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# Physiological responses of the Chilean scallop *Argopecten purpuratus* to decreasing salinities

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## Abstract

*Argopecten purpuratus* (Chilean scallop) is a filter-feeding bivalve which inhabits sheltered areas of the north and central Chile. Considering that culture of this species has started in the south of Chile, it is of great interest to know the tolerance of this bivalve to conditions of decreasing salinity, which can occur in these locations. For this purpose, different physiological processes related to the acquisition and utilisation of energy (clearance rate, absorption, oxygen uptake and excretion) were measured at different salinities (30, 27, 24, 21 and 18‰) on a wide range of body size after the scallops had been acclimatised to the experimental salinities for a week at 12°C. Clearance rate showed higher and similar values at 30 and 27‰, decreasing significantly at the lower salinities. Oxygen uptake increased with decreasing salinity from 30 to 24‰, showing the lowest value at the extreme condition of 18‰. A similar pattern was presented by the excretion rate, which also increased within the range 30-24‰, to show a reduction with decreasing salinities. The O/N ratio also decreased with reduction in salinity in the 5 and 10 g size classes. A negative relationship was observed between the size of *A. purpuratus* and the O/N ratio. Scope for growth was highly affected by low salinities, with positive values only between 27 and 30‰. Negative scope for growth was observed at all the other experimental salinities. The data obtained suggest that the selection of sites to cultivate this species must take into consideration the tolerance of this species to the salinity, and positive growth rates can be expected at salinities over 27‰. © 1998 Elsevier Science B.V. All rights reserved.

*Keywords:* Salinity; Tolerance; *Argopecten purpuratus*; Scallop; Scope for growth

## 1. Introduction

*Argopecten purpuratus* (Chilean scallop) is a filter-feeding bivalve which inhabits sheltered areas of the coasts of Peru and north and central Chile. This species has high

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commercial value, and the natural stocks occurring in the north and central Chile are over-exploited. Aquaculture is the only possible means of increasing the production of this species. Important aquaculture centres have been developed in the north of Chile during the last years, which have increased the production. However, to increase the production of scallops significantly, it is necessary to consider the large potential of the south of Chile, where there are many well protected areas. Preliminary results of its culture in the south of Chile have shown reduced rates of mortality and high growth rates, however low growth rates and significant mortalities have been observed in places with prolonged periods of low salinity (Winter, 1989).

Salinity is one of the dominant environmental factors controlling species distribution and influencing physiological processes in marine and estuarine organisms (Kinne, 1967, 1971; Davenport, 1979; Widdows, 1985a). Typical responses in bivalves include reduced feeding activity and slower growth rates at low salinity (e.g., *Mytilus edulis*: Bohle, 1972; Widdows, 1985a) and also valve closure (e.g., *Crassostrea virginica*: Hand and Stickle, 1977; *Modiolus modiolus*: Shumway, 1977a). The scope for growth represents the energy available for production of tissue (somatic and/or reproductive) and has been used as a suitable predictor of stress because it represents the integrated response of all the processes related to energy acquisition (ingestion, absorption) and energy losses (respiration, excretion). Widdows (1985a) observed that when *M. edulis* is exposed to a fluctuating salinity regime, between 20 and 30‰, clearance rate, oxygen uptake and scope for growth (energy balance) are maintained at nearly constant levels, whereas they all decrease at salinities below 20‰.

*A. purpuratus* has been introduced in the south of Chile as an alternative species culture. It is of interest to know its physiological response (mainly potential growth) to decreasing salinities similar to those observed in the natural environment during the periods of heavy rain, which are common during winter in the south of Chile.

The main objective of this study was to determine the effects of decreasing salinities on the physiological response of *A. purpuratus*, using the scope for growth and O/N ratio as physiological stress indices. In view of the commercial importance of this species and its potential for aquaculture, information on its response to low salinity has implications in the selection of suitable sites for its cultivation in the south of Chile, as well as for the support of the operations of controlled laboratories to maintain reproductive stocks to produce seed of *A. purpuratus*.

## 2. Materials and methods

### 2.1. Experimental animals

*A. purpuratus* were collected from pearl nets in the bay of Hueihue, Chiloé, south of Chile. Three size classes of scallops were selected, ranging in shell height from 25 to 100 mm (0.1–5.7 g dry tissue weight). They were acclimated at each of the five experimental salinities (18, 21, 24, 27 and 30‰) for one or two weeks before the physiological measurements were carried out. During this time the scallops were maintained at 12°C and fed with an axenic culture of *Isochrysis galbana* ($30 \times 10^6$ cells $l^{-1}$). All the experiments were carried out at 12°C, which represent the annual mean temperature of the south of Chile (Navarro et al., 1993). The physiological measurements were done on six or more replicates of individual scallops. Separate groups of animals were used for the different experimental salinities. Physiological rates were standardised to 0.5, 1, 5 and 10 g dry tissue weight using the formula given by Bayne and Newell (1983):

$$Y_s = (W_s / W_e)^b \cdot Y_e$$

where $Y_s$ = the physiological rate for an animal of standard weight, $W_s$ = the standard weight of the animal, $W_e$ = the observed weight of the animal, $Y_e$ = uncorrected (measured) physiological rate, $b$ = the weight exponent for the physiological rate function.

### 2.2. Physiological rates

Clearance rate represents the volume of water cleared of particles per unit of time. It was determined using a static system, in which the decrease in algal cell density in the experimental aquarium was monitored in relation to time (Widdows, 1985b). These measurements were carried out using a particle counter (Elzone 180XY, Particle Data), fitted with a 120 μm orifice tube. A homogeneous mixture of the experimental medium was maintained by aeration in each experimental aquarium. The experiments were carried out over a period of 8 h in aquaria of 7–10 l of seawater containing individual scallops of different sizes. One additional aquarium, but with no scallop, was used as a control. All the experiments were carried out at 12°C and at 18, 21, 24, 27 and 30‰ salinity. The experimental food concentration was $30 \times 10^6$ *I. galbana* cells $l^{-1}$, corresponding to 0.90 mg dry wt. $l^{-1}$ (18.75 kJ $g^{-1}$ AFDW (Whyte, 1987).

Ingestion rate represents the amount of food ingested per unit of time. It was estimated as the product of the clearance rate and the weight or the energy content of the experimental diet.

Net absorption efficiency was estimated by using the organic and inorganic content of the food ingested and the faeces, following the ratio method of Conover (1966). In contrast to gross absorption efficiency, net absorption takes account of the ‘metabolic faecal losses’ (Bayne and Hawkins, 1990), which represent the organic material which is secreted or abraded into the gut lumen, and subsequently passed with the faeces, during the processes of digestion and absorption. Absorption rate was calculated as the product of the organic ingestion rate and absorption efficiency.

Oxygen uptake was determined for individual scallops using a polarographic analyser (Model YSI 5351). The output signal was monitored continuously on a chart recorder. The water in the respirometer was mixed by placing a magnetic stirrer under the temperature-controlled water bath where the respirometer was immersed. The volume of the respiration chambers varied from 1.5 to 2.5 l as appropriate for the size of the scallops. Considering that the experimental scallops were maintained under good feeding conditions before the experiments, the measured rates of oxygen uptake are assumed to represent the routine metabolism of *A. purpuratus*. Values of oxygen uptake were expressed as milliliter of $O_2$ $h^{-1}$ and transformed to energy equivalents using the conversion factor 1 ml $O_2$ = 19.9 J (Elliott and Davison, 1975).

Ammonia excretion was determined by the phenol–hypochlorite method of Solorzano (1969). Scallops were well fed and then placed individually in glass beakers containing 0.1–1.0 l of filtered (0.45 μm) seawater, according to the size of the animal. One additional beaker containing filtered seawater, but with no animals, served as a control. Following an incubation period of 4 h, samples from the water containing the scallops and from the control were analysed for ammonia. Values for excretion rate were expressed in microgram of $NH_4$–N $h^{-1}$ and transformed to Joules using the conversion factor: 1 mg $NH_4$–N = 24.8 J (Elliott and Davison, 1975).

The O/N ratio is considered as another useful physiological index which measures the balance between the catabolic processes, giving information on the effects of stress of one or more environmental factors. It is calculated on basis of the oxygen uptake and ammonia nitrogen excreted, expressed in atomic equivalents (Widdows, 1985b).

Scope for growth was calculated by the equation given by Widdows (1985b). The energy lost in respiration and excretion was subtracted from the energy absorbed from the food ($A$), after converting all the physiological rates to Joules per hour:

$$P = A - (R + U)$$

where $A$ is the energy absorbed from the food and $R + U$ the energy lost in respiration and excretion, respectively.

### 2.3. Statistical analysis

Physiological rates were related to dry meat weight by linear regression analysis, after log-transformation of all variables. Analysis of covariance was applied to compare the regression lines (slopes and elevations) of the different physiological rates in relation to salinity. Analysis of variance followed by a Tukey test of significance was carried out to compare absorption efficiency measured at the different salinity combinations. In all statistical tests differences are considered significant when $P < 0.05$. All these analyses were carried out with the statistical package Systat for Windows, v. 5.0.

## 3. Results

### 3.1. Clearance and ingestion rate

*A. purpuratus* showed similar values of clearance rate at the higher experimental salinities, with values of 2.6 and 2.3 l $h^{-1}$ at 30 and 27‰, respectively, in a scallop of 1 g dry tissue weight (Fig. 1). This rate was significantly reduced with decreasing salinities from 1.5 l $h^{-1}$ at 24‰ to 0.12 l $h^{-1}$ at 18‰ (Fig. 1). Similar trends were observed when clearance rates of scallops of 0.5, 5 and 10 g dry tissue weight were measured at different salinities. The analysis of covariance (ANCOVA) showed that there were no significant differences ($P > 0.05$) between the slopes of clearance rate vs. dry weight regressions when the five experimental salinities were compared. Similar results were obtained for the different salinity combinations. Significantly different elevations ($P < 0.05$) were found when all the salinities as well as pairs of salinities

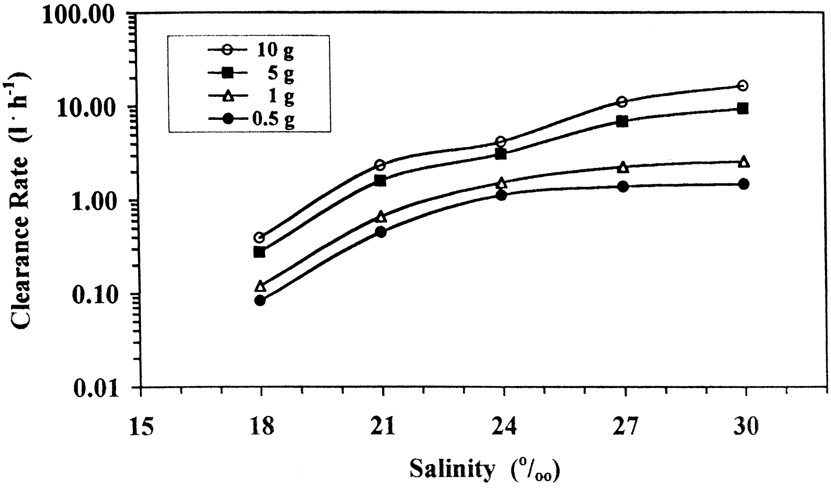

Fig. 1. *A. purpuratus*. Clearance rate for different body sizes exposed to decreasing salinities.

were compared, the only exception being the combinations 30–27‰ and 27–24‰, where no differences were found ($P > 0.05$).

Ingestion rate followed a similar trend to that described for clearance rate, with values of 2.4 mg $h^{-1}$ at 30‰ for a scallop of 1 g dry tissue weight, decreasing with the decrease in salinity, to show values as low as 0.11 mg $h^{-1}$ at 18‰, which represents only 4.6% of the food ingested at 30‰. The organic ingestion rate represented a large fraction of the total ingestion rate, ranging between 2.1 mg $h^{-1}$ at 30‰ and 0.09 mg $h^{-1}$ at the lower experimental salinity (18‰) for a scallop of 1 g dry tissue weight. Similar results were obtained for the other weight individuals.

### 3.2. Absorption efficiency

Absorption efficiency ranged from 65 to 76% in a scallop of 1 g dry tissue weight within the range of salinity tested (Table 1). As this physiological process was independent of body size ($P > 0.05$) at all the salinities, values for the different sizes were pooled (Fig. 2) and means of absorption efficiency compared by analysis of variance followed by a Tukey test of significance. The results showed that there were no significant differences between absorption efficiency measured at the different salinity combinations (ANOVA: $F = 0.90$, *df* 4.67, $P > 0.05$). The absorption ration was highly reduced with the decrease in salinity, from 1.57 mg $h^{-1}$ at 30‰ to 0.07 mg $h^{-1}$ at the lower salinity tested for a scallop of 1 g dry tissue weight. The comparison of the regression equations by ANCOVA showed that there were no significant differences between the slopes at the different salinities combinations. However significant differences were found in many cases when the elevations of the regressions were compared.

### 3.3. Oxygen uptake

Highly significant regressions were found between oxygen uptake and dry tissue weight at four experimental salinities (30, 27, 24 and 21‰) but not at 18‰ ($b = 0.38$),

Table 1
*A. purpuratus*. Regressions between physiological processes (clearance rate, absorption efficiency, oxygen uptake, excretion rate) and dry tissue weight (g)

| Salinity (‰) | *n* | Clearance rate ($l\ h^{-1}$) | *r* | *P* |
|---|---|---|---|---|
| 30 | 15 | $CR = 2.45\ W^{0.80}$ | 0.92 | $< 0.01$ |
| 27 | 12 | $CR = 2.08\ W^{0.69}$ | 0.78 | $< 0.01$ |
| 24 | 12 | $CR = 1.33\ W^{0.44}$ | 0.68 | $< 0.05$ |
| 21 | 12 | $CR = 0.36\ W^{0.55}$ | 0.42 | NS |
| 18 | 8 | $CR = 0.06\ W^{0.52}$ | 0.78 | $< 0.05$ |
| Salinity (‰) | *n* | Absorption efficiency (%) | *r* | *P* |
| 30 | 23 | $AE = 72.7\ W^{-0.03}$ | 0.14 | NS |
| 27 | 15 | $AE = 68.0\ W^{0.067}$ | 0.39 | NS |
| 24 | 15 | $AE = 70.0\ W^{-0.027}$ | 0.19 | NS |
| 21 | 11 | $AE = 62.4\ W^{0.085}$ | 0.23 | NS |
| 18 | 8 | $AE = 75.2\ W^{0.041}$ | 0.33 | NS |
| Salinity (‰) | *n* | Oxygen uptake ($ml\ O_2\ h^{-1}$) | *r* | *P* |
| 30 | 12 | $VO_2 = 0.30\ W^{0.55}$ | 0.79 | $< 0.01$ |
| 27 | 13 | $VO_2 = 0.63\ W^{0.49}$ | 0.67 | $< 0.05$ |
| 24 | 20 | $VO_2 = 0.78\ W^{0.48}$ | 0.90 | $< 0.01$ |
| 21 | 11 | $VO_2 = 0.37\ W^{0.58}$ | 0.82 | $< 0.01$ |
| 18 | 8 | $VO_2 = 0.29\ W^{0.38}$ | 0.78 | NS |
| Salinity (‰) | *n* | Ammonia excretion ($\mu g\ h^{-1}$) | *r* | *P* |
| 30 | 19 | $VNH_4\text{–}N = 20.4\ W^{0.67}$ | 0.87 | $< 0.01$ |
| 27 | 14 | $VNH_4\text{–}N = 36.1\ W^{0.60}$ | 0.85 | $< 0.01$ |
| 24 | 20 | $VNH_4\text{–}N = 38.4\ W^{0.76}$ | 0.91 | $< 0.01$ |
| 21 | 16 | $VNH_4\text{–}N = 27.7\ W^{0.72}$ | 0.85 | $< 0.01$ |
| 18 | 14 | $VNH_4\text{–}N = 17.5\ W^{0.70}$ | 0.83 | $< 0.01$ |

*P* represents the significance of '*b*' respect to zero. NS, not significant according to the expression $Y = aW^b$.

which appears to be a salinity at which *A. purpuratus* behaves erratically (Table 1). Oxygen uptake increased from 0.54 ml $O_2$ $h^{-1}$ at 30‰ to 0.84 ml $O_2$ $h^{-1}$ at 24‰ salinity in a scallop of 1 g dry tissue weight. The lowest value was observed at 18‰ (Fig. 3). The analysis of covariance showed that there were no significant differences between the slopes when all the combinations of salinities were compared. However significant differences were found between the elevations at some of the salinity combinations.

### *3.4. Ammonia excretion*

The excretion rate for a scallop of 1 g dry tissue weight increased with decreasing salinity, from 22.3 to 41.9 μg $NH_4$–N $h^{-1}$ at 30 and 24‰, respectively. The lowest value (19.7 μg $NH_4$–N $h^{-1}$) was observed at 18‰ (Fig. 4). The ANCOVA showed that there were no significant differences between the slopes, however significant differences were found between elevations at most of the salinity combinations, especially when 30 and 27‰ were included in the analysis.

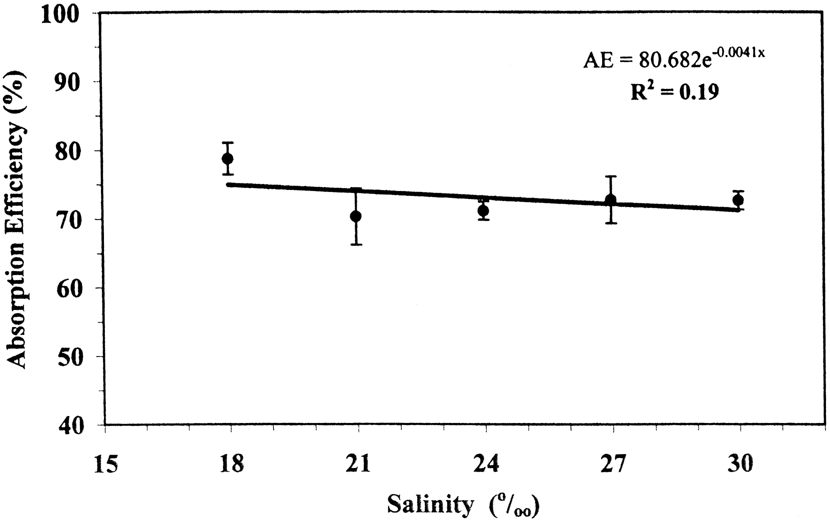

Fig. 2. *A. purpuratus*. Absorption efficiency at different salinities. Values are means of different sizes classes ± standard error.

### 3.5. O / N ratio

The O/N ratio for *A. purpuratus* varied between 9 and 32 at the lowest (18‰) and highest (30‰) salinity tested, respectively (Fig. 5). A negative relationship was observed between the size of *A. purpuratus* and the O/N ratio. Scallops of 0.5 g dry tissue weight showed O/N ratios between 24 and 33 at 18 and 30‰, respectively, with the lowest value at 21‰ (18). The O/N ratio varied between 9 to 23 within the same range of salinity in scallops of 10 g dry tissue weight (Fig. 5).

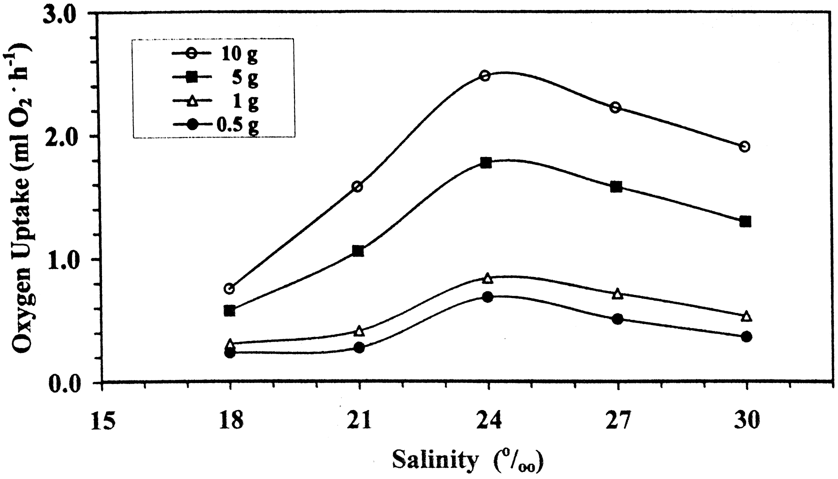

Fig. 3. *A. purpuratus*. Oxygen uptake for different body sizes exposed to decreasing salinities.

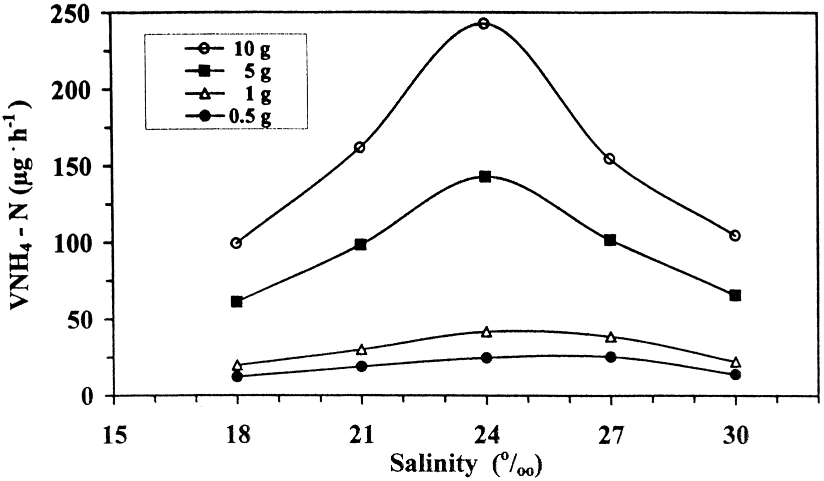

Fig. 4. *A. purpuratus*. Ammonia excretion for different body sizes exposed to decreasing salinities.

### 3.6. Scope for growth

Positive values of scope for growth were registered only at 27 and 30‰, ranging between 3.1 and 133 J $h^{-1}$ for 0.5 and 10 g dry tissue weight, respectively (Fig. 6). However, this index was negative at all the other experimental salinities (18–24‰), with values as lower as $-4.07$ J $h^{-1}$ for a scallop of 0.5 g dry tissue weight exposed to 18‰

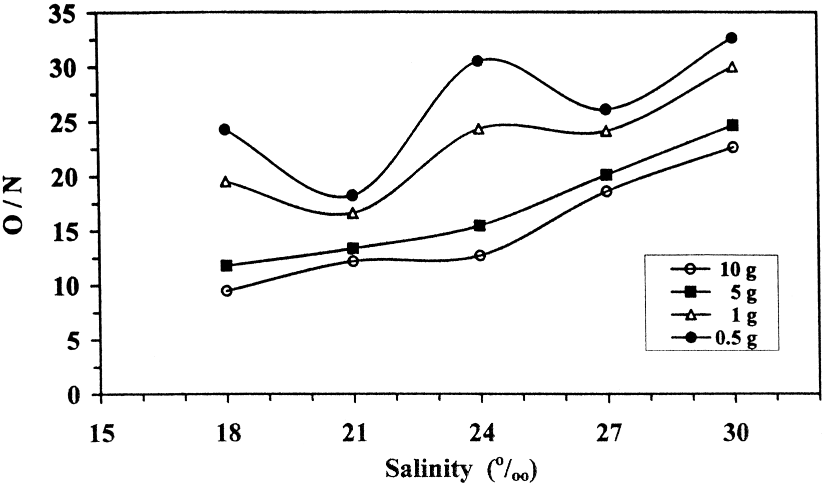

Fig. 5. *A. purpuratus*. O/N ratio for different body sizes exposed to decreasing salinities.

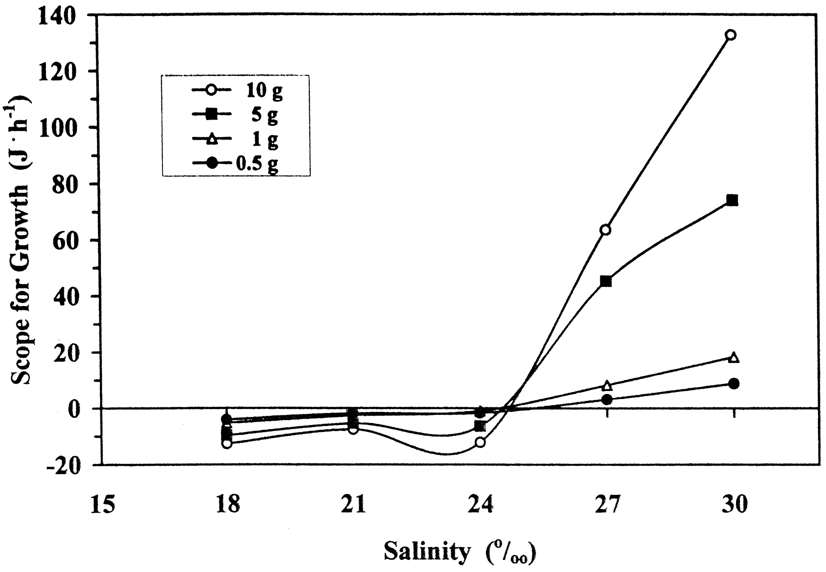

Fig. 6. *A. purpuratus*. Scope for growth for different body sizes exposed to decreasing salinities.

of salinity and $-12.6$ J $h^{-1}$ for a scallop of 10 g dry tissue weight exposed to the same salinity (Fig. 6).

## 4. Discussion

Marine invertebrates inhabiting estuarine and coastal areas are exposed to short-term (tidal) and long-term (rain periods) changes in salinity. Thus the time that these organisms are exposed to lower salinities is an important factor of stress, with the corresponding reduction in the growth rates (Bohle, 1972) as a result of the physiological adjustments that the organism needs to perform to be able to survive under these conditions. There have been numerous studies on physiological energetics in several species of scallops (MacDonald and Thompson, 1985, 1986; Thompson and MacDonald, 1991), however only a few physiological studies have been carried out in relation to salinity (Shumway, 1977a,b).

The constant clearance rates shown by *A. purpuratus* between 27 and 30‰ and the significantly reduced feeding activity at 21 and 18‰, are in agreement with the results described for *A. irradians* (Palmer, 1980) and also for *M. edulis* (Bohle, 1972; Widdows, 1985a) and *Choromytilus chorus* (Navarro, 1988). In contrast to other bivalves (e.g., mussels, clams, oysters), the anatomical characteristics of *A. purpuratus* and scallops in general do not allow it to close its valves for prolonged periods of low salinity. Similar observations have been reported on *Chlamys opercularis* (Shumway, 1977a) and *Patinopecten caurinus* (Bernard, 1983), suggesting negative effects of prolonged periods of exposure to low salinity, when these organisms are not able to isolate their tissues from these environments. These characteristics could have important effects on the performance and osmoregulatory mechanisms of these species, reducing significantly the ingestion rate and scope for growth (Fig. 6).

Available data suggest that scallops do not differ markedly from other bivalves in their absorptive capabilities (Bricelj and Shumway, 1991). Thus absorption efficiency in *A. purpuratus* is independent of body size and it is very constant within the range of salinity tested (18–30‰). The values obtained in the present study (65–76% for a scallop of 1 g dry tissue weight) are slightly lower than those described by other authors for other species of bivalves (Peirson, 1983; Navarro, 1988). However these can be considered higher than those recorded under natural conditions, where the inorganic fraction of the seston is significantly higher than in an unialgal culture.

The significant increase in oxygen uptake observed on scallops transferred from 30 to 24‰ salinity can be explained by an increase in activity related with the catabolism of amino acid, where they could be utilized as osmolytes to solve osmoregulatory problems. This is in agreement and directly related with the highest excretion rates measured on this species. However this response could be transitory under an acclimated respiratory response, resulting in minimal effects on the energy balance at this moderately low salinities. The decrease of oxygen uptake at salinities of 21 and 18‰ seems to be related with the decline in, or the cessation of the feeding activity, being this indicative of isolation as a way of evading osmotic stress. A very similar pattern of oxygen uptake has been described for other species of bivalves (Stickle and Sabourin, 1979; Widdows, 1985a).

*A. purpuratus* showed an increase in ammonia excretion with a decrease in salinity from 30 to 24‰, suggesting that it regulates the cellular volume by the breakdown of amino acids as intracellular isosmotic regulators following the reduction in salinity. Our results are supported by Livingstone et al. (1979), which described an increase in ammonia excretion in *M. edulis*, associated to the increase in amino acid concentration in the hemolymph with decreasing salinities. The high rate of ammonia excretion at 24‰ of salinity (mainly in the larger individuals) suggests that *A. purpuratus* may also be able to mobilise protein as a major metabolic substrate during the periods of reduced ingestion rates. Similarly to other species (e.g., *C. opercularis*, *M. modiolus*, *M. edulis*) studied by Shumway (1977a), *A. purpuratus* appears as an osmoconformer at salinities below 24‰ (Figs. 1 and 3), which would appear to be a disadvantage due to the reduction of the feeding and locomotory activity caused by the increase in the cellular volume by the absorption of water.

The ratio between oxygen consumed and nitrogen excreted in atomic equivalents (O/N ratio) represents the degree to which protein is utilised in energy metabolism by marine invertebrates (Shumway and Newell, 1984). According to Bayne (1973), values of O/N above 50 are representative of healthy mussels, whereas values of 30 or below are generally indicative of stressed animals, with a relatively high protein catabolism. The oxygen/nitrogen ratio (O/N) in *A. purpuratus* decreased with decreasing salinities, this behaviour being clearly observed in larger individuals (i.e., 5 and 10 g dry tissue weight). According to Mayzaud (1973), the minimum value of the O/N ratio is 7, which corresponds to the exclusive catabolism of the proteins. Barber and Blake (1991) described a theoretical minimum O/N ratio of 9.3 when the amino acids resulting from protein breakdown are deaminated and totally excreted as ammonia and the carbon skeletons are fully oxidized to $CO_2$ and $H_2O$. Barber and Blake (1985) described values between 6 and 22 for the scallop *A. irradians concentricus*. The values obtained for *A. purpuratus* varied between 9.5 and 32.6, and following the results of scope for growth, it is possible to conclude that O/N ratios lower than 15 represent unsuitable conditions to obtain positive growth rates in larger individuals, this threshold being higher for smaller scallops.

The scope for growth is a useful index to estimate the effect of the environmental or anthropogenic stressors on the overall performance of an individual (Widdows, 1985b). This index was highly affected by a reduction in salinity, showing positive values only between 27 and 30‰. The slightly negative scope for growth observed at 24‰ was related to the highest values of energy invested in oxygen uptake and ammonia excretion and not with a reduction in ingestion rate, which was not significantly different to the higher salinities. The low feeding activity (clearance, ingestion and absorption rates) and the relatively high energy lost by excretion and respiration obtained at the lowest salinities (18 and 21‰) results in a negative scope for growth. This shows that *A. purpuratus* is less euryhaline that other bivalves, such as *M. edulis* (Widdows, 1985a) and *Ch. chorus* (Navarro, 1988), where a negative scope for growth is observed at salinities below 20‰. This can be explained because *A. purpuratus* is a common organism inhabiting marine environments of the North of Chile where salinities are higher than 30‰ (Rodriguez et al., 1991), whereas mytilid species are common organisms inhabiting estuarine environments where short and long-term fluctuations (tidal, seasonal) of salinity are observed. Our results are valid for an acclimatory period of one week; conditions that can be considered similar to the intermittent and sudden decreases in salinity experienced in the south of Chile during the heavy rain of the winter months, where salinity can decline to values as lower as 20‰. However it is possible that the physiological responses recorded at lower salinities can be transitory and the magnitude of the changes would be time-dependent over longer periods of time. If this occurs then is possible to expect that SFG and the O/N ratio as indices of salinity stress change in the course of the acclimation, as a consequence of adaptation to salinity. The present results can be considered as useful information in the selection of suitable places in the south of Chile to culture this species and also to support the operation of aquaculture systems, such as hatcheries.

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