
AbSTRACT: An original growth model is fitted on data from reared sea urchins, *Paracentrotus lividus*. Quantile regressions are used instead of least-square, for they are insensitive to the dimension of the measurement and accommodate more than just symmetrical distributions. Quantile regressions allow comparison of fittings on various parts of the size distributions, including large competitors versus small, inhibited animals, in the presence of a size-based intraspecific competition. The model has functionally interpretable parameters and allows quantifying of the intensity of inhibition. An extension of this model, called ‘envelope model’, fits the whole data set at once, including size distributions. Its parameters are constrained using information about underlying biological processes involved, namely asymptotic growth with inhibition in early ages due to intraspecific competition whose intensity depends on the relative size of the individual in the cohort. The new model appears most adequate to describe growth of *Paracentrotus lividus* and probably of many other sea urchins species as well as other animals or plants. It is an intermediary model in a hierarchy of asymptotic growth models ranging from the simplest one (von Bertalanffy 1) to more complex ‘dimensional’ and ‘transitional’ groups. A general asymptotic growth model, being both ‘dimensional’ and ‘transitional’, is proposed.

KEYWORDS: growth model, intraspecific competition, fuzzy logic, quantile regression, sea urchin.


AbSTRACT: Effect of delayed metamorphosis and food ration on late (competent) larvae and postlarvae of *Paracentrotus lividus* were investigated. Metamorphosis of competent larvae was either not delayed or delayed from 1 up to 4 days. Larvae were starved or submitted to two different food rations of the algal species *Phaeodactylum tricornutum*. Larvae during the prolonged competence period and the resulting postlarvae were characterised by: (1) the size of the larval body, (2) the size of the rudiment, (3) the rate of metamorphosis, (4) the size of postlarvae 24 h after metamorphosis, (5) the rate of opening of mouth and anus, (6) the rate of survival, and (7) the growth rate of early postmetamorphic individuals. Both the width of the larval body and the diameter of the echinus rudiment grew in competent larvae that were fed. Unfed larvae did not grow. There was no significant difference in growth between the two food rations. The rate of metamorphosis was higher with larvae that metamorphosed soon after they became competent. Lower capacity of larvae to metamorphose during the delay period was associated with treatments yielding a greater larval width and rudiment diameter during the same period. Postlarval development was affected by a delayed metamorphosis treatment inflicted on competent larvae before metamorphosis. Acquisition of exotrophy happened earlier in postlarvae issued from prolonged competent larvae whatever the larval food rations. The delay treatment negatively affected the development of the digestive tract through it positively affected the growth of early postmetamorphic individuals during the first 6 days following metamorphosis. However, selective mortality occurred afterwards as bigger individuals died preferentially.

KEYWORDS: Larvae, metamorphosis, *Paracentrotus lividus*, plutei, sea urchin.


AbSTRACT: This study assessed the use of extruded feeds, in the form of pellets, for growing of the echinoid *Paracentrotus lividus* within a closed culture system. Two feeds types, one with soybean protein, the other with both soybean and fish protein were compared to dried *Lessonia* sp. and fresh *Laminaria* sp. as food sources. Pellets present a very high conversion efficiency (about 80%) against about 50% for *Laminaria* and 35% for *Lessonia*. 

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However, since pellets are less absorbed, somatic growth is statistically equivalent for the sea urchins fed with pellets and Laminaria: between 2 and 2.2 g of soma day\(^{-1}\). Sea urchins fed pellets produced significantly more gonadal tissue in a shorter time. Resulting in a gonadal index twice higher (6.5\%) than Laminaria (3\%) in the second month of the experiment. Dry Lessonia does not promote gonadal growth. This study shows that extruded feeds are well assimilated by P. lividus and promote both somatic growth and production of gonadal tissue.

KEYWORDS: Sea urchin, aquaculture, artificial food, somatic growth, roe, digestion.


ABSTRACT: A starvation and then feeding method was developed to produce about 100% marketable sea urchins, Paracentrotus lividus, in 3 ½ months. This method is needed because the reproduction cycle is desynchronized in the conditions imposed during the somatic growth stage in land-based closed systems. The major advantages of starving the animals are resetting the reproductive cycle to the spend stage (gonads almost devoid of sexual cells) and stressing the individuals so that they mobilize and restore the nutritive phagocytes, filling them with nutrients. Batches of sea urchins starved for 2 months beforehand were fed ad libitum for 45 days with enriched food under eight combinations of four temperatures (12°C, 16°C, 20°C and 24°C) and two photoperiods (9 and 17 h daylight). In our system, the best combination was 24°C and 9 h daylight for growth as well as for gonad quality. The gonadal indices obtained (in dry weight) were over 9\% at 16°C and over 12\% at 24°C, which are better than what is found in the field for this population.

KEYWORDS: Gonad, growth, temperature, photoperiod, sea urchin, Paracentrotus lividus.


ABSTRACT: The general allometric equations for the logarithmic helicospiral can fit many extraconical shapes, but the isometric conditions traditionally used limits study only to conical growth. We present evidence to show that in real gastropod shells, the logarithmic helicospiral equations fit the suture. Poor location of the coiling axis and/or an inappropriate pole for the logarithmic helicospiral has often led to the rejection of this model. The differences between the errors associated with measurements or previously available models, are discussed. Two methods, based on suture trace measurements, are proposed to locate the coiling axis both in apical and lateral views. The first is a graphical method based on an elementary property of the logarithmic spiral. The second, computational method is based on iterative reprojections of the suture. It is shown that the protoconch and the teleococonch must be treated separately. The precision of the new methods (especially the computing method) enables deviations from logarithmic helicospiral trajectory to be identified and differentiated from irregularities of the shell and sequential growth phases. Application of these methods may be useful not only for other gastropod morphological features, but also for other taxa such as brachiopods and other molluscs.

KEYWORDS: Coiled shell, coiling axis, gastropod, mollusc, morphometry, suture.


ABSTRACT: Echiniculture, or sea urchin aquaculture, is more and more considered as an alternative or a complement to fisheries but it is not implemented yet on a commercial scale. This is because rearing methods still have to be optimized. We developed a mathematical model to simulate and predict sea urchins' production according to various rearing methods and exploitation strategies. Simulations using this model demonstrate how the variation of production has a complex and sometimes counterintuitive relationship with both the rearing method and the exploitation strategy. Intraspecific competition and spread in sizes in reared batches are taken into account in the model. Hence, an accurate estimation of the time required to grow a whole cohort of reared echinoids to the market...
size is obtained. This tool allows a rapid determination of best rearing methods and should speed up the optimization process. At a later date, this model could help in rationalizing stock management in future sea urchin farming activities. By applying this model to wild sea urchin populations, it could also help in the establishment of sustainable fishery policies.

KEYWORDS: Somatic growth, dynamic model, aquaculture, intraspecific competition.


ABSTRACT: Several measurements can be employed to quantify the body size of echinoids. We evaluate here the accuracy of three measurements on the sea urchin *Paracentrotus lividus* (test diameter, fresh body weight and immersed weight - the weight of the sea urchin when immersed in seawater) and discuss their respective potentials. The immersed weight appears to be by far the most accurate, providing it is standardized, but also the most time-consuming measurement. Allometric relationships and formula for calculating a standard immersed weight for *P. lividus* are also provided.

KEYWORDS: Echinoid, morphometry, weight, diameter.


ABSTRACT: The gonad maturity index cycles of the echinoid *Paracentrotus lividus* and their relations with environmental abiotic parameters are assessed after 2 years of observation in southern Brittany, France. The gonadal cycle is briefly described and eight gonadal stages are characterized. The annual cycle, the time of spawning and the period of gonadal growth are well established, suggesting they are controlled externally. The reproductive cycle has three main phases: the growing phase (late autumn and winter) when gonads accumulate reserve material; the maturation phase (spring and early summer) in which gametogenesis then spawning take place; and the spent/regenerating phase when relict gametes are resorbed by the nutritive phagocytes, the gonads being virtually devoid of sexual cells. The maturity index based on the histological diagnosis of gonads and the use of circular data and polar graphical representation make it possible to reliably determine the spawning period, the rate of gametogenesis and the synchronization of males and females among the echinoid population. From this analysis, we can reasonably say that the gonadal cycle (represented by the gonad index), the rate of gametogenesis, and the end of the spawning period are influenced by temperature whereas the first spawning event appears to be triggered by day length.

KEYWORDS: Echinoid, reproduction, maturity index, gonadal cycle, abiotic parameters.


ABSTRACT: In the framework of echinoid cultivation, whose objective is to succeed in continuously producing large amounts of edible sea urchins (*Paracentrotus lividus*) under controlled conditions (aquaculture), gonadal growth is to be optimized. Among the various parameters influencing the production of roe, the quantity of food distributed was tested for optimization. After a 1-month fast, echinoids were fed artificial food pellets (enriched in soybean and fish proteins) for different periods of time over 48 h, the food thus being available ad libitum for 8, 16, 24, 32, 40 and 48 h; the cycles were repeated for a month. The results show that the quantity of food intake and the gonad index peak after about 35 h of food availability. This suggests food should be distributed discontinuously for optimal gonad production and minimal waste.

KEYWORDS: Aquaculture, food ration, gonad growth, artificial diet, sea urchin.

ABSTRACT: Today, most sea urchins fisheries worldwide must deal with overexploitation. Better management of exploited field populations and/or aquaculture is increasingly considered necessary to sustain sea urchin production in the future. In this context, we evaluate the potential of land-based, closed-cycle echiniculture. A long-term experiment with the edible sea urchin Paracentrotus lividus has been done on a pilot scale. The process allows total independence from natural resources, because the entire biological cycle of the echinoids is under control (closed-cycle echiniculture), and all activities are performed on land. Furthermore, a method has been set up to control the reproductive cycle with the aim to produce marketable individuals all year long. Performances obtained on each stage of the rearing process are quantified and analyzed. Overall, the results of this experiment are promising; however, some problems remain to be solved before we can claim profitability. The most important finding is that land-based, closed-cycle echiniculture is a potential viable supplement to fisheries to sustain worldwide sea urchin roe production.

KEYWORDS: Sea urchin, Paracentrotus lividus, aquaculture, larval culture, metamorphosis, growth, roe enhancement.


ABSTRACT: Multimodal size frequency distribution (i.e., a few individuals growing very fast and a few individuals growing very slowly) among an originally homogeneous cohort of juveniles Paracentrotus lividus is observed in reared conditions when they are 6-24 months old. The splitting of this cohort into homogeneous size-classed subgroups results in an increased growth of the smaller animals that catch up with the bigger ones in 4 months time. This indicates that the smaller animals are not genetically less productive and suggests they were inhibited in their growth due to the presence of larger ones. Supposing such growth inhibition also occurs in the natural environment, the observed mechanism could be very efficient in stabilizing field populations of aggregative echinoid species by maintaining a protected pool of small individuals with high growth potential but inhibited by the density of larger ones.

KEYWORDS: Echinoid, growth, population dynamics, size-frequency distribution.


ABSTRACT: Gonad and genital pore development was observed on field and cultivated juveniles of the echinoid Paracentrotus lividus. The gonad condition was evaluated by counting the number of acini per gonad following dissection. Presence of the genital pores was determined for each individual, plate by plate, after partial digestion of the tissues. Progressive and relative development was determined. The gonads first appear as a filament which starts to bud and develop acini that eventually fill up with genital material. The pores are pierced from the inside out when the gonads have reached a certain growth stage. Both gonads and pores do not develop simultaneously but in a certain order. In addition, statistical analysis shows that size has more influence on the condition of the genital apparatus than age.

KEYWORDS: Echinoid, gonads, growth, reproduction, development.
Colloques internationaux

  
  Voir publication correspondante.

  
  Voir publication correspondante.

- **Aquaculture '98, Las Vegas, 1998. Présentation orale en session spéciale.** Ph. Grosjean, Ch. Spirlet & M. Jangoux. Is land-based closed cycle echiniculture (sea urchins aquaculture) a viable alternative to fisheries today?
  
  ABSTRACT: Today, most world sea urchins fisheries have to deal with overexploitation or yields drop problems. Better management of exploited field populations and/or aquaculture are more and more considered as necessities to sustain sea urchins’ production in the near future. In this context, we evaluate here the potentials of land-based closed cycle echiniculture.

  A long-term experiment with the edible violet sea urchin (*Paracentrotus lividus*) has been done at a pilot scale in France. The process used allows total independence against natural resources, since the whole biological cycle of the echinoids is under control (closed cycle echiniculture) and all activities are performed on land. Also, a method has been set up to gain control over the reproductive cycle of these animals and to produce marketable individuals all year long.

  Overall conclusions of this experiment reveal great potentials, but also point out some pitfalls that remains to be eliminated before pretending for profitability. The most critical pitfalls identified are (1) poor control of extremely variable growth rates due to intraspecific competition, (2) poor control on inorganic carbon in closed or semi-closed systems due to a high demand in carbonates for skelettogenesis and (3) needs for increased quality of gonads (the edible part of the urchins) thanks to a specific artificial diet that remains to be formulated.

  One important aspect comes to light: land-based closed cycle echiniculture should have a very low impact on other mariculture or touristic activities that usually compete strongly for space on the coastline in many places. This should be a major advantage considering tomorrow’s aquaculture diversification.

  KEYWORDS: Sea urchin, *Paracentrotus lividus*, aquaculture, larval culture, metamorphosis, growth, roe enhancement.

  
  ABSTRACT: The closed-circuit cultivation of sea urchins offers the opportunity to optimize their growth by controlling the rearing parameters, but the question whether water pollution would result from the waste produced is critical. Little is known about the requirements of cultivated sea urchins in terms of food composition. The effect of two prepared feeds (soybeans and soybeans-fish pellets) versus fresh and dried kelp (the natural food of *Paracentrotus lividus*) on feeding, digestion and somatic growth has been investigated under semi-intensive cultivation. The total amount of waste produced at different levels of feeding, digestion, and assimilation has been measured. Both prepared feeds are used as efficiently as fresh kelp for somatic growth, but wastes are reduced by 20% due to a much higher conversion efficiency. These preliminary results suggest that a drastic improvement of
feeding strategies in the culture of sea urchins would be obtained soon by appropriate formulations of prepared feeds. On-land aquaculture of sea urchins with prepared feeds provides a means of controlling the wastes produced. It would prevent environmental pollution and would allow recovery of the large amounts of material still rich in organic material that may be used for other purposes.

KEYWORDS: Artificial food, digestion, somatic growth, sea urchin, aquaculture.


ABSTRACT: Among the technological choices to develop aquaculture of new species, open-sea versus "on-land" cultivation is a major one. On-land based systems are more expensive but offer the possibility to control the environmental conditions, possibly leading to better performance. In the case of echinoderms, ecophysiological responses are insufficiently understood to decide at the present time which is the best strategy. To investigate this crucial question, one should (1) set up a good cultivation system, (2) develop an experimental methodology adapted to the specificity of echinoderm biology, and (3) quantify the responses of the animals against gradients of environmental parameters. As an illustration of the promising perspectives this approach offers, the case of *Paracentrotus lividus* is discussed.

A pilot system has been set up to control all life stages of reared sea urchins, from fertilization to gonad filling; the used protocol is being carefully standardized.

A rapid (3 weeks) but accurate method has been developed to measure feeding, digestion, and somatic growth of reared sea urchins under various environmental conditions. Both technical and statistical improvements have been made to increase the significance of the results.

Two of the most important abiotic factors (photoperiod and temperature) have been investigated and let us to model their effects on sea urchins. Photoperiod has an impact on the feeding rate, but not on absorption or somatic growth. Optimal temperature for juveniles appears to be higher than for adults (respectively 23-24°C and 19°C). Moreover, juveniles are more sensitive to departure from this optimum. Hence, a strict control of temperature is a more critical issue for juveniles than for adults.

Integration of our results in a wider model concerning the entire rearing structure shows that the apparent food conversion efficiency results in several complex phenomena: feeding and digestion of course, but also degradation of food that in addition depends on temperature. In cultivation, the highest productivity is obtained by making a compromise between a high somatic growth at optimal temperature and a high apparent food conversion efficiency at a lower temperature.

KEYWORDS: Echinoid, aquaculture, food conversion, temperature, photoperiod.


ABSTRACT: Multimodal distribution (i.e., few individuals growing very fast and few individuals growing very slowly among an originally homogeneous group of sea urchins *P. lividus* of the same strain) is often observed in controlled cultivation. The splitting of this group into homogeneous size-classed subgroups induces an increased growth of the smaller individuals that achieve the same size than the others in 3 months. This indicates that the smaller animals are not genetically less productive and suggests they are inhibited in their growth due to some environmental constraints.

KEYWORDS: Echinoid, population dynamics, intraspecific competition, growth.

ABSTRACT: Within the context of an ECC financed research program on echinoid cultivation which objective is to succeed in continuously producing large amounts of edible sea urchins (*Paracentrotus lividus*) under controlled conditions (aquaculture), the performances of a closed-circuit rearing structure was tested. The rearing structure consists of toboggans measuring 4 m long and 60 cm wide on 3 levels, the whole overhanging a reserve/settling tank of the same length, 80 cm wide and 80 cm high. The sea urchins are placed on the toboggans in 5 to 10 cm running sea water. A 2.5 months follow-up of 2 structures do not show any significant increase of the biomass, mortality being barely compensated. An assessment of the quality of the water, done simultaneously reveals that CO$_2$ is continuously oversaturated from 300 to 400 %. This factor could be likely the cause of the poor growth of the echinoids.

KEYWORDS: Sea urchin, aquaculture, closed-circuit system, growth, CO$_2$.


ABSTRACT: Within the context of a research on sea urchin cultivation (*Paracentrotus lividus*), the effect of light on the amount of food ingested and of faeces produced per echinoid per day has been investigated. Three sets of 20 adults were subjected to particular light conditions (constant light, constant darkness or 12 hours of light per day) for 6 days. Measurements were done for each of the 60 investigated echinoids. Calculation of the mean daily feeding and absorption rates for each set of individuals indicates that the highest values were obtained for echinoids at constant darkness and the lowest for echinoids subjected to light/darkness alternation (values for the three sets of individuals are significantly different).

KEYWORDS: Echinoid, feeding rate, absorption rate, light, photoperiod.

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