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Use of intensive rearing systems as back-up for coastal lagoon aquaculture: an experience with eels, *Anguilla anguilla* L., in the Comacchio lagoons

R. ROSSI, A. CARRIERI & M. G. RIZZO *Institute of Zoology, University of Ferrara, Italy*
M. LUCCHINI *Societa Itticultura Valli di Comachio, Italy*

Abstract. The possibility of using eels from intensive rearing ponds to restock natural basins has been investigated by comparing growth, survival and rate of yellow-to-silver metamorphosis of 'wild type' eels and of eels from an intensive rearing pond. A total of 2243 marked eels were released into a closed natural environment of 22 ha; 1254 were wild type (average length 45·6 ± 9·0 cm), and 989 from an intensive rearing pond, split by a mechanical grader in two groups. The first group was made of 617 well-growing eels (44·9 ± 3·0 cm), the second one of 372 smaller eels (36·9 ± 4·3 cm) which had not adapted to the artificial conditions.

The starting size being equal the animals grew to the same extent; in some cases the animals previously adapted to the artificial pond grew better than the wild type. The rate of metamorphosis from yellow to silver eel was 28·4% for the wild type eels and 22% for the others, although the latter became mostly silver males. Survival of the wild type eels (starting with the 35-cm size class and covering the period from April to December) was calculated by mark-recapture at approximately 98·6%. For the eels previously well adapted to the intensive rearing pond it was only 85%, indicating some difficulty in competing in the natural environment. The good growth shown by the smaller eels, with a survival of about 90%, would seem to indicate that these animals might be effectively used for restocking purposes, thus favouring an integration between the intensive ponds and the extensive environments.

Introduction

The methods used for fish culture are schematically divided into extensive and intensive. In extensive culture the energy flow which reaches the animals and enhances production is exclusively derived from the nutritional sources from the environment; in intensive culture it is totally provided as supplementary energy through artificial feed. In Italy eels, *Anguilla anguilla* L., are reared extensively in the brackish coastal lagoons with a yield of about 1000 tons per year. In addition to natural recruitment, all the north Adriatic lagoons, which are the most important, are also artificially restocked with elvers of about 5–20 g, from both Mediterranean and north European countries. In the natural environments, however, the eels have a rather long growth cycle, female silver eels taking as long as 6–7 years to reach the most profitable size (Rossi & Colombo 1979). Since the 1970s, both in the north and in the south, eels have been reared in intensive rearing plants (about 3000 tons per year) where the growth cycle is markedly shortened, from 2 years in the south to 3 years in the north where the temperature is less favourable. At that time, while lagoon aquaculture was seen as a production system of a natural traditional type, intensive rearing was interpreted as being

Correspondence: Professor Remigio Rossi, Institute of Zoology, University of Ferrara, Via Borsari 46, 44100 Ferrara, Italy.

merely industrial. Thus the two activities appeared separate, constituting two different intervention policies for the wetlands.

In recent years, however, profit margins in intensive rearing have reduced significantly, especially in the north where these plants arose to defray the economic crisis in lagoon extensive aquaculture. Due mostly to an increase in production costs which were not offset by an equal increase in the internationally fixed eel price, this has marked an end to the original reason for this intervention. On the other hand, intensive rearing plants may avail themselves of hydraulic power, energy waste and fishing products which are potentially useful as support for lagoon aquaculture, and then the possibility of an integration between the two activities can be investigated. Since the main problems of the lagoon aquaculture are the recruitment and the duration of the rearing cycle, two different approaches were tried: (1) the use for lagoon restocking of the intensive rearing production tails, i.e. the eels not perfectly adapted to artificial food; and (2) a trial of a 'mixed technique' — in this form stocking takes place with animals which have passed an initial period of artificial rearing in the ponds of an intensive rearing system, but are of a size so as to guarantee a high survival rate and to allow for a good growth rate (so as to require only one rearing season in the natural environment).

The aim of the present work carried out in the Comacchio lagoons (north Italy) was to study the ability of eels coming from intensive rearing ponds to adapt themselves to natural conditions exploiting whatever the environment offers.

Materials and methods

The experiment took place in Valle Scagna, a 22-ha basin of the Comacchio lagoons isolated by a reinforced concrete construction work equipped with a double grill. All the 'white fish' were captured so as to weed out competitors and/or predators but the eels. The study took place over a 9-month period from March 1984 to January 1985; salinity ranged between 20 and 32‰, temperature between 0 and 30°C. In January 1985 unusual atmospheric conditions were encountered so that the basin was completely ice-covered for more than 1 month.

The eel population in the basin was, first of all, made up of those naturally residing there (thus called 'wild type' — WT). The number of these was estimated by a simple mark-recapture experiment (Begon 1979). To this purpose 1254 WT eels were caught, individually marked by freeze-branding (Rossi, Carrieri, Franzoi & Bianchini 1986) using a four-figure number, and released. To the natural population 989 eels from an intensive rearing pond were added. They were split by a mechanical grader into two groups: the first group (617 eels) was made up of well-growing eels (RWG) perfectly adapted to the artificial environment; the second group (372 animals) was composed of the smallest yellow eels (RSY) which had not been able to grow to the same extent. The RWG were individually marked with three-figure numbers; the RSY with three smaller sized marks.

Estimate of growth in length was obtained by subsequent measuring (± 1 mm) of the marked animals previously anaesthetized with acetone-chloroform. Measurement reliability limit was checked on a stock of 170 eels by repeating the measurement twice, one day apart: the average difference was $0{\cdot}46 \pm 2{\cdot}74$ cm. Since many eels presented their stomach full of prey, to obtain the equivalent growth in weight a length–weight relationship ($W = aL^b$) was calculated for each stock. Ten stomachs from eels from each group were qualitatively examined. The weight increment was then obtained in absolute units by subtracting the expected mean weight per length class from the expected weight after the 7-month growth period, and relatively as specific growth rate (SGR = (($\ln W_t - \ln W_o$)/days)* 100).

To effect a final check on survival rate a mark-recapture technique was used (Jones 1976). Robson & Chapman's (1961) procedure was adopted following the decrease in the number of marked animals captured during the autumn fishing season.

Results

Estimate of the WT eel density by mark-recapture

In order to estimate the WT eel population density in Valle Scagna at the beginning of the experimental period, from 10–21 March 1984, a total of 1254 eels were captured, measured, (average length 45·62 ± 8·97 cm), marked and released. Of these, 35 — seven which were presumably male (average length 38·7 ± 2·2 cm) and 28 which were certainly female given their size (58·1 ± 7·9 cm) — presented many characteristics typical of the silver eel: strongly coloured pectoral fins, broad ocular diameter, dark back and silvery abdomen.

On 2 April 1984 a second sample was taken capturing 826 eels, of which 170 were marked (average length 51·45 ± 8·97 cm). Using the Lincoln-Petersen index (Begon 1979) estimation of the WT population density proved to be equal to 6093 ± 387. The reported figure is certainly underestimated, because of the selectivity of the fyke nets (Rossi *et al.* 1986).

On 4 April 1984, the Valle Scagna was seeded with 989 marked eels from an intensive rearing pond: 617 RWG, with an average length of 44·9 ± 3·0 cm (4 of these were 'silvery'), as well as 372 RSY, average length 36·9 ± 4·3 cm. The latter represent the 'runts' of the rearing pond, i.e. those animals which did not feed satisfactorily.

Thus it was possible to estimate that between marked and unmarked animals there were at least 7000 eels in the basin. Since the average weight of the eels sampled was around 150 g, approximately 1100 kg of eels were thought to be in the Valle Scagna. To check this estimate during the fishing period from October to December 1984 a total of 4145 eels were fished, equal to a total of 814 kg, average weight 196 g. Following the frost of January 1985 the same basin was partially dried and practically all the remaining eels had died. Some 793 kg of dead eels were recovered, although they were in no condition to check eventual marks; only by chance, were four WT eels recognized and measured. Thus the total population of the basin was made up of at least 1600 kg of animals corresponding to about 8200 eels. The estimate of 7000 eels is about 15% lower, an error that may be considered acceptable for the purpose of evaluating stocks.

Growth

Of the 4145 animals caught during the period from October to December 1984, 671 (about 16%) showed the mark. Of these, 316 (47%) were WT, 355 (53%) were from the intensive pond: 100 (15%) were RSY (the runts), 255 (38%) RWG.

Table 1 reports the average length increments, by initial length class, for yellow eels of the three groups which were still yellow after approximately 9 months in the natural environment. Table 2, on the other hand, shows the average growth increments for those eels which, during the same period, had changed from yellow to silver.

Table 1. Average increment in length (±SD) for yellow eels from different stocks during a 9-month period

Initial length class (cm)	Wild type		Previously reared: Well growing		Previously reared: 'Runts'	
	n	Increment (cm)	*n*	Increment (cm)	*n*	Increment (cm)
25–30					3	10·4 ± 1·0
30–35	13	10·0 ± 2·7			7	8·3 ± 4·4
35–40	36	8·1 ± 2·4			43	7·9 ± 2·8
40–45	38	5·7 ± 2·3	116	5·9 ± 2·0	18	6·0 ± 2·5
45–50	55	3·5 ± 1·9	78	4·9 ± 2·3	1	3·8
50–55	41	2·2 ± 1·6	9	3·2 ± 1·5		
55–60	15	2·3 ± 1·4				
60–65	12	2·0 ± 1·2				
65–70	5	2·2 ± 1·1				
70–75	2	0·8 ± 1·1				

Table 2. Average increment in length (±SD) of yellow eels from different stocks which had become silver in the 9-month period

Initial length class (cm)	Wild type		Previously reared: Well growing		Previously reared: 'Runts'	
	n	Increment (cm)	*n*	Increment (cm)	*n*	Increment (cm)
30–35	1	9·0				
35–40	14	3·9 ± 1·6			16	3·6 ± 2·6
40–45	8	2·0 ± 1·3	45	2·6 ± 2·4	11	2·3 ± 0·9
45–50	23	2·6 ± 2·0	5	4·7 ± 2·9		
50–55	28	1·7 ± 1·3	2	3·6 ± 1·1		
55–60	7	0·8 ± 0·8				
60–65	1	0·0				
65–70	3	0·7 ± 0·7				
70–75	1	2·6				

Among the yellow eels (Table 1) it seems that, except for the length class 45–50 cm where the RWG eels grew more than the WT ones ($P < 0·01$), the growth increments were the same for the three groups. The main items in the trophic web and in the examined stomach of yellow eels of the three groups were: *Palaemon* sp., *Crangon crangon*, Isopoda, Amphipoda and Polychaeta. It would therefore appear that the yellow eels from the rearing pond had perfectly adapted to the natural environment; in some cases they grew more than the WT and there was an evident resumption of growth also for the RSY, which had previously showed a slow growth rate in the rearing pond.

The eels which had become silver on average grew less than those which had remained yellow. The difference is significant (*t*-test, $P < 0·05$) for the eels of all three groups in the length interval 35–45 cm ($P < 0·01$), and for the WT eels in the length class 55–60 cm. As has already been mentioned, 35 of the WT and four of the RWG eels marked and released were 'silvery' eels. Only one out of four RWG was recaptured in November, its length having increased from 40·4 to 44·2 cm. Of the seven WT silver males four were recaptured; their average size had increased from 38·6 to 41·8 cm, with an average increase of 3·2 ± 1·6 cm. Of the 28 WT silver females nine were recaptured at the same time: the average length had increased from 63·7 to 64·6, an increase of only 0·9 ± 1·0 cm. These data and those of Table 2 appear to confirm clearly that once the eels have become 'silvery' growth is at a minimum and it is certainly not sufficient to justify keeping these animals in a fishing or rearing environment.

To evaluate the weight increments for each length class, a length–weight relationship for each stock was calculated (Table 3). The slopes are significantly different, both because of the particular characteristics of each stock and because of differences in the considered length intervals. The computed weight increments are reported in Table 4 and confirm the results already shown with the length increments.

Table 4 reports also the specific growth rate per length class, which shows a decreasing trend from the smallest class upwards, and the daily per cent increment, i.e. the percentage of body weight by which the eels must have grown each day to reach their average weight at the

Table 3. Length–weight regression parameters ($W(g) = a\,L^b(cm)$) of the eels in the Valle Scagna

	n	*a*	*b*
Wild type	1564	0·00049 ± 0·0030	3·2886 ± 0·0136
Previously reared			
Well growing	144	0·00247 ± 0·0340	2·8795 ± 0·0743
Small yellow	81	0·00025 ± 0·0470	3·4576 ± 0·0541

Table 4. Average computed increment in weight (g) by initial length class for the yellow eels from the different stocks

	Wild type				Previously reared: RWG				Previously reared: RSY			
		Weight increment				Weight increment				Weight increment		
Initial length class (cm)	Mean weight (g)	Abs (g)	Daily %	SGR	Mean weight (g)	Abs (g)	Daily %	SGR	Mean weight (g)	Abs (g)	Daily %	SGR
25–30									24	48	0·97	0·23
30–35	46	65	0·67	0·18					42	51	0·57	0·16
35–40	74	66	0·43	0·13					69	68	0·47	0·14
40–45	111	57	0·24	0·09	121	55	0·22	0·08	107	57	0·25	0·09
45–50	160	42	0·13	0·05	166	54	0·16	0·06				
50–55	222	32	0·07	0·03	222	41	0·09	0·04				
55–60	300	41	0·07	0·03								
60–65	395	43	0·05	0·02								
65–70	508	57	0·05	0·02								
70–75	643	24	0·02	0·01								

SGR = $(\ln W_f - \ln W_o)$*100/days.

end of the experiment. The daily per cent increment is good, even if compared with that observed in intensive rearing conditions (Koops & Kuhlmann 1981).

Percentage of yellow-to-silver metamorphosis

The percentage of yellow-to-silver metamorphosis for the WT eels is 28·4% (86 out of 303 specimens recaptured which were initially yellow), 20% for the RWG (52/254) and 27% (27/100) for the RSY. Since all the silver eels with an initial length (yellow stage) greater than 45 cm can be reasonably considered females, splitting the total percentage between males and females we obtain: 7·6% males and 20·8% females for the WT eels; 17·7% RWG males and 2·8% RWG females respectively; and 100% of male silver eels for the RSY. Thus, even if the total percentage does not differ between the stocks, the majority of the eels previously reared became silver male, with a consequent reduction of their weight increase.

Mortality

During the fishing season (October–December) 25% of the marked-released WT eels were recaptured, as well as 41% and 27% of those from the rearing pond (the growing stock and the runts respectively). Using the ratio between the number of marked and unmarked eels present in subsequent catches (Table 5) an estimate was made of the eels' natural mortality, by the Robson & Chapman (1961) method. Assuming a constant mortality rate throughout the entire study period, for the WT eels the mortality proved to be 0·0141 (survival rate 98·6%); for the RWG 0·165 (S = 84·8%), and for the RSY 0·1043 (S = 90·1%), pooling

Table 5. Estimate of the survival rate from a single marking experiment with several recaptures (i); n_i: total number of eels in each sample; m_i: marked animals present in the sample; $y_i = (m/n)*1000$

				From rearing			
	Wild type			Well growing		Runts	
i	n_i	m_i	y_i	m_i	y_i	m_i	y_i
1	351	19	54·1	69	196·6	20	57·0
2	232	19	81·9	42	181·0	13	56·0
3	175	23	131·4	19	108·6	6	34·3
4	307	36	117·3	16	52·1	3	9·8
5	211	17	80·6	15	71·1	4	19·0
6	274	20	73·0	11	40·2	5	18·3
7	244	20	82·0	8	32·8	4	16·4
8	429	24	55·9	14	32·6	8	18·7
9	121	8	66·1	9	74·4	2	16·5
10	241	19	78·8	8	33·2	1	4·2
11	619	36	58·2	16	25·9	9	14·5
12	273	15	54·9	10	36·6	5	18·3
13	234	16	68·4	8	34·2	9	38·5
14	179	16	89·4	4	22·4	4	22·4
15	255	24	94·1	6	25·5	7	27·5
Total	4145	312		255		100	

together the classes when the marked animals present in the sample are less than 5. Not only the scarcity of recapture of RSY makes the estimate for this group less reliable but also the other ones remain only an unsupported estimate, due to the difficulties encountered in the final catch of all the animals: the pond was covered with ice and all the animals died. The end of the experiment was actually planned for April 1985, after 1 year's extensive rearing. This notwithstanding, the data suggest that the reared animals had some difficulty in adapting to life in a natural environment. The presence of wild eels in the basin, required to compare growth, may have given rise to competition and predation between the two classes of animals.

Discussion

Comparisons between the growth rates of wild type yellow eels and eels from intensive rearing indicate that, once seeded in a natural environment, the latter are able to return to feeding habits which make possible growth equal to, if not greater than, the former. However, eels from an intensive rearing pond show a lower survival rate than the wild type. It would therefore be advisable to seed them in basins free of predators (including wild yellow eels themselves) or at least submit them to a true phase of readaptation to life in the wild through farming them in suitable adapted basins. On the other hand, in light of the data, the reseeding of animals well adapted to intensive rearing, and which in the natural environment present a lower survival rate than the WT animals, and a rather high percentage of specimens which become silver males, does not seem to be economically advantageous. An interesting point was found in the seeding of 'runts', which demonstrated good ability to resume growth. These immature animals, from the first year of rearing, are the production tail (in essence the waste) and they might represent the raw material for massive, quick stocking of the lagoons. The biogenic capacity of the latter would thus be more fully exploited, and, at the same time, there would be a marked shortening of the lagoon production cycle. Finally, economic recovery in intensive rearing systems would be significant as a portion of their by-products would be upgraded and their function reassessed.

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References

Begon M. (1979) *Investigating Animal Abundance.* Edward Arnold, London.

Jones R. (1976) The use of marking data in fish population analysis. *FAO Fisheries Technical Papers* **153**, 1–42.

Koops H. & Kuhlmann H. (1981) Annual variation of feeding and growth rate of eels farmed in thermal effluents of a conventional power station. *Proceedings of the World Symposium on Aquaculture in Heated Effluents and Recirculation Systems*, Stavanger, 28–30 May 1980. Berlin, 1981. Vol. II, 205–11.

Robson D.S. & Chapman D.G. (1961) Catch curves and mortality rates. *Transactions of the American Fisheries Society* **90**, 181–9.

Rossi R., Carrieri A., Franzoi P. & Bianchini M. (1986) Freeze-branding in population assessment of the eel *Anguilla anguilla* (L.). *Oebalia* **13**, 15–25.

Rossi R. & Colombo G. (1979) Some observations on age, sex and growth of silver eels (*Anguilla anguilla* L.) in North Adriatic lagoons. *Rapports et Procès-verbaux des Réunions du Conseil International pour l'exploration de la Mer* **174**, 64–9