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Mussel production management: Raft culture without thinning-out

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ABSTRACT

Mussel raft culture as traditionally practiced in Galicia (Spain) represents an extreme case of aggregation, where culture density along growth ropes is maximized to achieve greater commercial yields. However, to maintain high growth rates during the entire cultivation period the initial density must be reduced through a process called "thinning-out" when rope weight increases by a factor of 10.

In raft culture, the annual commercial cycle is superimposed on a production cycle that can last up to 18 months. For this reason, the thinned-out mussel ropes can only occupy 75% of the usable surface area of the raft. Additionally, the rope handling process has a pronounced impact on production costs, affecting both labor and material costs.

With the objective of optimizing economic yields in mussel raft culture, we conducted a study to compare a new technique without thinning-out with the traditional method, and we evaluated the effect of density on mussel growth for both techniques.

For this purpose, three different densities were prepared for the no thinning-out ropes (800n, 1000n and 1200n mussels/m), and the other three for the thinning-out ropes (400y, 500y and 600y mussels/m).

At the end of the experiment, average length and average live weight for mussels cultured without thinning-out were significantly lower than values observed for mussels cultured with thinning-out. However, the no thinning-out technique did not result in a lower total biomass production.

The technique without thinning-out has a production cycle of 12 months, which coincides with annual production. On the other hand, the culture with thinning-out technique has a 15-month cycle (seeding and thinning-out processes); thus annual production was 20% lower than total production. Under these conditions, production at the two highest densities (1000n and 1200n) was significantly higher than production at all densities with thinning-out.

If we consider economic yield per raft per year, which also takes into account the higher price of mussels with increasing size, the difference between the two culture methods is smaller. Only the 1200n ropes still produced a higher economic yield than the 600y ropes. On the other hand, the shortening of the cultivation time and the elimination of the thinning-out reduce the production costs.

In conclusion, the results obtained with the new culture technique without thinning-out at high seed densities enable substantial improvements in terms of biomass, economic yields, and operating costs for mussel production.

1. Introduction

The trophic conditions of Galician rias, coastal ecosystems of the NW Iberian Peninsula, makes them exceptional sites for extensive culture of the mussel (*Mytilus galloprovincialis*) on floating rafts (Figueiras et al., 2002). As a consequence, these rias support the highest mussel production in Europe, where over three thousand rafts-with an area of 500 m^2 and 500 hanging ropes 12 m long-yield 250 × 106 kg $year^{-1}$ (Labarta et al., 2004).

The traditional process in the Galician mussel culture may be divided in three stages: (i) obtaining the seed; (ii) growing the seed; (iii) thinning culture ropes and growing them until commercial (adult) size. After obtaining the seed, it is attached to culture ropes, which are submerged in the seawater for 4–6 months. During this period mussels grow considerably reaching 35–50 mm long, and the ropes can increase 10 times their initial weight (Pérez and Román, 1979). Over time, mussel growth slows down and becomes heterogeneous requiring a thinning-out process, where mussels are dislodged from the ropes and reattached again at lower densities and with a more homogeneous set of individuals. During this last stage, lasting 10–12 months, individuals are grown until reach commercial sizes.

Aquaculture in suspended systems represents an extreme case of aggregation, particularly for mussels, as their density must be

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maximized to obtain higher commercial yields. Overstocking can lead to severe production losses in many bivalve aquaculture sites (Frechette et al., 2005). The negative effect of density on mussel growth and yields is well known by Galician producers (*bateeiros*). With the thinning-out process these *bateeiros* can control mussel density, minimize culture time, and reduce product losses from dislodgement due to excessive mussel density and rope weight (Labarta et al., 2004). This fact has been a major concern in aquaculture, agriculture and forest management (Westoby, 1984).

It is well known that the highly dense multilayered disposition of mussels can lead to space and food limitations (Alvarado and Castilla, 1996; Fréchette et al., 1992; Okamura, 1986) and to self-thinning as the individuals grow (Fréchette and Lefaivre, 1995, 1990; Guiñez and Castilla, 1999; Guiñez et al., 2005; Hughes and Griffiths, 1988; Petraitis, 1995). However, despite that several authors have analyzed self-thinning in mussel populations (Alunno-Bruscia et al., 2000, 2001; Filgueira et al., 2008; Fréchette and Lefaivre, 1990; Fréchette et al., 1996, 2010; Guiñez and Castilla, 1999; Hughes and Griffiths, 1988; Lachance-Bernard et al., 2010; Petraitis, 1995) some aspects of the biomass/mass–density relationships need to be revised. Cubillo et al. (2012c) reviewed the self-thinning (ST) models, regression methods and discrimination criteria currently applied for gregarious sessile species through its application to mussel populations (*Mytilus galloprovincialis*) grown in suspended culture, and Fuentes-Santos et al. (2013) checked and compared a dynamical model approach with the classical ST models. The dynamical approach detected the effect of culture density on the competitive behavior of individuals and allowed to analyze the temporal evolution of intra-specific competition by estimating the ST exponent trajectory. Moreover, this approach provided an ecological interpretation of any possible value of the ST exponent.

There are few studies on the influence of seeding density on mussel growth in suspended culture, despite its importance to the mussel farming industry (Cubillo et al., 2012a; Lauzon-Guay et al., 2005, 2006; Pérez-Camacho and Labarta, 2004). Cubillo et al. (2012a) observed a differential growth along the density gradient in industrial mussel culture in Galician rías. The authors also observed that the negative effect of density on mussel size and weight increased as individuals grew, especially over 66 mm long. Additionally, Cubillo et al. (2012b) confirmed the existence of asymmetric competition effects at high densities, wherein larger individuals capture a higher share of resources, and interfere with the growth of smaller individuals.

In terms of culture management and optimization, besides production techniques, the main natural factors affecting production are phytoplankton concentration and current velocity, which determine the availability of food (Pérez-Camacho et al., 1995). Empirical evidence (data presented by Pérez-Camacho et al., 1991) as well as common sense suggests that larger rafts allow larger yields. However, part of the mussels may be food limited, as water flow beneath the raft is cleared from food particles by mussels, with potential negative implications in raft yields (Pérez-Camacho et al., 1995).

The bivalve culture management is included in ecosystem-based management strategies (Byron et al., 2011) and specifically in the Ecosystem Approach to marine Aquaculture (EAA) (Costa-Pierce, 2008). This ecosystem perspective in raft mussel culture in Galicia was first approached in the rias of Arousa and Muros (Tenore and Gonzalez, 1975; Tenore et al., 1982).

Raft culture production is limited by the superimposition of the annual commercial cycle and the production cycle lasting up to 18 months. Seed and thinned-out ropes coexist in the raft and, in the best scenario each seed rope produces three thinned-out ropes, which can only occupy 75% of the raft (Perez-Camacho and Labarta, 2004). The thinning-out is a technique exclusively used in the Galician rias. Seed rope production and thinning-out processes significantly affect operating costs, both in terms of labor hours and cost of materials. Hence, it becomes necessary to adapt culture densities to food levels, while sustaining production levels and economic profitability. Duarte et al. (2008) showed that in Galician rias, the density of mussels per raft is close to its carrying capacity. Furthermore, maximizing production does not necessarily correspond to maximizing profit. In fact, according to Ferreira et al. (2007), producers who base their decisions on average or total production and revenue principles will obtain less profit than the ones using marginal analysis.

We designed a study to optimize economic yields in mussel raft culture, either by eliminating the thinning-out process, which increases usable raft surface area for commercial production and reduces costs, or by adapting mussel density on the ropes to environmental conditions. We conducted our study in the intermediate zone of Ria de Arousa. We compared the production yield obtained by the new technique without thinning-out to that obtained with the traditional technique. We evaluated the effect of density on mussel growth for both techniques, and estimated the annual production rates per rope and raft, as well as the economic yields for each commercial mussel category produced.

2. Materials and methods

The objective of our study, as explained above, was to compare mussel raft culture production using the traditional method used in Galicia (with pre-seeding, thinning out, and reseeding) to that obtained using a new one-stage method without thinning out, maintaining culture density from start to finish. We conducted our experiments on a raft situated in the intermediate zone of the Arousa ría, close to the extreme northwest point of Arousa Island, using seed mussels with a mean length of 25.13 ± 6.82 mm and mean weight of 1.69 ± 0.82 g that were collected from a raft located in the same culture zone.

For the no thinning-out experimental condition, we prepared three density groups of six culture ropes each, with densities of 800, 1000 and 1200 mussels/m (800n, 1000n and 1200n, where n denotes no thinning-out). The ropes remained in the raft for 12 months before harvesting. For the traditional culture condition (with thinning-out), we prepared 10 culture ropes with a density of 900 mussels/m, cultured them in the first stage for 3 months before conducting the thinning out process. At the end of the first stage, we observed a density of 751 mussels/m of rope, with a rope weight of 127.6 ± 8.11 kg, and we proceeded with the traditional harvesting, selection, and removal of smaller mussels. With the maintained mussels (mean length 57.54 ± 6.82 mm and mean weight 13.93 ± 4.06 g), we prepared three groups of six ropes each, at densities of 400, 500 and 600 mussels/m (400y, 500y and 600y, where y stands for “yes” and denotes thinning-out). These ropes were cultured in the raft for another 12 months. All the culture ropes measured ~16 m in length, of which 13 m was submerged in seawater and 12 m within the submerged length was available for mussel culture (from −1 m to −13 m).

At monthly intervals, we used a digital dynamometer (0.1 kg precision) to weigh the ropes in the water (PW) and we estimated the supported mussel weight (PVT) using the equation PVT = 4.966 PW + 7.011 ($R^2 = 0.9896$). We made our calculations from samples taken at different times for a total of 36 ropes of commercial culture, from different rafts of different mussel weights and sizes. We weighed the ropes in water at the moment when the tides changed to eliminate any current effects; then we harvested and weighed the mussels from the ropes.

To calculate final production, at the end of each experiment, we harvested three ropes for each experimental condition and weighed the mussels from each of the harvested ropes. Before unwinding each rope, we took two samples of about 250 mussels each, at depths of 4–8 m, and determined average length and average live weight for each sample. We then selected 20 mussels at 10 mm length intervals on either side of the average, and determined fresh meat, dry meat,