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A factorial approach to deriving dietary specifications and daily feed intake for mulloway, *Argyrosomus japonicus*, based on the requirements for digestible protein and energy

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ABSTRACT

This study applied a factorial approach to predicting the requirements for digestible protein (DP) and digestible energy (DE) for mulloway throughout the production range. Published data relating to protein and energy utilisation and protein and energy requirements for maintenance and growth of this species were consolidated with quantitative descriptions of proximate whole body composition and an assessment of growth potential undertaken over a range of temperature and fish sizes. Factorial modelling of the data provided estimations of the decreasing requirement of the ratio of DP:DE for mulloway with increasing body size up to 2 kg. Piecewise regression analyses identified significant changes in the requirement for DP:DE at key growth stages. From this information diet specifications and suggested daily feed intake were iteratively derived applicable for the different dietary requirements dependant on body size. Four growth stages with corresponding dietary requirement for DP:DE are suggested; 10–100 g = 31.3 g DP MJ DE^{-1}, 100–500 g = 24.8 g DP MJ DE^{-1}, 500–1100 g = 20.8 g DP MJ DE^{-1}, 1100–2000 g = 19.1 g DP MJ DE^{-1}. Sensitivity analyses was used to test the response of the factorial model to small perturbations of individual parameter values on the predicted optimal ratio of DP:DE. Protein and energy utilisation coefficients and the whole body composition coefficients for protein and energy were identified to have the greatest influence on the predicted requirement for DP:DE while the growth model exponent value becomes increasingly influential for fish >200 g.

1. Introduction

Nutrient requirements in fish have traditionally been determined empirically using a dose–response approach, typically with weight gain or nutrient retention expressed as the response criteria and the relationship analysed using regression analyses. Evaluating diets by testing all combinations of nutrient inclusion levels against various response criteria and under various culture conditions will undoubtedly yield the most accurate definitions; however, this approach is neither cost effective nor practical to implement. Mathematical modelling in animal nutrition provides an extremely useful tool in the development of practical feed evaluation systems (i.e. feeding standards and practices) to describe and predict nutrient requirements, body composition and growth of the animal (Cho, 1992; Dijkstra et al., 2007). Bioenergetics is the quantitative study of energy gains, losses and transfers within the whole organism based on thermodynamic principles (Bureau et al., 2002; Haynie, 2001; Jobling, 1994), and has been widely applied to animal nutrition and the development of feed evaluation systems over the past several decades (Brody, 1945; Bureau et al., 2002; Cho et al., 1982; Dumas et al., 2008; Kleiber, 1961).

Traditional bioenergetic systems are factorial; i.e. total energy requirements are calculated as the sum of energy required for maintenance, activity, growth, reproduction, etc. (Baldwin and Sainz, 1995). The partitioning and quantification of dietary energy is important in the study of nutritional energetics because it provides a convenient platform to predict the energy balance of individuals based on body weight, sex, activity, physiological state, environment, and amount and nutritive value of the feed eaten (Baldwin and Bywater, 1984). This information can then form the basis for practical diet formulation and evaluation (Baldwin and Bywater, 1984; Bureau et al., 2002). It is important to recognise that the factorial method is empirical in form; models based on the digestion, metabolism and utilisation of nutrients need to be considered in the context of relevant culture conditions to accurately predict growth and feed requirements. Validation against independent feeding trials will determine the predictive accuracy of the models and assess the need for adjustment of the input data defining the model parameters.

It is recognised that the bioenergetic approach has its limitations; most notably the presumption of additivity of functions (factors) without interaction (Baldwin and Sainz, 1995) and the fact that animals continue

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to deposit protein while losing lipids when fed maintenance levels of digestible energy (DE) (Bureau et al., 2002; Sandberg et al., 2005; van Milgen and Noblet, 2003). There are indications that some bioenergetic models have not been well evaluated over the ranges of conditions to which they have been applied (Bajer et al., 2004), although this seems to indicate issues with the application of the models rather than the principles and fundamental concepts of bioenergetic theory. Bioenergetic models can therefore be regarded as relatively inflexible in their adaptability (Bureau et al., 2002) which is, in part, an artefact of the empirically derived nature of the sub-models. The adequacy of some feed evaluation systems has also been questioned as they are devised to meet animal requirements rather than predict animal response, which has seen a shift (back) towards nutrient-based mechanistic models to meet modern animal production demands (Dijkstra et al., 2007; Dumas et al., 2008). However some mechanistic models, while being theoretically correct, may be considered too complex for implementation in practical feed evaluation systems (Bureau et al., 2002).

In spite of these limitations, the factorial approach remains a very useful and practical method in constructing feed evaluation systems. Several models have been successfully developed to predict growth, feed requirements and feed efficiencies in a number of fish species using these principles (Cho and Bureau, 1998; Glencross, 2008; Lupatsch and Kissil, 2005; Lupatsch et al., 2001; Lupatsch et al., 1998; Zhou et al., 2005). Factorial models based on bioenergetic principles which also integrate a nutrient-based approach have the greatest flexibility and can be adapted to formulate feeds based on specific nutrient requirements (e.g. Lupatsch et al., 1998) or predict waste outputs of inorganic compounds (e.g. Hua et al., 2008). Furthermore, these types of “hybrid” models (*sensu* Dumas et al., 2008) can provide greater and more relevant application in the context of commercial production when calibrated using on-farm data (e.g. Bureau et al., 2003; Glencross, 2008; Lupatsch et al., 2003a).

The factorial modelling method for defining nutrient requirements in fish has seen advances made in recent years with the work by Lupatsch et al. (1998) and Cho and Bureau (1998). The premise behind the factorial method being that the requirements for digestible protein (DP) and DE can be partitioned into production and maintenance costs based on the assumption that the two are additive (Lupatsch and Kissil, 2005; Lupatsch et al., 2001; Lupatsch et al., 1998). This can expressed as:

$$\textit{Total nutrient requirement} = ax \ \mathrm{BW(kg)}^{b} + cx \ \mathrm{Growth} \tag{1}$$

where a = maintenance requirement; b = weight exponent; c = utilisation coefficient

The advantage of this method over the more traditional empirical based dose response methods is that it can be used to describe DP and DE requirements for growing fish throughout the production cycle and estimations are not necessarily restricted to within the size range of the test species. Key to achieving this however are establishing the utilisation efficiencies and maintenance requirements for DP and DE, an assessment of the protein and energy whole body composition as a function of fish size and establishing the growth potential under a given set of culture conditions.

The requirements for DP and DE for maintenance and growth and aspects of metabolism relating to fasting and feeding physiology have been described for mulloway, *Argyrosomus japonicus* (Pirozzi and Booth, 2009a,b; Pirozzi et al., 2010, in press); this study consolidates those published data to establish a practical feed evaluation system for this species using the factorial approach. The main objectives of this study were twofold; firstly, to use the factorial method to describe the requirements for DP and DE for mulloway up to 2 kg and, secondly, to iteratively derive diet specifications and daily feed intake based on the requirements for protein and energy. Further, this study also presents a growth model applicable over a range of temperatures relevant to Australian aquaculture conditions and also provides a quantitative description of the whole body composition of mulloway. Sensitivity analyses was used to test the response of the factorial model to small perturbations of individual parameter values on the predicted optimal ratio of DP:DE.

2. Materials and methods

2.1. Growth model

A data set was compiled from growth records of mulloway held at New South Wales Department of Primary Industries, Port Stephens Fisheries Institute (NSW DPI, PSFI) and a commercial mulloway farm. Farm data were based on cohorts held in sea cages or saline ponds where fish were fed to apparent satiation with commercial diets. Data from mulloway at PSFI were obtained from fish grown in 10,000 l recirculating aquaculture systems or 1 m^3 cages in an outdoor saline pond. Water temperatures ranged from approximately 18–30 °C and averaged approximately 23 °C. All growth data were expressed as mean body weight (BW g) of sub-sampled cohorts where total $n>3000$ individual fish. Data outliers or cohorts where feed intake was considered spurious were excluded from the analyses. The growth model component in this study is based on body weight however workers on commercial farms often measure growth based on body length as it is a much more convenient measurement to obtain particularly if sampling from sea cages. Therefore the relationship between standard body length (SL mm) and BW was established to allow conversion from length based data to estimate BW. SL allows accurate body length measurements as it is not influenced by the condition of the caudal fin which can sometimes be damaged; however, total length (TL) is still often used. Using a range of fish from approximately 25–1860 g the relationship between SL and TL was also established to allow conversions based on TL. This relationship was linear and can be described as:

$$SL = 0.9428(TL)–13.3832\left(r^2 = 0.997;\ n = 1072\right) \tag{2}$$

The relationship between SL and BW was allometric (Fig. 1) and can be described as:

$$BW = 6.163 \times 10^{-5}(SL)^{2.758} \ \left(r^2 = 0.99;\ n = 3531\right) \tag{3}$$

2.2. Whole body composition

The proportional content of energy, lipid and moisture to the BW of fish are not constant throughout the growing phase and composition also varies between species (Lupatsch et al., 2003b; Shearer, 1994). The relationship between the proximate composition and body weight of mulloway was determined using groups of equal size fish ranging from 2

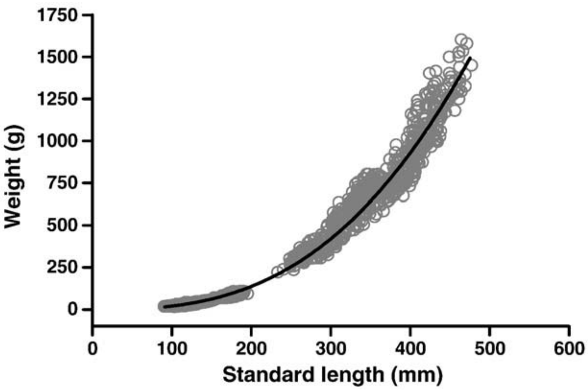

Fig. 1. Relationship between standard length (mm) and body weight (g) of mulloway. Weight measurements range from 12 to 1600 g. ($r^2 = 0.99$; $n = 3531$).