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Early development and allometric growth patterns of beluga *Huso huso* (Linnaeus, 1758)

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Summary

Hatchery reared beluga (*Huso huso*) were observed from hatching until the juvenile stage in order to analyse their early development and allometric growth patterns using bivariate and multivariate allometric analyses for different body regions (e.g. head, trunk, tail) and test whether there existed similarities in the growth patterns of beluga compared to other fish species, especially other sturgeon species belonging to the genus *Acipenser*. Results from Principle Component Analysis on morphometric characters (total length, head length, head height, trunk length, rostrum length and eye diameter) in specimens showed that there were shifts in the relative growth of these characters in early development (length at metamorphosis, L_m). A first stage comprised of hatching to 17.03 ± 0.14 mm in total length (L_{m1}), a second stage was between 17.03 and 25.41 ± 0.21 mm (L_{m2}), and a third developmental stage at larger sizes (larvae larger than L_{m2}). Most morphological (feeding, swimming, sensorial and respiratory systems) and morphometric changes in beluga development took place during the second growth stanza, which may be considered as a transitional period from the larval to the juvenile stage, whereas at larger sized fish may be considered as early juveniles. The allometric growth of beluga matched developmental and behavioral events (e.g. swimming-up, schooling and free benthic swimming) observed in the early ontogeny of this species, and showed the priority of growth of the cephalic and tail regions in beluga pre-larvae for feeding and respiratory functions, and the tail for cruising and escape reactions prior to the full development of the digestive system. This study provides information on the ontogeny of the species, establishing a reference for its normal development that might be useful for evaluating the suitability and quality of fish produced for restocking purposes and improving the current beluga management plans.

Introduction

Fish often go through very complex processes of morphogenesis and differentiation during early life stages. The duration of the free embryo period is relatively short and fish are extremely vulnerable whereby they are easily affected by critical environmental factors and predators, which adversely influence their survival (Blaxter, 1963; Osse and van den Boogaart, 1995; Hardy and Litvak, 2004). Therefore, it is very important to understand how the various organs essential for embryo and juvenile life are formed and developed. It is well known that major morphological changes and their developmental components in fish during early life stages reflect the close relationships between form and function (Fuiman, 1983; Osse and van den Boogaart, 1999). Important quantitative morphometric changes take place during the larval stage, and these are responsible for a progressive transformation of recently hatched specimens from a larval body shape to a juvenile or adult form in a relatively short time, suggesting that growth functionally optimized for survival is a common feature among fish (Osse and van den Boogaart, 2004). This development is regulated by gene expression and influenced by the environment (Gilbert and Bolker, 2003), thus resulting in different phenotypes with differential relative growth rates defined as allometry.

Allometric processes are an important factor in defining the final shape variation in fish. During early growth phases, fish experience a change in shape in relation to increasing their ability to perform vital biological functions, (e.g. respiration, feeding and locomotion); consequently, body structures develop according to their importance for primary functions (Osse and van den Boogaart, 1995; Simonovic et al., 1999; Russo et al., 2007; Ben Khemis et al., 2013). Studies of the allometric growth in sturgeon at early life stages are limited and restricted to species belonging to the genus *Acipenser* (Dettlaff et al., 1993; Gisbert, 1999; Gisbert et al., 1999; Gisbert and Doroshov, 2006), with no information on other species in this order of primitive fishes. The great sturgeon or beluga, *Huso huso* (Linnaeus, 1758), is an important commercial species in the Caspian Sea and one of the most threatened fish species according to the IUCN Red List of Threatened Species™ (IUCN, 2013). In addition, this species is a good candidate for aquaculture because of its fast growth and easy propagation in captivity; however, high mortality rates during beluga larval rearing of up to 80% in some cases have been identified as one of the most serious bottlenecks for its culture (Asgari et al., 2014). Knowledge