The Magnitude of Natural Recruitment in a Cultured Population of Japanese Scallop

*Patinopecten (Mizuhopecten) yessoensis* on Yubetsu Seabed (Japan), Sea of Okhotsk

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**Abstract:** Recruitment of naturally occurring Japanese scallops (*Patinopecten (Mizuhopecten) yessoensis*) into sowing-culture grounds has important implications for the population dynamics and aquaculture management because it can cause unfavorable lower growth due to high density and a highly variable size range, which can lead to increased costs for harvesting and selecting market-sized scallops. In the present study, the occurrence and magnitude of natural recruitment in a scallop population cultivated at Yubetsu seabed (northern Japan) was investigated. Assessment was done through a photocensus at 4 culture areas, A, B, C and D, which contained 1-, 2-, 3- and 4-year classes of seeded scallops, respectively. The magnitude of natural recruitment varied annually among the culture areas. In 1990 and 1991, natural recruits composed 20 and 32% of the scallops in area C and B, respectively. In 1992, few natural recruits were observed in area A (8%) and C (7%). The highest number of natural recruits occurred in 1993 in area A (≥ 41%). These results suggest that routine monitoring of density throughout the whole period of culture is indispensable. Transfer of scallops from high-density areas caused by natural recruitment to low-density areas should be considered.

**Key words:** aquaculture management, bottom culture, *Patinopecten (Mizuhopecten) yessoensis*, photocensus, recruitment, scallop

**INTRODUCTION**

Scallops are very valuable shellfish and the subject of various important commercial fisheries around the world. In Japan, the most common and exploited cold-water scallop species is *Patinopecten (Mizuhopecten) yessoensis*. *P. yessoensis*, generally known as the Japanese scallop, represents a major portion of the total world production (FAO 1997). In Japan, Hokkaido is the largest landing base for this species. In 1998, about 400,000 tons (24% of the total marine production in Hokkaido) was landed.

Even though scallops are a late entrant on the shellfish farming scene (Grant 1996; Cruz & Ibbara 1997), in Hokkaido, culture trials have been attempted since 1936 (Kinoshita 1949). Nowadays, the scallop industry in Hokkaido is based largely on bottom culture of *P. yessoensis*. Of the total scallop production in Hokkaido recorded in 1998, about 60% resulted from bottom culture (Department of Fisheries and Forestry Hokkaido 2000). This method is considered the cheapest way of carrying out the final stages of commercial grow-out (Hardy 1991). Bottom culture has been extensively conducted in coastal waters along the Sea of Okhotsk shoreline in northeastern Hokkaido (Fuji 1987; Goshima & Fujiiwara 1994; Kurata 1999). Along this shoreline, Yubetsu is an important commercial culture ground (Fuji 1987; Kurata 1999).
In the bottom culture of scallops, natural recruitment (i.e., recruitment into the culture ground by naturally occurring (non-sowed) scallops) can cause scallop densities on the grounds to be higher than desired, which can lead to unfavorable growth rates (Kurata 1999). Natural recruitment can also cause the size range of a cultured scallop population to become highly variable and lead to reduced harvest size (Paturusi 2001). As a consequence, natural recruitment can cause predicting output to become difficult and market prices to drop. Measuring recruitment in bottom-cultured populations, therefore, is important both ecologically and economically.

Various aspects of the ecology of *P. yessoensis* have been studied (Ito 1991), such as its reproductive ecology (Maru 1985), distribution and abundance (Goshima & Fujiwara 1994), feeding (Kurata et al. 1991) and growth (Maru & Obara 1967; Fujita & Mori 1990; Kurata 1999), but little attempt has been made to estimate natural recruitment. In the present study, we examine the natural recruitment that occurred into a seeded scallop population within a culture ground at Yubetsu. The implications of this recruitment on aquaculture management strategy are then discussed.

**MATERIALS AND METHODS**

**Culture ground**

The culture ground at Yubetsu is a subtidal seabed located parallel to the shoreline situated between 44°12' and 44°19' N, and between 143°37' and 143°50' E (Fig. 1). The ground is on a gentle slope with depths ranging from 30 to 60 m extending 7 km offshore. Coarse sand to small gravel are the dominant sediment in the area. The culture ground is divided into four areas (Fig. 1), and during each year, a different area is seeded. As a result, the seeded scallops within each area are of a single year class, and these classes differ among areas.

Oceanographic conditions on the ground are affected by the warm-water Soya Current (Aota 1975), which flows northward through the Sea of Japan (East Sea) and passes southeastward through Soya Strait (Iida 1962; Moriyasu 1972). This current flows along the coast of northeastern Hokkaido at about 1–4 km/hour (Ito 1991), bringing warm water to the Sea of Okhotsk (Maeda 1968; Aota 1975). The Soya Current and the southward-flowing East Sakhalin Cold Current determine the environmental characteristics on the culture ground at Yubetsu. Average water temperatures recorded at about 50-m depth approximately 5–6 km from the coastline from 1983 to 1995 ranged from −1.2°C in winter to 17°C in summer (Yubetsu Fishermen’s Cooperative Association, unpublished data).

**Culture system**

Seeds are first produced through the process of spat collection and intermediate culture. Spats are captured using collectors suspended in the water column where a spawning stock is kept, such as in Saroma Lagoon or in coastal areas of the Sea of Okhotsk. In intermediate culture, the collected spats are reared in suspended nets during the first year until they reach a shell height of 30 to 50 mm. The seeds are then released on the culture seabed for a 3-year grow-out period. In May of each year from 1991 to 1994, 215,956,000 to 221,513,000 juveniles were released onto one of four culture areas (Table 1).

**Sampling system**

To obtain data on bottom-cultured scallops, underwater
photocensuses were conducted. The underwater camera system used took 0.25 m² (0.5 m × 0.5 m) or 1 m² (1 m × 1 m) photos of the seabed. The location of each photograph was precisely determined using the Global Positioning System (GPS). A detailed description of the system is provided by Goshima & Fujiwara (1994).

For sampling, each culture area was divided into 96 to 110 subareas measuring 1000 m × 500 m. Photographs were taken at five randomly selected spots in each subarea. Photographs were taken four times in 1994 (April, June, August, and October). No photos were taken of the 1-year class (area A) in April because the ground had not been seeded yet. The surface area in each photograph measured 1 m². To increase the accuracy of the counts and measurements of the newly released seeds, the surface area in photographs taken in June and August of the 1-year class was 0.25 m².

Data analysis

The total population density was estimated by counting the number of live scallops recorded in the photographs. Counting and recognizing the live shells were conducted by divers with experience in observing scallops under natural conditions. Densities were determined as number of scallops per 1 m² area. An average of the nearly 500 photographs taken in each area was determined to estimate the mean density within each area.

Recruitment into each area was estimated by analyzing size-frequency distributions. These distributions were separated into component age groups, and cohort analysis was conducted on shell length data set provided through the measurement of shell size from the photographs.

Shell length data was collected by scanning and saving the photographs using Adobe photoshop™ as a PICT file format. Using NIH image software, the shell length of each scallop recorded in the pictures was individually measured as the greatest distance between the anterior and posterior ends. The procedure used to measure the shell lengths is described in detail by Paturusi (2001). The shell length data set was then analyzed using Progean™ Ver. 4.1 E (Tsutsumi 1999). This program was used to create a size-frequency distribution and to identify possible cohorts within a range of a size distribution. These results were used to compute the percentages of each cohort within each culture area. The density of each cohort was then calculated by multiplying the total density and the percentage of each corresponding cohort.

RESULTS

Population structure and natural recruitment

Due to the shifting culture system used, the age of seeded scallops in each culture area was known (Table 1). The initial planting shell height of 1-year-old seed scallops ranged from about 30 to 60 mm with a mean of about 42 mm. On the seabed, individuals with shell size beyond this range were assumed to be either natural recruits or individuals not collected in the previous harvest.

The wide range of shell sizes in each area indicates that natural recruitment of native scallops occurred in all areas. This was confirmed by cohort analysis, which revealed a polymodal size structure in each area (Fig. 2).

(1) 1-year-old released scallops

Figure 2A displays the results of cohort analysis conducted on the 1-year class in area A. Scallop in this area comprised three cohorts, indicating natural recruitment occurred into this area. The first cohort representing 88 to 90% of the total population (June: 88%, August: 88%, October: 90%) was 1-year-old scallops. This cohort was considered to be formed mainly by the individuals released in May 1994 and presumably natural recruits. The second cohort composed 8–9% of the total (June: 9%, August: 8%, October: 8%) and was composed of 2-year-old scallops. These scallops recruited into area A in 1992 or 2 years before the seed scallops were released. The third cohort was the largest size class and might have been included individuals that were not collected at the previous harvest (June: 3%, August: 3%, October: 1%).

(2) 2-year-old released scallops

At least three cohorts were found in area B, where 2-year scallops were cultured (Fig. 2B). The main cohort representing 58 to 67% of the population (April: 67%, June: 59%, August: 60%, October: 58%) was composed of 2-year-old scallops, which were presumably mostly those released in 1993. The other cohorts were considered to be natural recruits and those missed in the previous harvest. One-year-old natural recruits representing 3 to 5% (June: 4%, August: 3%, October: 5%) were observed in the samples between June and October. These scallops recruited into the area in the year of seeding (1993). High natural recruitment representing 27 to 35% (April: 27%, June: 33%, August: 32%, October: 35%) of the population occurred in 1991 or 3 years before seeding. As shown in Fig. 2B, the largest size class (1–6% of all individuals) was thought to be formed by scallops.
remaining by the previous harvest (April: 6%, June: 4%, August: 3%, October: 1%).

(3) 3-year-old released scallops

In area C, 3 cohorts were recorded in all samples from April to October (Fig. 2C). Scallops on the seabed before and after sowing were clearly visible from the cohort analysis.

Three-year-old scallops, which were presumably composed mainly of seeded ones, was 68–79% of the total population (April: 79%, June: 74%, August: 68%, October: 69%). Natural recruitment was observed to take place at the time of and after seeding. About 4–8% of the total population recruited into the area in 1992, the year of seeding (2-year-old recruits; April: 7%, June: 4%, August: 8%, October: 8%). About 14–23% of the total population recruited into the area before seeding occurred (4-year-old recruits; April: 14%, June: 22%, August: 23%, October: 23%). A wide range of size classes was observed in these natural recruits (Fig. 2C), suggesting that recruitment might have occurred 1 and/or 2 years before the seed scallops were released.
Natural recruitment of Japanese scallop

4-year-old released scallops

Two cohorts were clearly recognized from the samples taken just before harvest (April) and those taken during the harvest period (June, August and October). The main cohort, which had a large size and represented 71 to 96% of the total population (April: 96%, June: 92%, August: 83%, October: 71%), was considered to be composed mainly of released scallops, and the other cohort (April: 4%, June: 8%, August: 17%, October: 29%) with a smaller size class was composed of natural recruits (Fig. 2D). The wide size range observed indicates that recruitment occurred over several years.

Population density and natural recruitment

Density data at each sampling time were pooled to determine an average density for each culture area (Table 2). For the 4-year class, because of decreasing percentages of released scallops by size-specific harvesting from June to October (Fig. 2), only data from the April sample were used. In other year classes, all data on percentages of continuous cohorts from April to October within a given year class were pooled. In the areas where 1- and 2-year class seeded scallops were cultured, the total number of scallops was about 59% (area A) and 19% (area B) higher than those of released scallops. The number of 1-year-old scallops (area A; 6.98 m⁻²) was 41% higher than the total number of released seeds (4.94 m⁻²), so at least 41% of the 1-year-old scallops in culture area A were natural recruits.

Table 2. Density (no. individuals m⁻²) of total and released scallops, and their respective percentages observed for each year class. Density data were pooled at each sampling time for each year class. Initial stocking density of each year class was calculated from the total number of released seeds divided by the size of the seeded area (see Table 1). Percentages of total density and target year-class density assumed to be released scallops to the initial density are also shown. The percentages of the target year-class scallops will indicate the survival rate of each released year class if there is no natural recruitment.

<table>
<thead>
<tr>
<th>Culture area</th>
<th>Age of released seeds (year)</th>
<th>Initial density of released seeds (no. scallops m⁻²)</th>
<th>Total density (no. scallops m⁻²)</th>
<th>% that the total density formed of the initial density</th>
<th>Density of target year-class assumed to be released (no. scallops m⁻²)</th>
<th>% of target year-class density to the initial releasing density</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>4.94</td>
<td>7.84</td>
<td>158.7</td>
<td>6.98*</td>
<td>141.2*</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>6.03</td>
<td>7.18</td>
<td>119.0</td>
<td>4.38</td>
<td>72.6</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>4.95</td>
<td>4.78</td>
<td>96.5</td>
<td>3.49</td>
<td>78.4</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>5.14</td>
<td>3.52</td>
<td>68.4</td>
<td>3.38</td>
<td>65.7</td>
</tr>
</tbody>
</table>

* mixing with natural recruits.

DISCUSSION

The size distribution of scallops in areas where the known age of released seeds were being cultured was much greater than the range of a given age. This wide size range indicates some individuals entered the sampling area before and/or after the seeding. Cohort analysis confirms that both native scallops and released scallops occurred together in the cultured population (Fig. 2).

In culture area A, where 1-year seeded scallops were cultured, the total density was as much as 159% of the initial seeds at 5 months after sowing, and at least 41% of the 1-year-old scallops in culture area A were natural recruits (Table 2). Since the natural recruits were of the same age as the seeded scallops, this recruitment occurred in 1993, a year before the seeds were released. In the adjacent culture area B, only 4% of the total population was composed of 1-year-old natural recruits (Table 3), indicating that recruitment in 1993 was high only in culture area A. Two-year olds composed only 8% and 7% of the individuals in areas A and C, respectively, indicating recruitment was low in 1992. Recruitment in 1991, however, was notably high as recorded in area B (32%), but no 3-year-old natural recruits were observed in culture area A. In 1990, recruitment occurred only in area C. The largest size classes in areas A and B, which was considered to be post-harvest remaining stocks, might also have contained 4-year natural recruits. However, they composed only 3% of the total number of individuals in each area. The results of natural recruitment observed in all areas between 1990 and 1993, therefore, suggest that the magnitude of recruitment was different among years and culture areas (Table 3).
Cohort analysis was unable to detect the recruitment that occurred the year before seeding because the natural recruits would have been the same age as the released scallops. So far, the only way to confirm the occurrence of natural recruitment resulting in recruited scallops at the same age as the released seeds is based on the density alteration as was clearly shown in culture area A (Table 2). Apart from improvements in the whole culture process (e.g., increased initial seed size, improved techniques and procedures of seeding) leading to higher survival (Kurata 1999), natural recruits could have caused overestimates of survival for each year class (Table 2). The present study also revealed that natural recruitment differs from year to year and from culture area to culture area. Possible causes for this phenomenon could not be determined in the present study, however environmental instability, which has been recorded at a sowing-culture ground around the Abashiri district (Fujita & Mori 1990), might have caused the sporadic recruitment in the Yubetsu culture areas.

Natural recruitment in culture areas can cause overcrowding and lead to reduced growth rates (Ventilla 1982; Parsons & Dadswell 1992; Cote et al. 1994; Kurata 1999). If many small sized scallops occur together with the harvestable population, this can lead to increased costs for harvesting and selecting market-sized scallops and cause serious problems when marketing the scallops. The ability to accurately predict natural recruitment could be used to adjust the density of released scallops in order to keep the actual density near a desirable level. If future recruitment in a particular area cannot be estimated before seeding, routine monitoring of the density throughout the whole period of culture is needed.

Scallops from high-density areas could then be transferred to low-density areas. Such removing and replanting scallops has already been done in Sarufutsu on the coast of the Sea of Okhotsk (Sarufutsu Fisherman’s Cooperative Association, personal communication). Before any such managerial steps are taken to control cultured scallop populations, labor costs and the economic viability of maintaining a desired density must be considered.

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**REFERENCES**


Grant, J. 1996. The relationship of bioenergetics and the

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**Table 3.** Percentage that natural recruits composed of each year class in each culture area on which a given year class of released seeds was cultivated.

<table>
<thead>
<tr>
<th>Culture area</th>
<th>Age of released seeds (year)</th>
<th>Natural recruits (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-year</td>
<td>2-year</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>(?)</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>–</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>–</td>
</tr>
</tbody>
</table>

(?) ; none.

(?) ; undetected by cohort analysis due to the same age/size as released seeds.

(?)* ; at least 41% natural recruits indicated by 141% of 1-year-old scallops.

** ; probably included 1- and 2-year recruits.


