

Positive Effect of Suspended Culture to the Growth of Pectinids

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Abstract

Scallop production from the wild is undeniably declining due to the natural and man-made perturbations. With this, aquaculture seems to be an essential way to restore and meet the economic demand in marine molluscs, which is one of the important sources of highly nutritious animal protein. Scallop culture falls into two categories: suspended and bottom culture. Though studies are available comparing the growth between these two different culture methods, information on the effect size as a quantitative measure of the magnitude of difference between these culture methods is still lacking. To address this gap, a meta-analysis was conducted which synthesized different available studies on growth of Pectinids using bottom and suspended cultures. The result of the analysis revealed that suspended culture has a significant positive effect on growth of Pectinids. Specifically, higher growth rates were observed in suspended than in the bottom culture. Sensitivity analysis indicates that the result of this meta-analysis was robust. The synergistic effect of food, temperature and biofouling acting in relation with other environmental variables that differ in surface and bottom waters plays a profound consequence in the growth of Pectinids. Therefore, information provided herein is very significant to aquaculturist and conservationist as basis on what culture method is best to adopt for better scallop production.

Keywords: *culture method, growth variability, suspended and bottom culture*

Introduction

Scallops are invertebrate animals under Phylum Mollusca, Class Bivalvia and Family Pectinidae that occurs in most seas of the world. They inhabit the range of climatic zones from the polar to tropical regions (Brand, 1991; Waller, 1991; Peña, 2001). Worldwide, about 40 scallop species belonging to the supra-genera *Chlamys*, *Mimachlamys*, *Aequipecten*, *Palliolium*, *Decatopecten* and *Pecten* are commercially or potentially commercially exploited for human consumption (Waller, 1991; Minchin, 2003). Today, despite of different available culture technique for scallop production, fisheries and scallop populations in many countries had collapsed due to environmental changes, habitat deterioration, pollution, irregular recruitment and heavy fishing pressure (Gould & Fowler, 1991; Orensanz *et al.*, 1991; Bull, 1991; Lu & Blake, 1997; Strand & Volstad, 1997; Stotz & Mendo, 2001). According to Bourne (2000), no large unexploited scallop stocks are known at present. Most of the fisheries are currently harvesting stocks at the maximum yield. Hence, to meet the market demand, efforts such as aquaculture (Ventilla, 1982; Guo *et al.*, 1999; Stotz, 2000)

and restoration of endangered species are aimed through stock enhancement and conservation programs (Cliché & Giguere, 1998; Dao *et al.*, 1999; Arnold, 2001; Stotz & Mendo, 2001; Tettelbach *et al.*, 2002; Drummond, 2004).

Aquaculture is the most promising tool and the most rapid growing food producing sector in the world (FAO, 2002) being practiced for culturing fish and marine molluscs which dates back several hundreds of years B.C. (Mann, 1984; Gosling, 2003). The need to support the increasing demand for human consumption is one of the main reasons to initiate the culture of a species (Christophersen, 2005). Compared with the cultures of other bivalve such as oysters, mussels and clams, scallop culture is relatively new. Modern scallop culture began essentially in Japan in the 1960's (Ventilla, 1982) and grow rapidly as evidenced by the rapid increase in the worldwide production between 1987 until 1996 (Mendoza *et al.*, 2003). The techniques for culturing scallop species fall into two categories which is either suspending the organism into the water column or the bottom type of culture (Ventilla, 1982; MacDonald *et al.*, 1988; Hardy, 1991; Bergh & Strand, 2001). In a suspended culture, the

animals are cultured in the water column within lantern nets, cones, cages and other containers (Emerson *et al.*, 1994; Mendoza *et al.*, 2003) or using the ear hanging technique (Cano *et al.*, 2000; Hamada *et al.*, 2001; Grant *et al.*, 2003). On the other hand, various method has been suggested for a bottom culture. These include corals, pockets, sleeves, fences and other equipment (Bergh & Strand, 2001; Freitas *et al.*, 2001; Mendoza *et al.*, 2003). However, the ecological adaptations of each particular species must be considered in developing suitable culture techniques, since no strategy is likely suitable for all pectinids (Mendoza *et al.*, 2003).

Development of scallop farming as a new industry demands direct research efforts. The main areas of research were considered such as the consistent production of juveniles, health control and prophylaxis, an improved understanding of the impact of the environment on scallop survival and growth, and the predator control, particularly in the suspended and bottom culture (Bergh & Strand, 2001). The aim of this review is to provide an overview of results from several research and investigations focusing on the culture of Pectinids. More specifically, it focuses on growth (shell height) of Pectinids cultured using bottom and suspended in open waters. Factors affecting growth between these two-culture methods were also identified. Results of this synthesis will be beneficial to aquaculturist and conservationist on the best culture practice to be adopted for better scallop production.

Materials and Methods

Data selection

Systematic search of peer reviewed literature was carried out in January to March 2019 which involved gathering of empirical evidences on growth of Pectinids in bottom and suspended culture. Studies were located using terms and keywords 'scallops', 'growth', 'suspended culture', 'bottom culture', 'depth', 'culture design', and 'environmental parameters' searched from Google Scholar. All literature selected used both bottom and suspended techniques in culturing scallop species. Studies were selected regardless of the design they used in suspended as well as in bottom culture. For suspended culture, different culture design was used in each of the study. These include cages, lantern nets, cones, sacs, pearl nets, pocket nets and ear hanging. On the other hand, cages or any enclosure located on the bottom up to 1 m above the bottom substrate were considered for bottom

culture. To explore the effect of culture method, variable such as growth rate of scallop species was selected from each study. Only studies that provides all necessary data such as monthly average growth rate (shell height), standard deviation and sample size were included. Data were extracted from graphical figures within the literature using digitizing software (PlotDigitizer; <http://plotdigitizer.sourceforge.net>).

Studies included within the meta-analysis contributed more data points, that is the number of measurements in individual unit of observation, than other studies. For instance, Mendoza and colleagues (2003) determined the growth of *Lyropecten nodosus* using three different design for suspended culture (sacs, cone and lantern); thereby contributing three data points to the meta-analysis. Similarly, Kleinman and co-workers (1996) determined the growth of *Placopecten magellanicus* in three different sites in Lunenburg Bay, Nova Scotia and contributed three data points. In contrast, determining the growth of *Euvola zizac* (Velez *et al.*, 1995), *Chlamys farreri* (Yu *et al.*, 2010), *Placopecten magellanicus* (Grant *et al.*, 2003) and *Pecten maximus* (Cano *et al.*, 2000) contributed only single data point towards the meta-analysis. In this study, the difference in growth of the extractive species of Pectinids, between the experimental (suspended) and control (bottom) was treated as separate data points, provided that the selection criteria described above were met. Due to the limited number of studies to be included in this meta-analysis, multiple observations from a single study were used though it can decrease the independence of the data points (Kerrigan & Suckling, 2016).

Data Analysis

All studies used in this meta-analysis compared the growth rate of scallop species grown in suspended culture and bottom culture (control). Therefore, standardized mean difference was used as the effect size. Effect size is used as a quantitative measure of the magnitude of difference between groups with the difference expressed in standard deviation units (Sullivan & Feinn, 2012). For most type of effect size, a larger or positive absolute value always indicates a stronger effect indicating that the experimental group performed better than the control group. In contrast, the negative value of effect size indicates under performance. Effect size of zero indicates no difference between experimental and control group (Kerrigan & Suckling, 2016). For each data point, standardized mean difference was expressed as Cohen's d which was calculated using the equation, $Cohen's\ d = (M^E - M^C)/SD_{pooled}$ which give a biased

estimate of effect size when sample sizes are small (<20) (Hedges and Olkin, 1985). To avoid being biased in the effect size, 'Hedge's g ' was used which was calculated from Cohen's d using equation, Hedge's $g = \text{Cohen's } d' \times [1 - (3/4(nE + nC) - 9)]$; where nE and nC represent sample size for the experimental and control group respectively (Gurevitch *et al.*, 2001; Lakens, 2013). By squaring the standard error in effect size (SED) using the equation, $SED = \sqrt{[(nE + nC)/nEnC] + [d2/2(nE+nC)]}$ the variance in effect size could be determined (Gurevitch *et al.*, 2001; Lakens, 2013).

The studies used in this meta-analysis varied due to interspecific differences between species (e.g., growth rate) and differences in culture design as well as site specific variations. Therefore, a weighted mean size effect was calculated using random-effects model. Random-effects model account for two sources of sampling error which is within study variance and between study variances. In within-study, the variance is given by V_D ; whereas in between study, variance (r) was calculated by subtracting degrees of freedom ($n-1$) from total variance and then divided by a scaling factor using equations given by Borenstein and colleagues (2007). The sum of V_D and r gives the total variance for each data point. w_i (the reciprocal of V_{D_i}) was used to determine the weighting that each data point carried within the combined effect.

Weighted mean effect size (T) was calculated in each of the study. All data points from each study were combined using the equation, $T = \sum (w_i T_i) / \sum w_i$, where T_i is effect size (Hedge's g). The standard error of mean effect size (SE_T) was calculated using the equation, $SE_T = \sqrt{1/\sum w_i}$. The significance of weighted mean effect size was assessed by constructing 95% bootstrapped confidence intervals around weighted mean effect size using equations given by Borenstein and colleagues (2007). The weighted mean effect size can be considered significant if the 95% confidence intervals do not cross zero (Borenstein *et al.*, 2007). Total weighted mean effect size (T^*) was then calculated by combining all the computed weighted data points from all studies. Lastly, a forest plot also known as blobbogram was constructed as a graphical display of the estimated results from the different studies (weighted mean effect size \pm SE). The framework provided by Neyeloff *et al.*, 2012 was used as a guide in computing effect size. All calculations were performed using Microsoft Excel 365.

Sensitivity

A sensitivity analysis was performed to test the robustness of findings using the method employed by

Kroeker and colleagues (2010). To summarize, those studies with the largest effect size were systematically removed from the analysis, which was then rerun to determine what effect or changes had on the meta-analysis outcome. Similarly, those studies contributing more than single data points were removed and the meta-analysis was analyzed.

Results and Discussion

Growth of Pectinids

The monthly growth rate of Pectinids from different studies was extracted to accurately compare growth increment using suspended and bottom culture. Out of six studies that were reviewed (Figure 1), 66.67% revealed positive effect of suspended culture on the growth of Pectinid species indicating that suspended culture is a better culture method than bottom culture with 33.33% growth rates (Table 1).

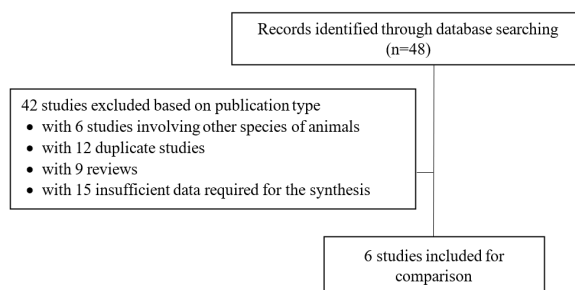


Figure 1. Flowchart on selection of studies on determining treatment effect culture condition on study outcomes.

Effect size of suspended culture on the growth of Pectinids

Effect size as the quantitative measure of the magnitude of difference between bottom and suspended culture were determined to properly distinguish the best culture method for culturing Pectinid species. With this, six studies were found comparing the growth of scallop species using suspended culture with bottom culture. From these studies, 10 data points were extracted and incorporated within the meta-analysis. The result of the analysis revealed that suspended culture had an overall significant positive effect on the growth rates of Pectinids, as indicated by the total weighted mean effect

Table 1. Mean monthly growth rate of Pectinids using suspended and bottom culture

| Species | Daily Growth Rate (µm) | | References |
|---------------------------------|------------------------|-----------|-------------------------------|
| | Bottom | Suspended | |
| <i>Lyropecten nodosus</i> | 255.06 | 343.98 | Mendoza <i>et al.</i> , 2003 |
| <i>Placopecten magellanicus</i> | 110.66 | 80.61 | Kleinman <i>et al.</i> , 1996 |
| <i>Euvola ziczac</i> | 127.49 | 78.66 | Velez <i>et al.</i> , 1995 |
| <i>Chlamys farreri</i> | 249.11 | 284.69 | Yu <i>et al.</i> , 2010 |
| <i>Placopecten magellanicus</i> | 116.04 | 141.61 | Grant <i>et al.</i> , 2003 |
| <i>Pecten maximus</i> | 185.65 | 270.44 | Cano <i>et al.</i> , 2000 |

size (T* = 0.76; Figure 2).

On the other hand, sensitivity analysis was performed to test the robustness of result within the meta-analysis. In this paper, the study of Cano and colleagues (2000) had the highest effect size among the six studies that were reviewed (ES = 3.28). The removal of the highest effect size did not alter the significance of the total weighted mean effect size. Therefore, the sensitivity analysis revealed that the findings of this meta-analysis is robust indicating that the data provided herein are enough to confirm that suspended culture is a better way of culturing Pectinids due to high growth increment than the bottom culture.

Various authors revealed that the growth of bivalves has always shown differences between a suspended and a bottom culture (Velez *et al.*, 1995; Lodeiros *et al.*, 2002; Mendoza *et al.*, 2003; Uddin *et al.*, 2007). In fact, this meta-analysis revealed significant positive effect of suspended culture on the growth of Pectinid species suggesting that suspended method is a viable technique in culturing different species of scallops (total weighted mean effect size = 0.76). Specifically, growth of Pectinids were faster in suspended than that of the bottom culture. The differences in growth between these two-culture methods were probably due to environmental factors such as but not limited to food, temperature and biofouling that differed in the surface and bottom waters (Broom & Mason, 1978; MacDonald & Thompson, 1986; Parsons & Dadswell, 1992; Maguire & Burnell, 2001).

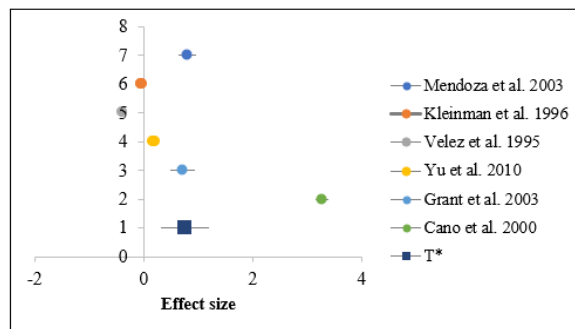


Figure 2. Forest plot of the results in the growth of Pectinids in suspended culture relative to bottom culture (weighted mean effect size ± 95% confidence interval). Each horizontal line and the circle indicate the individual studies analyzed and the box represent the overall point estimate for all studies pooled (total weighted mean effect size, T*). The x-axis is in log scale (-2.00 to 4.00) and the distance of the box from the vertical line demonstrates the magnitude of the experimental effect between the test and the control.

Species of scallop that grow best in suspended culture includes *Lyropecten nodosus* (Effect size (ES) = 0.79; Mendoza *et al.*, 2003), *C. farreri* (ES = 0.19; Yu *et al.*, 2010), *P. magellanicus* (ES = 0.50; Grant *et al.*, 2003) and *P. maximus* (ES = 3.27; Cano *et al.*, 2000). Higher growth rates of these species were all environmentally related such as to foods and temperature, which has been also demonstrated by various authors to have significant influence on scallop growth (Wallace & Reinsnes, 1985; Thouzeau *et al.*, 1991; MacDonald *et al.*, 2006; Thebault *et al.*, 2008). For instance, food supply has consistently shown to be the most influencing factor which affect bivalve growth since without this, sustained growth is impossible (Seed & Suchanek, 1992). In the wild, growth has been shown to be correlated with phytoplankton abundance (Utting, 1988; Smaal & Stralen, 1990; Gosling, 2003), wherein, growth rates may increase with increasing phytoplankton concentrations (Cahalan *et al.*, 1989). This source of food is more readily available to bivalves in suspended culture than to benthic-dwelling bivalves (Gosling, 2003). The differences in food quantity and quality between suspended and bottom culture may strongly affect the growth in scallops (MacDonald & Thompson, 1985; Thompson & MacDonald, 1991; Lodeiros & Himmelman, 1994). In order to meet their energy requirements, bivalve populations must exploit non-phytoplanktonic carbon in the form of re-suspended sediment, a complex mixture of benthic microflora, microalgae, fine organic detritus as well as quantities of inorganic material. (Gosling, 2003).

Differences in availability of food and the composition of particulate matter with depth no doubt influence the growth in Pectinids (Leighton, 1979). For instance, the scallops *C. farreri*, *P. magellanicus* and *P. yessoensis* grow faster in suspended culture than in the bottom culture due to better access to high-quality food particles in the water column. In contrast, the high concentrations of low-quality food seston near the bottom such as allochthonous detrital material, resuspended sediment plus phytoplankton (Sundet & Vahl, 1981), a mixture which is not as energy-rich phytoplankton alone (Vahl, 1980) was the main reason for reduced growth of these scallop species (Emerson *et al.*, 1994; Silina & Zhukova, 2007). Therefore, the differences in growth between suspended and bottom culture are mainly due to the quality of food available which may differ due to the light intensity which was lower in deeper water thus affecting the distribution of phytoplankton in the bottom (Yu *et al.*, 2010). In general, bivalve growth rates have been described as a logarithmic function of food ration (Bayne & Newell, 1983).

Temperature is one of the important physical factors affecting marine organisms (Hildreth & Stickle, 1988) and was found to be a vital limiting factor in the culture system (Huo *et al.*, 2017). It can affect the immune response, physiological response, embryonic development, growth and survival (Huo *et al.*, 2017). In the wild, temperature varies with varying depth whereas warm water temperature was observed in the shallow areas while bottom water remains cold (Gosling *et al.*, 2003). Various authors reported that growth variability in scallop between suspended and bottom culture was affected by differences in temperature. Suspension culture often increases growth due to the relatively higher temperature, more importantly, higher food levels in the surface than the bottom waters (Leigton, 1979; Wallace & Reinsnes, 1985; MacDonald, 1985; Dadswell & Parsons, 1992; Kleinman *et al.*, 1996; Thorarinsdottir, 1994; Lodeiros *et al.*, 1998). In contrast, the advantage of bottom culture is that the culture species may suffer less bad weather than the suspended culture (Mendoza *et al.*, 2003).

On the other hand, limited instances revealed that Pectinid species in suspended culture shows negative effect size on growth. Species of scallops that shows negative growth rate in suspended culture includes *P. magellanicus* cultured in Lunenburg Bay, Nova Scotia (ES = -0.02; Kleinman *et al.*, 1996) and *E. ziczac* (ES = -0.38; Velez *et al.*, 1995) that thrived best and showed faster growth in the bottom than in the suspended culture. The slow growth rate of these species in suspended culture are primarily

attributed to fouling organism that have negative impact on the cultured species. Number of studies demonstrate that fouling on the shells of the scallop and on culture enclosures can have a strong negative impact on growth because they diminish the food supply (Claereboudt *et al.*, 1994; Lodeiros & Himmelman, 1994; Ross *et al.*, 2004). Colonization of scallop nets by mussels, barnacles and hydroids is greater near the surface. This fouling organism undoubtedly reduces the flow of water and suspended food particles to scallop by competing scallops in food resources (Gosling, 2003). Therefore, fouling can negate the positive effects of increased temperature and abundance of suspended food in the surface (Cote *et al.*, 1993). In *C. farreri*, growth rates were high when the load of fouling organisms was heavy during the first year in suspended culture, however, during the last three months of the experiment, scallops in the bottom culture grew faster than the suspended culture. This is due to the rapid development of fouling organisms in the lantern nets (Yu *et al.*, 2010). Hence, the frequent removal of fouling organisms and cleaning the culture medium are essential to lessen the worst effect of fouling especially on the growth of cultured species. In contrast, fouling organism are less in the bottom, possibly this is due to sedimentation that decreased the development of fouling organism or because fouling organism were eaten by bottom consumers (Mendoza *et al.*, 2003). With such negative impacts of fouling in suspended culture, fouling can have a beneficial effect in the bottom. For instance, the epizoic sponges on the upper valve of various species of *Chlamys* greatly inhibit predation by starfish. The sponges reduce adhesion of the starfish tube-feet, but the tactile camouflage also can be involved (Brand, 1991). In addition, distasteful chemicals in the sponge may prevent fish predators (Pitcher & Butler, 1987).

In summary, the result of the meta-analysis presented herein reveals that each culture method (bottom and suspended) has advantages and disadvantages (Wildish *et al.*, 1988). Further, it appears that suspended culture could be used to successfully culture different species of Pectinids due to higher growth increment than in bottom culture. This method of culturing scallops has not been economically feasible due to higher inputs and husbandry. But this may change if the value of the landed scallops remains at the high price. On the other hand, alternative cage design could be used in suspended culture that would considerably improve the economic viability of the culture method. However, the type of culture method used depends on local circumstances and preferences; its effectivity varies between species, since no strategy is likely suitable for all Pectinids. With the knowledge provided in this meta-analysis, public

awareness on consequences between suspended and the bottom cultured can be made. Thus, the significant positive effect of suspended culture on the growth of Pectinids which was reported herein will be an essential basis for future aquaculturist and conservationist of what culture method augmented higher growth rates on Pectinids.

Conclusion and Recommendation

The result of the meta-analysis suggests that growth of Pectinids shows variability between bottom and suspended culture with higher growth rates incurred in suspended than in bottom culture. The synergistic effect of food, temperature and bio-fouling acting in concert with other environmental variables plays a profound consequence in growth of Pectinids. Temperature and food availability were the prime environmental factors that affect growth between bottom and suspended culture.

This meta-analysis focuses only on growth (shell height) of Pectinids between suspended and bottom culture. Though growth comparison is herein provided, analysis regarding survival rate using these two culture methods is highly recommended. To further guide future aquaculturist on economic viability of these two-culture method, further analysis on cost and return using these two culture techniques should be provided.

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