Journal of Cleaner Production 116 (2016) 100–109

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Environmental impacts of genetic improvement of growth rate and feed conversion ratio in fish farming under rearing density and nitrogen output limitations

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ARTICLE INFO

Article history:
Received 16 September 2015
Received in revised form
22 December 2015
Accepted 23 December 2015
Available online 31 December 2015

Keywords:
Life cycle assessment
African catfish
Feed efficiency
Recirculating aquaculture system
Selection
Thermal growth coefficient

ABSTRACT

Today, fish farming faces an increasing demand in fish products, but also various environmental challenges. Genetic improvement in growth rate and feed conversion ratio is known to be an efficient way to increase production and increase efficiency in fish farming. The environmental consequences of genetic improvement in growth rate and feed conversion ratio, however, are unknown. In this study, we investigated the environmental consequences of genetic improvement in growth rate and feed conversion ratio in an African catfish farm, using Recirculating Aquaculture System (RAS). In RAS, total fish production of the farm is limited by rearing density or by the capacity to treat dissolved nitrogen. To evaluate the environmental consequences of genetic improvement in growth rate and feed conversion ratio, we combined life cycle assessment and bioeconomic modelling of genetic response to selection. We explored different impact categories, such as climate change, eutrophication, acidification and energy use, and we expressed impacts per ton of fish produced. Results show that the environmental impact of genetic improvement in growth rate and feed conversion ratio varies among impact categories and depends on the factor limiting production at farm level (i.e. rearing density or nitrogen treatment capacity). Genetic improvement of feed conversion ratio reduces environmental impacts in each scenario tested, while improving growth rate reduces environmental impacts only when rearing density limits farm production. Environmental responses to genetic selection were generally positive and show similar trends as previously determined economic responses to genetic improvement in growth rate and feed conversion ratio in RAS. These results suggest that genetic improvement of growth rate and feed conversion ratio for species kept in RAS will benefit both the environmental impacts and the economics of the production system.

1. Introduction

Fish farming is the fastest growing animal food-producing sector in the world, due to the joint effect of an increase in demand of fish products and a stagnation of fisheries captures (FAO, 2014). Fish farming, however, also faces some environmental challenges, such as eutrophication resulting from emission of pollutants during fish rearing and the use of natural resources for feed (Folke et al., 1994; Naylor et al., 2000; Read and Fernandes, 2003). Previous life cycle assessments (LCA) showed that production of feed and fish farming are chain stages that contribute most to environmental impacts of fish farming (Aubin et al., 2006; Pelletier et al., 2009). Several studies have investigated the potential of

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http://dx.doi.org/10.1016/j.jclepro.2015.12.084
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alternative feed compositions (Boissy et al., 2011; Papatryphon et al., 2004; Pelletier and Tyedmers, 2007) or alternative rearing systems (Aubin et al., 2009; Ayer and Tyedmers, 2009; d'Orbcastel et al., 2009) to reduce the environmental impacts. These studies found trade-offs between different environmental impacts, such as climate change and eutrophication, when changing feed composition or rearing conditions.

Genetic improvement has potential to reduce various environmental impacts simultaneously but this aspect of selective breeding has not been explored so far in fish production. In many fish species, genetic response to selective breeding is high due to high heritability of commercial important traits, high intensity of selection and high genetic variation (Gjedrem et al., 2012). Genetic improvement, obtained through selective breeding programs, is a powerful tool to generate cumulative change in animal population. A genetic change in fish performances is expected to improve not only economic benefit of farms (Besson et al., 2014; Ponzoni et al., 2007), but to reduce also environmental impacts, as shown in livestock (Bell et al., 2011; Buddle et al., 2011). Wall et al. (2010) suggested to evaluate these environmental impacts of genetic improvement by calculating environmental values (ENV), based on the principle of economic values (EV) from Hazel (1943). These environmental values express the difference in environmental impacts between a base situation and a situation with genetic improvement in one trait while keeping the other traits constant (Groen, 1988). From the whole farm perspective, genetic improvement in a trait can alter feeding strategy, management practices and also purchase of inputs like feeds (van Middelaar et al., 2014). Moreover, the impact of genetic improvement on farm management changes according to the factor limiting production at farm level (Gibson, 1989; Groen, 1989). Evaluating the environmental impacts of genetic improvement requires, therefore, (1) to model the whole farm, using, for example, a bio-economic model and (2) to evaluate the environmental impacts of changes at farm level, which can be performed using LCA.

Van Middelaar et al. (2014) combined bioeconomic farm modelling with an LCA to calculate EV and ENV in dairy production. They found that genetic improvement of milk yield and longevity increased economic benefit at farm level and decreased greenhouse gas (GHG) emissions along the production chain of one ton of fat-and-protein-corrected milk (FPCM). In fish farming, we developed a bioeconomic model for a farm producing African catfish (*Clarias gariepinus*) in recirculating aquaculture system (RAS) and investigated the EV of growth rate and feed conversion ratio (Besson et al., 2014). Growth rate and feed conversion ratio are considered key production parameters by fish farmers. In Besson et al. (2014), we showed that genetic improvement of both traits could increase farm income by improving the production of the farm and/or by improving production efficiency (fish produced per unit of feed consumed). Modelling the whole farm showed that the impact of genetic improvement on farm income depends on the trait and on the factor limiting the production of the farm: the capacity of the bio-filter to treat nitrogen or the maximum rearing density in the system studied.

Changes in production and production efficiency are expected to decrease environmental impacts also, by diluting fixed environmental impacts over more fish produced and by reducing the use of feed per ton of fish produced (Wall et al., 2010). In fish farming, however, the impact of genetic improvement on the direction and on the magnitude of a change in environmental impacts is not known. Moreover, possible synergies or trade-offs between EV and ENV are unknown. In this study, therefore, environmental values of growth rate and feed conversion ratio of African catfish reared in a RAS were calculated by combining the bioeconomic model developed in Besson et al. (2014) with an LCA of fish production.

2. Method

2.1. Bioeconomic model

The bioeconomic model used in this study was developed in Besson et al. (2014) using R (R Development Core Team, 2008). This model describes a RAS producing 500 tons of African catfish per year. Tanks were restocked after fishing all along the year and during a one year period, the model assumes that all stocked fish have a common genetic value. The model was based on information provided by private companies. The RAS was composed of four main compartments: (1) a series of 20 rearing tanks (6 tanks of 6 m^3 for fish from 13 to 80 g and 14 tanks of 50 m^3 for fish from 80 to 1300 g), (2) a mechanical filter, which remove solid waste, (3) a bio-filter where nitrifying bacteria brake down the ammoniacal nitrogen (NH_3-N) excreted by the fish into nitrites and nitrates and (4) a denitrification reactor where denitrifying bacteria processes nitrates into nitrogen gas (N_2). Clean-up water was re-used in rearing tanks and only 30 m^3/day of effluent water was directed to a municipal waste water treatment plant. The bioeconomic model was divided in 3 parts: (1) fish model, estimating individual fish growth using thermal growth coefficient (Dumas et al., 2007) and estimating individual emission of pollutants using mass-balance (Cho and Kaushik, 1990; Cowey and Cho, 1991); (2) batch model, estimating the maximum stocking density of a batch according to the two limiting factors, the density at harvest (230 kg/m^3) and the maximum treatment capacity of the bio-filter (40 kg of dissolved NH_3-N per day); (3) farm model, estimating annual fish production, pollutants emission, feed consumption and finally annual profit by combining technical and economic parameters. Further details about the bioeconomic model are given in Appendix A.1. The outputs of the bioeconomic model were used to generate inventory data for the LCA.

2.2. Life cycle assessment

2.2.1. Goal and scope

LCA is a standardized method to calculate the environmental impact of a production chain, from raw material extraction up to the product's end-of life (Guinée et al., 2002). In this study, we applied LCA according to the main specifications of ILCD standards (Joint Research Center, 2010). The system was defined from cradle-to-farm-gate and included five distinct sub-systems (Fig. 1): (1) production of purchased feed, including cultivation of ingredients, processing, and transportation; (2) production of energy expended at farm level (electricity and gas); (3) production of farming facilities and equipment used; (4) fish farming, including nutrients emission from biological transformation of feed after onsite treatment of wastewater; (5) offsite treatment of effluent at a municipal wastewater treatment plant. The functional unit in which environmental impacts were expressed was ton of fish produced at farm level on a basis of one year of routine production.

2.2.2. Life cycle inventory

(1) *Production of purchased feed* – Crop-derived ingredients used in fish feed originated from Brazil and France (e.g. soybean meal from Brazil and wheat bran from France), whereas fish-derived ingredients originated from the Peruvian and the Norwegian fish milling industry (e.g. fish meal from Peru and fish meal from fish trimming from Norway). The exact diet composition is given in Appendix A.2. Economic allocation was used to calculate the environmental impacts of processes yielding multiple products. We choose economic allocation because it has the advantage of stimulating the use