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EVOLUTIONARY BIOLOGY & MOLECULAR ECOLOGY | SHORT COMMUNICATION

Evaluating the relationship between the growth of fish and energy component of their prey

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Abstract: Fish growth analysis is a fundamental part of research in fisheries biology, aquaculture, and physiology. However, there is the question of whether the addition of mass and length depends on the amount of energy a prey can deliver. This study tested the hypothesis that there is an effect on the length/weight ratio of the predator, under the premise that fish that ingest prey with a greater amount of energy will have greater mass growth, in contrast to those that ingest food with lesser energy. The fish in this experiment was under controlled laboratory conditions under two types of food treatment and one control (low energy vs high energy amount). The energy-rich treatment had a significant effect on the mass increase (GLM; $F = 2.72$; $P = 0.031$), and the length/weight ratio was greater in the fish under the energy-rich treatment (ANCOVA; $F = 3.59$; $P = 0.043$). However, the IGR showed that fish presented low rates of intrinsic size growth (ANOVA; $F = 0.189$; $P = 0.828$).

Subjects: Fisheries Science; Animal Physiology; Freshwater Biology; Marine & Aquatic Science; Natural History

Keywords: feeding; dietary physiology; fish nutrition

1. Introduction

What does a species eat? How do individuals eat? What is the energy contribution of prey in the diet of predators? These are questions of research in natural life that respond to hypotheses of different levels of ecology and resource management. It is in this context that the study of trophic ecology becomes a key point for understanding trophic dynamics from individuals to ecosystems



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PUBLIC INTEREST STATEMENT

We consider this article to be appropriate for the readers of the journal, as it describes how the energy component of the food has an effect on weight addition. These inferences can be used for good fisheries management and aquaculture patterns, especially in times when interactions between prey and predators take on real importance for sustainability.

(Liedke et al., 2016). Specifically for fish, the dynamics between food supply and energy demand for nutrients play a crucial role in how communities are structured in the environments where fish inhabit (Albo-Gaeta et al., 2018; Puigserver et al., 2017; Wuenschel, Jugovich, & Hare, 2006). The environment provides the food, but also exerts a demand on the fish (Ross, Nielsen, Gislason, Nielsen, & Andersen, 2018) for example, low ambient temperatures increase the energy demand of fish that regulate their temperature—e.g. sunfish, tuna and some sharks—to maintain their body temperature (Wegner, Snodgrass, Dewar, & Hyde, 2015) other extreme, fish that do not regulate their body temperature also require higher energy to maintain their metabolic rates when the environmental temperature increases. The latter is based on the mechanism proposed by Blaxter (1989) who points out that high ingestion rates increase metabolic rates as a consequence of the “extra work” required for the capture, digestion and assimilation of prey, which is called “Temperature Increase by Feeding” (HiE) (Gliwicz et al., 2018). The foundation of the theory of food preference in fish (Wainwright & Richard, 1995) is based on eco-morphological processes, where the combination of information on prey size and predator mandibular components allow inference of prey use and selection (Gaeta et al., 2018) diet composition and food preference may change throughout an individual’s life history due to different effects such as prey supply, environment, ontogeny, reproductive, behavioral and anthropogenic effects (Wootton, 1990). This study evaluates the premise that fish that ingest prey with a greater amount of energy will have greater mass growth, in contrast to those that ingest food with a lesser amount of energy, and that this will have an effect on the length/weight ratio of the predator. The main objective of this study was to analyze changes in body length and weight in individuals of goldfish *Carassius auratus* (Linnaeus, 1758) under two food treatments (high and low energy) for 30 days in controlled laboratory conditions.

2. Materials and methods

Twenty-seven specimens of *Carassius auratus* were used. This species was chosen because of its adaptability to experimentation under controlled conditions, its easy handling and low level of stress (Popescu et al. 2008). Individuals were chosen according to size (2.8 ± 0.27 cm) and weight (1.3 ± 0.25 g), which showed no significant differences among treatment group at the beginning of the experiment (ANOVA; $F = 0.147$; $P = 0.864$). The fish sample came from ornamental fish culture systems. When they arrived at the laboratory they were acclimatized for 2 days and then placed in their final aquarium. Each specimen occupied an individual aquarium (Figure 1). The 27 tanks were in an experimental room was under controlled laboratory conditions with 12/12 light-dark (Zhou, Wu, Randall, & Lam, 2001) constant temperature of $15.3^{\circ}\text{C} \pm 0.5$. All experimental tanks (25 L) were maintained with dissolved oxygen content 6.4 mg/L ± 0.1 . Figure 1 shows an example of the division of treatments, where all specimens were fed 0.1 g daily. The experimentation was divided into three groups: Treatment 1 (T1) ($n = 9$ tanks) plant-based (*Spirulina* sp.), treatment 2 (T2) ($n = 9$ tanks)

Figure 1. Example of the experimental set-up for feeding tests.

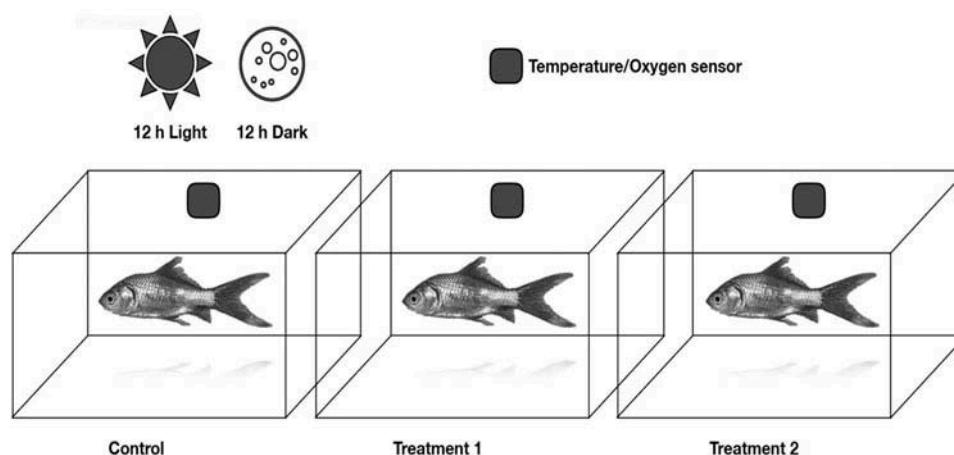


Table 1. Dietary values used in the different treatments. T1; treatment based on plants (*Spirulina* sp.). T2; treatment based on animals

	Control	Treatment 1 (T1)	Treatment 2 (T2)
% Proteins	42	37	52.5
% Fat	6	0	7
Kcal (0.1 g)	0.308	0.238	0.389

Table 2. Results of the variation in weight and length of individuals. W: weight in grams; S: size in centimeters; IGR: instantaneous growth rate and PIW: percentage length increase with respect to weight

	Initial measurement		Final measurement		IGR	PIW
	Wi (g)	Si (cm)	Wf (g)	Sf (g)		
Control	1.31 ± 0.33	2.80 ± 0.19	1.84 ± 0.55	2.88 ± 0.36	0.44	40.70
Treatment 1	1.27 ± 0.20	2.67 ± 0.12	1.72 ± 0.29	2.83 ± 0.28	0.29	36.00
Treatment 2	1.33 ± 0.23	2.98 ± 0.37	2.25 ± 0.28	3.37 ± 0.72	0.47	65.50

animal protein base, and a control (C) (n = 9 tanks) mixture of animal and plant protein (Table 1). At day 30 of experimentation each individual was euthanized with excess BZ-20 anesthetic (Fathallah, Medhioub, Medhioub, & Boussetta, 2010) the fish was immobile and floating on the surface of the sedation aquarium, its size and final weight were immediately measured. The values of the treatments were compared with a general lineal model (GLM) followed by an *a posteriori* test; an analysis of covariances (ANCOVA) test was carried out to establish the relation between size and body weight. The instantaneous growth rate (IGR) was calculated in proportion to the size and the percentage increase with respect to weight (PIW)(Persson, Leonardsson, & Alanärä, 2018) De (De Raedemaeker, Brophy, O'Connor, & O'Neill, 2012; Vega et al., 2015) following equations:

$$IGR = 100 \times \frac{LN(LS_f) - LN(LS_o)}{t}$$

$$PIW = \frac{W_f}{W_i} \times 100$$

LS_f is the size (cm) of the individual at the end of the experiment, LS_o is the size (cm) of the same individual at the beginning, t corresponds to the time interval, W_f is the final weight (g) of the individual and W_i is the initial weight. These treatment values were compared to a one-way ANOVA. All calculations and statistical analyses were done with the software R (R Core Team, 2018).

3. Results and discussion

The average values for each treatment after 30 days of experimentation are summarized in Table 2. All fish grew in weight and size with the two types of treatment (Figure 2). No significant difference in body size was found among food treatments (Figure 2a) (GLM; F = 0.147; P = 0.864), indicating that there was no effect of diet type on fish body size. The IGR ratified the previous assertion (Table 2), since the fish presented low rates of intrinsic size growth and no significant difference was observed (ANOVA; F = 0.189; P = 0.828) (Figure 3).

However, the fish did show changes in their final weight with respect to the initial weight (Figure 2b). The animal protein-based treatment (T2) had a significant effect on the increase in fish mass (GLM; F = 2.716; P = 0.0311), compared to those under the vegetable protein-based treatment (T1). Moreover, individuals under treatment T2 showed a 68.5% weight increase versus

Figure 2. Box and whisker graphs of changes in body size (a) and weight (b) based on food treatments. T1; treatment based on vegetal (*Spirulina* sp.). T2; treatment based on animal.

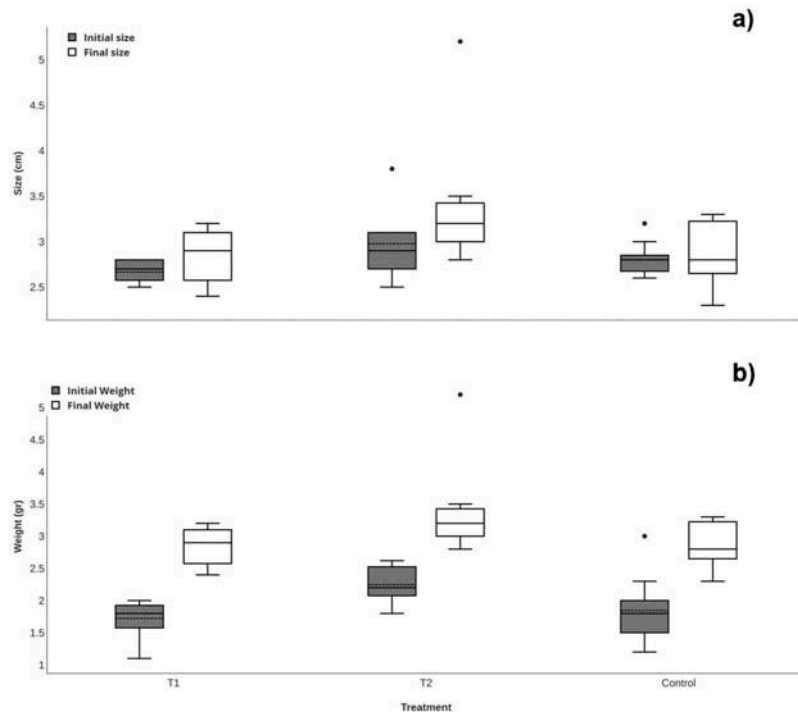
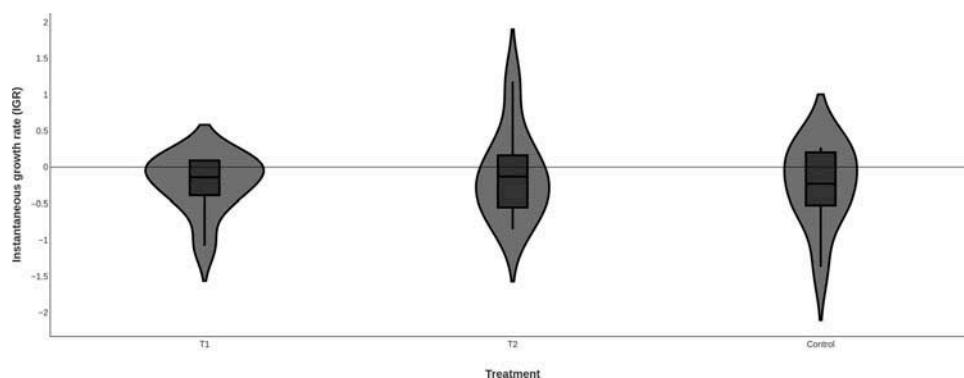


Figure 3. Violin diagram for instantaneous growth rate (IGR) in the fish studied. T1; treatment based on vegetal (*Spirulina* sp.). T2; treatment based on animal.



36% of specimens under treatment T1 (Table 2). The length/weight ratio of fish under different feed treatments indicated that T2 is the treatment that produced significant variation (ANCOVA; $F = 3.59$; $P = 0.043$). T1 and the control did not have a significant difference in the length/weight ratio (ANCOVA; $F = 1.53$; $P = 0.22$). Therefore, the diet based on animal protein (T2), which is also rich in energy, was a determining factor in the relationship of mass and size increase of the fish in this study.

Specimens under different food treatments all increased their body size by feeding daily. There were two situations with respect to the increase in length and mass; the energy present in the treatments did not influence the increase in fish length (Figure 2a), contrary to what was found in the addition of mass, where there was an effect of the treatment with greater energy (T2), resulting in a significant increase in weight (Figure 2b). Growth in length and weight is complementary processes but are independent; their rates of increase depend on the amount of prey energy (Wootton, 1990). This experiment lasted 30 days, which is a limited time to measure growth rate in fish. However, the fact that energy-rich prey had an effect on mass addition can be seen as a short-term effect and thus aid inferences in dietary studies.

This study corroborated that there is an effect of the amount of energy present in the prey with weight increase, as well as in the ratio of size and length (Figure 3). An energy-rich diet ensures that fish can have a high consumption rate, thereby covering the costs of maintaining metabolism and synthesizing new tissue (Wuenschel et al., 2006). On the contrary, fish that do not have an energy-rich prey intake rate will allocate the energy budget to basal maintenance, affecting their consumption rates and assimilation efficiency (Buurma & Diana', 1994) other authors (Pulgar et al., 2013; Ruohonen, Vielma, & Grove, 1998; Seo & Lee, 2008) that the diet of some fish should be complete and should include proteins, lipids, carbohydrates, vitamins, and minerals. It is important to mention that the nutritional requirements for an individual or a population are difficult to catalog because they can vary depending on environmental conditions, size, age, reproductive condition and physiological activity (Ross et al., 2018), especially in aquatic systems where anthropogenic activities modify and replace predator-prey dynamics. Finally, this study has just evaluated the hypothesis that there is an effect on the length/weight ratio of the predator; therefore, fish that ingest prey with a greater amount of energy will have greater mass growth.

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Ethical statement

This experiment was previously approved by the bioethics committee of the College of Life Sciences at Universidad Andres Bello. The animals were adequately euthanized according to the current protocols of our institution.

Competing interests

The authors declare no competing interest.

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