

Review of scallop grow-out methods in tropical and temperate marine waters

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Abstract. A review of the scallop grow-out techniques was undertaken using secondary data from published literature. The search strategy includes the following terms: suspended+and+bottom+growout+culture+of+scallop. The literature searches were conducted in December 2017 and January 2018 using Google Scholar (<http://scholar.google.com>). The study was able to identify 12 scallop species from the tropical (3), warm-temperate (6), and cold-temperate (5) regions. The dominant species with their corresponding number of literature reviewed were *Nodipecten subnodosus* (3) for warm-temperate and *Lyropecten nodosus* (2) in the tropical region. Culture using lantern net/cage constitutes the majority (26%) of the methods used. The mean stocking densities (%) for both tropical and temperate regions were below the suggested 33% coverage of the floor area of the culture enclosure. Tropical species were cultured in shallower water depth. The growth of cultured scallop in the tropical region (0.17 mm day^{-1}) was significantly faster than the two temperate regions ($P=0.0663$, $\alpha=0.10$). However, survival was significantly lower compared to the scallops cultured in the cold-temperate regions ($P=0.0235$, $\alpha=0.05$). The lower growth rate in the temperate regions was attributed to the decrease in growth rate during winter, while the observed predation in the tropical region may have caused low survival of the tropical species.

Key Words: initial stock density, shell growth, size at stocking, survival, culture period.

Introduction. Scallops (family Pectinidae) occur in all seas of the world with about 400 known living species (Brand 2006). The commercial fisheries and mariculture operations of scallops worldwide are dependent on these natural populations in the coastal ecosystems (Shumway & Cembella 1993). Numerous authors have documented scallop production from either wild population or aquaculture production in different countries. In Asia, the scallop industry was popular in Japan (Kosaka & Ito 2006) and China (Guo & Luo 2006). The successful scallop culture in Asian countries created interest for the scallop culture in Europe (Norman et al 2006), north western Pacific Russian Federation (Ivin et al 2006), Eastern North America (Blake & Shumway 2006), West Coast of North America (Lauzier & Bourne 2006), New Zealand (Marsden & Bull 2006), and Scandinavia (Strand & Parsons 2006). Scallop fisheries and aquaculture were also reported in countries like Chile (von Brand et al 2006), Argentina (Ciocco et al 2006), Mexico (Felix-Pico 2006), Venezuela (Lodeiros et al 2006), Brazil (Rupp & Parsons 2006), and Australia (Dredge 2006).

The scallop production in 2016 reached about 2.1 million metric tons, with the majority of production coming from Asia. Over 88% of this production is produced by China, while Japan contributes about 10%. Other notable production was contributed by countries like Peru, Russia, Chile and South Korea (FAO 2018). In China for example, almost all scallop produced (>99%) came from aquaculture production. The Zhikong scallop (*Chlamys farreri*) is the most important commercial species (Guo & Luo 2006). In Japan, the industry of the Japanese scallop (*Mizuhopecten yessoensis*) aquaculture has grown to become the most successful marine shellfish farming venture (Shumway 1991 and Bourne 2000 in Radiarta et al 2008) contributing over 40% of the scallop production (FAO 2007 in Radiarta et al 2008). The thriving culture of scallop in Japan ignited the enthusiasm in Europe with *Pecten maximus* and *Aequipecten opercularis* as the species

of interest. Later, *Mimachlamys varia*, *Chlamys islandica*, and *Flexopecten flexuosus* have then also been considered for farming (von Brand et al 2006).

Several aquaculture techniques have been developed in the grow-out culture of different scallop species. One of the conventional methods used is the Japanese suspended culture technology which was also used and applied successfully to some tropical scallop species. Such species include the northern scallop (*Argopecten purpuratus*) in Chile (von Brand et al 2006), *Euvola ziczac* (Lodeiros & Himmelman 1994; Lodeiros & Himmelman 1996; Lodeiros & Himmelman 2000; Lodeiros et al 2006), and *Lyropecten nodosus* Linnaeus 1758 (Lodeiros et al 1998; Lodeiros et al 2006) in Venezuela. Culture operations for scallops have different successive stages that started from spat or seed collection, followed by an intermediate culture before final grow-out period. Different culture stages used different culture methods and design, e.g. Japanese culture methods that used spat collector bags, pearl nets, and lantern nets for the different culture stages respectively (Ventilla 1982). Other than the most common Japanese culture method, various methods have been developed and described by different authors in both tropical and temperate environments.

This paper reviewed the available literature on scallop grow-out culture techniques and practices to generate a recommendation for possible methods for scallop grow out that can be adopted in the Philippines. Specifically, this study aims to answer the following research questions: (1) what are the different scallop species (tropical, warm-temperate, and cold-temperate) being cultured? (2) What are the major culture methods/designs used? Finally, what are the growth and survival rates of scallops cultured in different regions?

Material and Method. The scope includes any research investigating the growth and survival of scallops (Pectinidae), both tropical and temperate species throughout the world. The literature searches were conducted in December 2017 and January 2018 using Google Scholar (<http://scholar.google.com>). The terms used was: suspended + and + bottom + growout + culture + of + scallop. The study only includes literature that provided data on culture methods, culture period, stocking density, growth rate (or initial and final weight) and survival rate. Excluded in the review were studies with data not explicitly stated in the text but only in graphical figures, and those stated in the text but not for the whole original culture period (e.g., for only a certain season or a month period). Studies lacking in those data but are deemed significant are included in the discussion. The literature was grouped into biogeographic regions (tropical, warm-temperate, and cold-temperate) as proposed by Briggs & Bowen (2012).

In this study, only the results coming from different methods, and species are considered as data points. If a study considered different variables such as depth and stocking density as functions of growth and/or survival, the experimental group or groups not significantly different are clustered and the mean constitute one data point. However, if the data is significantly different, the data was regarded as a separate data point. If the data is presented as a pooled data (e.g. Grant et al (2003) on depth), the mean of the pooled data was used. If the data is presented in range, the mean of the range was used.

Several studies included within the review contributed more data points than other studies. For example, Mendoza et al (2003) examined the growth and survival of *L. nodosus* during final grow-out when maintained in various types of culture enclosures (sacs, cones, lantern nets, and corrals), thereby contributing four data points. In contrast, Maeda-Matinez et al (2000) describes the results of a commercial culture project for the Catarina scallop, *Argopecten ventricosus* using a new bottom culture method (net sleeve) which contributed only one data point. Although using multiple observations from a single study can decrease the independence of these data points, it was necessary due to the limited number of studies suitable for inclusion (e.g., Kroeker et al (2010) as cited by Kerrigan & Suckling (2016)).

Density (%) was estimated as the area occupied by the scallop assuming it has a circular shape. The growth was computed as the difference between the final and initial shell height divided by the culture period. One-way Analysis of Variance (ANOVA),

followed by the least significant difference (LSD), was used to determine the significant difference in the growth and survival of the cultured scallops in different regions.

Results

Literatures reviewed. A total of 17 literatures on scallop grow-out culture have been reviewed, with the tropical, warm-temperate, and cold-temperate regions contributing 3, 10, and 4 published literatures respectively. For the different variables (density, culture period, depth, initial stocking size, growth, and survival) being studied, literatures from the tropical region contributed 10 data points each. For the warm-temperate region, 24 data points were contributed for all variables, except for density (19 data points) due to the identified ear hanging method. In the cold-temperate region, all variables have 10 data points, while density have nine.

Cultured species. A total of 12 cultured scallop species were identified from tropical (3 species), warm-temperate (6 species) and cold-temperate region (5 species). The species *Nodipecten subnodosus* cultured in the warm temperate region has the most number of literatures reviewed (3). In the tropical region, *L. nodosus* has two literatures reviewed. Other dominant species like *Pecten fumatus*, and *P. maximus* were cultured in both warm-temperate and cold-temperate regions and has both two literatures reviewed (Table 1).

Table 1

Frequency (count) of the number of publications on cultured scallop species reported in at different biogeographic regions

<i>Species</i>	<i>Frequency (count)</i>	<i>Biogeographic regions</i>	<i>References</i>
<i>Nodipecten subnodosus</i>	3	Warm-temperate	Arellano-Martinez et al (2011); Barrios-Ruiz et al (2003); Villalejo-Fuerte et al (2004)
<i>Nodipecten nodosus</i>	2	Tropical	Mendoza et al (2003); Velasco et al (2009)
<i>Mimachlamys varia</i>	2	Warm-temperate	Cancelo et al (1992); Rathman et al (2017)
<i>Pecten maximus</i>	2	Warm-temperate & Cold-temperate	Cano et al (2000); Maguire & Burnell (2001)
<i>Pecten fumatus</i>	2	Warm-temperate & Cold-temperate	Cropp & Hortle (1992); O'Connor et al (1999)
<i>Euvola ziczac</i>	1	Tropical	Freites et al (2000)
<i>Argopecten nucleus</i>	1	Tropical	Velasco et al (2009)
<i>Aequipecten tehuelchus</i>	1	Warm-temperate	Narvarte (2003)
<i>Argopecten ventricosus</i>	1	Warm-temperate	Maeda-Martinez et al (2000)
<i>Placopecten magellanicus</i>	1	Cold-temperate	Grant et al (2003)
<i>Chlamys farreri</i>	1	Cold-temperate	Yu et al (2010)
<i>Aequipecten opercularis</i>	1	Cold-temperate	Roman et al (1999)

Culture methods. Two types of culture methods were used, one is the suspended culture and the other one is bottom culture. Majority (89%) was cultured suspended in the water column, while bottom culture method constitutes 11% of the methods used. Thirteen different types of culture design/enclosures were identified in the review (Table 2).

Table 2
Frequency (count) of the number of publications on culture designs/enclosures used in scallop mariculture

<i>Culture design/enclosures</i>	<i>Frequency (count)</i>	<i>%</i>
Lantern net/cage	11	26
Ear hanging	6	14
Square cage	6	14
Plastic tray	4	9
Plastic mesh disk	3	7
Pearl nets	3	7
Corral	2	5
Nestier basket	2	5
Sleeve	2	5
Cone	1	2
Sack	1	2
Circular cage	1	2
Triangular cage	1	2
Total	43	100

Lantern nets (Figure 1) in suspended culture were the major enclosure used in the culture of scallops regardless of environment, which comprises 26% of all design/enclosures used. Other major culture design/enclosures include the ear hanging (14%) and the use of square-shape cage (14%). For the bottom culture method, sleeves, corrals and square cage was used to grow scallops. Majority (3 out of 5) of the bottom culture methods were used in the tropical region.

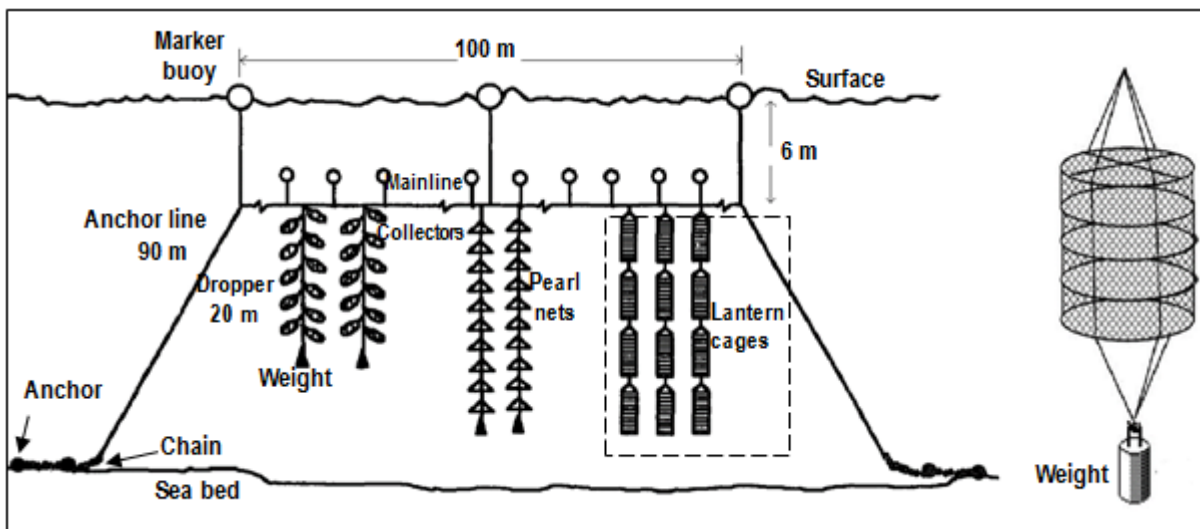


Figure 1. Schematic representation of lantern cages (left, enclosed in broken lines) cultured in long line retrieved from Cropp & Hortle (1992), and single lantern net (right) used for scallop culture extracted from Mendoza et al (2003).

Culture period and stocking size. The culture period for the entire data ranged from 79 to 944 days. The mean culture period in tropical region (141 days) was relatively shorter than that of the warm-temperate (354 days), and cold-temperate environments (354 days). The mean initial stocking size in the tropic was 34.70 ± 9.89 mm. Similar stocking sizes were observed in the warm-temperate (31.62 ± 15.95 mm), and cold-temperate (43.51 ± 8.17) regions (Table 3). For the entire data, the biggest (*P. maximus*) and smallest (*C. varia*) initial stocking size (6.47 mm and 64.3 mm, respectively) was both found in temperate environment.

Table 3
Scallop culture parameters (mean±standard deviation) in different biogeographic regions

Biogeographic regions	Stocking size (mm)	Culture period (days)	Density (%)	Depth (m)
Tropical	34.70±9.89	141±44	30.10±18.04	6.50±1.15
Warm-temperate	31.62±15.95	354±221	18.89±15.05	10.59±8.75
Temperate	43.51±8.17	275±95	32.07±7.18	7.86±6.33

Density and depth. Overall, the stocking density (%) for the entire data ranged from 1.6% to 60% of the floor area of the culture enclosures. The mean density of cultured scallops in the tropical region is 30.10±18.04%. Similar density was observed in the cold-temperate region with 32.07±7.18%. Lowest density of 18.89±15.05% was observed in the warm-temperate region. Densities for all regions are considered low, since the values fall below the 33% (1/3 of the floor area) suggested stocking density for scallop culture. Scallops are generally cultured in shallower water depth (6.5±1.15 m) in the tropical region. In the cold-temperate region, mean culture depth was 7.86±6.33 m. Deepest culture depth was observed in the warm-temperate region (10.59±8.75 m), (Table 1).

Growth and survival. The highest growth rate of 0.34 mm day⁻¹ was observed for the species *N. nodosus* cultured in pearl net at 25% density, while lowest growth rate (0.02 mm day⁻¹) was observed in *A. nucleus* cultured in lantern net at 60% density (Velasco et al 2009). Both species were cultured in the tropical environment. The highest mean growth rate of 0.17 mm day⁻¹ was observed in the tropics. Species in warm-temperate region had a growth rate of 0.12 mm day⁻¹. Lowest growth rate was observed for the scallops in the cold-temperate region (0.10 mm day⁻¹) (Figure 2). The mean growth rate of scallops in the tropical region was significantly faster than those in the warm-temperate and cold-temperate regions (P=0.0663, α=0.10).

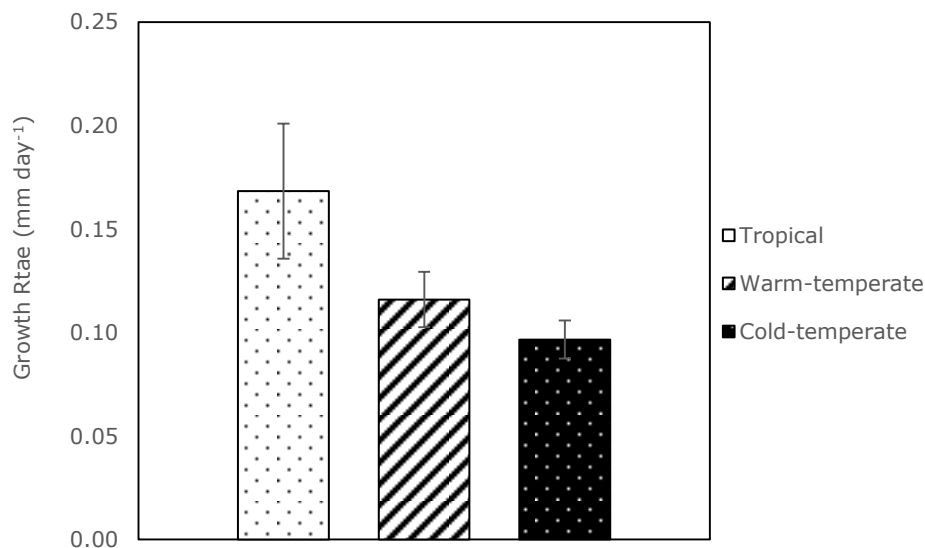


Figure 2. Growth rates of scallops cultured in different biogeographic regions.

The highest mean survival rate was found in cold-temperate environment (93.27%). In the warm-temperate and tropical regions, lower survival rates were observed (73.53% and 68.90%, respectively) (Figure 3). The mean survival rate in the cold-temperate region was significantly higher than the tropical region, but not with the warm temperate-region (P=0.0235, α=0.05).

In the tropical region, the mean growth and survival rates in the suspended culture is higher than the bottom culture method. Using suspended culture method, growth and survival rates were 0.18 mm day⁻¹ and 72%, respectively. On the other hand, for bottom culture method, the growth was 0.15 mm day⁻¹ while survival rate was 61%.

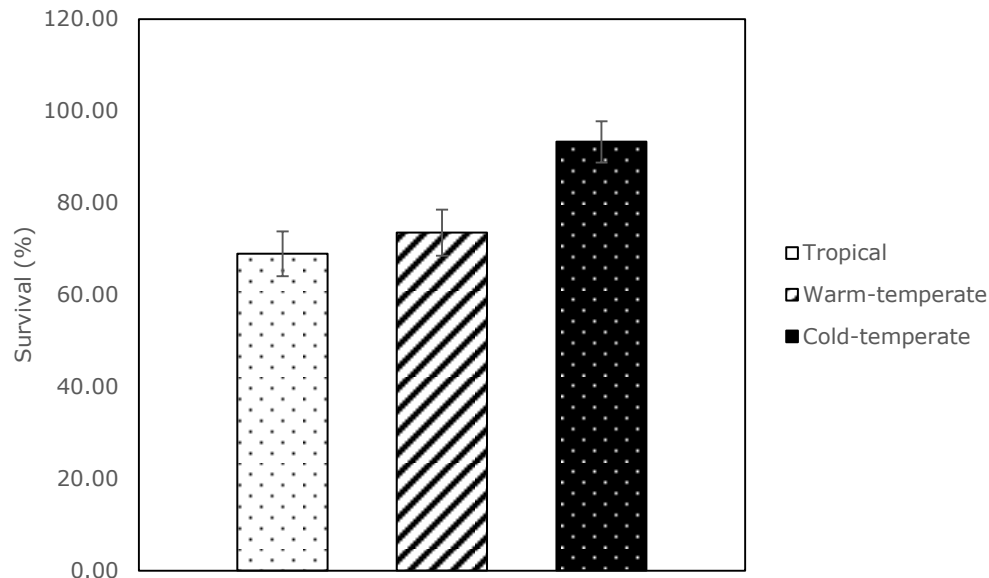


Figure 3. Survival rates of scallops cultured in different biogeographic regions.

Discussion. The study reveals the different scallop species being cultured throughout the world, including the culture methods and design/enclosure used. High growth and survival rates, and bigger shell height are some of the general considerations for choosing species for aquaculture. For example Velez & Lodeiros (1990) cited by Mendoza et al (2003) reported that the tropical species *L. nodosus* attain shell length of 120–150 mm. Under culture condition, this species can grow at about 0.18 mm day⁻¹, with a survival rate of 80% (Mendoza et al 2003). For the culture methods, suspension culture seems to favor good growth and survival as compared to bottom culture. Higher growth rates for scallops cultured in suspension have been reported by different authors (Leighton 1979; Wallace & Reinsnes 1985; MacDonald & Thompson 1985; Avendaño et al 2007; Yu et al 2009). The high growth rate of scallops in suspension can be explained by the better access to high-quality food particles in the water column (Leighton 1979; Yu et al 2009). The low survival rate in the bottom culture was attributed to predation, (Freites et al 2000; Mendoza et al 2003).

Suspended culture using lantern net has been the mostly utilized method for grow-out culture. The enclosure was described to permit good water flow, with the thin monofilament strands resisting heavy settlement of algae and silting; has flexibility in water; compact for easy transportation, handling and storage; and relatively cheap and can last about 4–5 years (Ventilla 1982). Different variations of lantern nets have been used by different authors. For example, Maguire & Burnell (2001) used lantern nets measuring 80 cm in diameter with 20 floors separated by 50 cm for the culture of temperate species *P. maximus*. In the tropical environment, Mendoza et al (2003) used lantern net 50 cm in diameter with four floors to culture *L. nodosus*, while Velasco et al (2009) utilized a 10-compartment nets with a 45 cm floor diameter in growing *A. nucleus*. Another major scallop culture design is the ear hanging method. Ear hanging is a method where a hole of 1.3-1.5 mm drilled at the front eared beak of left valve through the right valve notch or through both front ears near a byssal notch (Kosaka & Ito 2006). In the study of Cano et al (2000), a pair of scallop (*P. maximus*) was attached to an 8 mm rope using a 1.5 mm nylon thread that passed through a 2 mm hole drilled in the ear of the shell. Each pair of scallop was spaced 20 cm from the next pair. On the

other hand, O'Connor et al (1999) conducted ear hanging culture of *P. fumatus* individually attached to a loop but spaced at every 10 cm.

Difference in growth and survival was observed between culture enclosure and ear hanging method. Cano et al (2000) observed a growth rate of 0.27 mm day⁻¹ in ear hung *P. maximus*, while growth rate of 0.13 mm day⁻¹ was observed in the cultured species in rigid plastic cage at density of about 18%. On the other hand, Maguire & Burnell et al (2001) observed a slower growth rate (0.12 mm day⁻¹) for the same species cultured in lantern net at 33% density. Similar result was observed for the species *P. fumatus* (O'Connor et al 1999) and *P. magellanicus* (Grant et al 2003), where growth was faster in ear hanging as compared to the culture in enclosures. This could imply that the type of culture design or method seems to affect growth rates of cultured scallops. The slow growth rate was attributed to the decrease in food ration due to flow inhibition from the cage, especially in the event of fouling (Cropp & Hortle 1992; O'Connor et al 1999; Cano et al 2000; Grant et al 2003). Cropp & Hortle (1992) observed evidence of algal fouling in the lantern cage such as the accumulation of fecal materials and silts, causing the decrease in water flow rate. According to Claereboudt et al (1994), the mesh of the cages impedes the flow of water causing limited food conditions even in the absence of fouling.

Survival on the other hand, was low for ear hung *P. maximus* (46%) as compared to cage culture and was attributed predators to (e.g. *Octopus vulgaris*), and barnacles (*Balanus* sp.) that occur near the bottom (Cano et al 2000).

The density (%) of cultured scallops in all regions was low. In fact, the mean densities fall below the recommended 33%, about 1/3 of the floor area of culture enclosure (Ventilla 1982). Hardy (1991) and Roman et al (1999), suggested densities ranging from 10% to 35% coverage. For this reason, density could not be the factor affecting the difference in growth among regions. For instance, the tropical species *N. nodosus*, cultured at the standard 33% stocking density has growth rate was 0.16 mm day⁻¹ (Mendoza et al 2003). On the other hand, *N. nodosus* cultured at both low (25%) and high densities (50%) both shows a relatively higher growth rates (0.34 mm day⁻¹ and 0.32 mm day⁻¹ respectively) (Velasco et al 2009).

Significantly higher growth rate was observed for the scallops cultured in the tropical region. Density and water depth cannot explain the variation in growth among regions, since the lowest density in the warm temperate region did not translate a higher growth rate. In addition, the densities observed in all regions were low. In the warm-temperate and cold-temperate regions, the low growth rates may be due to the occurrence of slower growth during the onset of cold winter season. Grant et al (2003) reported that shell growth for caged and ear-hung *P. magellanicus* was 20% and 55%, respectively, lower than those observed during fall. In the study of Cancelo et al (1992), growth of *C. varia* was lower in winter and fall as compared to spring season. Cote et al (1994) correlated this seasonal change in growth with temperature and food availability. Temperature has been reported to affect growth of cultured scallops (Cropp & Hortle 1992; Arellano-Martinez et al 2011), and so with food availability (Cancelo et al 1992; Villalejo-Fuerte et al 2004; Arellano-Martinez et al 2011). The lower winter and higher summer temperatures may have led to the reduced metabolic rates, thereby causing reduction in growth rate (Cropp & Hortle 1992).

The result of the survival rates was observed to be opposite of the growth rates. While faster growth rate was observed in the tropical region, survival rate was lowest. One obvious reason is that most of the bottom culture method was reported in this region, thus, affected by predation. Mendoza et al (2003), reported the presence of holes in the dead scallop shells, and broken shells of *N. nodosus*, which could have resulted from gastropod drilling and crab attacks. Similar observation was reported by Frietes et al (2000), suggesting that the low survival rate of *E. ziczac* was affected by predation of decapod crab juvenile. In addition, high temperature has also affected the survival of *N. nodosus* (Velasco et al 2009), considering the shallow culture depth of the region.

Conclusions. Scallops cultured in the tropical regions shows higher growth rate than in other regions, although survival rate was lower. Densities observed for all regions are low. Scallops in the tropical region are generally cultured in shallow waters. Lantern net has been mostly used for the culture of scallops. With the generally fast and high survival rates of scallops, grow-out culture has been a promising venture. Although there were more species reviewed in the temperate environment, nonetheless, the data generated from the analysis can provide information that may guide possible culture operations of scallops in the Philippines. The following recommendations are made:

1. Lantern net can be used as enclosure for scallop culture;
2. Stocking density of 33% surface area coverage should be used with initial scallop size of about 35 mm shell height;
3. Culture in suspended shallow water should be used to minimize predation;
4. There is a need for future studies for scallops in the Philippines, since growth and survival are both species specific and site specific.

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