The Growth and Energetics of Perch (*Perca fluviatilis* L.) in Intensive Culture

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Doctoral Thesis
Swedish University of Agricultural Sciences
Umeå 2009

Acta Universitatis Agriculturae Sueciae
2009:71

Cover: Eurasian perch (*Perca fluviatilis* L.)(Photo: Roald How)

ISSN 1652-6880
ISBN 978-91-576-7418-0

Print: Arkitektkopia AB, Umeå 2009

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Abstract

In commercial aquaculture, knowledge about and means for predicting growth rates, feed intake and energy requirements of the farmed animal in different conditions is essential for the viability of the enterprise. As Eurasian perch (*Perca fluviatilis* L.) is relatively new in culture, no growth models or suitable models for evaluation of the daily feed allowance of this species was available. There was also a large gap in information regarding management practices and optimal culture environment for juvenile and adult perch. Therefore the focus of this thesis was to evaluate the growth potential and energy requirements of perch of different body size and at varying temperature conditions, and to assess the effect of different rearing conditions on growth and energy expenditures of perch.

Growth, feed intake and energy requirements of perch reared under different conditions (temperature, size of fish, tank colour, light intensity and disturbance) were studied in experimental tanks. Growth (the Thermal Unit Growth Coefficient, TGC) of perch was found to be affected both by body size of the fish and by temperature. However, in limited temperature intervals, TGC was quite stable. Furthermore, the digestible energy need (DEN) of perch was found to be affected by body size of the fish, but not by temperature. A growth model and an energy requirement model were developed and then combined to create a model for estimation of the theoretical daily energy requirement of perch in intensive culture. The developed models produced realistic results if compared to reference and validation data.

The sensitivity of perch to disturbance was found to be high. The effects of stress on growth and energy expenditures were dramatic, and care should be taken to reduce stress of perch in culture in order to improve welfare of the fish, growth rates and thus farm economics. No specific tank colour seemed to be preferred by the fish, which was attributed to the ability of perch to adjust its body colour according to the surroundings. However, tank colour in combination with light intensity affected growth and feed intake of the fish. Selection of a suitable colour for rearing tanks should therefore be performed in accordance with ambient lighting conditions in the rearing facility.

Keywords: Eurasian perch, *Perca fluviatilis*, growth, energy requirement, daily feed allowance, tank colour, light intensity, disturbance, management practices.

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Till Theodor

"With earth's burgeoning human population to feed, we must turn to the sea with new understanding and new technology. We need to farm it as we farm the land…"

Jacques Cousteau, 1973

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Strand, Å., Magnhagen, C., Alanärä, A. Growth performance and energy requirements of Eurasian perch (*Perca fluviatilis* L.) in different temperatures and of different body sizes (submitted manuscript).

II Strand, Å., Overton, J.L., Alanärä, A. The energy requirements of Eurasian perch (*Perca fluviatilis* L.) in intensive culture (submitted manuscript).

III Strand, Å., Magnhagen, C., Alanärä, A. (2007). Effects of repeated disturbances on feed intake, growth rates and energy expenditures of juvenile perch, *Perca fluviatilis*. *Aquaculture* 265, 163-168.

IV Strand, Å., Alanärä, A., Staffan, F., Magnhagen, C. (2007). Effects of tank colour and light intensity on feed intake, growth rates and energy expenditure of juvenile Eurasian perch, *Perca fluviatilis* L. *Aquaculture* 272, 312-318.

Papers III and IV are reproduced with the permission of the publishers.

The contribution of Åsa Strand to the papers included in this thesis was as follows:

I Planning and executing the experiments jointly with the co-authors, processing of data and compiling the manuscript.

II Planning the data management jointly with the co-authors, processing of data and compiling the manuscript.

III Planning and executing the experiment jointly with the co-authors, processing of data and compiling the manuscript.

IV Planning and executing the experiment jointly with the co-authors, processing of data and compiling the manuscript.

Abbreviations

DE	Digestible energy content of the feed (kJ·g^{-1})
DEN	Digestible energy need (kJ DE·g^{-1})
FA	Daily feed allowance (g·day^{-1})
GE	Energetic growth efficiency
K	Fulton's condition factor
SGR	Specific growth rate
TER	Theoretical daily energy requirement (kJ·day^{-1})
TGC	Thermal unit growth coefficient
T*Wi*	Theoretical weight increment per day (g·day^{-1})

1 Introduction

With the world human population steadily increasing, there is a growing demand for both meat and fisheries products. Furthermore, over the last 40 years, the consumption of both meat and seafood per capita has increased steadily (faostat.fao.org). As the world fishery catches has been relatively stable in the past decade (FAO, 2009), the growing demand for fish and shellfish has mainly been met by an increase in aquaculture. Aquaculture is the fastest growing form of food production in the world. Worldwide, the sector has grown at an average rate of 8.8 % per year since 1970 compared to 2.8 % for terrestrial farmed meat production over the same period (FAO, 2007), and in 2006, the total aquaculture production of fish and shellfish reached approximately 52 million tonnes which accounted for 47 % of the total supply of sea food in the world (FAO, 2009).

There are almost twenty-eight thousand species of fish in the world (Nelson, 2006), and in 2004, approximately 336 species were used in culture for food production (FAO, 2006). Between 1952 and 2006, on average five species were added to culture per year, although the most rapid growth in terms of number of species added per year occurred between 1980 and 1990 with 9.5 species per year (FAO, 2006). There are estimates that 1 000 new species are being evaluated for their culture potential (Brown, 2003).

Eurasian perch (*Perca fluviatilis* L.) is one of the fish species receiving increasing attention in the area of freshwater aquaculture. Perch is highly valued as food fish, and has an already established market with varying requirements regarding size of fish (Fontaine *et al.*, 1993; Tamazouzt *et al.*, 1993; Watson, 2008). Furthermore, the market demand in central Europe is not met by commercial fisheries (Fontaine *et al.*, 1993; Tamazouzt *et al.*, 1993; Tribiloustova, 2005). Thus, from a market point of view, the potential for perch culture seems promising, but more information regarding the species biological performance in culture needs to be gathered.

1.1 Growth models

In commercial aquaculture, knowledge about and means for predicting growth rates, feed intake and energy requirements of the farmed animal in different conditions is essential for the viability of the enterprise. For evaluation of growth rates and feed requirement, mathematical models can be used, which also can be very useful tools from both a production planning and feed management point of view. However, the different growth rate expressions available have different strengths and weaknesses, and care should be taken when selection of a model is made to describe fish growth in culture.

1.1.1 Expressions of growth rate

The most commonly used estimate of fish growth is the specific growth rate (SGR; Ricker, 1979). SGR is expressed mathematically as:

$$\mathrm{SGR} = (\ln W_2 - \ln W_1) \,/\, \Delta t \cdot 100 \qquad \text{(Equation 1)}$$

where W_2 is the final weight (g), W_1 is the initial weight (g) and Δt is the number of days between weight measurements. The form of the equation assumes that fish weight increases exponentially. However, this assumption is only valid for young fish cultured for short periods of time, and consequently, SGR is not suitable for evaluation of growth rates of large fish or longer culture periods (Hopkins, 1992). Furthermore, as an organism increases in size, the rate of its metabolic activities slows down (Brett, 1979; Brett & Groves, 1979; Jobling, 1994) and as a result, the relative growth rate will decrease. Any growth increment (in real terms) is also smaller for a large individual. Thus, SGR will decrease as the size of the fish increases (Brett, 1979; Iwama & Tautz, 1981; Jobling, 1983; 1994). Moreover, as fish are ectothermic animals, the ambient water temperature will affect metabolic rates of the fish, with increasing metabolic rates at increasing temperatures (Brett & Groves, 1979; Jobling, 1994; 1997; De Silva & Anderson, 1995). Consequently, at high temperatures the relative growth rate will be higher than at low temperatures, and SGR will therefore increase with increasing temperature (Brett, 1979; Jobling, 1994; Wootton, 1998). The temperature and size dependence of SGR make data collection for model construction very time consuming and labour demanding, and as a consequence, only a few models describing SGR for fish in culture are available (Alanärä *et al.*, 2001).

To reduce the problem of body size and temperature, the thermal unit growth coefficient (TGC) was developed by Iwama & Tautz (1981) and later modified by Cho (1990). TGC is expressed mathematically as:

$$\mathrm{TGC} = (W_2^{1/3} - W_1^{1/3}) \;/\; (T \cdot \Delta t) \cdot 1000 \qquad \text{(Equation 2)}$$

where T is the water temperature (°C). Instead of using the logarithm of the fish weight ($\ln W$) for calculating growth rate as SGR does, TGC uses a power function ($W^{1/3}$). This mathematical adjustment provides a better fit of the growth coefficient to the actual growth pattern of the fish (Cho, 1992). Thus, due to the power function and the inclusion of temperature, TGC is thought to be less affected by body size of the fish (Kaushik, 1995; 1998; Bureau *et al.*, 2000) and temperature (Azevedo *et al.*, 1998; Cho & Bureau, 1998; Bureau *et al.*, 2000; Bailey & Alanärä, 2006) than SGR. In addition, the TGC coefficient predicts growth over time quite accurately (Bureau *et al.*, 2000). Consequently, in contrast to the complex SGR models, TGC data collected for fish of a given size at one temperature may ideally be used to predict the weight increment of fish at other sizes and temperatures. The TGC model has to date only been validated for salmonids, but preliminary observations suggest that it is also valid for some non-salmonid species, for example Nile tilapia (*Oreochromis nilotica* L.) (Bureau *et al.*, 2000). However, there are also some indications that TGC may not be as stable as previous studies have shown (Jobling, 2003; Rónyai & Csengeri, 2008) which would reduce the advantages of the coefficient.

1.2 Bioenergetics models

According to Cho *et al.* (1982), the principles of bioenergetics were applied to fish already in 1914 by Ege & Krogh and several years later by Ivlev (1939), and Cui & Xie (2000) states that the first bioenergetics model for fish was developed by Kitchell *et al.* (1974). Models based on similar principles had been proposed earlier by other researchers (Ursin, 1967; Kerr, 1971), but the model developed by Kitchell *et al.*, (1974), is probably the most influential (Cui & Xie, 2000).

1.2.1 The energy budget

The simplest form of a bioenergetics model can be derived from the basics of bioenergetics: "*any change in body weight results from the difference between what enters the body and what leaves it*" (Jobling, 1997). Growth can thus be expressed as the net energy gain obtained when all energy expenditures are subtracted from the total energy ingested. To provide a more detailed view of the energy budget, the energy expenditures can be divided into smaller units and the energy budget can then be expressed as:

$$I = F + E + M + G \qquad \text{(Equation 3)}$$

where I is the energy content of the ingested feed, F is the energy lost in faeces, E is the energy lost to excretion, M is the energy lost in metabolism and G is the energy retained as growth and gonad production (Brett & Groves, 1979; Tytler & Calow, 1985; Jobling, 1994; De Silva & Anderson, 1995; Figure 1).

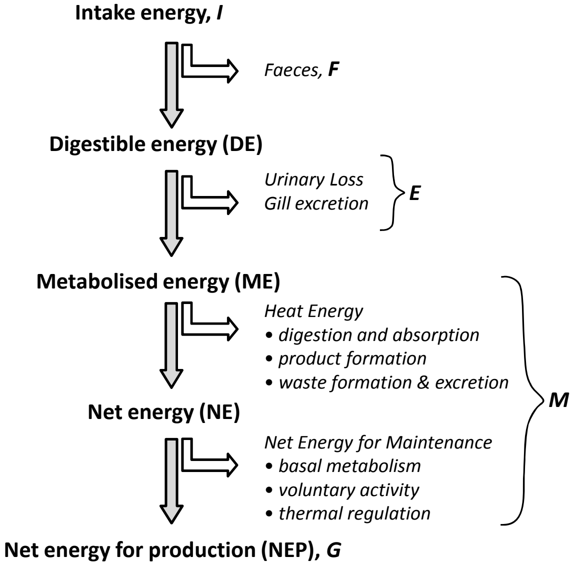

Figure 1. The classical bioenergetics model. I is the energy content of the ingested feed, F is the energy lost in faeces, E is the energy lost to excretion, M is the energy lost in metabolism and G is the energy retained as growth and gonad production.

As can be expected, several problems arise when the different units of the energy budget are to be measured. So far it has not been possible to determine all the components in the energy budget simultaneously, and often one or more of the major units have been estimated "by difference" to produce a balanced budget (Jobling, 1994). Different experimental procedures will also produce differing results (Talbot, 1985). Furthermore, bioenergetics studies of fish have largely been theoretical and performed in laboratories (Knights, 1985), and the experiments also often impose unnatural or unrealistic feeding regimes and living conditions on the fish which exposes the fish to both acute and chronic stress (Talbot, 1985). Despite improvements in methodology, the bioenergetics approach is thus often associated with measurement errors (Brafield, 1985) and several of the developed energy budgets prove to deliver inaccurate results when tested (Cui & Wootton, 1989; Ney, 1993; Cui & Xie, 2000). Thus, the experimental approaches used to develop energy budgets tend to produce results that are rarely transferable to aquaculture (Alanärä *et al.*, 2001).

1.2.2 A simplified energy budget

Due to the problems with the classical bioenergetics approach, a more general method for evaluation of the digestible energy needed to obtain one unit of biomass gain (DEN; kJ $\mathrm{DE \cdot g^{-1}}$) of fish in culture was developed by Alanärä *et al.* (2001). The DEN is calculated as:

$$\mathrm{DEN} = (FI \cdot DE) \,/\, (W_2 - W_1) \qquad \text{(Equation 4)}$$

where *FI* is the feed intake (g) and *DE* is the digestible energy content of the feed ($\mathrm{kJ \cdot g^{-1}}$).

From a fish farmer's point of view, the details concerning where energy expenditures occur are less important than obtaining the maximum gain in biomass per unit input. Thus, the advantage with the model is that since the values for the different energy expenditures need not be quantified, estimates of DEN can be made when the fish are being raised under experimental conditions similar to those in commercial culture.

In order to transfer DEN data into an energy requirement model, the DEN values need to be combined with the daily growth increment of the fish (Alanärä *et al.*, 2001). The daily growth increment can be calculated using SGR or TGC. A model describing the theoretical daily energy requirement of the fish (TER; $\mathrm{kJ \cdot day^{-1}}$) can thus be expressed as:

$$\mathrm{TER} = \mathrm{T}Wi \cdot \mathrm{DEN} \qquad \text{(Equation 5)}$$

where T*Wi* is the theoretical weight increment per day ($g \cdot day^{-1}$). For evaluation of the daily feed allowance of the fish (FA, $g \cdot day^{-1}$), the following calculation is then made:

$$FA = TER \cdot n / DE \qquad \text{(Equation 6)}$$

where n is the number of fish in the unit. The TER model has been tested by Bailey & Alanärä (2001) with good results on hatchery-reared rainbow trout (*Oncorhynchus mykiss* Walbaum).

1.3 Factors affecting growth and energy requirements of fish in culture

Growth and feed intake of fish in culture is governed by a variety of abiotic and biotic factors, for example temperature, light and other rearing conditions, as well as size of the fish and social interactions (Brett, 1979; Jobling, 1994; Kestemont & Baras, 2001). Generally, for fish, feed intake, growth rate and growth efficiency will increase with increasing temperature to a maximum close to the species optimum temperature, and then decrease when temperature is increased further and approach the species upper thermal tolerance limit (Brett, 1979; Jobling, 1994; 1997; Wootton, 1998). The decrease in appetite at high temperatures has been attributed to limitations in the capacity of the respiratory and circulatory systems to deliver oxygen to the respiring tissues under conditions of very high oxygen demand (Jobling, 1997). Furthermore, the reduction in growth efficiency is caused by an increase in maintenance energy cost as temperature increases (Brett & Groves, 1979; Jobling, 1994; 1997; Wootton, 1998). Thus, as feed intake is reduced at high temperatures while energy expenditures remain high, growth is reduced.

Fish held in culture are also sensitive to disturbance, and feeding activity and growth may be severely reduced by exposure of the fish to stressful events such as cleaning of tanks (Head & Malison, 2000; Kestemont & Baras, 2001), inappropriate feeding regimes (Brännäs *et al.*, 2001) or rearing environments (Malison & Held, 1992; Brännäs *et al.*, 2001; Papoutsoglou *et al.*, 2000; 2005), handling (Acerete *et al.*, 2004; Jentoft *et al.*, 2005) and social dominance hierarchies (Brännäs *et al.*, 2001). Culture management should therefore aim to optimize the farming environment to maximise growth and welfare of the fish.

1.4 Objectives

As perch is relatively new in culture, some knowledge gaps for evaluation of the species production potential can be identified. Firstly, despite available information on the time required for perch to grow to market size, no growth models are available. Furthermore, the existing models regarding daily feed allowance of the fish does not account for the energy content of the feed or rearing temperature, nor can they be adjusted to local conditions or different strains of fish. There is also a large gap in information when it comes to management practices and optimal culture environment for juvenile and adult perch.

The focus of this thesis has two principal areas of interest. The first area deals with an evaluation of the growth potential and energy requirements of perch of different body size and at varying temperature conditions (paper I & II). The second area is connected to the effects of rearing conditions on growth and energy expenditures of perch (paper III & IV). More specifically the aims are covered as follows in papers I-IV:

I To establish the relationship between commonly used expressions of fish growth and energy requirements against body size and temperature for perch.

II To develop a growth and feed budget model for perch in intensive culture.

III To evaluate and quantify the effect of repeated daily disturbance similar to ordinary farming procedures in intensive culture on growth rates and energy expenditures of perch.

IV To evaluate and quantify the effect of tank colour and light intensity on growth rates and energy expenditures of perch in intensive culture.

2 Material and methods

2.1 Fish and rearing

Young-of-the-year perch were bought from a fish hatchery (located in Söderköping: 58°48′N; 16°34′E, Sweden) and transported to the university research facility in Umeå, Sweden. The juveniles were hatched from eggs collected from wild spawners, and the fry were habituated to dry feed before they were delivered to the research facility. At the research facility, the juveniles were placed in square, grey, indoor (0.3 m^3) fibreglass tanks with a water temperature of approximately 17 °C and 12L:12D light regime. The fish were fed formulated feed delivered by automatic point source feeders set to deliver feed in excess.

2.2 Experimental setup

The experimental setup was identical in all four papers. Twelve cylindrical, dark green plastic tanks were used in the experimental setup. Inside each tank was a plastic cone connected to a hole in the tank bottom, creating a space (approximately 55 l) with tilting walls (Figure 2). An automatic point source feeder was placed above each tank. The feeders were set to deliver formulated feed (Dana feed, DAN-EX 1344, 13 % fat, 44 % protein) in excess. The daily feed ration was divided into two meals, at 07.00-09.00 and 18.00-19.00. At the start and end of each experiment, the feed in the feeders were weighed. Feed waste and faeces were automatically evacuated from the tanks daily at pre-programmed time intervals and the number of pellets flushed out from each tank was counted daily. In all studies, feed intake was calculated as weight of the feed delivered to each tank minus the number of collected pellets from the same tank multiplied by the average weight of one pellet. The feed intake was then expressed as % feed intake of average fish body weight per day and per fish. The light regime used was long day:short night, with light (125 lux at surface except for in paper IV) switched on at 06.00 and off at 22.00. Flow rates to the experimental tanks varied between experiments, but turn-over rates were always over 1.2 times·hour^{-1} (i.e. at least 2.3 l·kg^{-1} fish and minute). All tanks were separated by black plastic sheets. At the start and end of each experiment, the fish were tranquilized with Aquacalm (Marinil, Syndel Laboratories Ltd.) and their weight and length was recorded.

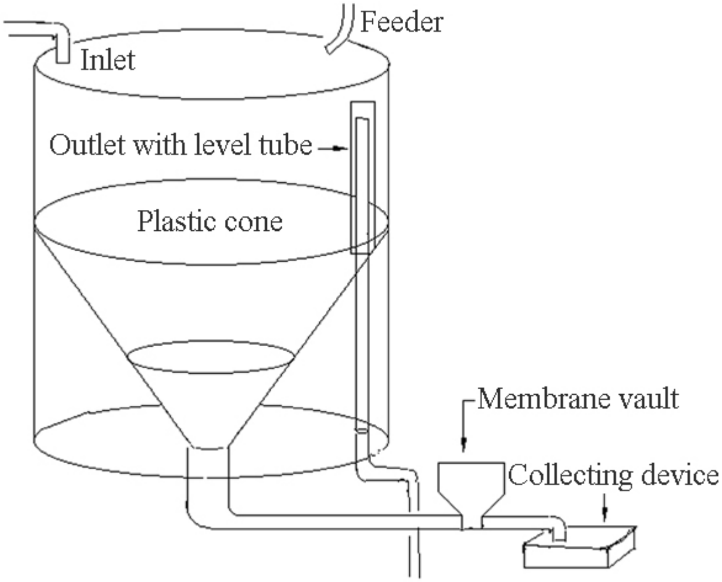

Figure 2. Schematic drawing of the experimental tanks. The tanks were built from cylindrical, dark green plastic tanks. Inside each tank was a plastic cone connected to a hole in the tank bottom, creating a space (approximately 55 l) with tilting walls. An automatic point source feeder was placed above each tank. The water inlet was placed on one side of each tank, and the water outlet (by a level tube) was placed on the other side. Feed waste and faeces were automatically evacuated from the tanks daily using timer controlled, air pressure driven membrane vaults and the effluents were collected in a mesh collecting devise, allowing for excess water to run off but leaving the solid materials in the collecting devise.

The digestible energy (DE) available in the feed used in the trials was calculated using the information presented in table 1. By multiplying the gross energy value of each macronutrient (Brett & Groves, 1979) with a digestibility coefficient (ADC) for that substance (pers. comm. M. Jobling), the digestible energy available in each macronutrient was obtained. The digestible energy available in each macronutrient was thereafter multiplied by the occurrence (in %) of the substance in the feed, after which the resulting available energy for all three macronutrients were combined to calculate the total digestible energy available in the feed.

Table 1. *Energy values of macronutrients (protein, fat and carbohydrate; obtained from Brett & Groves, 1979) and apparent digestibility coefficients (ADC; pers. comm. M. Jobling) used to calculate the digestible energy content (DE) of the feed used in the studies.*

	Gross energy ($kJ \cdot g^{-1}$)	ADC	DE ($kJ \cdot g^{-1}$)	DAN-EX 1344*	Ecostart 17#
Protein	23.7	0.87	20.6	9.1	9.9
Fat	36.7	0.90	32.7	4.2	7.5
Carbohydrate	17.2	0.65	11.2	2.8	1.4
Total DE				16.1	18.8

*44 % protein, 13 % fat, 25 % carbohydrate

#48 % protein, 23 % fat, 12.5 % carbohydrates

2.3 Experiments

2.3.1 Paper I

In paper I, the main objectives were to estimate the effects of temperature and fish body weight on growth and digestible energy need (DEN) of perch. In two separate laboratory experiments, feed intake (% of average fish body weight per day and per fish), growth (SGR, equation 1 and TGC, equation 2) and energy expenditures (DEN, equation 4) of perch were measured at different temperatures and on fish of different body sizes.

In the temperature experiment, fish weighing on average 28.3 g were kept in five different temperature categories with average temperatures of 8.5, 12.9, 18.2, 23.1 and 27.1 °C. Six fish were used in each group. For the high temperatures (18.2, 23.1 and 27.1 °C), two tanks were used per temperature treatment and the experiment was repeated three times. For the low temperatures (8.5, 12.9 °C), three tanks were used per temperature treatment and the experiment was repeated twice. This resulted in 6 replicates per treatment.

In the size experiment, fish ranged from 20 to 110 g and were kept in 21.1 °C. To avoid crowding and to maintain an even rearing density, number of fish in each group was reduced as body size of the fish increased. In size range 20 to 50 g six fish, in size range 50 to 80 g five fish, and in size range 80 to 110 g four fish were placed in each group. The experiment was repeated twice, but due to technical problems with feeding, only 20 replicates were obtained. Fulton's condition factor (K; Fulton, 1904) was calculated as the average condition factor of all individuals in a group. The K is calculated as:

$$\mathrm{K} = W_1 / L_i^3 \cdot 100\,000 \qquad \text{(Equation 7)}$$

where L_i is the initial length of each fish (mm).

2.3.2 Paper II

In paper II, the purpose was to develop an energy requirement model for intensive culture of perch reared at rational temperatures. This was done by evaluation of the growth potential and the minimum amount of energy needed to produce one unit of weight gain (DEN) of perch. Data for the model creation was collated from eight growth studies performed during the work with this PhD project. Based on results obtained in paper I, temperatures between 17 and 23 °C were considered rational for intensive culture of perch, and the model data was therefore limited to this temperature interval. The data was divided into temperature (17, 21 and 23 °C) and size (20, 35, 50, 65, 80, 105, 130, 155 and 180 g) categories, resulting in a dataset comprising of 241 groups arranged into different categories.

For evaluation of the growth potential and the minimum amount of energy needed to produce one unit of weight gain (DEN), the dataset was sorted for declining TGC (equation 2) and increasing DEN (equation 4) within each temperature and size category. As number of groups in each category varied largely, a limit of five replicates was set to allow an even number of replicates to be obtained per category without including the lowest (for TGC) or the highest (for DEN) values. The temperature and size categories were only used to compile a dataset for further analysis. In the statistical analysis of the data, actual weights and temperatures were used instead of categories. The effect of body size and temperature on TGC and DEN was evaluated using regression analysis with average size of the fish and temperature as factors. From the data, a growth (TGC) model and a model describing the digestible energy need (DEN) of perch were developed. The two models were then combined to evaluate the theoretical daily energy requirement (TER, equation 5) of perch of different sizes and in different temperatures. Fulton's condition factor (K, equation 7) was calculated as the average condition factor of all individuals in a group. The growth model was validated against data obtained from a commercial growth trial.

2.3.3 Paper III

In paper III, the effect of repeated disturbances on feed intake, growth rates and energy expenditures of perch was evaluated. In the study, groups of six fish were exposed to one of three treatments including control (no disturbance), moderate disturbance (shadows from movements above the tanks) and severe disturbance (shadows from movements above the tanks + cleaning of tanks). Two different temperatures (16.6 and 22.7 °C) were used. Six groups were used for each treatment category in each temperature category. Average weight of the fish was 39.6 g. Feed intake (% of average fish body weight per day and per fish) and growth rates (SGR, equation 1) were registered, and to evaluate energy expenditures, the energetic growth efficiency (GE) was used. GE is the ratio between the energy of the weight increase of the fish and the total energy intake of the fish (Larsson & Berglund, 2005):

$$GE = (J \cdot (W_2 - W_1)) \ / \ (FI \cdot DE) \qquad \text{(Equation 8)}$$

where J is the conversion factor of mass to energy for percids (5.0 $kJ \cdot g^{-1}$ wet weight) (calculated average from Hewet and Kraft, 1993 [*P. flavescens* L.] and Bryan *et al.*, 1996 [*P. flavescens* L. and *Stizostedion vitreum* Mitchill]).

2.3.4 Paper IV

In paper IV, the objective was to evaluate how different combinations of tank colour and light intensity affected feed intake, growth and energy expenditures of juvenile perch. Feed intake (% of average fish body weight per day and per fish), growth rate (SGR, equation 1) and energetic growth efficiency (GE, equation 8) were measured using groups of perch exposed to different combinations of tank colour (white, grey or black) and light intensity (200 or 1100 lux). Six groups of six perch were exposed to each colour/light combination. The initial mean weight of the fish was 59.6 g. Temperature was kept at an average of 21.0 °C.

3 Results

3.1 Paper I

Growth (SGR and TGC) proved to be significantly affected by body size of the fish and by temperature, while DEN was only significantly affected by body size. SGR, TGC and feed intake followed a similar pattern and increased with temperature from 8 to 23 °C, and was then reduced at 27 °C (Figure 3).

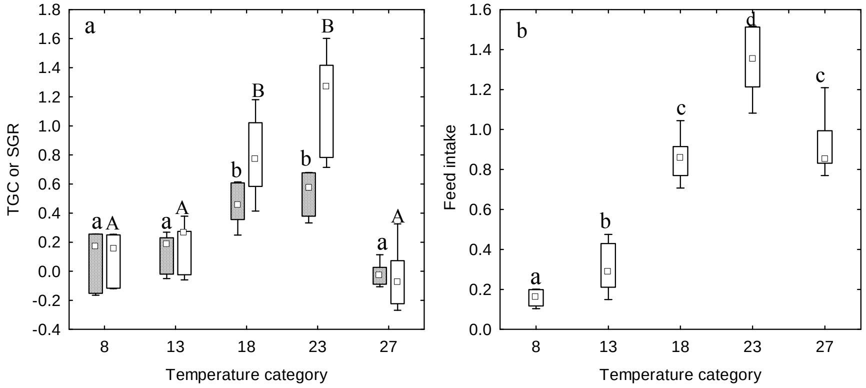

Figure 3. Box plots of growth rates (3a; TGC: grey boxes and SGR: white boxes) and feed intake (3b; % of average fish body weight per day and fish) of Eurasian perch (*Perca fluviatilis* L.) in different temperature categories (8, 13, 18, 23 and 27 °C). Square symbols within boxes represent the median of the sample, boxes represent quartiles and the whiskers show non-outlier range. Identical letters indicates no significant differences (P>0.05) between temperature categories. Lower case letters corresponds to TGC (3a) and feed intake (3b), and upper case letters correspond to SGR (3a).

DEN was not affected by temperature at or below optimal temperatures for growth, but as temperature increased further, energy expenditures increased exponentially. Furthermore, SGR, TGC and feed intake decreased, and DEN and K increased, with increasing body size of perch. Growth rates and feed intake increased, and DEN decreased as the experiments progressed.

3.2 Paper II

By linear regression, TGC and DEN were found to be significantly affected by body size but not by temperature. Thus, for the TGC and DEN data, models including only initial body weight were selected. The models were constructed using curve estimation and the resulting models were:

$$\mathrm{TGC}_{mod.} = 0.373 + 8.024 \;/\; W_1 \qquad \text{(Equation 9)}$$

$$\mathrm{DEN}_{mod.} = 6.422 + 3.407 \cdot \ln W_1 \qquad \text{(Equation 10)}$$

The TGC model was validated by comparison with data obtained from a commercial growth trial, and was found to evaluate final weight of the fish with high accuracy. The mean deviation between the actual final weights of the fish in the growth study and the final weights calculated from identical initial weights using the growth model was 5 %. The expected final weight of the fish (W_2, g) was solved for from equation 2, resulting in equation 11:

$$W_2 = (W_1^{\,1/3} + (\mathrm{TGC} \;/\; 1000 \cdot T \cdot \Delta t\,))^3 \qquad \text{(Equation 11)}$$

T*Wi* was then obtained by calculating the final weight of the fish after one day of growth (Δt = 1), substituting TGC in equation 11 for the developed TGC model (equation 9) and subtracting the initial weight of the fish. Thus, by combining the theoretical daily weight gain at different temperatures and initial weights and the DEN model (equation 10), a model describing the daily theoretical energy requirement (TER, $\mathrm{kJ \cdot d^{-1}}$) at different temperatures and for fish of different sizes was developed. The resulting equation was:

$$\mathrm{TER} = 0.039 \cdot T \cdot W_1^{0.614\,-\,0.014/T} \qquad \text{(Equation 12)}$$

Furthermore, the condition factor (K) of the fish increased significantly with increasing size of fish.

3.3 Paper III

In the stress study, feed intake, growth rates (SGR) and growth efficiency (GE) were significantly reduced by disturbance treatment. At both temperatures, disturbed groups of fish had lower feed intake and growth rates than undisturbed groups of fish, but the effect on growth efficiency was significant only at 17 °C ($P<0.05$) although a similar trend could be seen at 23 °C (Figure 4). The overall effect of temperature was significant for feed intake and growth rates with higher feed intake and growth rates at 23 than at 17 °C. Feed intake and growth rates of the fish were reduced as the experiment progressed.

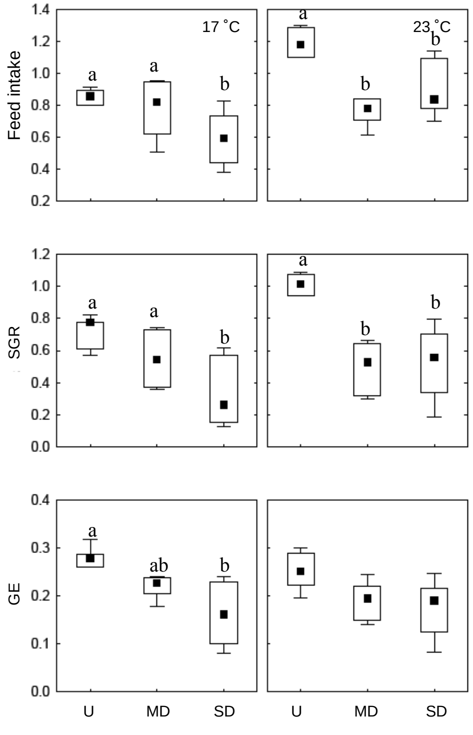

Figure 4. Feed intake (% of group average weight per individual and day), growth rates (SGR) and energetic growth efficiency (GE) of groups of Eurasian perch (*Perca fluviatilis* L.) exposed to different disturbance treatments (U: undisturbed; MD: moderately disturbed; SD: severely disturbed) and temperatures (17 and 23 °C). Square symbols in boxes represent the median of the sample, the boxes represent quartiles and the whiskers show non-outlier range. Identical letters indicates no significant differences ($P>0.05$) between disturbance treatments. In the graph with no letters, none of the results differed significantly between treatments.

3.4 Paper IV

In the tank colour/light intensity study, a significant overall effect of tank colour was found for feed intake and growth rate (SGR), but not for energy expenditures (GE). Both feed intake and growth rates increased from dark to light tanks (Figure 5). There was no significant overall effect of light intensity on feed intake, growth rate or growth efficiency. A significant interaction between light intensity and tank colour was, however, found for feed intake. Feed intake increased significantly from dark to light tanks only under low light conditions (Figure 5). Feed intake and growth rates of the fish decreased as the experiment progressed.

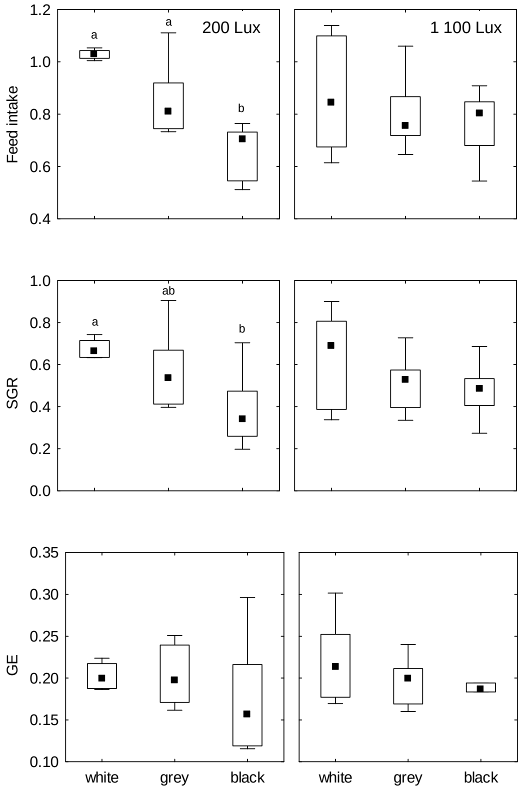

Figure 5. Feed intake (% of group average weight per individual and day), growth rate (SGR), and energetic growth efficiency (GE) of groups of Eurasian perch (*Perca fluviatilis* L.) kept for three weeks in tanks of different colours (white, grey or black) and at different light levels (200 or 1100 lux). Square symbols in boxes represent the median of the sample, the boxes represent quartiles, and the whiskers show the non-outlier range. Identical letters indicate no significant differences (P>0.05) between treatments. In the graphs with no letters, none of the results differed significantly between treatments.

4 Discussion

4.1 Growth

The stability of the TGC coefficient has recently been debated. Previously, TGC was thought to be unaffected by body size of fish (Kaushik, 1995; 1998; Bureau *et al.*, 2000) and temperature (Azevedo *et al.*, 1998; Cho & Bureau, 1998; Bureau *et al.*, 2000; Bailey & Alanärä, 2006). However, in 2003, Jobling warned for uncritical use of the coefficient as data indicated that the coefficient was not as stable as previously thought. This was also confirmed later by Rónyai and Csengeri (2008) who found that TGC of pikeperch (*Sander lucioperca* L.) was affected by temperature. The results obtained in paper I and II further demonstrate the validity of this warning as TGC was found to be affected both by temperature (paper I) and by size of fish (paper I and II). In paper I, TGC of perch was found to respond to a broad temperature range in a similar way as SGR, although the effect of temperature on SGR was more pronounced than for TGC. In contrast, in paper II where a temperature range of 17 to 23 °C was used, TGC was not affected by temperature. This was, however, not unexpected as results obtained in paper I indicated that in limited temperature intervals TGC was mainly unaffected by temperature. Growth models using TGC aiming at intensive culture of perch in limited temperature intervals should therefore not have to include temperature. Conversely, if evaluation of growth rates in cage culture with more varying temperature conditions is desired, temperature should be included in the model.

As perch is a warm water species, low growth and feed intake at low temperatures is to be expected. However, the reduction of TGC for perch at low temperatures is in contrast with data on rainbow trout (*O. mykiss* Walbaum) for which TGC has been found to be unaffected by temperature within a range of temperatures below the optimal for growth (Azevedo *et al.*, 1998; Cho & Bureau, 1998). There are indications that cold water adapted species have evolved a compensatory response to low temperatures, thereby maintaining a metabolic rate above the expected (Brett & Groves, 1979; MacDonald *et al.*, 1987). Thus, if feed is not restricted at low temperatures, cold water adapted species may have a higher growth potential than warm water adapted species due to this higher metabolic rate.

Furthermore, even though the size interval used in paper I and II was quite limited, a clear negative relationship was found between body size of perch and TGC in both studies. This is similar to the response of SGR with varying body size of fish (Brett, 1979; Iwama & Tautz, 1981; Jobling, 1983; 1994), but in contrast to previous reports for TGC (Kaushik, 1995; 1998; Bureau *et al.*, 2000). One assumption for use of the TGC coefficient is that the relationship between weight and length of the fish is constant, i.e. isometric growth occurs. Thus TGC as a single coefficient should only be used when the condition factor of the fish remains stable (Jobling, 2003). In both paper I and II, the condition factor of the fish was found to increase significantly with increasing body size. This may explain the size dependence of TGC found in these studies. However, as allometric growth is common in fish (Andersson & Gutreuter, 1983; Cone, 1989), TGC should be used with caution. To eliminate the problem of changing TGC with varying body size, a model including body weight of the fish should be developed (paper II).

4.2 Energy need

In contrast to what could be expected, DEN of perch was not affected by temperature (paper I and II). This is in accordance with data presented by Bailey & Alanärä (2006), where DEN of salmonids, percids and flatfish was shown to be unaffected by temperature. As standard metabolic rate of fish increases with increasing temperature (Brett & Groves, 1979; Jobling, 1994; 1997; De Silva & Anderson, 1995) so does the energy expenditures of the fish, and hence a connection between temperature and DEN should exist. However, at normal rearing temperatures the effect of metabolic costs might be too small to detect without excessive replication. At extreme temperatures though, the connection should be obvious. In accordance, in paper I, at 27 °C, three out of five groups demonstrated energy expenditures that were too high to allow positive net growth to occur. This supports the theory of an exponential increase in energy expenditures when temperature exceeds the normal range of growing temperatures.

Furthermore, in paper I and II, DEN of perch was found to increase with increasing body size of the fish. This is in contrast with data presented by Bailey and Alanärä (2006), who showed that the DEN value of percid fish was unaffected by size of the fish. However, the percid data presented in that article is quite scattered and mainly focuses on sea bass (*Dicentrarchus labrax* L.) and sea bream (*Sparus aurata* L.). Moreover, as fish increases in size, a shift in fish body composition occurs with increased deposition of fat in larger fish (Brafield, 1985; Jobling, 1994). The energy value of fat is almost two times higher compared to that of protein (Brett & Groves, 1979) and deposition of fat also leads to less deposition of water in the body compared to when proteins are deposited (Jobling, 1994). As a consequence, a positive relationship between body weight and DEN should exist for fish species that store fat. In accordance, perch seems to follow the same pattern of increased energy need with increasing body size as demonstrated for other species such as cod (Jobling, 1988; Björnsson *et al.*, 2001 [*Gadus morhua* L.]), flatfish and several different salmonid species (Bailey & Alanärä, 2006).

4.3 Daily feed allowance

In comparison to the classical bioenergetics approach, the model proposed by Alanärä *et al.* (2001) for evaluation of the theoretical daily energy requirement (TER) of fish has many advantages. The problem of erroneous energy requirement estimates obtained from the classical bioenergetics approach can be demonstrated using rainbow trout for which energy requirement data based on bioenergetics principles was estimated by Rasmussen & From (1991). Compared to a TER calculation based on DEN and SGR values for rainbow trout published by Alanärä *et al.* (2001), the energy requirement model given by Rasmussen & From (1991) overestimates the energy need of a 100 g fish at 15 °C by a factor of two. For practical use, that model would thus have predicted a daily feed ration twice as large as needed.

From the TER model developed in paper II (equation 12), daily feed requirements at different temperatures and for varying fish sizes can be estimated. An example of a feeding chart based on the developed TER model is demonstrated in table 2.

Table 2. *TER (kJ·day*$^{-1}$*) values for Eurasian perch (Perca fluviatilis L.) reared at different temperatures and of different sizes fed a diet containing 13 % fat and 44 % protein.*

		Size of fish (g)				
		20	**50**	**100**	**150**	**200**
Temperature °C	**16**	3.9	6.9	10.5	13.5	16.1
	18	4.4	7.7	11.8	15.2	18.1
	20	4.9	8.6	13.1	16.9	20.1
	22	5.4	9.5	14.5	18.5	22.1
	24	5.9	10.3	15.8	20.2	24.1

Optimal daily feed ration at 23 °C for small perch (<20 g) was previously evaluated by Fiogbé & Kestemont (2002), and for larger perch (3-300 g) by Mélard *et al.* (1996). As the TER model developed in paper II includes both body weight of the fish and temperature, application of the model in culture is easier compared to the models developed by Fiogbé & Kestemont (2002) and Mélard *et al.* (1996) as those models only include body weight of the fish. The developed TER model also seems to produce realistic results. For a 20 g fish at 23 °C, feed requirement (as % of fish body weight) was 2.2, 1.6 and 1.7 % for the models developed by Fiogbé & Kestemont (2002), Mélard *et al.* (1996) and our TER model, respectively. For larger fish (300 g), the TER model estimated a slightly lower feed requirement (0.6 %) compared to the model developed by Mélard *et al.* (1996) (0.8 %). During the experiments from which data for development of the TER model was obtained, care was taken not to disturb the fish. The higher energy requirements reported by Fiogbé & Kestemont (2002) may therefore be the result of higher energy expenditures in different experimental conditions.

4.4 Culture environment

Percid fish have been found to be disturbed by ordinary farming procedures such as handling (Acerete *et al.*, 2004; Jentoft *et al.*, 2005), cleaning of tanks and shadows created by human activities near tanks (Malison & Held, 1992; Nagel, 1996; Head & Malison, 2000). In accordance, in paper III, growth and feed intake of perch juveniles were found to decrease, and the energy expenditures were found to increase by daily disturbance resembling routine farm practices. Some authors argue that the lower growth rate demonstrated by a stressed organism is caused by a stress induced reduction in feed intake

(Pickering, 1993; Jobling, 1994). However, data presented in paper III show that fish exposed to disturbance also experienced increased energy expenditures compared to undisturbed fish. These findings are in line with results from other studies (Rice, 1990 [*Micropterus salmoides* Lacepède]; Jentoft *et al.*, 2005 [*P. fluviatilis* L. and *O. Mykiss* Walbaum]).

One way to reduce stress in culture is to keep the fish in a suitable culture environment. Fish may demonstrate a preference for a specific background colour, probably to decrease their conspicuousness (Bradner & McRobert, 2001). In general, dark tank colours are preferred by most species (Brännäs *et al.*, 2001). In paper IV, energy expenditures of juvenile perch were not affected by the tank colour or light intensity treatments, thus stress levels did not seem to differ between treatments. However, a clear difference in body colour of the fish was noted, with dark, almost black, perch coming from the black tanks and very pale perch coming from the white tanks (Figure 6). This is similar to the findings of other perch studies (Parker, 1948; Mairesse *et al.*, 2005).

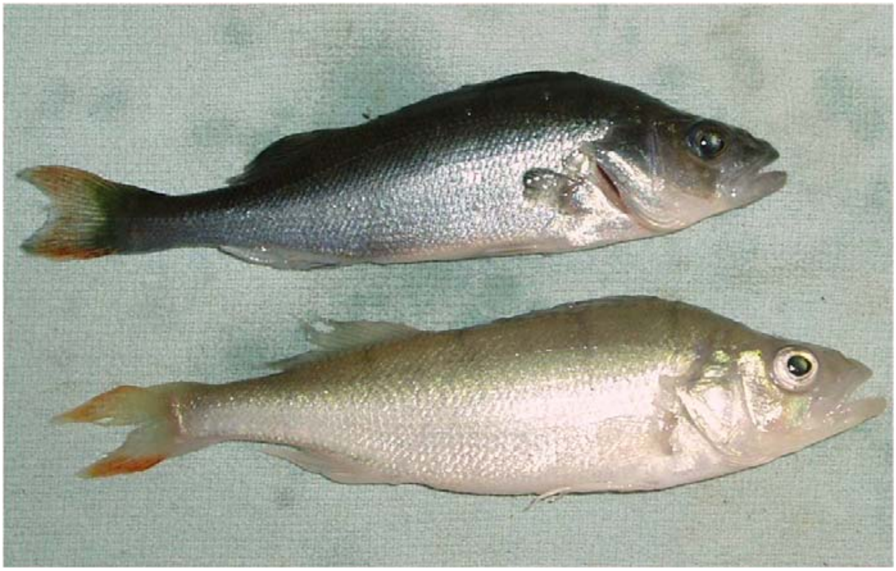

Figure 6. Photo of Eurasian perch (*Perca fluviatilis* L.) reared in black (upper fish) or white (lower fish) tanks (photo: Anders Alanärä).

The lack of effect of tank colour on energy expenditures of the fish thus indicates that the capacity of perch to change body colour in accordance with its background may reduce the problem of conspicuousness and thus reduce a potential source of stress for the fish. This is in agreement with results obtained by Staffan (2004), who performed an experiment in which perch juveniles could move freely between two tanks of different colours, but did not show general preferences for any specific colour.

However, the results in paper IV demonstrated a clear effect of tank colour on feed intake and growth rate of perch kept at low light intensities, with reduced feed intake and growth in tanks with darker walls. The higher feed intake and corresponding higher growth rates in light, compared to dark tanks, may be explained by the higher visibility of feed in light tanks, resulting from higher contrast between the feed and the tank's background. At high light intensity, however, the effect of tank colour was reduced and feed intake and growth rates were similar for all groups. This lack of colour effect may be caused by higher light intensities increasing the ability of fish to detect feed in dark tanks. The importance of a high contrast between the food object and the background has been previously demonstrated in studies on the effect of turbidity on feeding success in fish (Fiksen *et al.*, 1998; Utne-Palm, 1999).

4.5 Culture management aspects

4.5.1 Growth predictions

Based on the developed growth model (paper II, equation 9) and equation 11, growth scenarios of perch reared at different temperatures can be evaluated. As the growth model is not suitable for small fish, production time from hatching to 20 g fish in 23 °C was obtained from C. Mélard (pers. comm.) and was estimated to 140 days. Production times (number of days) from hatching and subsequent rearing at different temperatures and at varying rearing conditions are presented in table 3.

Data presented by Mélard *et al.* (1996) indicates that starting from larvae, perch of 130-150 g can be reached within a year when reared at 23 °C. The modelled growth is thus in accordance with reference data (Table 3). Furthermore, production time increases dramatically as temperature is decreased. In paper I, growth rates in 8 and 13 °C were only 17 and 25 % of those measured in 23 °C. This is well in accordance with data presented by Mélard *et al.* (1996), who demonstrated that growth rates at low temperatures (11 °C) were only 29 % of those observed in 23 °C.

Table 3. *Estimated production times (number of days) for rearing of Eurasian perch (Perca fluviatilis L.) at varying conditions. The production times are estimated using the growth model developed in paper II with a start value of 20 g, thus the production time of 140 days from hatching to 20 g is added to the estimated production time to obtain a complete production cycle. Karlskrona, Trosa and Umeå represent different locations along the Swedish coast in a gradient from south to north, and Vänern is the largest lake in Sweden. Temperature data for Karlskrona, Trosa and Umeå was supplied by the Swedish Meteorological and Hydrological Institute [SMHI, The Swedish Ocean Archive] and are average surface temperatures from time series of approximately 10 years. Temperature data for Vänern was obtained from a local fish-farmer.*

Rearing conditions		Number of days from hatching to 100 g	Size (g) after one year
Constant temperature	24 ˚C	287	163
	23 ˚C	294	154
	22 ˚C	300	146
	17 ˚C	348	109
Ambient temperature	Karlskrona (max: 15.9, min 1.9, average 8.0 ˚C)	576	40
	Trosa (max: 17.1, min 0.7, average 7.8 ˚C)	672	30
	Umeå (max: 15.1, min -0.1, average 5.7 ˚C)	822	28
	Vänern (max: 17.4, min 0.2, average 7.8 ˚C)	718	35
Moderately stressed fish at 23 ˚C		389	91
Severely stressed fish at 23 ˚C		484	67
Black tanks and low light intensity at 23 ˚C		424	80

If growth in cages is simulated using actual temperature regimes obtained from different locations in Sweden, production times to market size fish are estimated to vary between 576 and 822 days depending on location (Table 3). Rougeot & Mélard (2008) reported that market size fish of 80-100 g could be obtained in 800 days in cages in a lake with yearly temperatures ranging from 2-23 ˚C. The production times estimated using the developed growth model thus seems to be somewhat shorter compared to reference data. However, as TGC is affected by temperature (paper I), and as the model is not validated at lower temperatures, some uncertainty exists regarding the accuracy of the estimated production times.

In paper III, growth rates were found to be reduced by in average 33 and 49 % by moderate and severe disturbance, respectively. The effects of such reductions in growth rates are demonstrated in table 3, and production time to market size of fish will obviously be drastically prolonged. Furthermore, suboptimal rearing environments have similar effects as disturbance on production times to market size, thus knowledge of optimal rearing conditions for a species is essential for maximizing production.

4.5.2 Seasonal effects

In paper I, III and IV, even in constant temperatures, a clear effect of season was discovered, with an increase in growth rates and feed intake during spring (paper I) and a reduction in growth rates and feed intake during autumn (paper III and IV). Temporal cycling in food intake has been described for many species, and it appears that species living at high altitudes exhibit the largest seasonal fluctuations (Bairlein & Gwinner, 1994; Loudon, 1994). For fish, seasonal differences in appetite and growth are well known in several species (Brown, 1945 [*S. trutta* L.]; Eriksson & Lundqvist, 1982; Simpson *et al.*, 1996 [*S. salar* L.]; Karås, 1990; Staffan *et al.*, 2005 [*P. fluviatilis* L.]; Jobling *et al.*, 1998 [*Salvelinus alpinus* L.]). Bull *et al.* (1996) suggested that fish might have evolved a behavioural and physiological strategy of low activity and reduced appetite in response to a predictable reduction in the quantity of available food in late summer. In accordance, in late autumn perch migrates to deep, cool water for over-wintering (Wang & Eckmann, 1993; Eckmann & Imbrock, 1996; Craig, 2000). During winter, feed intake (Eckmann & Imbrock, 1996) and growth are low (Craig, 2000; Rougeot *et al.*, 2008) and metabolic rates are reduced more what could be expected at low temperatures (Karås, 1990). Thus, the temporal cycle displayed by perch in controlled environments may be the result of a predictable resource limitation in nature.

4.5.3 Estimation of the daily feed allowance

One factor determining the success rate when establishing culture of a new species is accurate information about growth potential of the species under different rearing conditions. As often no previous production records for the targeted species are available, growth models becomes a valuable tool for production planning purposes and evaluation of production costs. As the interest for intensive culture of perch is growing and commercial culture of the species is in realization, the growth model presented in this thesis may facilitate the process. By thorough and regular measurement of the growth of the fish, a farmer can adjust the presented model to local conditions by adding a conversion factor. As growth of the fish varies with strain (Mandiki *et al.*, 2004) and as energy expenditures vary with different rearing conditions, adjustment of the model becomes important for correct growth predictions. Even more so in regard of the seasonal variations in growth and feed intake demonstrated by perch, which are not accounted for in the model presented here.

The ability to predict the daily weight increment with accuracy is one prerequisite for calculation of the daily energy requirements and the daily feed allowance. Thus, the adjustment of growth estimates to local rearing conditions is the single most important factor for successful feed management. The other component in the TER model, DEN, is also possible to estimate under local rearing conditions, but the procedures are very costly and time consuming. Instead, data collection and model development can be done by researchers, producing species specific models that can be used by the fish farmers. By combining local growth predictions with a DEN model developed by researchers, strain specific feed budgets or feeding charts can be produced. The data presented in this thesis thus offer perch farmers a simple alternative to improve feed management in their facilities.

4.5.4 Data considerations

The data presented in this thesis is based on small groups and short rearing times. To directly and uncritically transfer the knowledge to commercial farming systems may therefore be risky. However, the results obtained regarding rearing environment still implies that special care should be taken when choosing rearing environment and that activity in the vicinity of the rearing tanks should be minimized. The effects of both factors should be further evaluated at commercial scale before recommendations regarding system design can be established. Moreover, even though the developed growth model performed well in relation to the validation data and the energy requirement model seem to produce reliable results in relation to reference data, both models need further validation by comparison with data from commercial facilities. Ideally, the energy requirement model should be tested in a similar way as the model developed for rainbow trout by Bailey and Alanärä (2001) before it is used in commercial fish production.

4.6 Conclusions

In conclusion, in this thesis it was demonstrated that growth (TGC) of perch is affected both by size of the fish and by temperature. The temperature and body size dependence of TGC for perch causes the same problems in data collection for growth model construction as does SGR. However, for creation of growth models limited to a small temperature range, TGC still have advantages compared to SGR. Furthermore, the digestible energy need (DEN) of perch was found to be affected by size of the fish but not by temperature. The developed model for evaluation of the theoretical daily feed allowance of perch in intensive culture seems to produce realistic results if compared to reference data.

The sensitivity of perch to disturbance was found to be high. The effects of stress on growth and energy expenditures were dramatic, and care should be taken to reduce stress of perch in culture in order to improve welfare of the fish, growth rates and thus farm economics. No specific tank colour seemed to be preferred by the fish, which was attributed to the ability of perch to adjust its body colour according to the surroundings. However, tank colour in connection to light intensity affected growth and feed intake of the fish. Selection of a suitable colour for rearing tanks should therefore be performed considering ambient lighting conditions in the rearing facility.

4.7 Future prospects

From the data presented in the thesis, some additional topics in need of development have been identified. The produced growth- and energy requirement models should be thoroughly evaluated, preferable against a commercial perch farm. One prerequisite for correct evaluation of the daily feed allowance for the fish is the existence of accurate digestibility coefficients (ADC values) for the different components in the feed. Today, no such values are available for perch and therefore ADC values for different feed substances need to be developed. Furthermore, the effect of seasonal variations on growth rates and feed intake need to be quantified and included in the growth- and energy requirement models. The effect of light intensity on sensitivity to disturbance of perch also needs to be evaluated further. As a final step, a model for evaluation of the economic potential of perch culture would be a valuable tool for entrepreneurs interested in perch farming.

5 Svensk sammanfattning

I kommersiell fiskodling är kunskap om tillväxtshastigheter, foderintag och energibehov för den odlade fisken, samt möjligheten att förutsäga dessa viktigt för odlingens lönsamhet. Eftersom abborre (*Perca fluviatilis* L.) är en ganska ny art inom odling fanns inga modeller för utvärdering av tillväxt eller dagligt foderbehov tillgängliga. Det saknades också information rörande skötselrutiner och optimal odlingsmiljö. Denna avhandling fokuserar därför på att utvärdera abborrens tillväxtpotential och energibehov för fisk av olika storlekar och i olika temperaturer, och att bedöma vilken effekt olika odlingsförhållanden har på tillväxt och energibehov.

Tillväxt, foderintag och energibehov för abborre under olika förhållanden (olika temperatur, storlek på fisk, olika trågfärg och ljusintensitet samt störning) studerades i laboratorieförsök. Abborrens tillväxt (TGC) påverkades av både temperatur och fiskens storlek, vilket gör insamling av data för konstruktion av tillväxtmodeller både tidsödande och komplicerat. Abborrens energibehov påverkades av fiskens storlek, men inte av temperatur. En modell för utvärdering av teoretiskt dagligt energibehov för abborre i intensiv odling utvecklades utifrån kunskapen om fiskens tillväxt och energibehov. I relation till referensdata verkar den utvecklade modellen producera realistiska resultat.

Abborrens känslighet för störning visade sig vara hög. Effekten av stress på tillväxt och energiutgifter var dramatisk, och åtgärder för att reducera odlingsrelaterad stress är därför viktiga för att öka fiskens välfärd och tillväxthastighet och därmed odlingens lönsamhet. Abborre verkar inte ha några specifika preferenser rörande trågfärg, vilken kan förklaras av dess förmåga att anpassa sin kroppsfärg till omgivningen. Däremot påverkade trågfärg i kombination med ljusintensitet abborrens tillväxt och foderintag. Vid val av lämplig trågfärg i en odlingsanläggning bör därför ljusförhållandena i anläggningen tas i beaktande.

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Acknowledgements

There are so many people that have been involved in my work with this thesis over the years and for that I'm grateful. I want to thank Eastern Norrbotten Research Station for providing financial support for this project and Carl Tryggers Foundation for financial support to the experimental setup. Thanks also to my supervisors Anders and Carin for supporting me and believing in me. Obviously, this would never have happened without you. There were times I wondered what I was actually doing, but you always got me back on track. And thanks to my "special people" at the department, Ingela, Bosse, Eva and Love, you always manage to make a bad day better and usually help me solve all (almost) of my problems ☺. Of course, thank you to the department, and to the library staff who managed to find the most obscure references for me, and to the janitors for supplying me with tools and tips for building the experimental setup.

To all the project groups I have had contact with ("Vilhelminagänget", "Söderköpingsgänget" and "Kalixgänget"), thank you for interesting discussions, trips and information. I hope all of you do great in the future. I also want to thank my "perch colleagues" abroad for good times and all information you have provided, and special thanks to Julia on Bornholm and Damien in Ireland for always answering my perch questions and for taking so good care of me.

And of course, all my friends, where would I be without you? Kattis, how many hours have we been walking (and talking) do you think? And Jenny and Tomas, our "newest" friends, thank you for being here ☺ Ylva, I miss our Uppsala dinners, and Ullis, I can always talk to you about anything. There are so many more, but for you not mentioned here, a big thank you!

Last, but not least, my family. Thank you for not getting tired of my endless talking about the job. And thank you for encouraging and supporting me all the way, never doubting that I would manage, but always

also reminding me what is really important. And sorry for all the times I have been stressed and snapped at you. My fantastic twin sister Ida, you are the best! What would I do without you? And Johan, you will always be my little brother, regardless of how old you get. Mum and dad, you are the best parents one could ever have. Andreas, my love. Thank you for always being there for me, and for the calming effect you have on me. Without you I would have crashed so many times. And you gave me Theo, the greatest gift ever. Theo, you put things in perspective and I always long to go home and play with you and hug you. You have the most wonderful smile, and of course, you are the best little boy in the world! I love you all.