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Use of maize as a food source for sea urchins in a recirculating rearing system

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Six diets were tested on the somatic growth and mortality of the sea urchin *Paracentrotus lividus* reared in a semi-closed system. Three of the diets were algal-based (*Palmaria palmata, Laminaria digitata* and a mix of *L. digitata* (80%) plus *P. palmata* (20%)), the other three being based on maize (pure maize or a mix of maize (80%) plus *P. palmata* (20%) and maize (80%) plus *L. digitata* (20%)). Best growth rates were obtained with the mix maize plus *P. palmata*, the lowest conversion rates were obtained with the algal-based diets. Mortality rates were not significantly different between the diets. Sea urchins (3791) were reared in a semi-closed circuit and fed a mix of maize plus *P. palmata*. Growth, size distribution and mortality were studied to an age of 23 months, when their mean diameter was 21.4 mm (size distribution from 6 to 46 mm). The fastest growing urchins reached 40 mm in 15 months. Size frequency histograms were extrapolated to show that 25% of the urchin population reach a size >40 mm in 41 months. Forty-nine months would be necessary for 50% of the population to reach that size and 63 months for 75% of the population.

KEYWORDS: Diet, Growth, Rearing, Sea urchin (*Paracentrotus lividus*), Semi-closed system

INTRODUCTION

In France, the decrease of natural stocks of the urchin, *Paracentrotus lividus*, in the Mediterranean and around Brittany, an increasing demand and a high selling price (Le Direac'h *et al.*, 1987; Le Gall, 1987) have led in recent years to an increasing number of studies aimed at culturing this invertebrate (Le Gall and Bucaille, 1987; Le Gall, 1989; Fernandez, 1990; Caltagirone *et al.*, 1991; Grosjean *et al.*, 1996). Numerous studies have been carried out on the feeding preferences of urchins (reviewed in Lawrence and Lane, 1982). Le Gall (1989) has studied the influence of feeding on the growth of *P. lividus* in rearing conditions and showed that *Laminaria digitata, Palmaria palmata, Ulva lactuca* and *Porphyra umbilicalis* were the main species of algae giving growth rates compatible with the commercial rearing of this species. He concluded that a mix of the brown alga *L. digitata* and the red alga *P. palmata* gave the best results with regard to consumption and somatic growth. Frantzis and Grémare (1992) showed that maximum growth can be obtained with the red alga *Rissoella verruculosa*. However, the use of algae in any culture involves two fundamental problems: the availability of good quality algae and the cost of stocking it. Alternatively, artificial feed can replace fresh algae (Caltagirone *et al.*, 1991;

Lawrence *et al.*, 1992; Jong-Westman *et al.*, 1995; Fernandez, 1996). Although growth obtained with artificial feed is comparable to that with fresh seaweed, cost remains important. Fernandez (1996) indicated that a mixed diet of animal and algal origin gives better growth rates than a diet based on algae alone. Other sources of feed can also be used. Hagen (pers. comm.), for instance, sometimes uses a phanerogam to feed *Strongylocentrotus intermedius*.

We have sought a source of feed with constant quality, which can easily be stored and has good resistance in seawater while being relatively cheap; maize fits these requirements well. Comparative studies have thus been carried out in a first experiment using maize as opposed to the standard feed defined by Le Gall (1989) with either *P. palmata* or *L. digitata* alone or mixed.

Besides growth, mortality and size-class dispersion (Cellario and Fenaux, 1990; Grosjean *et al.*, 1996) are also important. These parameters were studied in a second experiment for a long period of time in a semi-closed rearing system using maize as a source of feed.

MATERIAL AND METHODS

Feeding experiments

The urchins, *P. lividus*, used in these experiments, originated from a semi-closed rearing system (hatchery, nursery and on-growing). Eighteen lots of 120 urchins were randomly selected from urchins of mean (SD) 0.78(0.29) g fresh weight for a total weight per lot of 95.1(1.6) g. The experiment was carried out for three successive periods of 4 weeks with a measurement made at the end of each period (April–June 1996). Each measurement consisted of a count of total numbers and global weight (0.1 g) after drainage. The mean individual weight was calculated for each lot. Daily growth rate (GR in % day^{-1}) was calculated as follows:

$$GR = [(Wf/Wi)^{1/t} - 1] \times 100 \qquad (1)$$

where Wi and Wf are the mean initial and final weights and t the number of days of the experiment.

A mortality rate (M in % $month^{-1}$) was calculated as:

$$M = (Ni\text{-}Nf) \ / \ (Ni \times t \times 30 \times 100) \qquad (2)$$

where Ni and Nf are the initial and final urchin numbers and t the number of days of the experiment.

Six feeding diets were tested: *L. digitata, P. palmata,* maize, maize plus *L. digitata* (80:20% in dry weight), maize plus *P. palmata* (80:20% in dry weight) and *L. digitata* plus *P. palmata* (80:20% in dry weight). The dry weights of the algae and the maize were obtained after drying in a ventilated oven at 90°C until constant weight. The ratio fresh weight: dry weight was calculated:

$$DM = FW/DW \qquad (3)$$

where FW and DW are the fresh and dry weight respectively.

During this period, DM for maize was 0.88 (constant all year), DM for *L. digitata* was 0.11 and DM for *P. palmata* was 0.10. The algae were harvested twice a month and were held in aerated tanks.

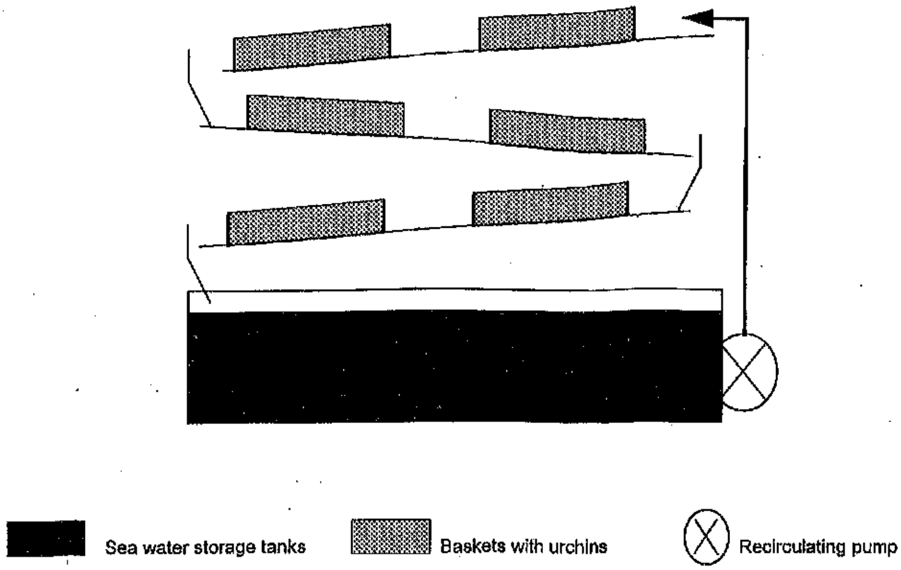

FIG. 1. Semi-closed rearing structure. Water is pumped from the seawater storage tank to the top storey and with gravity trickles down over the animals. Urchins are placed in rearing baskets. Water depth in the storeys is roughly 5 cm.

The analysis of nitrogenated compounds in the rearing water showed mean levels of 0.062, 0.034 and 0.970 mg N l^{-1} for ammonia, nitrites and nitrates, respectively. However, much higher levels such as 0.5 and 0.35 mg N l^{-1} for ammonia and nitrites were reached after a spawn. Nitrate levels of 3 mg N l^{-1} could be reached for no apparent reason.

After 1 month of rearing, total alkalinity reached values of between 2.0 and 2.5 meq l^{-1} and were sometimes as low as 1.5 meq l^{-1}. Sodium bicarbonate was added during periods 6 and 7 in order to maintain alkalinity between 3.5 and 4.5 meq l^{-1}. This was replaced by an increased water renewal rate of 240 l day^{-1} during period 8.

Growth rates were calculated from initial and final mean weights for each period using Equation 1. Another expression of the increase in fresh weight (GR') in g day^{-1} was calculated as:

$$GR' = (Wf\text{-}Wi)/t \qquad (5)$$

where Wi and Wf are initial and final weights per basket and t the number of days for the period.

Net production (nP) is the difference between the final and the initial biomasses, dead production (dP) is the number of dead urchins multiplied by the mean weight of an urchin in a given basket for a time period. Gross production is the sum of nP and dP.

Monthly mortality rate (M $month^{-1}$) was calculated following Equation 2. Survival

The urchins were fed *ad libitum*. The quantity of feed was weighed (g). The conversion ratio (*CR*) was calculated as:

$$CR = A / (Wf \times Nf - Wi \times Ni) \qquad (4)$$

where A is the quantity of ingested food converted to dry weight (g), Wi and Wf are the initial and final weights of the urchins (g) and Ni and Nf are the initial and final numbers of urchins.

The urchins were placed in 3 mm polyethylene mesh baskets. The baskets were rectangular (0.16 × 0.19 m), had a surface area of 0.03 m^2 and were placed in the toboggan-type rearing structure with circulating water (8 m^3 h^{-1}) as described in Le Gall (1989). Water depth was 5 cm and the water renewal rate of 20% day^{-1} enabled a good water quality in the rearing system to be maintained. Water temperature was held constant at 18(1)°C by a heat exchange pump.

The levels of ammonia were determined by the method of Koroleff (1970), those of nitrites by the method of Bendschneider and Robinson (1952) and those of nitrates by the method of Wood *et al.* (1967), as described in Aminot and Chaussepied (1983). Salinity and temperature were measured daily by a conductimeter/salinometer (WTW LF 196). pH was measured by a Methohm pH-meter. Carbonates were measured by dosing with hydrochloric acid with a Methohm dosimeter and calculations were made following the equations described by Copin-Montégut (1989).

Water characteristics were: temperature, 18(1)°C: pH; 8.3(0.1); alkalinity, 4 (0.5) meq l^{-1}, NH_{3-4}, < 0.5 mg N l^{-1}, NO_2, < 0.5 mg N l^{-1}; NO_3, < 2 mg N l^{-1}.

Evolution of a cohort

Urchins (3791) aged 7 months (from 6 to 20 mm) with a total biomass of 2665 g fresh weight were placed in 0.80 × 0.60 m baskets in the rearing structure from the beginning of October 1995 to the beginning of February 1997 (eight periods of 2 months). Every 2 months the urchins were graded by laying them on a lighted table where circles of diameter 8–50 mm, 2 mm apart, were drawn. This way of measuring was rapid and did not harm the urchins. Thirty individuals from each basket and for each size class were weighed individually (0.01 g). All urchins for a given size class and basket were globally weighed and counted. The lots were redistributed as a function of size class: such grading limits intraspecific competition.

According to the results of the first experiment, urchins were fed a mix of maize and *P. palmata* without limitation (80:20% dry weight). The change from a diet of pure seaweed to that of a mixed diet was progressive over the first period of 2 months.

The rearing structure used was a reduced version of that used in the first experiment; the structure comprised three sloped (2%) levels of 2.2 m × 0.6 m over a water storage tank (2.4 × 0.6 × 0.5 m) (Fig. 1). Seawater was pumped to the top storey with a 8 m^3 h^{-1} pump and circulated down with gravity over the animals at each level. The water volume was 750 l, of which 120 l were changed daily (240 l for the 8th period). Water temperature was held constant at 19(1.1)°C. The mean salinity was held at 34(1.5)‰ by adding salt when needed as the water originating from a drilled well reached salinities of 25–29‰ especially during period 8.

rate is the ratio between the number of survivors and the total initial number of urchins.

The spatial occupation coefficient of the baskets was calculated according to the formula given in Jangoux *et al.* (pers. comm.). Spatial occupation was estimated by multiplying the radius of the test by a constant K which determines the free space around each individual:

$$K = \sqrt{[S/(n \times \pi \times r^2)]} \tag{6}$$

where S is the surface area of the basket, n the number of urchins and r the mean radius of the urchin test. This coefficient was usually between 1 and 2 in our culture. This coefficient enables our results to be compared with others in the literature.

Supposing that size distribution frequency is Gaussian in shape, we can calculate the parameters of each curve by using the least squares method with: mean diameter (Dm), standard deviation (σ) and maximum frequency (Fmax). Size frequency distribution for the range of size $[D-1{:}D+1]$ is of:

$$F_{D-1,D+1} = F_{\max} \times \exp[-(D-Dm)^2/(2 \times \sigma^2)] \tag{7}$$

The data were treated by variance analysis (ANOVA) and by multivariable regression curves.

RESULTS

Influence of diet

Data concerning growth, conversion ratio and monthly mortality rates are given in Table 1. Variance analysis shows that feed has a strong influence on growth ($P<0.001$, $\alpha = 0.05$) and conversion ratio ($P<0.001$, $\alpha = 0.05$) but none on mortality ($P>0.1$, $\alpha = 0.05$). The mean mortality rate in this experiment was of 1.5% month^{-1}.

Growth rates were similar for urchins fed on *P. palmata* and *L. digitata* either pure or mixed together (1.13(0.15), 1.13(0.05) and 1.17(0.12)% day^{-1}, respectively). Maize alone gave a slightly lower growth rate than with algae but this was not significantly different ($P>0.05$, $\alpha = 0.05$). However, when mixed with any of the two algae, growth in weight was better than with algae alone. This was especially the case for

TABLE 1. Growth in weight (*GR* in % fresh weight day^{-1}), conversion rate (*CR* in g dry weight per g fresh weight) and monthly mortality (*M* in % month^{-1}) for each feed tested on *P. lividus*. The mean, the confidence interval (95%) and members of a set (ANOVA) are indicated in the table

Feed	*GR* (% *Pf* day^{-1})	*CR*	*M* (% month^{-1})
L. digitata	1.13(0.15)^a	1.46(0.16)^a	1.76(1.87)^a
P. palmata	1.13(0.05)^a	1.33(0.07)^a	1.90(0.59)^a
Maize	1.04(0.10)^a	2.47(0.27)^c	2.07(0.80)^a
Maize plus *L. digitata*	1.23(0.09)^a	2.02(0.24)^b	1.33(0.85)^a
Maize plus *P. palmata*	1.40(0.05)^b	1.78(0.14)^b	0.90(1.02)^a
L. digitata plus *P. palmata*	1.17(0.12)^a	1.47(0.13)^a	1.33(0.51)^a

the mix of maize and *P. palmata* which gave a growth significantly higher ($P < 0.001$, $\alpha = 0.05$) than all other feeds tested (1.40(0.05)% day^{-1}) representing 25% more weight growth as compared to the single feeds.

Conversion ratios were quite significantly different ($P < 0.001$, $\alpha = 0.05$) between the diets. The lowest conversion ratios were obtained for *L. digitata* and *P. palmaria* alone (1.47(0.16) and 1.33(0.08)) or mixed (1.47(0.13)) but were not significantly different. Conversion ratio with maize was clearly greater (2.47(0.27)), and very significantly different from the algal-based diets ($P < 0.001$, $\alpha = 0.05$). However, the ratio was lower for the mix maize plus alga, especially for the mix maize plus *P. palmata* (1.78(0.14)). It seems that the mix alga plus maize helps in the assimilation of the feed. No degradation of maize could be visually observed after 2 weeks in the rearing water.

Evolution of a cohort

Results of the evolution of a cohort for each basket and for each time period are given in Table 2. Mean growth rates per basket were calculated for each period, allowing a multivariable analysis of growth in function of the mean size of urchins for a given period. This analysis showed a highly significant effect of size on the weight growth ratio (C in % day^{-1}) ($P < 0.001$, $\alpha = 0.05$) and a significant effect of age ($P < 0.01$, $\alpha = 0.05$), meaning that, for the same size, the younger an urchin, the faster its relative growth rate. Mean relative growth rates range from 1.1% day^{-1} for the youngest urchins to 0.10% day^{-1} for those > 40 mm in size. Weight growth ratios (in g FW day^{-1}) increased with the size of the urchins and varied between 0.01 g day^{-1} for the young urchins of 1 g to 0.059 g day^{-1} for urchins of 15.5 g.

There was no significant effect of size ($P > 0.05$, $\alpha = 0.05$) or age ($P > 0.6$, $\alpha = 0.05$) on mortality in the same size class, but dead production per period increased with time ($P < 0.01$, $\alpha = 0.05$) as, although the number of dead remained constant, their weight had increased.

Total biomass increase (sum of nP) (Fig. 2) in the rearing system was linear with time for urchins of 7 to 23 months with a slope of 1023 g $month^{-1}$ ($n = 8$, $r^2 = 0.999$, $p = 0.0000$). Global survival ratio (Fig. 2) was linear with a slope of –0.925% month ($n = 8$, $r^2 = 0.978$, $p = 0.0000$), which corresponded to a mortality of 11.1% y^{-1}.

Figure 3 represents the evolution of size frequency with age of urchins. Certain individuals grew very rapidly, reaching 40 mm in 15 months, whereas others were very slow growers, barely reaching 8 mm in 23 months' rearing time. Figure 4 shows the evolution of the parameters to Gaussian curve (Equation 7) as a function of age, Fmax can be calculated with σ.

$$D_m = 9.375 \times \ln(Ag) - 8.562 \qquad (r^2 = 0.99,\ n = 9) \tag{8}$$

$$\sigma = 3.171 \times \ln(Ag) - 2.031 \qquad (r^2 = 0.92,\ \mathrm{n} = 9) \tag{9}$$

$$F_{max} = 200/(\sigma \times \sqrt{(2\pi)})$$

where Ag is the age of urchins in months.

This equation enables one to calculate the proportion of urchins of a given test size and age when reared in the conditions described above. The theoretical curves obtained are relatively close to the size distribution found in the rearing structure.

TABLE 2. Cohort evolution

Age (months)	Nº	*Gi* (mm)	*Gf* (mm)	*Ni*	*Nf*	*Wi* (g)	*Wf* (g)	Mean *W* (g)	*K*	*GR* (% day^{-1})	*GR*' (g day^{-1})	*M* (% month^{-1})	*nP* (g)	*mP* (g)	*gP* (g)
7–9	1	6–20	6–26	1904	1866	1222	2328	0.9	1.2	1.11	0.010	1.00	1106	35.8	1141.8
	2	6–20	6–26	1887	1867	1444	2489	1.0	1.2	0.93	0.009	0.53	1045	21.0	1066.0
9–11	1	20–26	20–32	379	369	1724	2256	5.3	1.6	0.46	0.024	1.24	532	53.2	585.2
	2	16–20	16–26	668	660	1473	2092	2.7	1.5	0.57	0.015	0.56	619	21.5	640.5
	3	12–16	12–24	1055	1007	1066	1445	1.2	1.6	0.55	0.007	2.13	379	58.5	437.5
	4	6–12	6–20	1631	1532	553	920	0.5	1.8	0.90	0.004	2.85	367	46.1	413.1
11–13	1	20–32	20–38	369	367	2256	2735	6.8	1.5	0.35	0.023	0.29	479	13.6	492.6
	2	16–26	16–30	660	658	2092	2668	3.6	1.4	0.43	0.016	0.16	576	7.2	583.2
	3	12–24	12–28	1007	995	1445	1890	1.7	1.5	0.49	0.008	0.63	445	20.0	465.0
	4	6–20	6–24	1523	1477	920	1374	0.8	1.5	0.76	0.006	1.59	454	35.2	489.2
13–15	1	24–38	24–40	431	423	3417	4014	8.7	1.3	0.26	0.023	0.98	597	69.6	666.6
	2	20–24	20–32	500	495	2032	2723	4.8	1.5	0.44	0.021	0.53	691	23.9	714.9
	3	16–20	16–26	870	845	1956	2376	2.5	1.4	0.32	0.008	1.51	420	63.1	483.1
	4	6–16	6–22	1696	1679	1262	1740	0.9	1.4	0.48	0.004	0.53	478	15.1	493.1
15–17	0	32–40	32–40	118	115	1625	1997	15.5	2.1	0.38	0.059	1.25	372	46.6	418.6
	1	24–30	24–36	310	307	2394	2973	8.7	1.5	0.37	0.032	0.48	579	26.1	605.1
	2	20–32	20–32	495	487	2803	3177	6.1	1.4	0.23	0.014	0.79	374	48.7	422.7
	3	16–26	16–28	845	827	2344	2823	3.1	1.3	0.34	0.010	1.05	479	55.6	534.6
	4	6–22	6–26	1679	1647	1769	2367	1.2	1.3	0.51	0.006	0.94	598	39.8	637.8
17–19	0	32–42	32–44	134	134	2271	2498	17.8	1.9	0.18	0.033	0.00	227	0.0	227.0
	1	26–32	26–36	308	302	2983	3012	9.8	1.5	0.06	0.006	1.12	29	59.0	88.0
	2	20–30	20–34	575	574	3609	4157	6.8	1.2	0.28	0.019	0.10	548	6.8	554.8
	3	16–24	16–28	1233	1186	3570	3878	3.1	1.1	0.23	0.007	2.20	308	144.7	452.7
	4	6–16	6–20	1143	1126	942	1163	0.9	1.7	0.44	0.004	0.86	221	15.8	236.8
19–21	0	36–44	36–44	20	20	511	563	26.9	4.2	0.14	0.038	0.00	52	0.0	52.0
	1	30–36	30–36	135	128	1800	1896	14.1	2.1	0.15	0.021	2.25	96	98.4	194.4
	2	26–34	26–30	450	442	3944	4608	9.6	1.3	0.25	0.024	0.77	664	76.7	740.7
	3	22–26	22–32	423	417	2410	3001	6.4	1.5	0.34	0.022	0.62	591	38.7	629.7
	4	18–22	18–28	805	801	2617	3182	3.6	1.3	0.29	0.010	0.22	565	14.4	579.4
	5	6–18	6–24	1389	1369	1634	2048	1.3	1.4	0.35	0.005	0.63	414	26.7	440.7
	take out	34–38		100		1813						0.00	−1813		−1813
21–23	0	38–44	38–46	20	19	563	570	29.1	4.3	0.10	0.030	2.46	7	29.6	36.6
	1	30–36	30–38	253	253	3497	3936	15.6	1.5	0.19	0.029	0.00	439	0.0	439.0
	2	26–30	26–34	350	348	3322	2756	10.8	1.4	0.21	0.019	0.28	434	20.4	454.4
	3	22–28	22–32	560	553	3715	3998	7.2	1.3	0.14	0.033	0.61	284	43.5	326.5
	4	18–22	18–26	898	876	3940	3334	3.5	1.3	0.25	0.009	1.20	394	77.8	471.8
	5	6–22	6–18	1096	1041	1261	1475	1.3	1.6	0.34	0.004	2.47	214	70.4	284.4

Age of sea urchins in months, identification of the rearing baskets (*No*), initial and final size range (diameter) in the rearing baskets (*Gi* and *Gf* in mm), initial and final numbers of urchins in each basket (*Ni* and *Nf*), initial and final biomass in each basket (*Wi* and *Wf* in g), mean weight of an urchin in each basket (mean *W* in g), spatial occupation coefficient *K*, mean growth (*GR* in % day^{-1} and *GR*' in g day^{-1}), mortality rate (*M* in % month^{-1}), net production (*nP* in g), dead production (*dP* in g) and gross production (*gP* in g) for each period are indicated in the table.

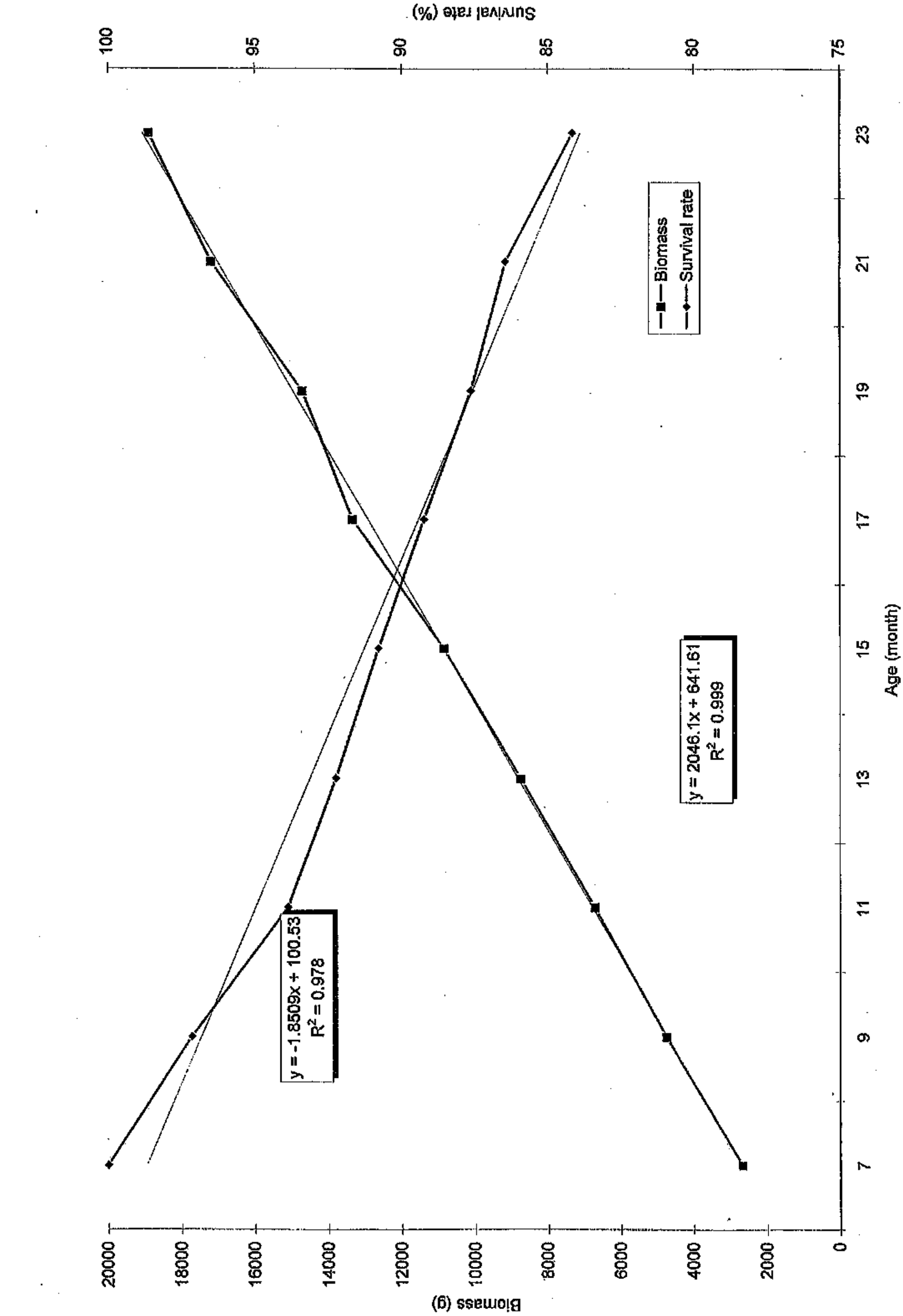

FIG. 2. Growth (squares) and survival rate (diamonds) of urchins reared in a semi-closed system.

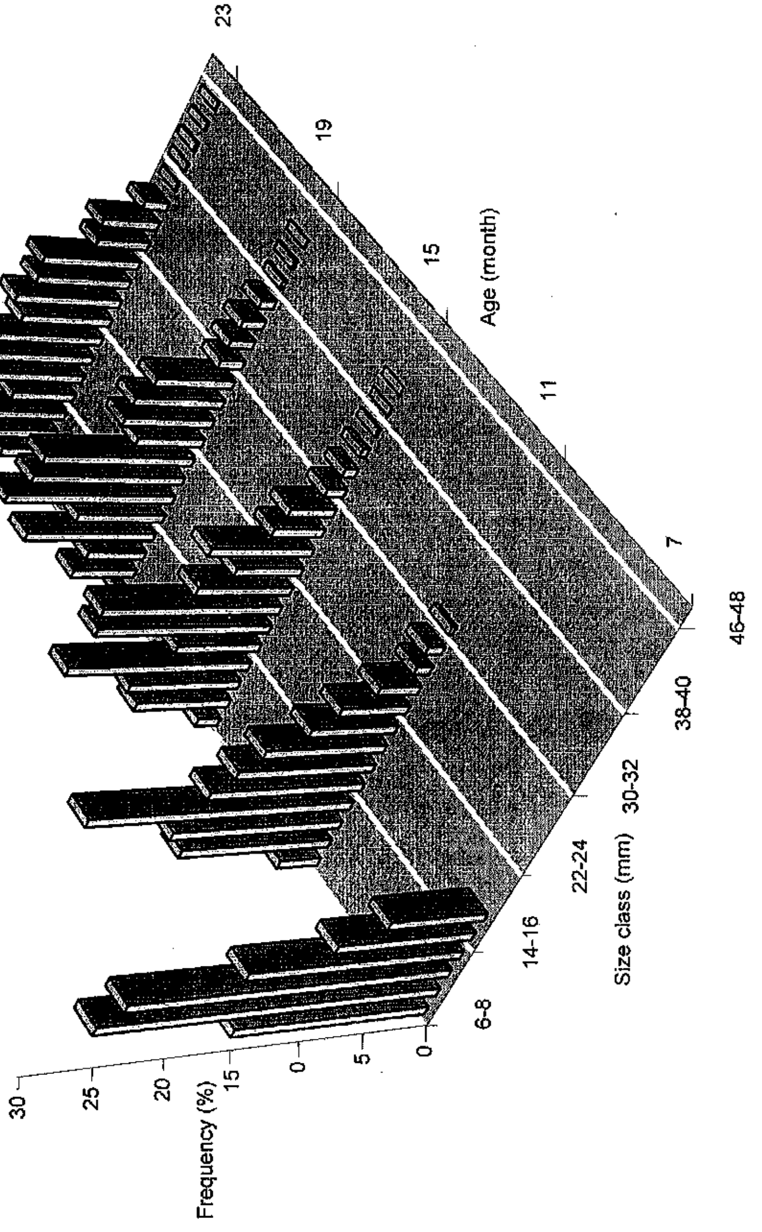

FIG. 3. Size frequency evolution of a cohort between 7 and 23 months.

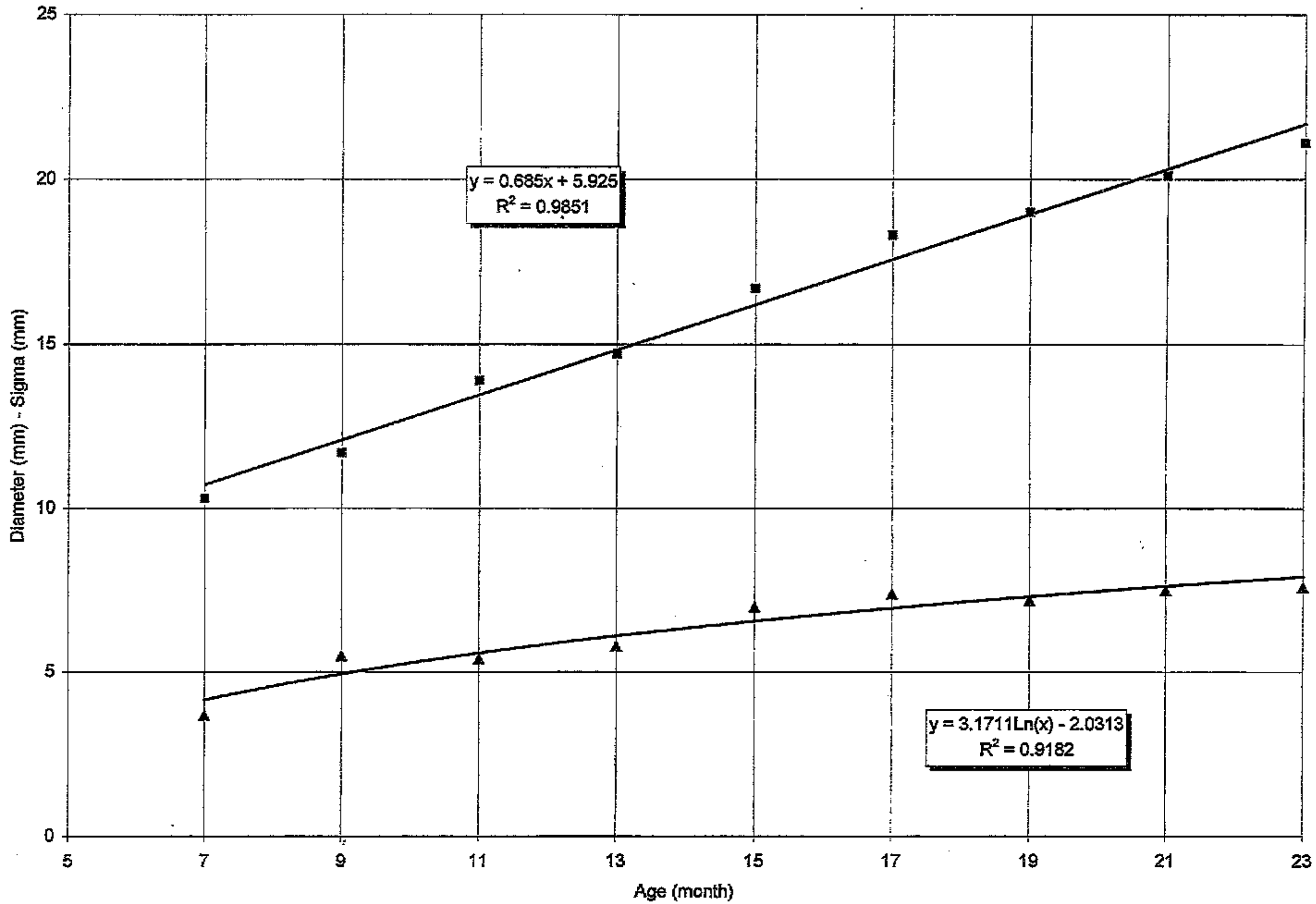

FIG. 4. Frequency curves parameters for a cohort of urchins as a function of age. Mean diameter (mm, squares) and half width of the Gaussian curve in its middle (sigma in mm, triangles).

Total biomass can be calculated from the size–weight relationship defined on a lot of 232 urchins and from the survival rate:

$$W = 0.000432 \times D^{2.98} \qquad (r^2 = 0.993,\ n = 232) \tag{10}$$

where W is the fresh weight (in g) and D the test diameter (in mm).

The model predicts a biomass of 2730 and 18 500 g at 7 and 23 months, respectively, whereas it is actually 2665 and 18 800 g. This shows that the model is quite accurate (Fig. 5).

The model can be extrapolated for older urchins. It would take 41 months for 25% of the urchin population to reach a size greater than 40 mm in the given rearing conditions. Forty-nine months would be necessary for 50% of the population to reach that size and 63 months for 75%.

DISCUSSION

P. lividus expressed no food preference when given the choice of maize plus one alga or two algae together (*L. digitata* and *P. palmaria*). Similar observations were made by Klinger *et al.* (1994) where *Lytechinus variegatus* had no preference between a plant or plant plus fish-based artificial feed. Lawrence *et al.* (1989) on *P. lividus* and McClintock *et al.* (1982) on *Lytechinus variegatus* made the same observations.

Results clearly show that a maize-based diet with fresh seaweed (*P. palmata*) as an additional component increases growth rates substantially. Our results using a seaweed-based diet were comparable to those of Le Gall (1989) who found that growth rates were similar between urchins fed *P. palmata* or *L. digitata* and the fact of mixing both algae did not add any benefit. However, the fact of mixing maize with *P. palmata* gave much better results than with maize or *P. palmata* alone. The same tendency was observed with conversion ratios. There seems to be a synergetic effect between maize and the algae resulting in a net increase in weight growth.

Maize is composed mainly of starch and very little protein (10% of dry weight). However, the efficient absorption of polysaccharides is variable according to species; Lawrence (1976) showed that several echinoids absorb soluble polysaccharides with the same ease as soluble proteins but Lilly (1975) concluded that proteins were better absorbed than polysaccharides in *Tripneustes ventricosus*. Fernandez (1996) showed that the absorption of glucids could vary according to the type of feed given. In our case, *P. lividus* ingested a food rich in starch but better growth was obtained when it was mixed with algae, especially one rich in protein. *P. palmata* has high levels of protein, up to 32 % of dry weight (Basuyaux, unpublished results). Growth thus improves significantly when a food rich in polysaccharides is mixed with one rich in protein. The lower growth recorded with the mix of maize and *L. digitata* would be due to its lower protein content (25% of dry weight).

However, this hypothesis would lead to lower growth rates in autumn when the protein content of algae is much lower (10% of dry weight in *P. palmata*). However, this was not observed in our population study where no influence of season was detected. A maize-based feed answers many of the culture's requirements: stability in water (no degradation), satisfactory growth, availability all year long, easy to

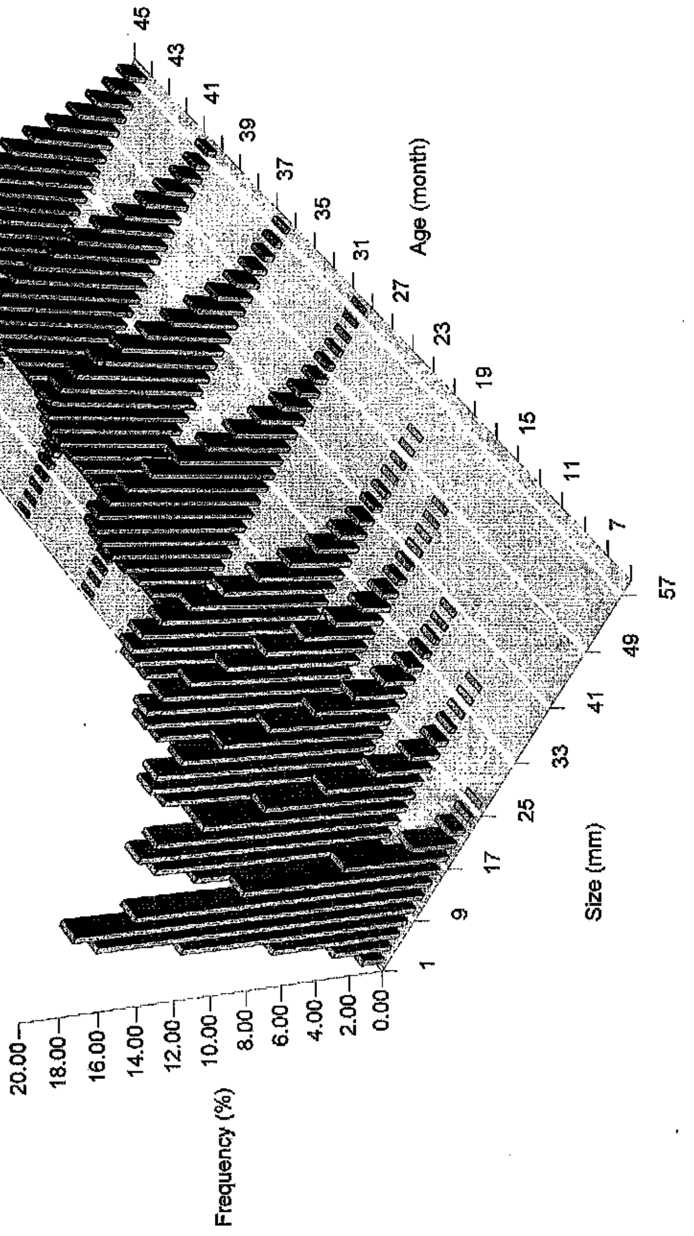

FIG. 5. Size frequency distribution as found by developed model.

store and low cost. However, an alga must be added but at much lower quantities than in a classic algae-based diet.

The growth of a *P. lividus* cohort in a closed circuit system with successive gradings is very regular with regards to biomass but dispersion increases with age. Certain culture parameters can limit growth. The rearing temperature of 19°C is a good compromise between the warmer temperature (24°C) favourable to small urchins and colder temperatures (15°C) more favourable to bigger urchins (Jangoux, pers. comm.). Carbonates have an important effect on the growth of urchins in culture as bicarbonates are used for the formation of their skeleton (Dafni and Erez, 1987; Dubois and Chen, 1989). Carbonate measurements in the rearing water show a clear decrease in the alkalinity which, potentially, can be growth reducing. This decrease in alkalinity was compensated by the addition of sodium bicarbonate or by an increased water renewal rate. However, these additions did not result in an increase in growth in the last three periods. Ammonia, nitrite and nitrate measurements showed levels under toxicity levels known for *P. lividus* (Basuyaux, pers. comm.).

If physicochemical parameters do not seem responsible for the decrease in growth, urchin density could be a prime factor. Jangoux *et al.* (pers. comm.) indicated that to obtain good growth and low mortality, the spatial occupation coefficient value (*K*) should be around 2. In most of the baskets, *K* varied between 1.3 and 1.5 but at the same time the mortality rate remained low (11.1% y^{-1}). However, it is difficult to assess our growth rate since we did not test different values of *K*. Lower densities would implicate a maximum quantity of 12 kg in the baskets whereas at the end of the last period we had 18 kg per basket. This decrease in density would substantially increase rearing costs. Numerous authors have observed an aggregation behaviour when animal density is high in relation to the quantity of available food (Vadas *et al.*, 1986; Himmelman and Nédélec, 1990; Hagen and Mann, 1994). When fed seaweed, urchins aggregate around the algae causing important concentrations in certain areas of the baskets. When fed maize this phenomenon does not occur as the food is more diffuse. Although animal density is important, their better distribution in the rearing baskets might explain the low mortalities observed.

The size dispersion observed in our cohort (6–44 mm at 19 months) is in the same range as that observed by Cellario and Fenaux (1990), although for an equivalent age the test diameter was less important. In their experiment, the mean test diameter of a cohort 551 days old (18.5 months) was 15.2 mm whereas in our rearing conditions it was 20.1 mm at 19 months. Experiments carried out by Grosjean *et al.* (1996) show equivalent size dispersal (10–44 mm at 18 months) but with a mean test diameter of 23 mm. However, their rearing densities are lower and their mortality rates more important (44% between 6 and 18 months' rearing time).

Some individuals in the cohort have a great growth rate and reach the minimal commercialization size (40 mm) in 15 months, but the extrapolation of our data shows that one would need 47 months for 50% of the animals to reach that size. The rearing time thus seems important because it increases the risks associated to the culture (Webber and Riordan, 1976). One could decrease this time by keeping only the bigger urchins after 1 y as it is noticeable that some of the small individuals grow very slowly even if graded.

CONCLUSIONS

1. A maize-based diet supplemented by the alga *P. palmata* is of interest in the culture of *Paracentrotus lividus*.
2. This feed enables one to obtain satisfactory growth and low mortality rates.
3. Resulting size dispersion of sea urchins is low when compared to algae-based diets.
4. Feed cost is low, availability and ease of storage are important elements in any culture.

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