

## Population estimates, extraction, and translocation of the pectinid *Argopecten purpuratus* within Mejillones Bay, Chile\*

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**SUMMARY:** The population of the scallop *Argopecten purpuratus* in Mejillones Bay, Chile (23°S) was estimated using diving-quadrat techniques between July and August 1999. The population, distributed over an area of 255 ha, was estimated at about  $18 \times 10^6$  individuals, having a mean length of about 68 mm. Of this number, about  $16 \times 10^6$  individuals were aggregated into a core area of 51 ha. A subsequent controlled harvest carried out in 33.5 ha of this area in November 2000 produced only  $2 \times 10^5$  individuals, strongly suggesting that large scale clandestine (illegal) harvesting had occurred since the original population survey. Reseeding of collected scallops was carried out in an interior area of the bay which had low densities of scallops but highly similar physical and chemical seawater characteristics. Post-seeding mortality of the translocated scallops, determined two weeks after the transfer, was 12.5%, with a mean of 2.5 indiv./m<sup>2</sup> in an 8.2 ha area. The low initial mortality, compared with values in the literature, suggested that the methods of retrieval, transport, and restocking the scallops could serve as a viable repopulation strategy in other areas in the future.

**Key words:** scallop, *Argopecten purpuratus*, stock evaluation, translocation, Chile.

**RESUMEN:** EVALUACIÓN DE LA POBLACIÓN, EXTRACCIÓN Y TRASLADO DEL PECTÍNIDO *ARGOPECTEN PURPURATUS* EN LA BAHÍA DE MEJILLONES, CHILE. – La evaluación directa mediante buceo realizada entre julio y agosto de 1999, del recurso *Argopecten purpuratus*, distribuido sobre un área de 255 Há en Bahía de Mejillones, Chile (23°S), indicó la existencia de una población de  $18 \times 10^6$  de ejemplares, con una talla promedio de 68 mm. De éstos,  $16 \times 10^6$  de individuos se concentraban en un área de 51 Há. Una posterior extracción controlada realizada en noviembre de 2000, de todos los ejemplares presentes en una superficie de 33.5 Há dentro de esta área, alcanzó los  $2 \times 10^5$  individuos, y puso en evidencia la fuerte presión de pesca ilegal que soporta este recurso a pesar de encontrarse prohibida su extracción. El traslado y siembra de estos ejemplares, hacia un área de baja densidad al interior de la misma bahía, y de características físico-químicas similares a las del área de extracción, permitió determinar una mortalidad post-siembra, después de dos semanas, de un 12.5%, distribuyéndose los individuos dentro de una superficie de 8.2 Há con una densidad media de 2.5 ind/m<sup>2</sup>. La baja tasa de mortalidad registrada, muestra que la metodología aplicada con el recurso en su extracción, traslado y siembra fue efectiva y se podría adoptar en otras situaciones similares.

**Palabras clave:** *Argopecten purpuratus*, Mollusca, Pectinidae, evaluación, traslado, siembra.

### INTRODUCTION

*Argopecten purpuratus* (Lamarck, 1819), distributed from Paita, Perú (5°S) to Valparaíso Chile (33°S) (Marincovich, 1973), is a scallop of high commercial

value. This species was recognised by Wolff (1987) as forming part of the subtropical fauna of these waters since the Miocene epoch, wherein the species retained some characteristics of a warm water species. Thus, in periods of unusual warming of coastal waters off S. America due to the "El Niño" phenomenon, *A. purpuratus* may experience a short-

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ening of its larval period as well as reduction of larval, juvenile, and adult mortality due to lowered predation and competition, which produces unusual population booms. Arntz and Fahrbach (1996), for example, reported that during the El Niño event of 1982-83 this resource increased in biomass by over 60X in Paracas Bay, Perú. Scallop populations of Mejillones and Antofagasta Bays in Chile supported an extraction of 4200 TM in 1984, representing 82% of the record (5000 TM) catch in Chile that year (Avenidaño and Cantillanez, 1997). Fishing pressure stimulated by the high yields obtained in years following the 1982-83 El Niño event quickly reduced the catch to 1410 TM in 1985 and only 492 TM in 1986 (SER-NAPESCA, 1986; 1987). As a result of this drop, total closure was imposed on harvesting scallops in subsequent years, but the banks showed minimal recovery (Wolff and Alarcón, 1993; SUBPESCA, 1995; Avenidaño and Cantillanez, 1997).

During 1997 and 1998 a major El Niño event occurred which affected the SE Pacific coast. This event was similar in magnitude to that of 1982-83, which was the most intense of the century (Tarazona *et al.*, 1999). In 1999, following this event, a systematic evaluation of the scallop resource was carried out in a sector of Mejillones Bay (23°S) along about 12 km of coastline. This study was carried out by the Port Complex of Mejillones Project (developer of the projected port in this bay), as requested by the National Committee on the Chilean Environment as a measure to protect the scallop population. At the end of 2000, subsequent to the conservation programme, authorisation was extended for the harvesting and relocation of scallops from a small portion of the bed surveyed in 1999 (projected to be affected by the first stage of the construction) to another area of the bay populated at very low density. This effort represented an experimental demonstration of the effectiveness of repopulation of natural banks, to promote their self-maintenance over time.

One complication encountered in this study was the occurrence of clandestine harvesting of scallops from the area studied. This activity, counter to the regulations protecting this resource, have introduced an uncontrolled variable into stock assessments and resource protection throughout Chile, and threatened the continued survival of the scallop population. The results of the present studies have demonstrated the deleterious effects on the scallop populations of clandestine harvesting, and are presented and discussed, along with the post-seeding results obtained with the translocated scallops.

## MATERIALS AND METHODS

### Determination of the area of distribution

The distribution of *A. purpuratus* in the study area was determined by diving reconnaissance. Size and continuity of the bank were estimated by occupying forty transects perpendicular to the coast and 300 m apart. The beginnings and endings of the transects were marked using buoys, whose geographical position was determined using a GARMIN Co. 12 XL global positioning system (GPS). Subsequent projection of the transects over the chart of the region was used to calculate population densities of scallops over each transect. Transect data were also used to estimate the entire surface area, using a ZETINF KP-27 polar planimeter with compensation.

### Pilot sampling

Once the area occupied by the scallop population has been determined, pilot sampling was carried out using one square metre quadrats as sampling units. For this, a symmetrical sampling grid was established using 14 transects perpendicular to the coast and separated by 900 m. Sampling stations were established at 6, 10, 14, 18, 22 and 26 m depths. Thus, 56 stations were established, and a total of 275 quadrats were sampled. After the data had been obtained, the minimum number of sampling units needed to estimate the total density and abundance of the *A. purpuratus* population was determined using the following expression (Thompson, 1992):

$$N_0 = \frac{N^2 * Z^2 * \Gamma^2}{D^2}$$

where:

$N_0$  = minimum number of samples

$N$  = total surface of the bank expressed in sampling units

$D$  = lower and upper limit of the true value of abundance (considered as 15% of the population estimator calculated from the pilot sample.)

$Z$  = normal distribution constant (1.964 for an  $\alpha = 0.05$ )

$\Gamma^2$  = variance of the mean of the number of individuals per sampling unit pilot sample.

### Definitive sampling

The definitive sampling carried out in August

1999 was done by designing a uniform sampling grid with separation intervals of 300 m on which stations were established located at each 4 m depth, covering the entire band of appearance of the organisms.

Because the densities of individuals obtained in the pilot sampling showed variability with respect to the position of the area sampled, the presence of a strong stratification with depth of the population was established. Due to this, the minimum number of units sampled determined in the estimation of the resource abundance in the total area of the bank (728 quadrats) was distributed in accordance with the differential assignation as a function of the weight of each stratum (depth), 179 quadrats in the area of high density and 549 in the area termed peripheral.

The coordinates of each station sampled were established by means of GPS. The depth was obtained using a ProMaster depth gauge, and the density of scallops at each station was determined by diving, counting the number of individuals present per m<sup>2</sup>, replicated five times at different points separated by 50 m. Replicates were chosen by haphazardly tossing a one-metre square metal frame at each station.

In order to determine which stations represented which stratum, the numbers of individuals per m<sup>2</sup> collected in the definitive sampling were arranged on the chart of the sampling area. Subsequently, the average value of the density and abundance were calculated for each stratum, according to Thompson (1992).

The estimator of the variance of the population was obtained by multiplication of the variance of the stratified mean by the square of the total surface area of the bank, expressed in sampling units (Thompson, 1992).

The analysis of abundance in each stratum was done by adding the data of the pilot sampling to the data obtained in the definitive sampling in order to further decrease the real limits of the abundance.

### **Determination of the demographic structure of the population**

At each station where the density of organisms was obtained, scallops from two quadrats were recovered and the maximum length (antero-posterior) was measured using a caliper accurate to the nearest 0.1 mm. These data were tabulated to obtain the size-frequency relation in order to determine the relationship between the different size groups within the distributional strata.

### **Harvest and reseeded**

Controlled harvest of all the scallops from an area of 33.5 ha (the "donor area"), representing the area with the highest density as determined in 1999, was authorised in November 2000. This was done as a conservation measure, repopulating an area within Mejillones Bay which had a low scallop density (0.1 ind/m<sup>2</sup>), and was 15 km from the extraction area. Before translocation of the scallops, simultaneous pilot sampling was carried out on physical and chemical properties of the ambient seawater at the donor site and receiving site in April, May and June 2000 to ascertain whether there were any qualitative differences between the sites.

Prior to relocation of the specimens, (Nov. 2000), the donor area was marked with buoys. The density and size frequency of the scallops in this area were determined by monitoring 10 stations previously sampled in August 1999. Data were obtained for 10 one-meter-square quadrats at each station. The majority of the scallops in the donor area were then harvested manually by seven divers (local fishermen) using hookah gear, working four hours daily for 12 days. Collector bags containing about 500 scallops each were hung from the workboats until the end of the daily dive period. Each day, two bags were manually tallied to estimate the total number of scallops obtained, and then all harvested scallops were transferred to the receiving area and scattered as uniformly as possible in the area, guided by marker buoys.

### **Evaluation of the seeding**

Two weeks after the transfer procedure an evaluation was made of the surface area seeded, the depth contours of the area and the density of scallops in the area by means of diving. For this, 49 stations were sampled at each 3 m depth, distributed over 10 transects perpendicular to the coast and 50 m apart. Living and nonliving scallops were tallied for five replicate 1 m<sup>2</sup> quadrats at each station.

## **RESULTS**

### **Natural distributional area of the resource**

The evaluation carried out in 1999 showed that *A. purpuratus* was distributed continuously over an area of 255.23 ha extending from 23°03'53.9"S,

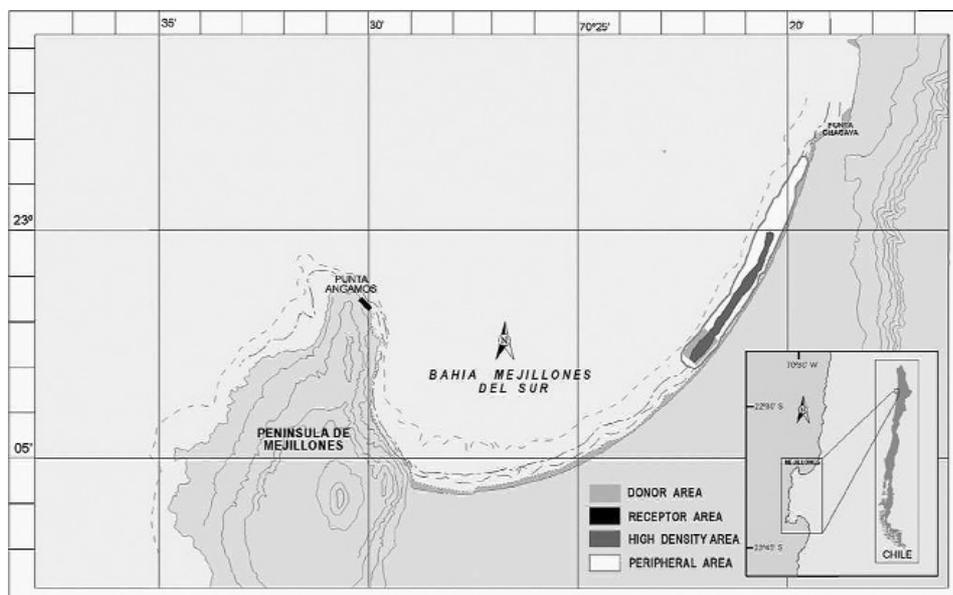


FIG. 1. – Location of the distributional area of *Argopecten purpuratus* in Mejillones Bay, evaluated in August 1999, also showing the donor and receptor areas for the scallops translocated in November 2000.

70°23'23.3"W to 22°58'38.0"S, 70°19'34.0"W at depths ranging from 8 to 24 m. In this area, the scallops were concentrated within an area of 51.43 ha over 5700 m parallel to the coast between the 12 and 20 m bottom contours (Fig. 1).

## Abundance

Results obtained from a universe of 1070 quadrats sampled in August 1999 showed the presence of  $16.622 \times 10^6$  scallops in the high density area (Fig. 2), with a mean density of 31.54 indiv/m<sup>2</sup> (std. dev. = 21.19). About  $2.02 \times 10^6$  scallops occupied the peripheral area, at a density of about 0.99 indiv./m<sup>2</sup> (std. dev. = 1.81). These data were used to

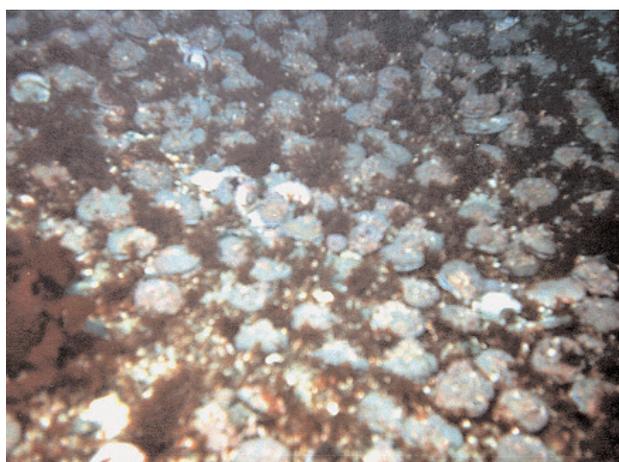


FIG. 2. – Underwater view of the high density area of *A. purpuratus* evaluated in August 1999 in Mejillones Bay.

calculate the abundance in the total area studied to be  $18.24 \times 10^6$  individuals (variance =  $5.33 \times 10^{11}$ ), with an average density of 7.14 indiv/m<sup>2</sup> (average stratified variance = 0.08).

## Size frequency

### High density area

This area was populated by individuals ranging from 9.3 mm to 99.9 mm, with an average size of 66.0 mm (std. dev. = 21.05). About 63.09% of the individuals in this sector were larger than 70.0 mm, though only 2.72% of these were of the legal size for extraction established in Chile of 90.0 mm (Figure 3A).

### Peripheral area

In the zone encircling the high density area the individual size ranged from 14.4 mm to 130.8 mm, with a mean size of 76.6 mm (std. dev. = 23.71). Individuals over 70.0 mm represented 69.45% of those in the sector, with 29.23 % above the minimum legal size (Fig. 3B).

The size structure of the entire population in August 1999 varied between 9.3 mm and 130.8 mm, with an average of 68.7 mm (std. dev. = 22.22). The analysis showed 64.69% to be over 70.0 mm and only 9.36% were above the minimum legal size (Fig. 3C).

The results obtained in November 2000 gave a density of 2.6 indiv./m<sup>2</sup> in the donor area (std.dev.=1.47), and a size structure which varied

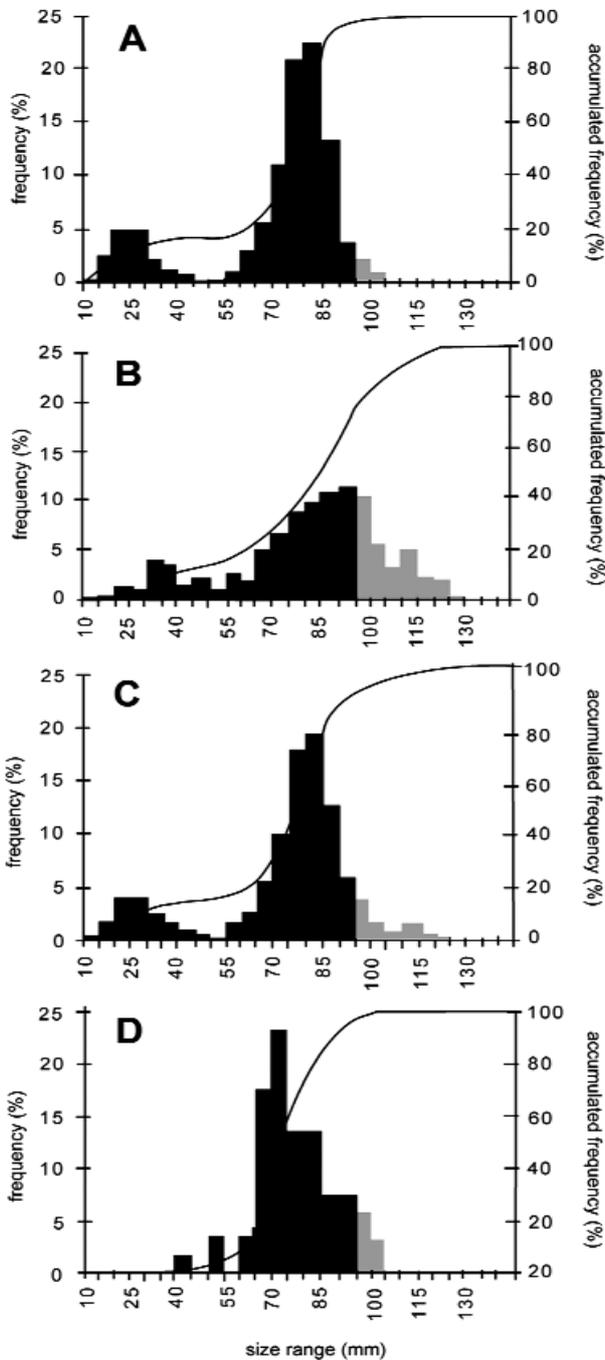


FIG. 3. – Distributions of size frequency of *A. purpuratus* in Mejillones Bay (MLS=minimum legal size). A, high density area, August 1999; B, peripheral area, August 1999; C, Complete population structure, August 1999; D, Population structure in donor area in November 2000.

between 36.8 mm and 97.4 mm, with an average of 71.4 mm (std. dev. = 11.92), as shown in Figure 3D.

#### Physical and chemical parameters of donor and receiver areas

The physical and chemical parameters measured suggested there were no important variations

TABLE 1. – Average density of individuals of *A. purpuratus* per stratum, and percentage mortality during the two weeks post-seeding.

Depth Stratum (m)	mean density indiv./m <sup>2</sup>	mean density nonliving indiv./m <sup>2</sup>	Mortality %
21-19	3.2 (± 3.2)	0.4 (± 0.6)	11.7
18-16	3.2 (± 3.2)	0.4 (± 0.7)	13.4
15-13	3.9 (± 3.2)	0.5 (± 0.7)	11.8
12-10	2.3 (± 3.2)	0.2 (± 0.6)	10.3
9-5	0.7 (± 1.0)	0.0	0.0

between the two areas. Values obtained from April to June 2000 at both sites gave values for chlorophyll *a* of 1.4 to 4.4 µg/l, pH = 7.7 to 8.0, dissolved oxygen of 2.2 to 4.3 mg/l, and T°C of 13.2 to 14.7 .

#### Harvest and reseeded

In November 2000, a total of  $2.09 \times 10^5$  scallops were removed from the donor area, with an average transfer of 2488 individuals daily per boat (max.= 7228, min.= 420).

Diving reconnaissance of the seeded area after seeding showed that the introduced scallops had taken up normal positions in the benthos within 24 h of their introduction.

#### Final evaluation of the seeding

Diving reconnaissance at two weeks post-seeding carried out at 44 of the 49 stations evaluated showed that *A. purpuratus* was present from 5 to 21 m depth over an area of about 8.2 ha. The results obtained from the stations (Table 1) gave a mean value for mortality of 12.5% and a mean density of (living) *A. purpuratus* of 2.5 indiv./m<sup>2</sup> .

#### DISCUSSION

As reviewed by Orensanz *et al.* (1991), the use of diving coupled with the quadrat method is probably the most effective way of estimating abundance and spatial pattern in the distribution of peccinid populations.

Results of the present study obtained in 1999 after the significant El Niño phenomenon of 1997-98 verified the presence of a large scallop population in Mejillones Bay which occupied an area of about 255 ha, with 88.9% of the individuals concentrated in about 51 ha. Previous data in the same region were obtained by Zuñiga *et al.* (1983) and

Avendaño and Cantillanez (1994). The latter data set reported a population of  $8.21 \times 10^6$  scallops occupying an area of 381 ha, with about 81% of the stock aggregated in about 102 ha. These data represented a year not associated with El Niño, and showed somewhat less than half the present numbers ( $18.2 \times 10^6$  scallops). The centrally aggregated distributions observed were typical of those observed with other pectinid species. These commercially exploited stocks occur in a continuous distribution at (more or less) uniform densities over a core area surrounded by a peripheral zone of lower densities (Caddy, 1989).

Low densities comparable with those of the peripheral zone of the present study have been found in Tongoy Bay (Coquimbo, Chile), and in the peripheral area which surrounds the scallop bank at La Rinconada (Antofagasta, Chile) (Alarcón and Wolff, 1991; Dames and Moore, 1995; Avendaño and Cantillanez, 1996), where the densities ranged between 0.16 and 1.12 indiv./m<sup>2</sup>.

The higher biomass indicated by the present study compared with the results in the same area in 1994 was related to the occurrence of the El Niño phenomenon of 1997-98, which strongly affected the coast in this region, producing favourable conditions for recruitment of this species (Arntz and Fahrbach, 1996). These authors cited historical "explosions" of *A. purpuratus* populations, as evidenced by subfossil accumulations of these shells in the Peruvian coastal desert.

### Clandestine harvesting

In spite of the increase in individuals of *A. purpuratus* enumerated on this bank in 1999, there was a low percentage of legal-sized scallops and also a decrease in the range of sizes in individuals measured in 2000 compared with 1999 (mean increment of 2.7 mm from one year to the next). This suggested a loss of larger-sized scallops from the bank which we attribute to clandestine harvesting (overfishing) of the resource. This became further evident in the controlled harvest carried out in the donor area 14 months later, in November 2000, in which it was estimated that over  $2 \times 10^6$  scallops would be obtained based on the densities recorded in 1999. In reality, only 10% of this figure ( $2.09 \times 10^5$  scallops) was obtained.

Clandestine harvesting of scallops interferes with the correct functioning of regulations established in order to conserve the resource (SUBPESCA, 1995).

Morales and Gezan (1986) suggested that bans and prohibitions on commercialisation of marine resources in this country are not respected by the fishing community, whose short-term interests outweigh long-term considerations related to rational long-term resource protection.

Strong fishing pressure on this resource, particularly after population increases brought about by the El Niño events, has been recognised in Perú by Arntz and Fahrbach (1996). These authors indicated that after the unusually high production of this species which occurred in 1983 in Perú, overfishing removed a major portion of the scallop population from Paracas Bay in 1984 and from Independence Bay in 1985. By the end of 1985, the government of Perú was forced to close all harvesting of the resource. In spite of the regulations, by 1986 the scallop populations had been completely exploited with the exception of a small number of individuals occurring below 30 m. Based on this, Wolff (in Arntz and Fahrbach, 1996) suggested that it may be unreasonable to expect long-term sustainable harvesting of this species following the high production generated by the El Niño events. He recommended that under conditions of high production, permission should be granted to exploit these increased populations. In Chile, incomes of the fishermen would be materially improved if permission for legal harvesting of the resource were granted in order to avoid the present clandestine harvesting and thus lower the price.

### Translocation

The harvesting, transport and reseedling of *A. purpuratus* described in this study represent one of the first experiments of this type carried out in Chile. Elsewhere in the world, successful repopulation has been carried out with *Patinopecten yessoensis* in Japan and *Pecten maximus* in France (Ventilla, 1982; Huelvan, 1985; Buestel *et al.*, 1987; Boucher and Dao, 1990; Brand *et al.*, 1991; Silina, 1994). Lake *et al.* (1987; cited in Brand, 1991) suggested that the best sizes with which to perform transplants were between 60 and 70 mm in length, as they were less susceptible to predation at this size. Buestel (1981) suggested that for *P. yessoensis*, a species widely used in repopulation by bottom seeding in Japan, survival rates were variable and fluctuated between 25 and 80%, with an estimated mean of 50%. This variability was primarily dependent on preparation of the bottom (predator control), while Ventilla (1982) sug-

gested that this species experienced a survival rate of 25 to 30% when seeding individuals measuring about 30 mm. However, it has now been shown that the greatest mortalities in the seeding activity occurred due to predation within the first week post-seeding. Caddy (1989) suggested that similar mortality observed with *P. yessoensis* occurred within the first 48 h of liberation of the scallops, presumably due to olfactory responses of the predators. Goldberg *et al.* (2000) observed no survival a week after seeding *Argopecten irradians* with an average length of 38 mm; in a second trial they observed total mortality two weeks after seeding. Only in a third trial were these authors able to observe survival of the translocated scallops after two weeks. In the above cited experiments, the authors observed broken shells in the seeding area due to predation. Barbeau *et al.* (1996) suggested that for *Placopecten magellanicus*, the density of seeded individuals stabilised after one to eight weeks post seeding, following an initial period of predation. Silina (1994) suggested that access of the seeded pectinids to predators was restricted to the first few days after seeding, during which the scallops re-assumed an effective escape strategy, thus reducing the probability of capture by predators.

In the present translocation experiment with *A. purpuratus*, the low initial mortality registered (12.5%) compared with the higher mortalities cited in the literature above is probably due to the fact that 94% of the translocated individuals were adults of between 60 and 100 mm in length. The initial mortality which affects pectinids after transfer may be attributable to the occurrence of breakages on the shell border due to handling in transport, which may delay their adaptation to the new environment based on the time required for them to repair shell damage (Pozdnyakova *et al.*, 1997). Stress involved in shell breakage and repair as cited by these authors was apparent during our diving observations in the present study, in which recently seeded *A. purpuratus* formed groups on the seabed which were highly exposed to predation by *Oliva peruviana* (Gastropoda) and crustaceans of the genus *Cancer*.

The post-seeding evaluation of the translocated scallops demonstrated that these had distributed themselves over the surface of the test area between the 13 and 21 m depth contours at densities which varied between >3 indiv./m<sup>2</sup> and <1 indiv./m<sup>2</sup>. These results permit the conclusion that, though little information is available on scallop transplants, the precautionary measures employed in the translocation of *A. purpuratus* were effective, and even more

successful than those cited in the above literature for *P. yessoensis* and *P. maximus*. These methods may be effective in future efforts toward repopulation of over-exploited scallop beds in Chile.

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