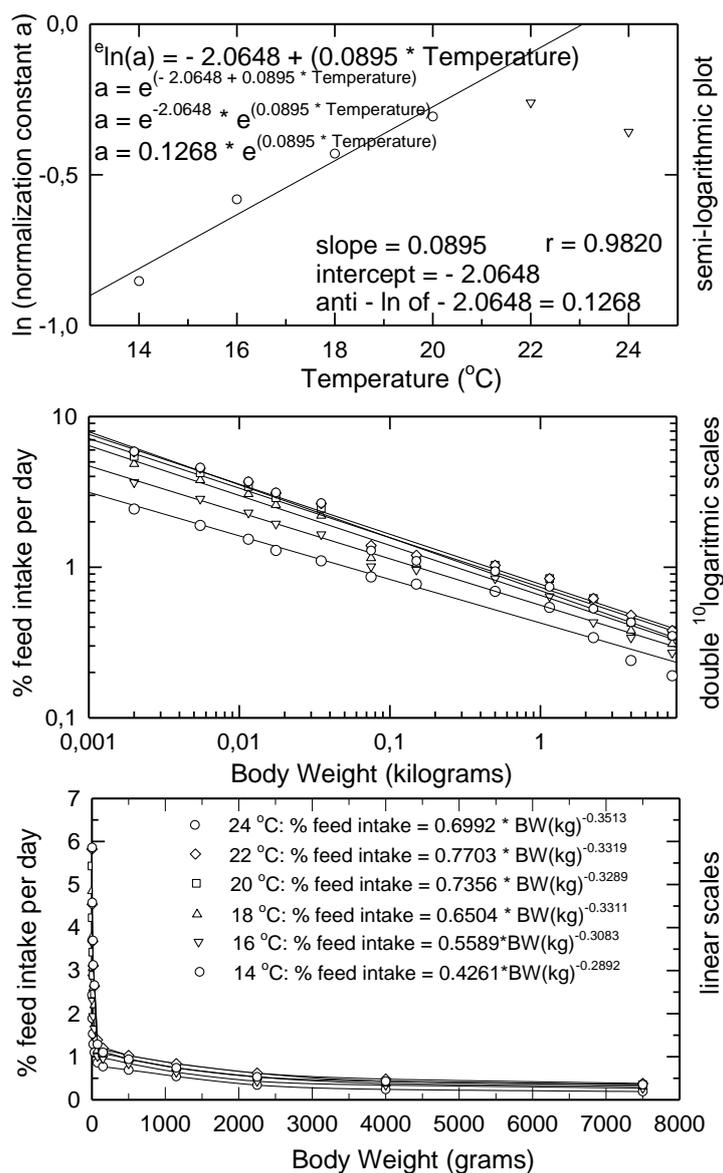
Figure 7
Feeding curves for sturgeon as recommended by Biomar.

<u>*Curve fitting of the feeding tables as recommended by Biomar:*</u>

For example, the feeding levels (Table 4a) expressed in % of body weight were plotted vs the body weights in kilograms for a temperature of 14 °C (Figure 7, middle panel). The regression line describing this linear plot was calculated to be :

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

$$\log (\% \text{ feed intake}) = - 0.3705 - 0.2892 * \log BW(kg)$$

$$\text{anti-log of} - 0.3705 = 0.4261$$

$$\log \% \text{ feed intake} = \log 0.4261 - 0.2892 * \log BW(kg)$$

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$$\log \% \text{ feed intake} = \log 0.4261 + \log (BW(kg))^{-0.2892}$$

$$\log \% \text{ feed intake} = \log 0.4261 + \log BW(kg)^{-0.2892}$$

$$\log \% \text{ feed intake} = \log (0.4261 * BW(kg)^{-0.2892})$$

$$\% \text{ feed intake} = 0.4261 * BW(kg)^{-0.2892}$$

(for the properties of logarithms, see Appendix 15)

The calculated allometric equations for the various temperatures are:

$$24\ ^{o}C: \% \text{ feed intake} = 0.6992 * BW(kg)^{-0.3513}$$
$$22\ ^{o}C: \% \text{ feed intake} = 0.7703 * BW(kg)^{-0.3319}$$
$$20\ ^{o}C: \% \text{ feed intake} = 0.7356 * BW(kg)^{-0.3289}$$
$$18\ ^{o}C: \% \text{ feed intake} = 0.6504 * BW(kg)^{-0.3311}$$
$$16\ ^{o}C: \% \text{ feed intake} = 0.5589 * BW(kg)^{-0.3083}$$
$$14\ ^{o}C: \% \text{ feed intake} = 0.4261 * BW(kg)^{-0.2892}$$

<u>note</u> that the body weights in these formulae are expressed in <u>kilograms</u>.

Thus, these allometric formulas or functions (of the general form $a*BW(kg)^{b}$) describe the % feed intake as a function of the body weights in kg. We can also convert these formula into allometric formulas that describe the feed intake per kg metabolic weight (per $BW(kg)^{0.80}$) as a function of the body weights. The formula to convert the feed intake expressed as % of body weight into the feed intake expressed in grams per metabolic weight (per $BW(kg)^{0.80}$) is (formula 1, page 12):

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

For example, at a temperature of 14 ^{o}C, the formula for the feed intake expressed as % of body weight is:

$$\% \text{ feed intake} = 0.4261 * BW(kg)^{-0.2892}$$

Substitution into the conversion formula gives:

Feed Intake per kg metabolic weight = c = $10 * (0.4261 * BW(kg)^{-0.2892}) / (BW(kg)^{-0.20})$ or

Feed Intake per kg metabolic weight = c = $4.261 * BW(kg)^{-0.0892}$

Similarly, the feed intakes expressed in grams per kg metabolic weight can be calculated for the other temperatures:

$$24\ ^{o}C: \text{feed intake (grams per kg metabolic weight)} = 6.992 * BW(kg)^{-0.1513}$$
$$22\ ^{o}C: \text{feed intake (grams per kg metabolic weight)} = 7.703 * BW(kg)^{-0.1319}$$
$$20\ ^{o}C: \text{feed intake (grams per kg metabolic weight)} = 7.356 * BW(kg)^{-0.1289}$$
$$18\ ^{o}C: \text{feed intake (grams per kg metabolic weight)} = 6.504 * BW(kg)^{-0.1311}$$
$$16\ ^{o}C: \text{feed intake (grams per kg metabolic weight)} = 5.589 * BW(kg)^{-0.1083}$$
$$14\ ^{o}C: \text{feed intake (grams per kg metabolic weight)} = 4.261 * BW(kg)^{-0.0892}$$

Conversely, the feed intake per kg metabolic weight can be converted into the feed intake expressed as percentage of body weight with the formula (formula 2, page 12):

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

For example, at a temperature of 14 $^{\circ}$C, the formula for the feed intake in grams per kg metabolic weight is:

feed intake in grams per kg metabolic weight (per BW(kg)$^{0.80}$)= 4.261* BW(kg) $^{-0.0892}$

Substitution into the conversion formula gives:

$$\% \text{ feed intake} = [(4.261 * BW(kg)^{-0.0892})/10] * (BW(kg)^{-0.20}) \text{ or}$$

$$\% \text{ feed intake} = 0.4261 * BW(kg)^{-0.2892}$$

The effect of the temperature on the feeding level of a sturgeon should be exponential, since the effect of the temperature on the metabolic rate or the energy expenditure of a sturgeon is also exponential. The energy required to support the metabolic rate or energy expenditure is supplied by the energy in the feed and therefore, the effect of the temperature on the energy or feed intake should be the same as the effect of the temperature on the metabolic rate or energy expenditure. Therefore, we will consider the effect of the temperature on the feed intake and on the feeding curves and levels as exponential.

Therefore, we also plotted the various normalisation constants of the feeding curves for the various temperatures of the fish feed company Biomar on a semi-logarithmic scale. When we plot the ln values of the normalisation constant vs the temperature, a linear plot arises (Figure 7, top panel). We did not include the data for the feeding curves at 22 – 28 $^{\circ}$C, since increasing the temperatures to 22 and 24 $^{\circ}$C did not substantially further increase the feeding level and a further increase of the temperature to 26 and 28 $^{\circ}$C even lowered the feed intake. The data of the normalization constants in Figure 7 , top panel, were analyzed by linear regression. The effect of the temperature (14 – 20 $^{\circ}$C) on the normalization constants as a function of the temperature can be described by the exponential function:

$$a = 0.1268 * e^{(0.0895 * \text{temperature})}$$

Thus, "a" represents the normalization constants for the various feeding curves as a function of the temperature T (14 – 20 $^{\circ}$C). We can now replace the value of "a" in each of the allometric equations for each temperature with $0.1268 * e^{(0.0509 * \text{temperature})}$ and the general formula that describes the feeding levels of Table 4a becomes then (the average scaling coefficient of the formulas at a temperature of 14 – 20 $^{\circ}$C in Figure 7 is – 0.3143):

$$\textbf{\% feed intake at temperature T} = 0.1268 * e^{(0.0895 * \text{temperature})} * \textbf{BW(kg)}^{-0.3143}$$

Example:
The normalisation constant as function of the temperature for the feeding levels is described by the formula:
The normalisation constant $a = 0.1268 * e^{(0.0895 * \text{temperature})}$
Thus the normalisation constant for a temperature of 18 $^{\circ}$C is then:
Normalisation constant a at temperature T = 18 $^{\circ}$C $= 0.1268 * e^{(0.0895 * 18)} = 0.6350$ (compare with the value of 0.6504 in Figure 7).

Example:
The % feed intake as a function of the temperature for the feeding levels is described by the formula:
% feed intake at temperature T $= 0.1268 * e^{(0.0895 * \text{temperature})} * BW(kg)^{-0.3143}$
Thus the % feed intake at a temperature of 18 $^{\circ}$C for a sturgeon of 2250 grams (2.25 kg) is then:
% feed intake $= 0.1268 * e^{(0.0895 * 18)} * (2.25)^{-0.3143} = 0.49\%$ (compare with the value of 0.53% in Table 4a)
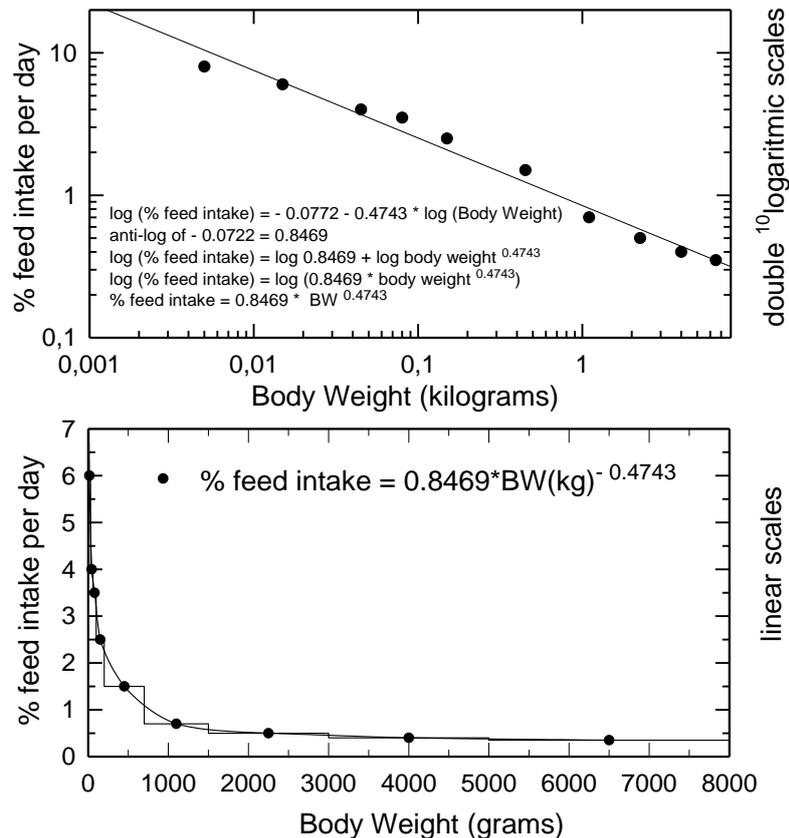

Curve fitting of the feeding tables as recommended by Billund-Aqua.

The fitted feeding curve as recommended by Billund-Aqua is given in Figure 8 is:

$$\% \text{ feed intake} = 0.8469 * BW(kg)^{-0.4743}$$

or

$$\text{Feed intake in grams per kg metabolic weight (per } BW(kg)^{0.80}) = 8.469 * BW(kg)^{-0.2743}$$

Figure 8
Feeding curves for sturgeon according to Billund-Aqua.

8 Construction of a General Feeding Curve for the sturgeon

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 sturgeon 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 sturgeon 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 sturgeon and dependent of the body weights and thus relatively less energy is used for growth and relatively more for maintenance when the sturgeon 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 sturgeon 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 an allometric scaling formula:

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

where "a" 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 sturgeon grows larger.

The sturgeon is a relatively fast growing fish species and has a growth rate that is higher than that of e.g. a trout. As a consequence, the feed intake is also relatively high. We could use a value of – 0.350 as the scaling coefficient for feeding curves for sturgeon and a value of 0.75 for the normalization constant and the feeding formula becomes then:

$$\text{\% feed intake} = 0.75 * BW(kg)^{\,-0.350}$$

and expressed in gram per kg metabolic weight (formula 1, page 12):

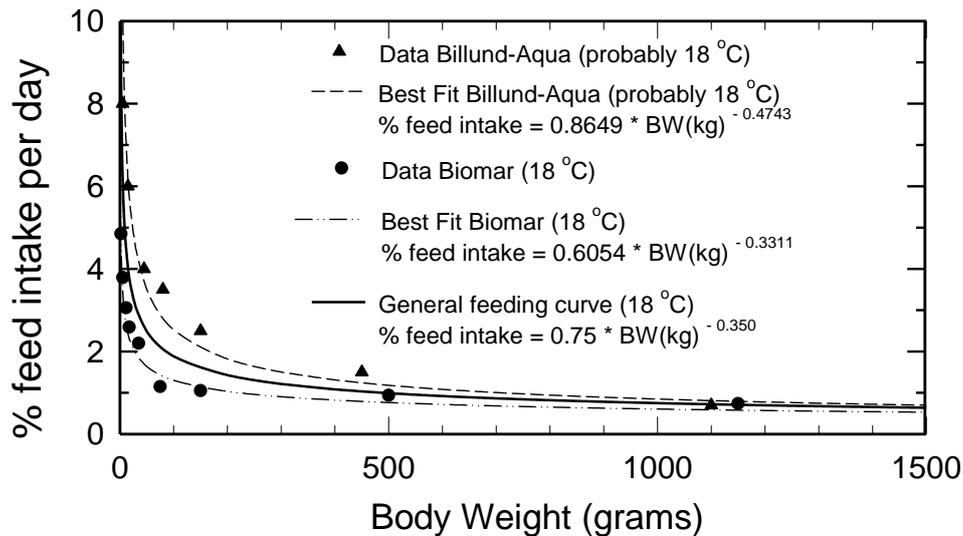$$\text{gram per } BW(kg)^{\,0.80} = 7.5 * BW(kg)^{\,-0.150}$$

These feeding levels expressed in % of body weight decreases when the body weight of the sturgeon 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 sturgeon 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 sturgeon 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 sturgeon can be generated.

The effect of the temperature on the feeding levels is exponential and is given by the formula (*see article "Feeding and growth parameters of trout*" for details, paragraph 7):

$$\text{feed intake at } T_2 = \text{feed intake at } T_1 * e^{0.095(T2 - T1)}$$

where T is the temperature in degrees Celsius and the temperature range is 14 – 20 $^{\circ}$C.

Figure 9
General feeding curve for sturgeon at a water temperature of about 18 – 20 ^{o}C compared with feeding curves as recommended by Biomar and Billund-Aqua.

Example: The feeding curve is:
(1) % feed intake = 0.75 * BW(kg) $^{-0.350}$ or
(2) feed intake (per BW(kg) $^{0.80}$) = 7.5 * BW(kg) $^{(-0.150)}$

We have for example a fish of 150 grams:
(1) % feed intake = 0.75 * BW(kg) $^{-0.350}$ = 0.75 * 0.150 $^{(-0.350)}$ = 1.46
The feed intake is then 0.0146 * 150 = **2.19** grams of feed.

(2) feed intake (per BW(kg) $^{0.80}$) = 7.5 * BW(kg) $^{(-0.150)}$ = 7.5 *0.150 $^{(-0.150)}$ = 9.96
The feed intake is then 9.96 * BW(kg) $^{0.80}$ = 9.96 * 0.15 $^{0.80}$ = **2.18** grams of feed.

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9 Growth Curves for sturgeon

(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 sturgeon, 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 sturgeon larvae and the power growth curve to describe the growth of larger size sturgeon.

The exponential growth curve is described by the formula:

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

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 10. 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):

$$α = \ln BW_{t=t2} - \ln BW_{t=t1}$$

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: $BW_1 = BW_0 \, e^{αt}$ for any value of BW_0.
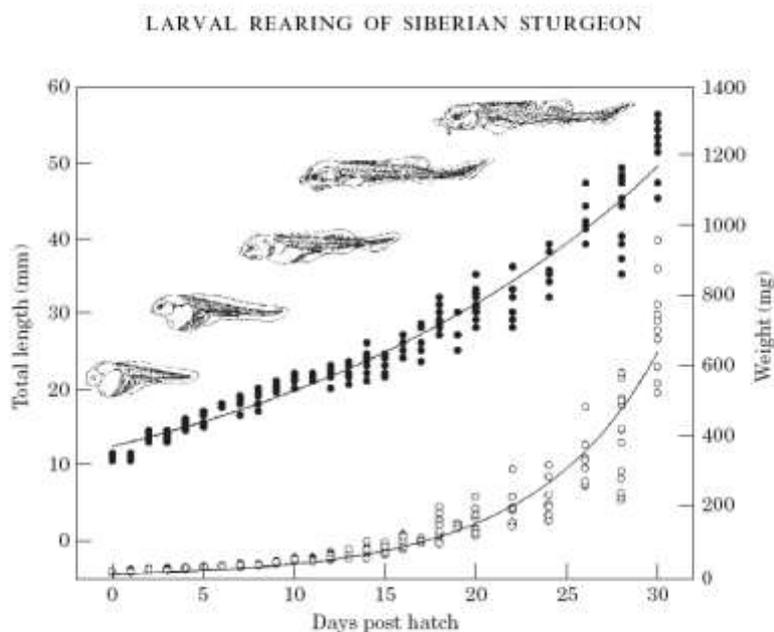

FIG. 5. Growth in length (●) (mm) and weight (○) (mg) of Siberian sturgeon larvae from hatching to 30 days post-hatch. Data were obtained from different females (*n*=21) and conducted under similar experimental rearing conditions (Gisbert, 1999; Gisbert *et al.*, 2000).

Figure 10
Exponential growth of Siberian sturgeon larvae (Gisbert and Johnston 2002)

The larvae growth rate of the Siberian Sturgeon can be described by the following exponential formula (18 $^{\circ}$C) according to Gisbert and Johnston (2002) (Figure 10):

$$BW(mg) = 8.08 * e^{\,days * 0.15}$$

Example: The growth of Siberian Sturgeon larvae is for example described by the exponential function:
$BW_1 = BW_0 * e^{αt} = 8.08 * e^{0.15t}$ where BW_0 is the BW at t = 0 and is in this example 8.08 mgrams
The body weight at t = 32 days is:
$BW_1 = 8.08 * e^{0.15*32} = 981$ mgrams.
The body weight after another 10 days is:
Method 1:
$BW_1 = BW_0 * e^{αt} = 981 * e^{0.15*10} = 4396$ mgrams
Method 2:
$BW_1 = BW_0 * e^{αt} = 8.08 * e^{0.15*42} = 4400$ mgrams.

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

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

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

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

When α = 0.15, then the time to double the body weights is: ln 2 / 0.15 = 4.62 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 (see article: *Some Aspects of Energy Metabolism in Homeotherm Animals and Poikilotherms Fish*)

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

And the % growth per day is ($t_1 - t_2 = 1$):

% growth per day = 100% * (e^α – 1)

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

Example: Suppose that we calculated from experimental data that α = 0.15 and we want to calculate the % growth per day, thus t_1-t_0 = 1 day.

% growth per day = 100% * (e^α – 1)
% growth per day = 100% * ($e^{0.15}$ – 1) = 16.18 % per day

This result means that the body weights will increase every day with 16.18%, 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 (15 vs 16% in the example above).
Similarly, we can calculate the % growth per 2 days, 3 days etc.

The power growth curve is described by the formula:

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

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 different from 1/3 has sometimes to be used to fit a power growth curve. The correct power coefficient 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 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 $BW_{day=0}$.

How to calculate the the DGC:

Method 1.
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.

Method 2.
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:

$$BW^d_{day=1} = BW^d_{day=0} + c*days$$

$$c = (BW^d_{day=1} - BW^d_{day=0}) / days$$

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.

$$Daily\ Growth\ Coefficient = DGC = 100\% * (BW^d_{day=1} - BW^d_{day=0}) / days$$

Figure 11 shows a power growth curve of the Siberian sturgeon. The best fit value of d (the exponent of the body weight) was 1/3 = 0.33. This value was found by trial and error, i.e. a linear graph is generated when the body weights raised to this power are plotted vs the time (see bottom panel of Figure 11). The graph indicates that there were two growth stanzas in the growth curve of the Siberian sturgeon. Dumas et al. (2007) reported that there were also various growth stanzas in the growth curve of the trout.

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

Final Body Weight = [(Initial Body Weight) $^{1/3}$ + (DGC/100) * days on diet)] ^{3}

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

Initial Body Weight = [(Final Body Weight) $^{1/3}$ – (DGC/100) * (days on diet)]^3

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:

Days on Diet = 100 * [(Final Body Weight) $^{1/3}$ – (Initial Body Weight) $^{1/3}$)] / (DGC)
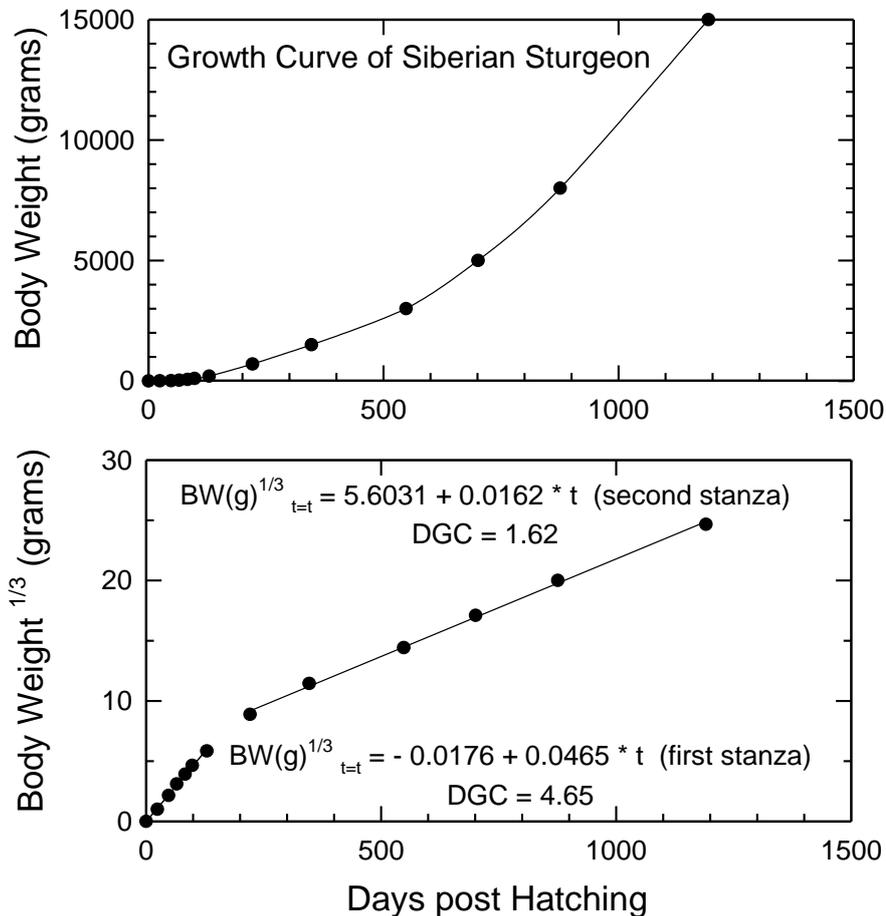
Figure 11
Power growth curves of the Siberian sturgeon. Data from Billund-Aqua (website: www.Billund-Aqua.dk)

Example: The body weight at day 48 is 10 grams and the body weight at day 98 is 100 grams and d = 1/3, thus number of days is (98 - 48) = 50 days, then the DGC is:

$$DGC = 100\% * (BW^{1/3}_{day=98} - BW^{1/3}_{day=48}) / days$$
$$DGC = 100 \times [(100)^{1/3} - (10)^{1/3}] / 50 = 4.97 \% \text{ (weight gain)}^{1/3} \text{ per day (compare DGC = 4.65 in Figure 11)}$$

Example: The initial body weight is 5000 grams and d = 1/3 and the DGC is 1.62. Then the body weight after 100 days can be calculated as

$$\text{Final Body Weight} = [(\text{Initial Body Weight})^{1/3} + (DGC/100) * \text{days on diet}]^3$$
$$\text{Final Body Weight} = [(5000)^{1/3} + (1.62 / 100)*100]^3 = 6560 \text{ grams.}$$

Example: The final body weight is 5000 grams at 701 days and the DGC is 1.62. Then the body weight at 500 days is (thus days on diet is 701 – 500 = 201 days):

$$\text{Initial Body Weight} = [(\text{Final Body Weight})^{1/3} – (DGC/100) * \text{days on diet}]^3$$
$$\text{Initial Body Weight at day 150} = [(5000)^{1/3} – (1.62/100) * (201)]^3 = 2653 \text{ grams}$$

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Example: The initial body weight is 5000 grams and d = 1/3 and the DGC is 1.62. How long does it take to double the body weight?

Days on Diet = 100 * [(Final Body Weight) $^{1/3}$ – (Initial Body Weight) $^{1/3}$)] / (DGC)
Days on Diet = 100 * [(10000) $^{1/3}$ – (5000) $^{1/3}$)] / (1.62) = 274 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 2500 grams and d = 1/3 and the DGC is 1.62. How long does it take to double the body weight?

Days on Diet = 100 * [(Final Body Weight) ^{d} – (Initial Body Weight) ^{d})] / (DGC)
Days on Diet = 100 * [(5000) $^{1/3}$ – (2500) $^{1/3}$)] / (1.62) = 271 days

The exponential growth curve is mostly used to describe the growth of sturgeon larvae whereas the power growth curve is used for larger size sturgeon. However, the power growth curve can also be used to describe the growth rate of sturgeon larvae, but a power coefficient smaller than 1/3 = 0.333 has to be used. The correct power coefficient has to be found by trial and error (see also article: "*Some Aspects of Energy Metabolism in Homeotherm Animals and Poikilotherms Fish*").

10 Body Composition of the sturgeon

The major components of the sturgeon 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. The compositinal data of the sturgeon are from: *Hung, S.S.O., Lutes, P.B. and Conte, F.S. (1987) Carcass proximate composition of juvenile white sturgeon (Acipenser transmontanus), Comparative Biochemistry and Physiology 88B: 269-272*, and we derived the following formulae.

The formulae for the percentages and total amounts of protein, fat, ash and water are:

Moisture (%) = 88.56 BW(g) $^{-0.0232}$
Protein (%) = 10.14 BW(g) $^{0.0706}$
Fat (%) = 1.62 BW(g) $^{0.1641}$
Ash (%) = 3.77 BW(g) $^{-0.0479}$
Energy (kJ/gram) = 2.942 BW $^{0.1011}$

mg protein / kJ = 34.46 BW $^{-0.0305}$

Moisture (g) = 0.8856 BW(g) $^{0.9768}$

Protein (g) = 0.1014 BW(g) $^{1.0706}$
Fat (g) = 0.0162 BW(g) $^{1.1641}$
Ash (g) = 0.0377 BW(g) $^{0.952}$
Energy (kJ) = 2.942 BW $^{1.01011}$

The data were derived from sturgeon (Acipenser transmontanus) in the weight range of about 0 – 450 grams and the mg protein / kJ were calculated from the body energy and the body protein data.
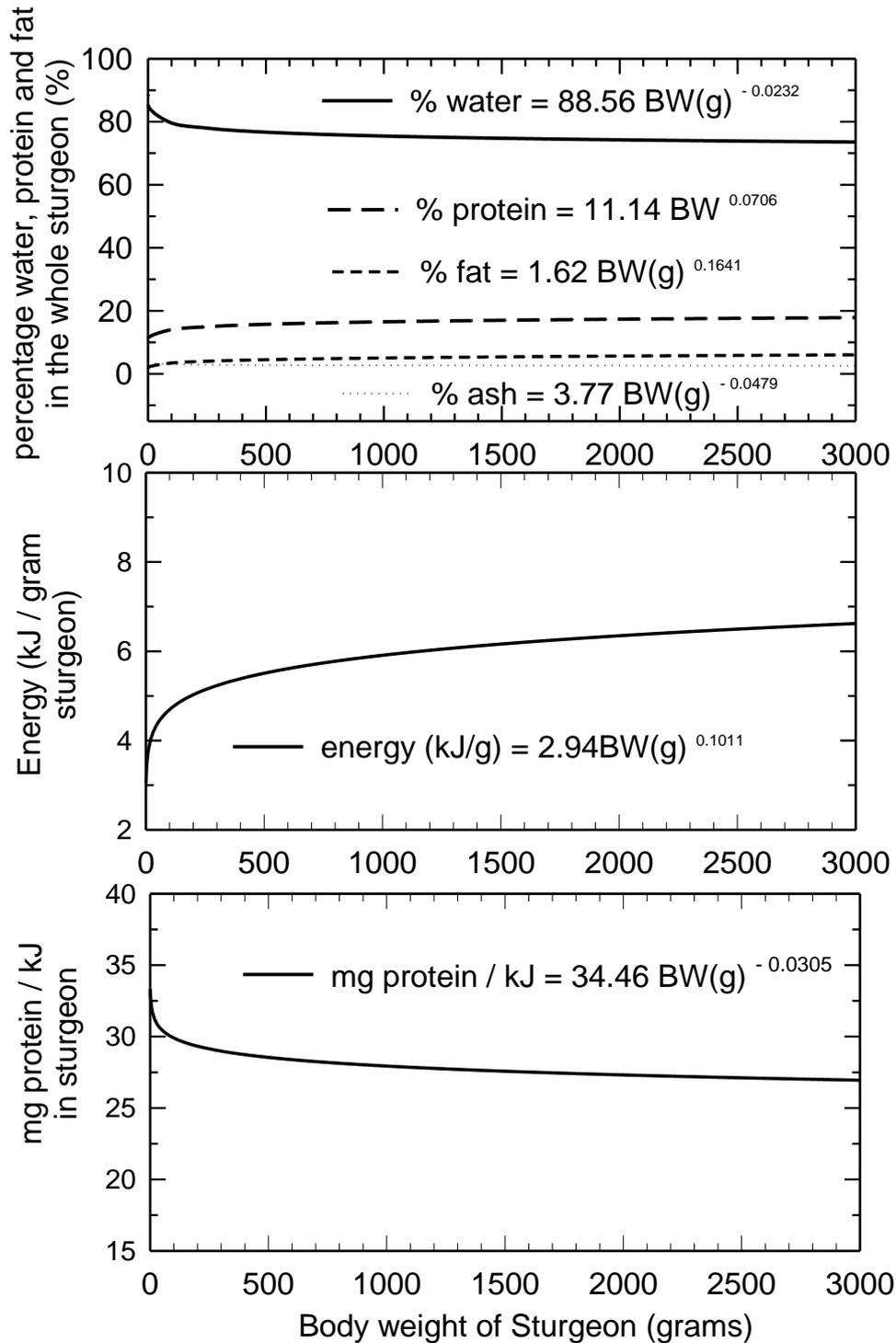
Figure 12
Body composition of the sturgeon

11   Factors that affect the Performance of a Sturgeon Feed: the 4 P's concept.

Protein drives the growth and the maximum growth of a sturgeon 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 energy to protein 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 sturgeon 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 sturgeon feed. The price should be right and the feeds should be cost effective.

Thus, the criteria for a good sturgeon feed (or a good sturgeon 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.

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13   Background and data from the literature

Protein and fat level in sturgeon diets: Diets for sturgeon have usually a high protein level but a low level of fat and the ratio of protein / digestible energy is relatively low. Sturgeon is a fast growing, carnivorous fish species, and therefore, the ratio of protein / digestible energy should be relatively low, since a relatively large amount of protein is needed for tissue accretion (protein) whereas relatively little energy is needed for maintenance (fat). Moore et al. (*Aquaculture 71: 235-245, 1988*) fed white sturgeon (*Acipenser transmontanus*) of about 145 grams (range of 91 – 219 grams) with diets containing about 13% fat and protein levels ranging from 20 – 52% at a water temperature of 23 – 26 ^{o}C. They found that the optimum level of protein for sturgeon was about 40% at a fat level of 13%. Other authors also reported that they use in their studies diets with levels of about 42 - 45 % protein and about 10 - 13% fat levels (*see Tabel 1 below*)

Table 1 Various feeding studies in sturgeon

Author	Initial weight (g)	Protein (%)	Fat (%)	Temperature	Species	Feeding Level (%)
					baeri	
Palmegiano (2005)	92	43	13	14 - 18	baeri	
Marzurkiewicz (2003)	6.77	50	10		baeri	
Köksal (2000)	9.2	45 - 47	10	16 - 22	baeri	See text
Medale (1991)	49	48	12 - 20	17.5	baeri	to satiation
Kaushlik (1989)	85 and 150	36 - 42	13	18	baeri	1.6
Buddington (1986)	88	45	10	21	White sturgeon	
Kolman (2005)	1975	46	13	20	cross hybrids	
Moore (1988)	145	20 – 52.7	13	23 - 26	white sturgeon	
Hung (Aquac.1987)	20 – 40 (28)	41	14	20	white sturgeon	0.5 – 4%
Hung (Aquac. 1989)	250	46	16	20	white sturgeon	0.5 – 2%
Hung (J Nutr 1987)	17 and 25	43	16	20	white sturgeon	4%
Hung (Aquac. N. 1997)	110	53 - 38	26 - 40	18	white sturgeon	2%
Mohseni (J Appl Ichtyol 2007)	137	40 and 45	10,15,20,25	13	Persian Sturgeon	to satiation

White surgeon, Acipenser transmontanus; Siberian sturgeon, Acipenser baer, Persian Sturgeon, Acipenser Persicus

Fat levels: Medale et al. (*1991*) fed Acipenser baeri with diets containing 48% protein and two levels of fat. i.e. 12 and 20% fat. They reported that the digestibility of the fat in the high fat diet was considerably lower than the digestibility of the fat in the low fat diet, but there was no difference in protein digestibility. Further, the feed conversion ratio (FCR) of the high fat diet group was also lower. The weight of the gastro-intestinal tract was higher in the sturgeon fed the high fat diet and this was related to an enhanced fat deposition along the gastro-intestinal tract in the group on the high fat diet. These results indicate that high fat diets may not be suitable for sturgeon, as also discussed by Buddington (*CBP 83A: 233 – 238, 1986*) . Sturgeon, which are carnivorous, have a relatively short gastro-intestinal tract and amylolytic and lipolytic acitivities decline following metamorphosis from the larvae to juveniles and from larval pelagic zooplanktivory to benthic carnivory (*Buddington, J. Fish Biology* 26: 715-723, *1985*).

Hung et al. (Aquaculture Nutrition 3: 281, 1997) fed white sturgeon, Acipencer transmontanus (110 gram) with high-fat salmon diets. The fat levels ranged from 26 – 40% and the protein levels from 53 – 38% (22.7 – 14.4 gram protein per MJ gross energy). The 4

diets that were fed had protein/fat ratios of 54/26; 50/30; 45/36 and 38/40.   Diets with the lowest protein/ energy ratio (38/40) had the lowest growth rates and feed efficiency whereas there were no major differences between the other three diets. Thus, the sturgeon was able to handle high fat diets. Further, the (38/40) diet had significantly higher lipid levels in the liver than the other 3 diets, that had similar liver lipid levels.

Mohseni (2006) fed Persian Sturgeon (acipencer persicus) of 135 gram with diets containing two levels of protein (40 and 45%) and 4 levels of fat (10, 15, 20, 25% fat). They observed that at both protein levels, the growth performance (growth, FCR) tended to improve when the fat levels increased. Further, they found that increasing fat levels in the diets increased the body fat (from 1.1% to 1.8% when the fat increased from 10 – 25% on the 40% protein diets and from 1.% - 2.3% when the fat increased from 10 – 25% on the 45% protein diets). They concluded that the best growth performance was obtained with a 40/20 protein fat ratio (the best FCR and PERvalues). The PER values improved at higher fat levels.

Stocking Densities of the sturgeon: Siberian sturgeon (Acipenser baeri) appear to be able to tolerate high stocking densities. Koksal et al. (2000) reported a density of 16 kg/m^3 in studies with 10 gram sturgeon. They used for larger baeri sturgeon (0.5 – 1 kg) densities of 20 – 25 kg/m^3. Steffens (1990) discussed that densities of 50 – 100 kg/m^3 are possible for larger sturgeon. Ruer (1987) discussed that densities of 25 kg/m^2 should be appropiate for the white sturgeon (Acipenser transmontanus). The sturgeon is a benthic feeder, and therefore it seems more appropiate to express the density in kg/m^2.

Feeding levels: Moore et al (*1988*) discussed a feeding level of 2% per day for sturgeon between 30 – 100 grams and a level of 1.5% for sturgeon of 150 – 300 grams. Köksal et al (2000) reported recommended feeding levels for Siberian sturgeon (Acipenser baeri) of 8% (5 – 10 gram), 6% (10 – 50 gram), 5% (50 – 100 gram), 4% (100 – 200 gram), and 3% (200 – 400 gram). Hung et al. (*1987*) studied various feeding levels in white sturgeon and they reported a optimum feeding level of 2% for sturgeon between 30 – 100 gram. Optimal water temperature for white sturgeon appeared to be about 23 ^{o}C (*Hung, 1993*).

Growth Rates: The growth rates of white sturgeons (Acipencer transmontanus) were studied by Hung et al. (1987) in various studies with sturgeons (1) in the range of 25 – 70 grams (8 weeks on a 43/16 diet, 4% feeding level, 20 ^{o}C (Hung et al. J Nutr 117; 328,1987), (2) in the range of 30 (20 – 40 grams) – 95 grams (8 weeks on a 43/16 diet, various feeding levels from 0.5% to 4.0%, 18 – 21 ^{o}C (Hung et al Aquaculture 65: 307, 1987), and (3) in the range of 250 – about 600 grams (8 weeks on a 43/16 diet, feeding levels of 0.5%, 1%, 1.5% and 2%, 18 ^{o}C, Hung et al Aquaculture 80: 147, 1989). The same diets were used in all these studies i.e. 43/16 protein/fat and the diets were semipurified fishmeal-free and based on casein and wheatgluten. The body weights of the sturgeon in experiment (1) increased from 25 to 67 grams in 8 weeks (SGR of) at a 4% feeding level, in experiment (2) from 28 to 95 grams in 8 weeks (SGR of) at a 4% feeding level and in experiment (3) from 250 to about 650 grams in 8 weeks at a 2% feeding level.

The Table 2 below indicate the effect of feeding level on the FCR. In the experiment with the sturgeon of 28 grams, there was a clear decrease in the FCR when the feeding level increased, a lower proportion of the dieary energy was used for maintenance and a larger proportion for growth.

Table 2

Effect of feeding level on growth and FCR in 28 grams sturgeon

Feeding level	0,5	1	1,5	2	2,5	3	3,5	4
FCR		0.80	0.75	0.78	1.00	1.30	1.60	1.70
Final body weight	34	54	61	84	95	76	87	95

The initial body weights were 28 gram, fed a 43/16 protein/fat diet. The diets were fed for 8 weeks. Water temperature was 20 ^{o}C. From: Hung et al Aquaculture 65: 307, 1987. The FCR decreased with increasing feeding level.

The study with 250 grams sturgeons (Table 3 below) suggests that there was initially an decrease in the FCR when the feeding level was increased, but subsequently again an increase of the FCR.

Table 3

The effect of feeding level on FCR in 250 grams sturgeons

Feeding level (%)	0,5	1,0	1,5	2,0
week 0 - 2	2,13	0,80	0,88	1,11
Week 2 - 4	3,13	1,10	1,00	0,97
Week 4 - 6	1,18	1,22	1,05	1,16
Week 6 - 8	1,89	1,04	0,95	1,12

The initial body weights were 250 gram, fed a 43/16 protein/fat diet. The diets were fed for 8 weeks. Water temperature was 20 ^{o}C. From: Hung et al Aquaculture 80: 147, 1989. There was a tendency to a lower FCR when the feeding level increased, but subsequently again an increase.

Vitamin C in the diet of sturgeon

The sturgeon is not a teleost and has a skeleton of predominantly cartilage. Vitamin C plays a role in the conversion of proline into hydroxyproline and hydroxyproline is a component of collagen, the matrix for the calcium and phosphor in the form of hydroxyapetite $(Ca_{10}(PO_4)_6(OH)_2))$ in the skeleton. Sturgeon are in contrast to e.g. trout and salmon able to synthesize vitamin C from glucose, and do essentially not need vitamin C in the diet. However, the capacity for the synthesis of vitamin C may not meet the requirement for the fast growing sturgeon (sturgeon is a fast growing fish species). Therefore, the diets of sturgeon are usually supplemented with vitamin C at a level of about 150 - 200 mg per kg feed.

14. 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)	(kJ/g)	H_2O generated (mol/mol)	(g/g)	O_2 consumed (mol/mol)	(g/g)	(L/g)	CO_2 generated (mol/mol)	(g/g)	(L/g)	RQ (CO_2/O_2)	$EeqO_2$[4] (kJ/g)	(kJ/L)	$EeqCO_2$[4] (kJ/g)	(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 allanton. 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 ^{o}C (273.15 ^{o}K).
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). *Excretion of the nitrogen in the form of urea*: 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) *Excretion of the nitrogen in the form of uric acid*: 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.

15   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 ^ (^{g}log a) = a

proof: ^{g}log a = ^{g}log a, and thus, per definition: g ^ (^{g}log a) = a)

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

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

proof:

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

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

(^{g}log a ^ (^{a}log b) = (^{g}log b)

a ^ (^{a}log b) = b

or

^{a}log b = ^{a}log b (see above)

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

proof:

^{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.

Note

10^1 = 10

$10^0 = 1$

$1^a = 1$

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

$\dfrac{0}{1} = 0$

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

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

The logarithms 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)