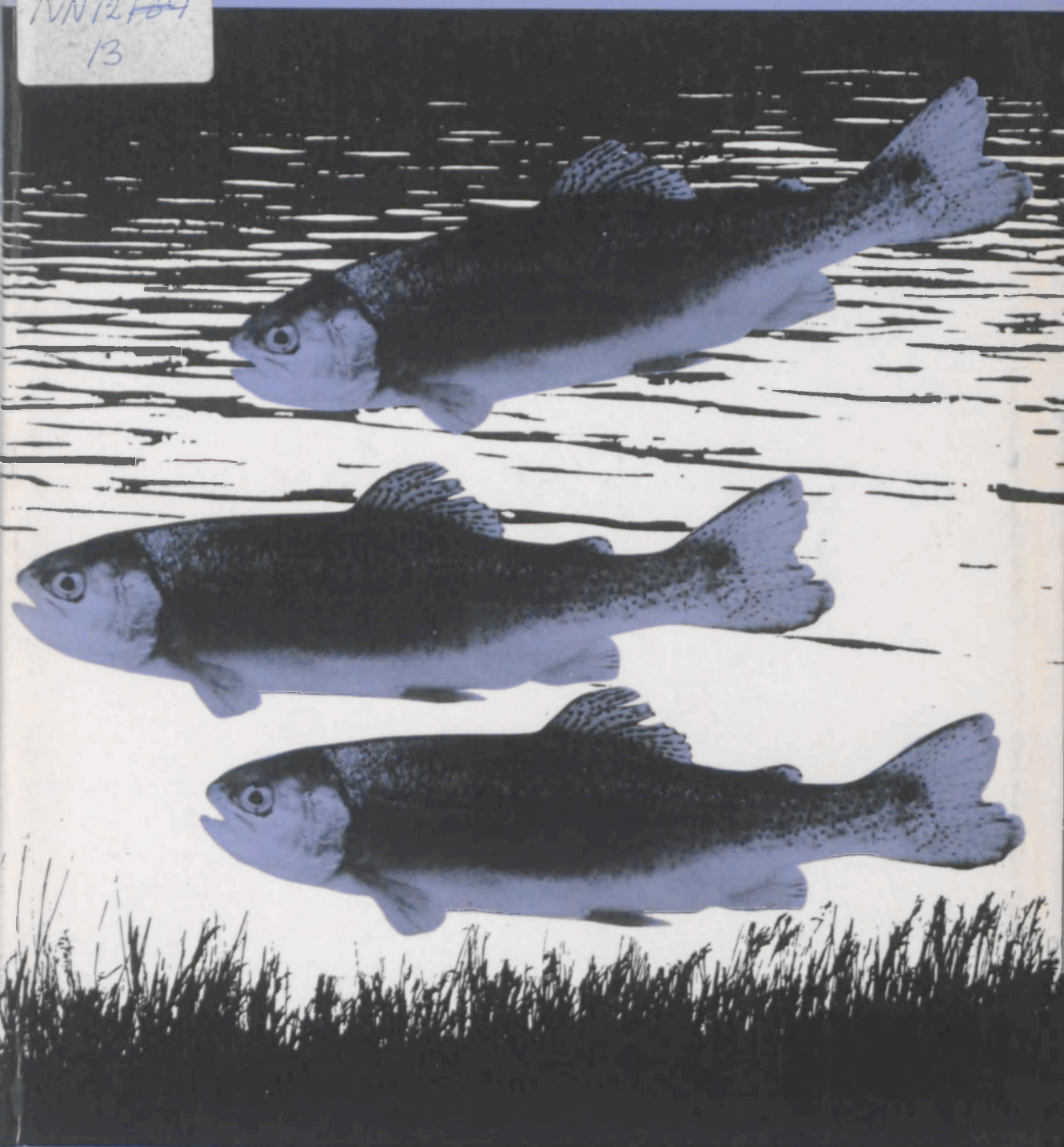
Aspects of fish culture and fish breeding



MISCELLANEOUS PAPERS 13 (1976)
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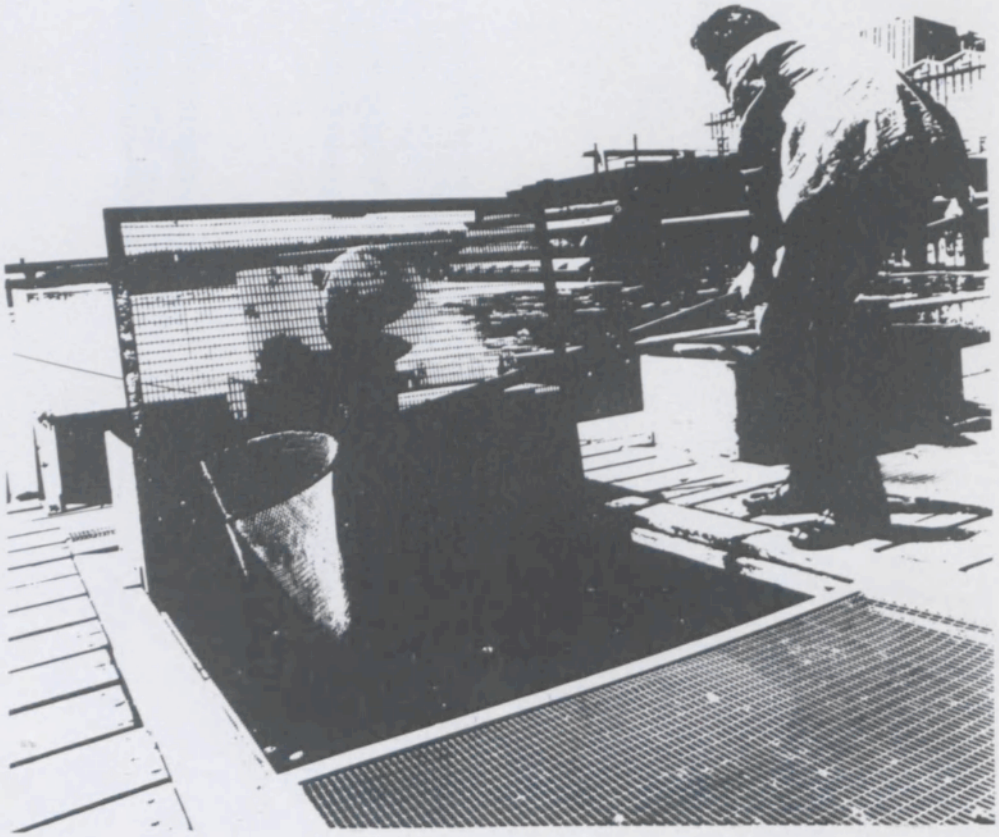

Fish Culture Station at Lelystad of the Organization for Improvement of Inland Fisheries (OVB).

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ASPECTS OF FISH CULTURE AND FISH BREEDING

EDITED BY

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INTRODUCTION

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The best way – in my opinion – to start an introduction to the field of fish culture is to repeat an old Chinese proverb, 'Give a man a fish and he will have food for one day; teach him how to grow fish and he will have food for the rest of his life'.

This saying illustrates the transition from fisheries to fish culture; from harvesting a natural crop to harvesting man-made production. This transition has been on from 500 BC, when Fan Lee wrote the first classic textbook on fish culture in China, until this century.

Although in some regions of the world fish culture has grown into a big enterprise supplying food for human society (China, Phillipines, Indonesia, Israel etc.), on the whole its importance in relation to fisheries is still supplementary: aquacultural production amounts to five or six million tons a year, whereas the total world catch from the aquatic ecosystem is about seventy million tons.

The world catch from fisheries has almost stabilized, despite the increasing fishing efforts during the last seven or eight years. Therefore, because of the growing demand for fish and fish products, fish culture can be expected to have a promising future in meeting this demand.

For a long time production of fish has been left to 'Mother Nature', man harvesting from a natural crop. The transition from hunting fish to producing fish has come with the construction of fish ponds.

A fish pond with an adjustable water level can be filled with water and afterwards drained for harvesting. This system incorporates one of the basic principles of man-made fish culture by providing opportunities for quantification and regulation. With a drainable fish pond man can control the fish species, year classes and number of fish, the presence and absence of predator fishes and other factors.

The production capacity of such a fish pond depends on the fish species and the abundance of fish food developing in the pond, and can amount to several tons per hectare per year depending on climatological conditions. Especially in tropical regions balanced polyculture of different fish species, predating on different trophic levels, leads to excellent results.

In a system like this the function of the fish pond is twofold.

In the first place the fish pond acts as a residence for the fish and secondly the pond represents the medium in which the food organisms will grow.

On a quantitive basis these two functions limit the production capacity of a fish pond.

At increasing fish densities normally the second function will become the first limiting factor in production capacity, the pond being unable to meet the demand for food organisms of the standing fish crop. This second function of the pond can be reinforced artificially by organic or inorganic fertilization, thus increasing the amount of food organisms available for the fish. But a further increase in fish production can be realised only by the introduction of additional food from somewhere else into the fish pond.

In relation to what extent the natural production of food organisms meets the demand for the food of the fish, different additional food stuffs can be used. At relatively low fish densities the role of the – high quality – natural food is rather important and therefore mostly poor quality cereals are used for additional feeding. But at high densities, where the natural food produced in the pond does not play an important role in relation to the total demand for food, fairly complete food stuffs have to be used in addition. These are now widely available in pelleted form. With help of additional feeding a harvest of some thousands of kilograms of fish per hectare per year in fish ponds with stagnant water is possible.

A fish pond, managed in this way, cannot be regarded as a medium for food organism production but only as a residence in which the fish can be kept and produced healthily.

However, if fish production increases further, this residence function too will be a limiting factor. This will happen as soon as the pond does not meet the environmental requirements of the fish. Further increase in fish density might cause a disbalance between on the one hand the oxygen production in the pond and the oxygen uptake from the air by the pond, and on the other hand the oxygen consumption in the pond, it might induce such an accumulation of excretory products that the fish cannot grow properly any longer.

Under these circumstances artificial aeration of fish ponds can be helpful and is practised especially in areas with a lack of water as for instance in Israel.

All these intensification procedures in fish pond management e.g. fertilization, additional feeding and aeration are practised more or less sophisticatedly all over the world and the productivity of this system strongly depends on the fish species cultivated, the equipment used and the climatological conditions. A harvest of 4–5000 kg/ha per year has been reported by SZUMIEC (1974) in Poland, of 8–9000 kg/ha by CHAUDHURI et al. (1975) for India, both for cyprinid fish. Extreme productions over 200 000 kg/ha with clariid fish have been reported for Thailand (see article of Richter, this issue).

However, when the residence function of a fish pond is limited further increase

in production can only be realised, providing 'additional' residence. In other words, the production threshold in ponds with stagnant water can be exceeded by carrying out fish culture operations in ponds with running water.

Fish culture in running water systems has already been practised for a prolonged period mainly in salmonid culture and more recently with other species too. In this system the pond acts only spacely as a residence and the water is only vehicle for oxygen supply and for discharge of metabolic products.

Fish culture in running water systems (ponds, tanks, cages, aquaria, etc.), has good prospects. As it depends on flow rate and not strongly on surface, this method of fish culture can be practised in compact units, for example installed in buildings. In this way many environmental conditions can be controlled. Water can be processed (heated, filtered, disinfected etc.) and so optimized for distinct fish culture purposes; length and intensity of daylight can be controlled; production procedures can be mechanized and automated. When the waste water of these units is properly treated the water can be recirculated within the unit to reduce production costs or risks of disease (BURROWS and COMBS, 1968; MESKE, 1973). As already mentioned production in these units does not depend on surface area but on rate of water flow and rate of water exchange in the unit. Therefore production is expressed in kg per year per 1/sec. flow rate. For comparison with the other fish culture systems already mentioned, however, we might express production in kg per m^3 production volume: production rates of 250–300 kg/m^3 per year are reported in literature for cyprinid culture, the highest values for fish culture in stagnant water being 0.5–1.0 kg/m^3 (SÄUBERLICH, 1972; HUISMAN and GORTER, 1976).

Fish culture under these extremely intensive circumstances, of course, is only possible when adequate food is available. Therefore knowledge of the food requirements of fishes, of food physiology, but also of food formulation and food technology is of basic importance for this type of fish culture.

As fish culture in running water with the help of technology offers great opportunities for the control of environmental conditions, fish can be produced independent of seasonal and climatological conditions and this applies not only to growth of fishes but sometimes also to fish reproduction.

In fish culture, just as in the other branches of animal husbandry, many disciplines and specialisms are involved (ichthyology, physiology, endocrinology, hydrobiology, technology, economics etc.). Therefore it is not possible to cover the whole field of fish culture in this Miscellaneous Paper.

In the next articles the authors report the present state of development in their special fields of interest.

The scientific background of this present state of development differs greatly in these articles illustrating the variety of levels at which the development in fish culture takes place.

Salmonid culture has been an important item in Europe since rainbow trout were imported from North-America, at the end of the last century. The propagation of this species was of great importance for some European countries, especially for Denmark and later on for Italy and France too. From this point of view it is not surprising that during the last decades so much research has been done on this and other salmonid species all over the world. Basic knowledge of zootechnics, food requirements and food formulation, of reproduction etc. is still increasing. One of the rather recent activities on optimalization of salmonid productions is 'selective breeding'. The article of Prof. Dr. H. Skjervold shows how this type of research can contribute to present-day salmonid culture as well as to the propagation of other fish species.

In contrast to the high level of research and management in salmonid fish culture, fish culture in tropical African regions, as reported in Dr. Richter's paper, is at a much poorer level. There are big gaps in knowledge on reproduction, zootechnical aspects of raising fish, as well as in knowledge on the food requirements of the native fishes to be cultivated. In general fish culture in these areas is in the phase of trial and error.

My paper on the hatchery and nursery operations in fish culture management refers mostly to fishes cultivated in moderate climatological zones. It is a compilation of the different methods and techniques used in fish culture for fertilization and gives some zootechnical aspects of egg incubation and raising of fish fry. Thus it takes an intermediate position between the other two papers, dealing with improvements in fish culture mainly by technological means. Many of these methods are already practised on an extensive scale in the culture of salmonid and other fish species, and they may be valuable and suitable for application under tropical conditions.

As mentioned before these papers are not intended to cover the whole field of fish culture, but merely to show its wide scope and different levels of activity. By doing this, it is also the aim to attract attention to the discipline of fish culture and to its importance for human society at present and maybe in the near and distant future.

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GENETIC IMPROVEMENT OF SALMONIDS FOR FISH CULTURE

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1. INTRODUCTION

In Norway during the last 15–20 years we have been developing cooperative breeding schemes within populations of dairy cattle, pigs and sheep. In the process we have done extensive calculations based on estimated values of phenotypic and genotypic parameters.

In evaluating alternative breeding schemes for pigs ten years ago, we needed a test population with large litters and many groups of half-sibs in each litter. This requirement directed our attention to fish.

After some studies, we chose salmonids for some preliminary breeding experiments. Since then the extent of this fish breeding experiment has increased considerably compared with the original plans.

Instead of going into detail about results obtained from these experiments, I will deal more generally with some breeding aspects in connection with sea-farming of salmonids. I shall also relate some of our findings to the possibilities of genetic gain in salmonids.

2. FISH FARMING – WHY SALMONIDS?

Fish farming is an important world-wide industry, and many countries including major industrial nations such as Japan, USA, France, Germany and the Soviet Union are farming fish for food on a large scale.

FAO has estimated the output from fish farming to be 3.02 million tons in 1965 and 7.33 million tons in 1970, which is 5 and 10 percent, respectively, of the human consumption of fish (Table 1). FAO forecasts the production of fish farming in 1980 to be 14.7 million tons, or as much as 16% of the human consumption of fish.These predictions rely on an expected shortage of fish for human consumption (Table 2).

It is expected that most of this progress on a world basis will be in the development of freshwater fish farming.

In the northern region where freshwater temperatures are rather low, our chief area of interest is the farming of fish in the sea or in brackish water. Thus we must exclude a large number of freshwater species for which a complete production

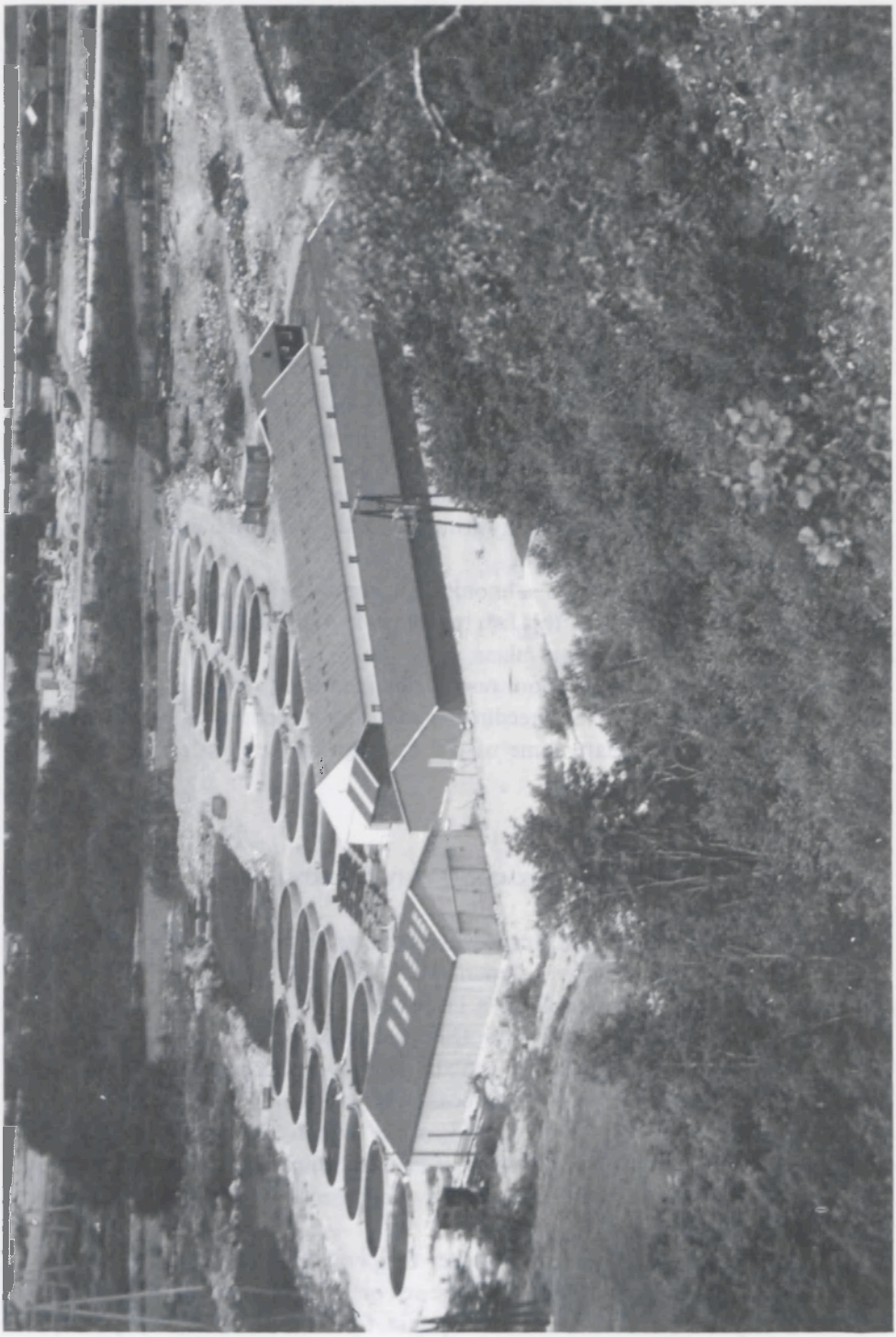


Table 1. Output from fish farming. (In millions of Short Tons live weight and percent of total fish consumed).

1965	1970	Forecast 1980
3.02 (5%)	7.33 (10%)	14.7 (16%)

Source: FAO

cycle (from eggs to sexually mature adults) has been determined.

Marine species usually require a high standard of management for their successful maintenance. Their natural dependence for survival is based on a balance between very high fecundity and very low survival rate. However, complete production cycles also have been developed for some species of marine flatfish such as plaice and sole.

Over a rather long period some cultivation work, such as artificial hatching and rearing of fingerlings, has been done with different species of salmonids and for these species rather complete production cycles have been developed.

The salmonids such as salmon, brown trout, sea trout and char are commercially important fish species in most countries in Western Europe.

Table 2. World demand for fish. (In millions of Short Tons live weight).

	1965	1970	1980
For human consumption	40.9	48.4	67.3
For fish meal	17.7	24.9	33.3
Total	58.6	73.3	100.6
Projected supply			92.0
Deficiency			8.6

Source: FAO

Fig. 1. The Fish Breeding Experimental Station, Sunndalsøra, Norway. The two large barns are 845 m^2 and 550 m^2 in area and contain a total of 266 × 2 m^2 and 140 × 1 m^2 fibre-glass fish tanks between them. Outside, there are 36 large concrete tanks, each of 10 m diameter, and 32 × 4 m^2 fibre-glass tanks. The Station is equipped with modern laboratory and office accommodation, a storage shed and a deepfreeze room, and has a staff of 10. Cold, fresh water is drawn from the Litledalselva River (top left of picture) and from the tailrace of a nearby hydro-electric power station (tailrace is at bottom left of picture). Warm, fresh water is taken from the power station cooling system, and sea water is pumped up from the nearby Sunndalsfjord. Water can be mixed to provide different parts of the Station with a variety of temperatures and salinities.

3. Animal breeding and the salmonids

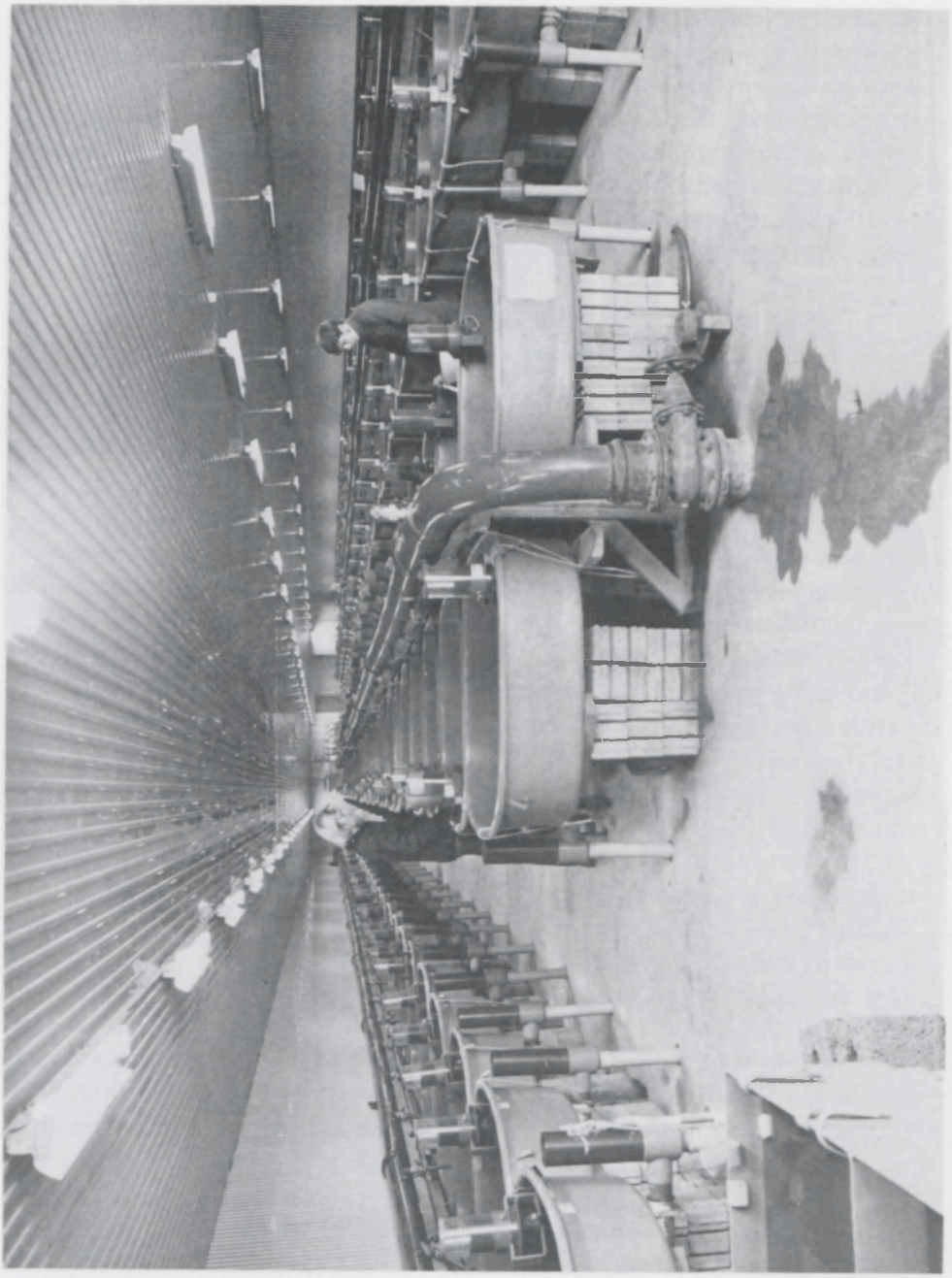
Compared with farm animals the salmonids have certain breeding advantages. Among the most important of these advantages are:

- Very high fertility. The average number of eggs per kg of female body weight range from 1500 in brown trout to 2500 in char. The litter size therefore ranges from about 1500 in brown trout to 10–12000 in the Atlantic salmon.
- Fertilization outside the body of the female. Thus in mating it is possible to make several combinations. For example, it is possible to get many litters of large numbers of half-sibs.
- The very high fertility among females makes it possible to practise:
  - some types of family selection. Even though we are working with traits which show very low heritability, the large family groups will in practice result in rather accurate estimation of the breeding value.
  - progeny testing among females. This can be carried out by using a mixed sample of semen, or semen from sires of which the breeding value is already known.
  - very intensive selection among these females.
- The combination of the high female fertility and an extrauterine fertilization improves the possibility of estimating non-additive genetic components.
- The extrauterine fertilization in most species of fish makes it possible to carry out some artificial manipulation of chromosome content as shown by Russian and English scientists.
- The very high female fertility means that these species are almost 'tailor-made' for some hybrid systems.
- Compared with most other groups of animals, fish show a remarkable potential for hybridization. Many crosses between species occur in nature and many more are possible by using artificial fertilization.

Of course we have also some disadvantages in the use of fish for breeding, and the most important are:

- A rather long generation interval. For example this interval may be 5 years in Atlantic salmon and 3 in rainbow trout. However, by use of tempered water the generation interval can be reduced to 3 years in salmon and perhaps down to 2 years in rainbow trout. These are still relatively long intervals and so the potential of these species as laboratory animals in breeding experiments is considerably reduced. By use of Moskito fish (Gambusia), for example, it is possible to achieve generation intervals as short as 4–6 months.

Fig. 2. View inside one of the large barns at the Fish Breeding Experimental Station, Sunndalsøra, showing the arrangement of tanks and their water supply. Each tank has an automatic feeder which is electrically timed and driven and delivers dry, sinking food pellets. Salmon parr and rainbow trout fingerlings are grown in these tanks until they are ready to be acclimatized to sea water. Each year about 150 families of fish from 40 strains are kept separately in these tanks and compared for various traits of production performance.



- Because the level of knowledge concerning the technology of fish farming is relatively low, we have a rather high frequency of practical problems and 'accidents' in experiments with fish.
- It is well known that fish populations frequently develop hierarchies and this may be an important factor in size variation in some populations. For example, in flatfish such hierarchies contribute greatly to the environmental variation for growth characteristics. However, roundfish seem less liable to this form of interaction. (PURDOM 1972).

4. OUR BREEDING EXPERIMENTS

After recognizing how interesting the salmonids could be for breeding experiments and appreciating the lack of previous work on them, we commenced to establish an experimental station on fish breeding.

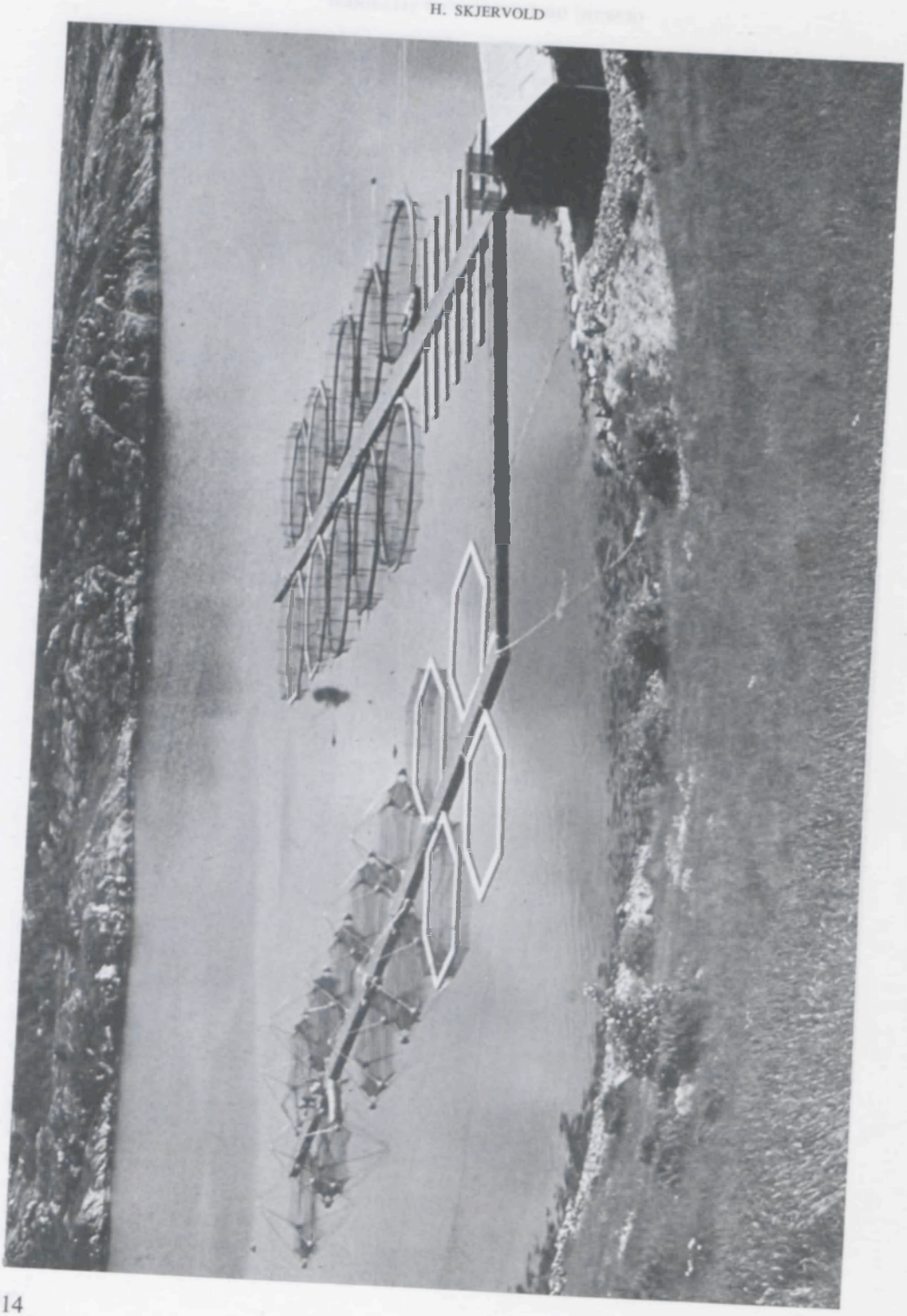
Breeding experiments started in 1966 on a rather small scale. However, after a few years we recognized that a very large amount of genetic variation existed for some of the most important traits. Thus there was the possibility for considerable genetic improvement of characteristics such as growth rate and food efficiency.

Parallel to these discoveries, results from a few pilot marine fish farms proved very promising with rainbow trout and Atlantic salmon. Later investigations have shown that on the West coast of Norway the environmental conditions are rather good for marine fish farming because:

- water temperature is almost ideal for farming the Atlantic salmon.
- there is good protection against storm (island and rocks).
- water depth is satisfactory.
- there is constant water replacement (the Gulf Stream).
- the sea-water is not too polluted.
- a great quantity of food exists (wastage from the fish industry).

This increasing interest in sea farming also improved our chance of obtaining the financial support which was needed to establish a permanent experimental station. In 1971 we obtained such support mostly from agricultural organizations and built the Fish Experimental station at Sunndalsøra. The station (Figs. 1–3) is located near a big hydro-electric plant so that we have access to large quantities of cooling water from the generators (this water has a temperature of 10°C above

Fig. 3. View of outside tanks at the Fish Breeding Experimental Station, Sunndalsøra. The small 4 m^2 fibre-glass tanks (foreground) have electric feeders and are used mainly in nutrition experiments. The concrete tanks are of 10 m diameter and are automatically supplied with dry food by compressed air. Salmon and rainbow trout fingerlings are transferred from indoor tanks to the concrete tanks to begin their acclimatization to sea water. Salinity is gradually increased until full sea water is reached, and the fish are then either sold to commercial fish farmers or taken to the Institute of Animal Genetics and Breeding's sea-cage unit at Ekkilsøy to grow to maturity.



the turbine outlet). In addition we have two other sources of fresh water, and a sea water pipeline.

In 1972 we were given money from the farmer organizations to establish a research unit for sea farming (Fig. 4). At this station we test families of salmon and trout as potential breeding stock. The tests are from fingerling stage to sexually maturity.

5. Experimental design

It was our object to achieve effective programs both for salmon living in captivity and in the wild, and this influenced our experimental design.

To evaluate the potential of Norwegian salmon it was necessary to compare populations from different rivers. Local fishing organizations were contacted for permission to collect salmon eggs, and 41 different rivers covering almost the entire coast of Norway are represented in the experiments.

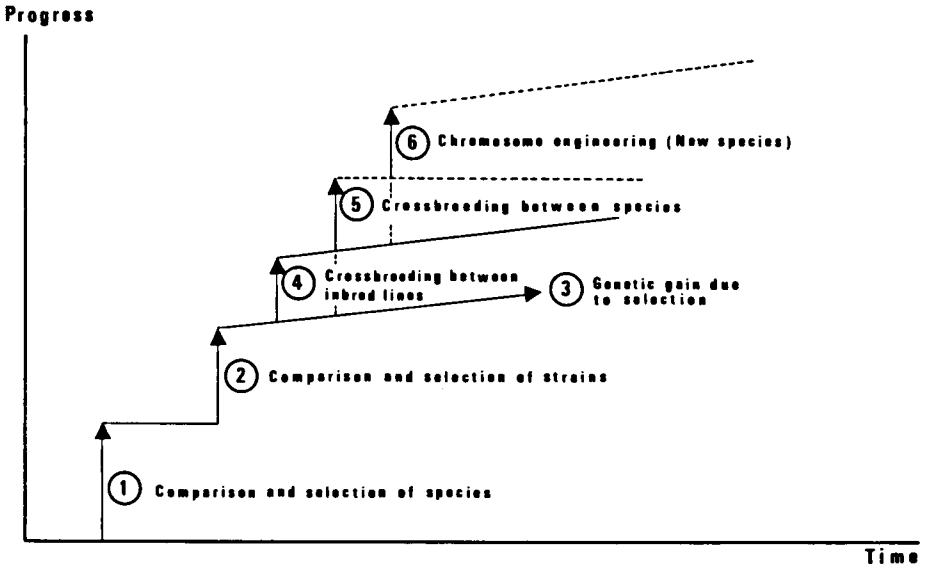


Fig. 5. The figure illustrates the stages of development through which genetic research on fish goes towards its goal of producing fish which give better yields under conditions of high-density commercial culture. Growers of terrestrial farm animals have for many years had the benefit of genetically improved strains, but the fish farmer often still uses wild strains. Genetic research will help to bring the young fish farming industry into parity with its terrestrial counterparts.

Fig. 4. The Institute of Animal Genetics and Breeding, Agricultural University of Norway's sea unit at Ekkilsøy near Kristiansund. Here salmon and rainbow trout grow to maturity or slaughter in floating net cages. 26 cages are in use, 10 of 500 m^3 and 16 of 300 m^3. The Unit is equipped with an office and workshop and employs a staff of 3. At Ekkilsøy strains and families of trout and salmon are compared for production traits such as growth rate to slaughter, meat quality and time to reach sexual maturity.

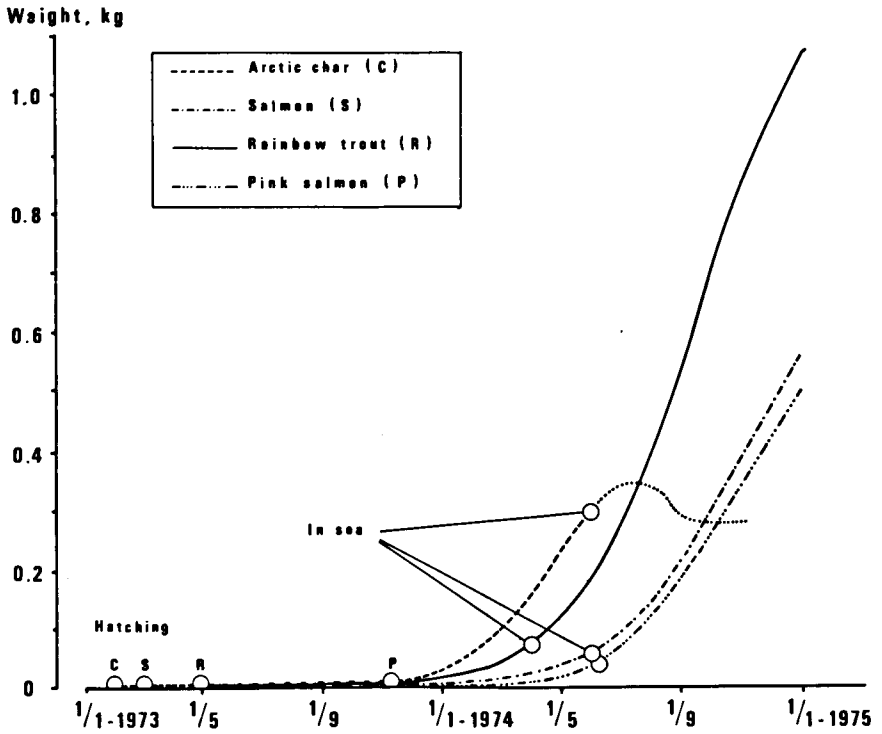


Fig. 6. Growth of Arctic char, Atlantic salmon, rainbow trout and pink (Pacific) salmon hatched at the Fish Breeding Experimental Station, Sunndalsøra, and reared in sea water at Ekkilsøy. The better growth of rainbow trout than Atlantic salmon on this occasion may be due to the trout getting an earlier start in the sea. Growth of pink salmon is considered to be promising for commercial culture, especially to produce a 'pan-sized' fish in one year in the sea. Like salmon, migratory Arctic char should run up rivers to spawn in autumn and winter. However, unlike salmon, they died when kept in floating cages in the sea and refused access to rivers. This is unfortunate, as their rapid early growth might otherwise give them potential for commercial culture. (Experiments of this type represent stage 1 of the research, Fig. 5).

Within each river two different mating systems were used. In one system the eggs from each of three females were divided into three portions and each fertilized with sperm from three different males giving a 3 × 3 set with 9 sib-groups and termed the 'factorial mating system'. For each river one to three sets were produced. This mating system was used in the 1971 collection, with the exception of Arctic char and sea trout where the females yielded too few eggs to divide effectively.

The second mating system was a simple hierarchical design, mating each male to three different females from the same river.

In addition to these mating schemes, hybrids between salmon from different rivers were produced.

The foundation stock, of rainbow trout were collected in 1966/67 from different trout farms in Denmark, Norway and Sweden.

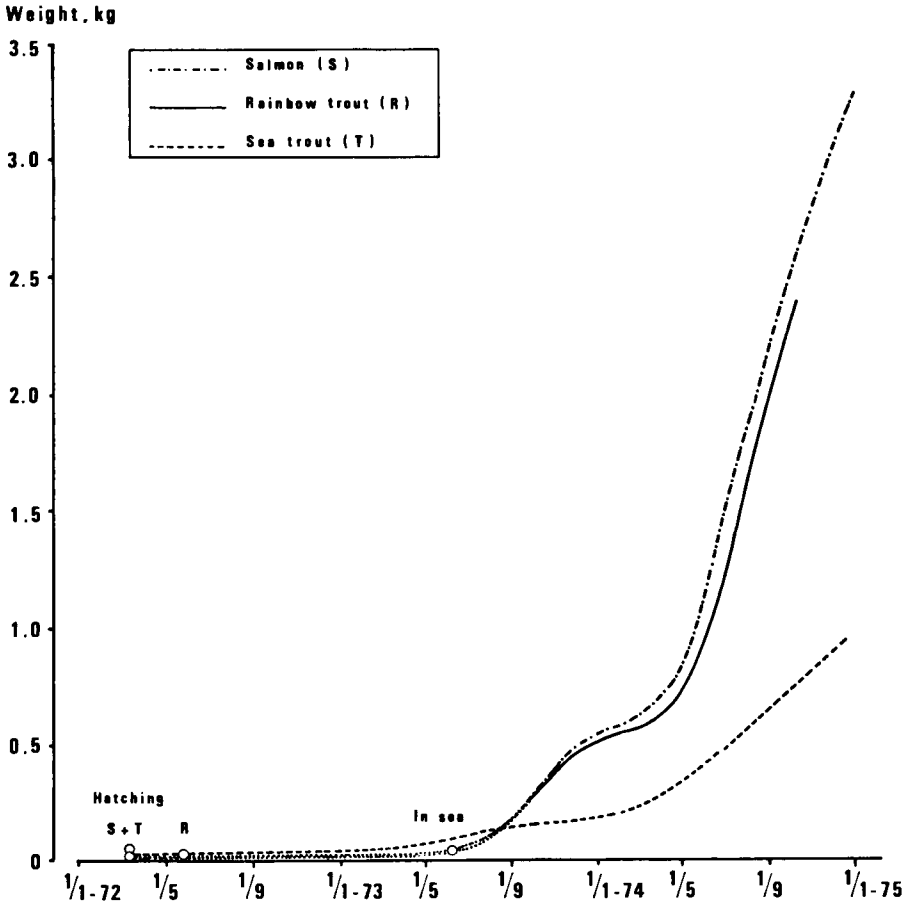


Fig. 7. Comparison of growth of salmon, rainbow trout and sea trout hatched at the Fish Breeding Experimental Station, Sunndalsøra, and reared in sea water at Ekkilsøy. It can be seen that growth of salmon and rainbow trout in sea water on this occasion was very similar, but that sea trout grow much more slowly. Salmon and rainbow trout are the two species which are grown commercially in sea cages in Norway (Stage 1 – Fig. 5).

To test for any interaction between the strain of salmon and the environment, the Fish Experimental Station co-operated with fish farms along the coast. The farms joining the project receive one part of the sib-groups from each river strain or progeny group. In addition, a sib-group of all progeny groups is represented at the Fish Experimental Station at Averøy (the sea-water station), and at this station the salmon are reared in floating nets in the sea.

In co-operation with the Water power and Electricity Board, smolt from some river strains will be released into four rivers under investigation. The primary aim of this project is to record recapture frequencies, growth rate, age at recapture and to determine whether there is an interaction between river strain and locality (Figs. 6 and 7, Table 3).

Table 3. Mean weights of Atlantic salmon from different strains after being hatched at the Fish Breeding Experimental Station, Sunndalsøra, and reared to 3 years of age in sea cages at Ekkilsøy. River of origin of each strain is shown, and the strains are ranked in order of final mean weight. It can be seen that fish from the fastest growing strains reach more than twice the size of fish from the slowest growing strains. Selective breeding in future will concentrate on improving the fast growing strains for cage culture. (Stage 2–Fig. 5).

River	Weight kg	River	Weight kg
Jordalsgrenda	5.1	Laerdalselva	4.4
Namsen	4.9	Alta	4.3
Rauma	4.7	Sandvikselva	4.1
Surna	4.7	Loneelva	3.9
Fosen	4.7	Driva	3.6
Gaula, Sunnfj.	4.6	Luleå	3.1
Etne	4.6	Usma	2.3
Målselv	4.5		

6. Possibilities for genetic gain in salmonids

During the long period of domestication of farm animals a great change in production traits has taken place. The genetic change has been particularly large during this century.

Not much systematic breeding work has been carried out with salmonids, and in Atlantic salmon, for example, wild brood stocks are still used in fish farming. Some attempts have been made with rainbow trout (Donaldson 1968 and Limback 1969).

The behaviour of wild fish in captivity suggests that they are living under stressed conditions. However, it is expected that systematic selection on performance will be partly a selection for behaviour and so increase the process of domestication.

The traits which are of greatest economic importance in fish farming are:
- growth rate
- feed efficiency
- viability and resistance to disease
- carcass quality
- age at sexual maturity.

In connection with other species, genetic response to selection in fish is mainly dependent on the four parameters:
- heritability
- phenotypic standard deviation
- selection differential, and
- the generation interval.

Our investigations have provided information on the first two of these parameters.

Table 4. Total numbers of salmon parr in each strain and the percentage which died in an outbreak of vibrio disease at the Fish Breeding Experimental Station, Sunndalsøra, in 1972. Obviously strains of salmon from some rivers are far more resistant to the disease than others. Vibrio disease bacteria are present naturally in the sea in many areas, where wild fish act as carriers. It is interesting that the Swedish strain of salmon, which suffered the highest percentage of deaths at Sunndalsøra, is the only strain represented which comes from an area where vibrio is not found in the wild. Presumably natural selection has produced more resistant strains from the other localities, but there is still sufficient variation between these strains for artificial selection to be applied to produce even more resistant fish (GJEDREM et al., 1974) (Stage 2 – Fig. 5).

Locality (river)	No. of fish in hundreds	Percent dead of vibrio disease
Alta	124	1.05
Målselva	57	1.50
Namsen	110	2.09
Fosen	111	1.58
Jordalsgrenda	41	2.42
Usma	19	4.59
Surna	58	8.90
Driva	40	1.01
Rauma	33	5.17
Gaula, Sunnfjord	150	5.98
Laerdal	42	8.08
Lone	20	4.09
Etne	24	0.87
Sandvik	153	4.59
Luleå (Sweden)	58	29.71

7. HERITABILITY

In the literature very few estimates of heritability are given for fish. In carp there are some estimates for growth rate (MOAW et al. 1966, NEMASKEW 1968 and KIRPICHNIKOV, 1969) and these seem to be about 0.1–0.2. From our work heritability estimates for growth rate in salmonids are between 0.1–0.2.

For resistance to vibrio disease in salmon, GJEDREM and AULSTAD (1974) estimated the heritability to be 0.07–0.10. These data consisted of 104 thousand fingerlings and the vibrio attack ranged from 0.9% to 29.7% between strains (Table 5).

8. VARIANCE

To be able to compare the size of variance of different traits it is convenient to look at the coefficient of variation: some estimates for different traits in salmonids are given in Table 6. The variance of growth rate in salmonids is 3 to 5 times that

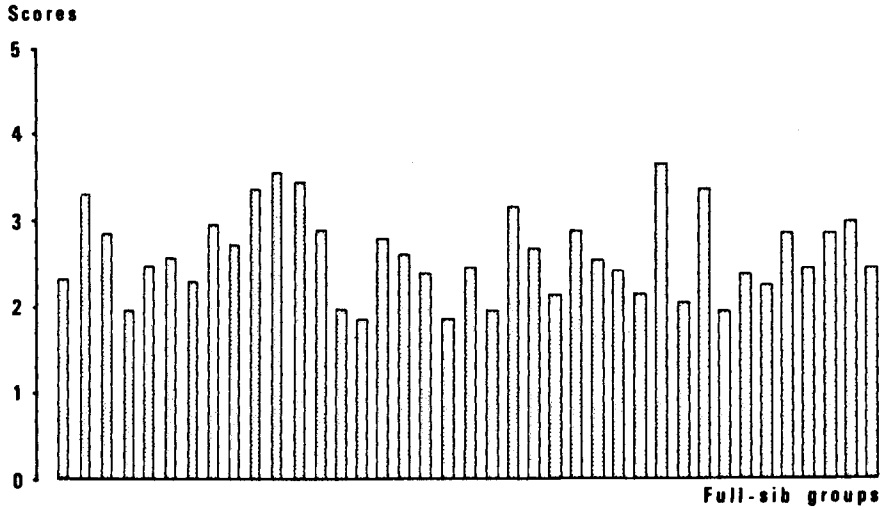


Fig. 8. Variation in meat colour in rainbow trout. Colour is scored by using a meter which electronically records the amount of light reflected from a standard preparation of flesh. Colour of meat is important in marketing fish, consumer preference being for a pink or red flesh. The considerable variation between families of fish in flesh colour found in this study shows that there is potential for breeding fish with a more coloured flesh. An alternative approach is to add pigments to the fish's food to colour the meat (GJEDREM, T., 1976, in press) (Stage 2 – Fig. 5).

of growth rate in livestock, so that substantial genetic gain in growth rate of salmonids should be possible. For carcass traits such as meat colour, meatness and carcass score, a coefficient of variation of about 30% has been obtained at Sunndalsøra (Table 6, Fig. 8).

9. GENETIC GAIN

To demonstrate the potential for genetic gain in growth rate of salmonids, an example is given, using our data.

If we assume that only phenotypic mass selection is practised, and that the animals of both sexes selected for breeding are the top 1 percent of the population, a selection differential of 2.66 units is expected. The standard deviation of the 1972 batch of rainbow trout was 0.95 kg, and the average body weight 2.5 kg. A generation interval of 3 years is possible in practice. Heritability for growth rate is considered to be 0.2.

The expected genetic gain* based on these parameters will be 0.17 kg/year or an increase of 8 percent. This is an exceptionally high genetic gain, which at first may

$$*\Delta G = \frac{2.66 \cdot 0.2 \cdot 0.95}{3} = 0.168$$

Table 5. Estimates of the heritability of a number of important production traits in salmonids, calculated from results obtained at the Fish Breeding Experimental Station, Sunndalsøra. Heritability gives an indication of the potential for improvement of a trait through selective breeding and, generally speaking, the higher the figure the more likely is the success of a selective breeding programme. The potential for improvement of salmonids through selective breeding seems good. Amongst those traits shown in the table the importance of mortality rates, weight (growth) and disease resistance are obvious. Percentage of salmon smolting i.e. becoming physiologically prepared to go to sea, early, is important as it cuts down the time taken for the fish to reach marketable size. Tolerance for acid water has recently become vitally important for wild stocks of fish, because acid precipitation caused by air pollution has lowered the pH of some lakes and rivers so much that many fish are unable to survive (Stage 3 – Fig. 5).

Trait	Salmon	Rainbow trout	Reference
Mortality of eggs	0.11–0.12	–0.20	KANIS and GJEDREM (1975)
Mortality of fry	–0.01	0.04–0.14	
Smolt percent	0.16		STEINE and GJEDREM (1975)
Weight of fingerlings		0.09–0.32	AULSTAD et al. (1972)
Resistance to vibrio disease	0.07–0.12		GJEDREM et al. (1974)
Tolerance for acid water		0.02–0.18*	GJEDREM (1976)

* Brown trout

Table 6. Phenotypic average and coefficient of variation for some production traits in different species. The coefficient of variation gives an indication of the potential for improvement in a trait by selective breeding. It can be seen from the table that the variance in growth rate of salmonids, estimated from data from the Fish Breeding Experimental Station, Sunndalsøra, is three to five times as high as for growth rate in farm animals. This large variance should make it possible to produce substantial genetic gains in the growth rate of salmonids (Stage 3 – Fig. 5).

Species	Trait	Average	Coefficient of variation (%)	Reference
Cattle	Growth rate	1.158 kg	7	FIMLAND, 1973
	Milk yield	5053 kg	15	SYRSTAD, 1966
Sheep	Weaning weight	36.8 kg	17	GJEDREM, 1967
	Fleece weight	4.53 kg	13	EIKJE, 1971
Swine	Growth rate	0.610 kg	12	STANDAL, 1973
	Backfat thickness	20.6 mm	10	STANDAL, 1973
Rainbow trout	Body weight	0.013 kg	33	AULSTAD et al., 1972
	Body weight	1.29 kg	40	GJEDREM, 1974
	Body weight	2.50 kg	38	GJEDREM, 1974
	Carcass score	2.77 score	31	GJEDREM, 1974
	Meat colour	2.63 score	34	GJEDREM, 1974
Sea trout	Body weight	0.012 kg	51	GJEDREM, 1974
Salmon	Body weight	5.0 kg	102	GJEDREM, 1974

look unrealistic. However, the selection intensity is less than can be practised. If the heritability is as low as 0.1, the genetic gain will still be as much as 4 percent/year. This is about four times as high as is common in populations of livestock when the most efficient selection schemes are used.

10. Selection methods

Progeny testing of both sexes can be used in salmonids, but because of the considerable increase in generation length it produces, it is of less interest.

Family selection based on full-sib and half-sib testing does not have the disadvantages associated with progeny testing. There is no increase of the generation interval when using family selection. Further, by means of family selection a trait of economic importance can be recorded with a high degree of accuracy, although if considerable dominance variance exists, the ranking on additive breeding value of full-sib groups will be somewhat biased. The accuracy of the ranking can, of course, be increased by taking into account the ranking of half-sib groups (Fig. 9).

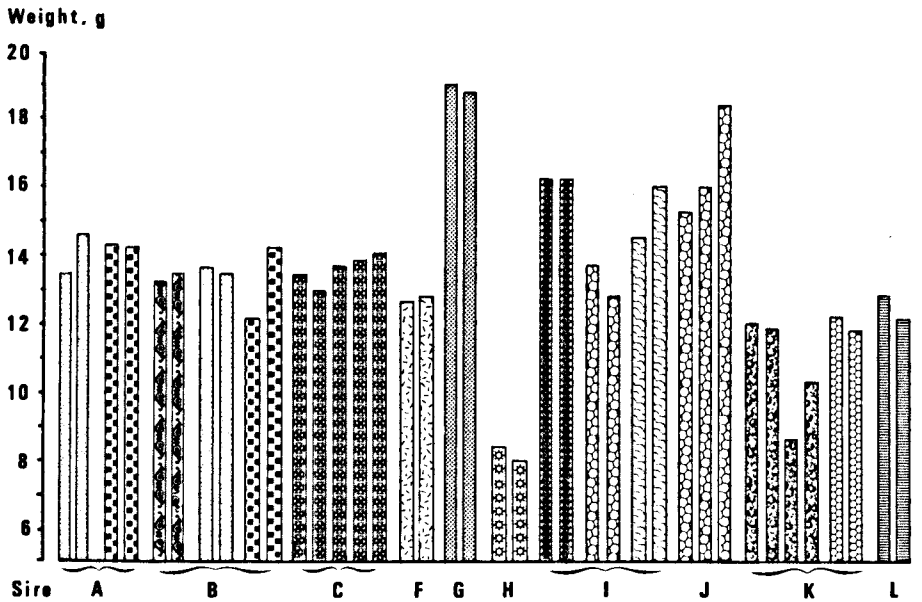


Fig. 9. Average body weights of groups of 500 rainbow trout fry 8 months after hatching from eggs produced from replicated matings. Similar bars denote the same dam. As expected, there are large differences in size between different crosses. However, what is important is the high repeatability of results for the same cross. This shows that it is possible to rank progeny groups for growth performance with confidence that the differences found are not produced by chance and are consistent (Stage 4 – Fig. 5).

In a breeding scheme for salmonids a combination of phenotypic and family selection should be used.

11. Depression of inbreeding

Table 7 shows a rather high depression of inbreeding especially for survival rate among fry and fingerlings.

The depression of inbreeding concerning growth rate, however, is on an expected level (Table 7).

Table 7. Amount of inbreeding depression in some traits in rainbow trout produced by a 10% increase in the coefficient of inbreeding. F. Hatchability, survival of young fish and growth are all decreased markedly as the degree of inbreeding increases. However, in future crossing of inbred lines can produce offspring which display heterosis, or hybrid vigour, and these fish might be very useful for production. (Gjedrem, 1974) (Stage 3 – Fig. 5).

Hatchability	10%
Viability of fingerlings	24%
Body weight, 2½ years old	3–7%

12. Hybridising species of salmonids

A considerable number of viable hybrids between different species of salmonids have been reported. The main purpose of such studies has been to provide basic biological information on:

- the ability to produce such hybrids
- the morphological features of them, and their potential for reproduction.

At Sunndalsøra in 1972 we commenced a hybridization experiment with salmonids. The main purpose of this experiment was to investigate the potential value of such hybrids for fish farming. We attempted to use brown trout, sea trout, salmon, Artic char and rainbow trout, but rainbow trout was subsequently eliminated because of difficulties in synchronising its spawning with other species. To study differences between sire and dam species, diallel crossing was conduced in two phases, namely freshwater followed by saltwater crossing.

Results for the freshwater phase only are available. All crosses of salmon × sea trout and salmon × brown trout have a growth rate below the average of their parental populations and this is shown in Fig. 10. The sea trout × brown trout crosses had an average body weight below the control group. All combinations of crosses with Artic char had a rate of gain significantly above the average of their respective parental species and the most promising results are obtained by crossing char × salmon. Char female × salmon male, gives hatchability equal to that of salmon, but the survival rate is significantly better in the hybrids.

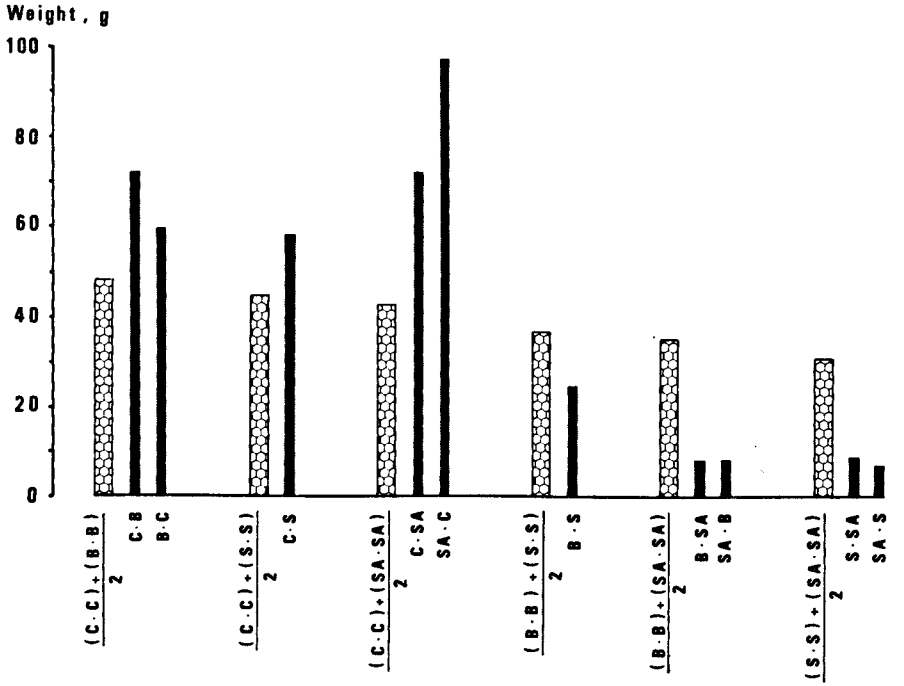


Fig. 10. Average body weights of parental fish and offspring of cross-matings, all at 11 months of age. Code: C = char, S = sea trout, SA = salmon, B = brown trout (crosses with rainbow trout were also tried, but survival was low). Dam species in a cross is shown first e.g. C.SA. = char dam, salmon sire. It can be seen that crosses of which one parent is char show superior growth to their parents, whereas other crosses tend to show poorer growth than parents. Char-crosses may therefore have a future in commercial fish culture (REFSTIE and GJEDREM, 1975) (Stage 5 – Fig. 5).

It will be of great interest to study the extent of sterility in this combination of crosses. Because of the great difference in number of chromosomes sterile hybrids are likely and if this is so we may have an interesting animal for fish farming.

Hybridization would seem to be of much interest in fish farming, and some other interesting species should be studied, particularly the pink salmon as its fry also survive in sea water.

Hybridization in combination with manipulation of the chromosome numbers directs our thinking towards 'genetic engineering' (Fig. 5).

13. ARTIFICIAL MANIPULATION OF THE CHROMOSOME NUMBER

Recently gynogenesis has been demonstrated by Russian, English and Norwegian scientists working with fish. High doses of radiation can be used to induce gynogenesis, the spermatozoa then being made genetically inactive. Such a treatment

destroys the chromosomes, but does not kill the sperm cell. After the fertilization by such radiated sperm and the second phase of meiosis, the egg contains only an haploid set of chromosomes.

Russian experiments with carp, and English experiments with flatfish show that among the gynogenetic offspring there is a small fraction (1–2%) of normal-looking embryos, which are in fact diploid. PURDOM (1972) has shown that by exposing eggs to a cold shock the frequency of diploid embryos in flatfish can be increased to as much as 80%. The elimination of one group of chromosomes as the 2nd polar body is then prevented. The diploid gynogenetic offspring have only maternal chromosomes so this produces a result similar to self-fertilization.

Experimentally such highly inbred lines would be of interest. Even with some crossing-over such diploid gynogenetic offspring will be reasonably homozygotes. Gjedrem and his coworkers have produced a small number of 13 diploid gynogenetic rainbow trout, but only 4 have survived.

14. INDUCED POLYPLOIDY

Such induced gynogenesis allows us to estimate the extent to which cold shock prevents the last part of the 2nd phase of meiosis. If very effective, it should be possible to induce *triploidy* by use of non-radiated sperm in combination with cold shock.

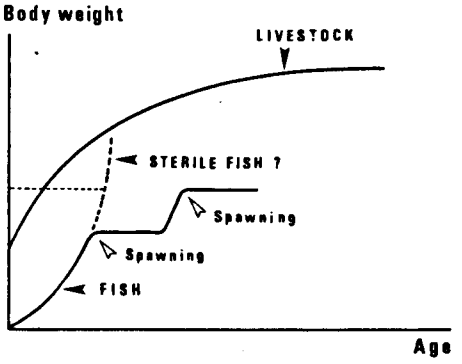


Fig. 11. Growth curves for domestic farm animals and fish. Unlike mammals, which reach a maximum size and then stop growing, fish keep growing bigger throughout their lives if sufficient food is available. However, for salmonids, in the year in which they mature and spawn very little extra growth in 'meat' occurs. Instead, all the energy from the food they eat goes into the development of the gonads. Except in brood stock, the fish farmer does not want this, and it is therefore usual to slaughter fish before they mature. Selective breeding for later spawning may enable larger fish to be grown in future. Alternatively, sterile fish might be produced by interspecific crossing, hormone-feeding, or induced triploidy. Sterile fish could theoretically be grown to a very large size if required (Stage 6 – Fig. 5).

Table 8. Attempted induction of polyploidy in salmonid eggs by treatment with the drug cytochalasin B. Cytochalasin B is known to inhibit cell division in mammals, while allowing chromosome division to continue. This results in the production of polyploid cells. Attempts were therefore made to induce polyploidy in salmonid eggs by treating them with this drug. Treatment was tried at different times after fertilization and for varying periods of exposure. Results were variable, but some polyploid eggs were produced. Refinement of this technique could lead to the production of sterile fish, the growth of which would not be inhibited by sexual maturation (Stage 6 – Fig. 5) (REFSTIE and GJEDREM, 1976, in press).

	Start of treatment after fertilization	End of treatment	No. of egg tested	Percent polyploid cells
Salmon	5 h	2 h after 2 cells	10	0–16
	8 h	2 h after 2 cells	14	0–20
	11 h	2 h after 2 cells	2	0
	5 h	4 cellstage	13	0–35
	8 h	4 cellstage	11	0–18
	11 h	4 cellstage	4	0
Rainbow trout	2 h	4 cellstage	14	1–68
	4 h	4 cellstage	6	0–14

Triploids have been produced in plaice and in plaice × flounder hybrids. However similar attempts to induce tetraploids have failed so far.

Triploids could be of great importance in fish farming for at least two reasons (Fig. 11):

- Their growth rate may be greater than that of diploids.
- Triploid organisms are usually sterile. By use of triploids we therefore could avoid sexual maturation, which results in decreased growth rate and increased death rate. In fish farming sexual maturation therefore results in wastage of energy and makes it almost impossible to market matured fish at a standard weight.

We have not yet been able to induce triploids in salmon or rainbow trout. There has also been a problem in identifying triploids as this could only be done by counting chromosomes. However, it is now possible to make chromosome preparations from leukocyte culture (GRAMMELTVEDT, 1974) so that the number of chromosomes can now be determined without slaughtering (Table 8).

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HATCHERY AND NURSERY OPERATIONS IN FISH CULTURE MANAGEMENT

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1. INTRODUCTION

In recent years technology has been introduced in fish culture with significant progress in the control of environmental factors such as temperature, daylength, oxygen pressure, water processing (filtering, heating, sterilization, etc.).

This so-called artificial propagation of fish is for economic reasons mostly limited to propagation from the early stages up to fingerlings, in other words to that part of the life cycle which is most vulnerable and therefore most suitable for intensively controlled systems.

This review of hatchery and nursery operations had to be restricted. It includes the operations connected with hatchery buildings and omits pond procedures. Secondly it considers only those species, with which we have more or less experience in the Netherlands.

2. HATCHERY OPERATIONS

Hatchery operations are defined here as operations from the collection of eggs and sperm to egg hatching.

2.1. *Collection of eggs and sperm*

Propagation of fish starts with the collection of eggs and sperm. Mostly these products are obtained by stripping the ripe spawners. In general the availability of spawners depends mainly on two sources, viz. the natural habitat, such as for pike, or a breeding stock which is kept at the farm. The latter is a suitable system for many cultivated fish species.

Spawners from the natural habitat are obtained by trapping the fish on their way to or at the spawning places. For pike *(Esox lucius)*, for example, it is essential to know what type of area the fish use for spawning. According to CARBINE (1943),

JOHNSON (1956), FABRICIUS and GUSTAVSON (1958), SVÄRDSON (1964) and KENNEDY (1969), the most favourable spawning conditions are in shallow places with bottom vegetation as for instance in the Netherlands the outer marshes, shallow ditches and occasionally spring flooded areas.

Ripe spawners are transported to the hatcheries for stripping (Fig. 1). When pikes cannot be stripped easily, they are kept for some days more and tried again or dismissed.

Others have tried to stimulate the ripening of the eggs by hypophysation with carp pituitaries (SORENSEN, BUSS and BRADFORD, 1966).

For other species, such as rainbow trout *(Salmo gairdneri)*, common carp *(Cyprinus carpio)* and European catfish *(Siluris glanis)*, it is usual to raise the brood stock on the pond farm itself, which may have advantages for selection.

Induced spawning is of no importance for trout. Normally the spawners are tested for ripeness rather frequently during the mating season and when ripe they are stripped (Fig. 2).

To collect sexual products from carp, grass carp and European catfish, the method of induced spawning with pituitary material often has to be applied (the so-called hypophysation technique).

Before hypophysation, however, the adults must reach a certain degree of ripeness. According to literature two environmental factors are of importance for gonad ripening. SASSMAN (1969) postulated that for carp it is necessary to increase the temperature of the water in a certain period up to a total sum of 1000–1200 day degrees after the first of January, before their gonads are completely ripe. Before they are ready for hypophysation carps must be kept in warm water for a certain period depending on the season, in which the fish are moved from the pond into the hatchery (TASNADI and GYANO, 1965; WOYNAROWICH and KAUSCH, 1967).

Another factor of influence may be the light. (WOYNAROWICH and KAUSCH, 1967). Literature on environmental control of teleost reproduction has been reviewed by DE VLAMING (1972).

From our experience with carp there is no reason to assume an influence of light or a well defined sum of warmth in day degrees. In an experiment at Lelystad spawners were transferred into the hatchery on December 22nd. at an outdoor temperature of 2.5°C. 10 Males and 10 females were kept in full darkness for 24 hours per day and another 10 males and 10 females were exposed to normal daylight. During a period of 5 days they were acclimatized to 23°C and on 15th January hypophysation was started. All females could be stripped and so could the males.

Fertilization rate was excellent for those kept in darkness (90.7%) as well as for those exposed to normal daylight (91.5%) (HUISMAN, 1974). After being stripped, spawners were bathed in malachite green to prevent fungal infection, fed antibiotics up to a level of 60 ppm terramycine on bodyweight basis for 10 days, acclimatized very slowly to outdoors temperature and put back into the ponds again.

For hypophysation many procedures can be found in literature (PLÜGGE, 1956;

Fig. 1. A female pike is stripped.

Fig. 2. Stripping a female rainbow trout.

STEFFENS, 1957; MESKE et al., 1968; WOYNAROWICH and KAUSCH, 1967; SASSMAN, 1969). Common use is first to inject the females with 0.3 mg/kg bodyweight of acetone-dried carp-pituitary material and after 18 hours give a second injection of 3 mg/kg. The males receive a dose of 0.3 mg/kg, given simultaneously with the second injection to the females. Normally 10 to 12 hours later the fishes give 'freely flowing' eggs. For European catfish we employ the same procedure. So, artificial heating of water and the technique of hypophysation can cause some fish species to reproduce independent of natural seasonal circumstances.

Of course hypophysation is like shooting a fly with a gun, and research has been carried out with synthetic products and hormones of warm-blooded animals as for instance Choriogonin (MITTERSTILLER and HAMOR, 1961), Prolan (MESKE et al., 1968, Gonabion (Anwand, 1963), H. C. G. (SNEED and CLEMENS, 1959), L. H. (DADZIE, 1970; SHEHADEH, 1976).

Although some of these preparations have been used successfully, the most dependable method up to now is the use of pituitary material (CHEN, 1972; DADZIE, 1970). The isolation of the active agents in fish pituitary should be recognized as a very important item of research for the future (SINHA, 1971).

Fish are usually stripped by hand, but other methods are being used, as for instance the Australian method of pressing air into the body cavity of salmonids.

The use of anaesthetics in stripping fish minimizes mechanical damage. A review of suitable anaesthetics was made by BELL in 1967. The anaesthetic MS222 is widely used, but rather expensive.

Cheaper chemicals are benzocaine, used as local anaesthetic in human and veterinarian medicine (MC. ERLEAN and KENNEDY, 1968), and chlorobutanol (BOHL, 1968). Chlorobutanol can be used successfully for most fishes in a concentration of 1 g/l. Contamination of eggs and sperm with anaesthetics should be avoided, because of the influence of anaesthetics on sperm motility (ALLISON, 1961).

After the ovulated egg is put into water, fertility gradually decreases and finally disappears completely. This occurs in any other medium but the rate of decrease differs greatly according to fish species, medium and conditions under which the eggs are being kept (GINZBURG, 1968). LINDROTH (1946) showed that pike eggs lose fertility in water of 10°C within one minute. In cavity fluid, however, this occurs only after about 48 hours. The same applies to sperm. Motility, and in correlation with that fertilizing capacity, is prolonged in physiological solutions and in cavity fluid (WERNER, 1943). Dry sperm can be kept at low temperatures without loss of fertilizing capacity for several days. Deep-freezing prolongs the fertilizing capacity up to 6 months as was shown by BLAXTER in 1955 for Atlantic herring *(Clupea harengus)*.

2.2 *Fertilization*

Since the Alsatians Remy and Gehin rediscovered the method of artificial fertilization, already described by JACOBI in the 'Hannoverschen Magazin' in 1765, this method has been widely used in fish culture.

Generally three different methods for artificial fertilization are in use. All methods have in common that sexual products are pressed out, by pressure on the sides and abdomen of the fish but they differ in the operations before fertilization.

a. Wet method of fertilization. The sexual products are stripped simultaneously into a pan filled with water.

b. Dry method of fertilization. Eggs are stripped into a dry pan, dry sperm is mixed with the eggs and water is added afterwards. This method was introduced in 1870 by the Russian Wrassky, and is illustrated in Figures 1 and 2.

c. Super – dry method of fertilization. This method is based on method b, but here the eggs are stripped in a sieve to get rid of the egg fluid.

To prolong the fertilizing capacity of the sperm, WOYNAROWICH (1962) advised the use of a solution of NaCl and urea.

A mixture of these solutions (4‰ NaCl and 3‰ urea) known as solution nr. 1 of WOYNAROWICH (1955, 1960, 1962), is used for removing the sticky layer of eggs. .After fertilized eggs, for instance of carp, have been mixed continuously with this solution for one hour, the eggs are washed in a second solution of 85‰ urea (WOYNAROWICH, 1962). SASSMANN (1969) used 1.6‰ tannic acid as solution nr. 2. According to Yugoslavian experience (personal communication Dr. N. Fijan, Zagreb) tannic acid is rather toxic to fish eggs and they use 0.35‰ tannic acid for 10 seconds (twice). A Russian publication reported that removal of the sticky layer negatively influenced embryonal development resulting in higher losses and smaller fry (KONO-

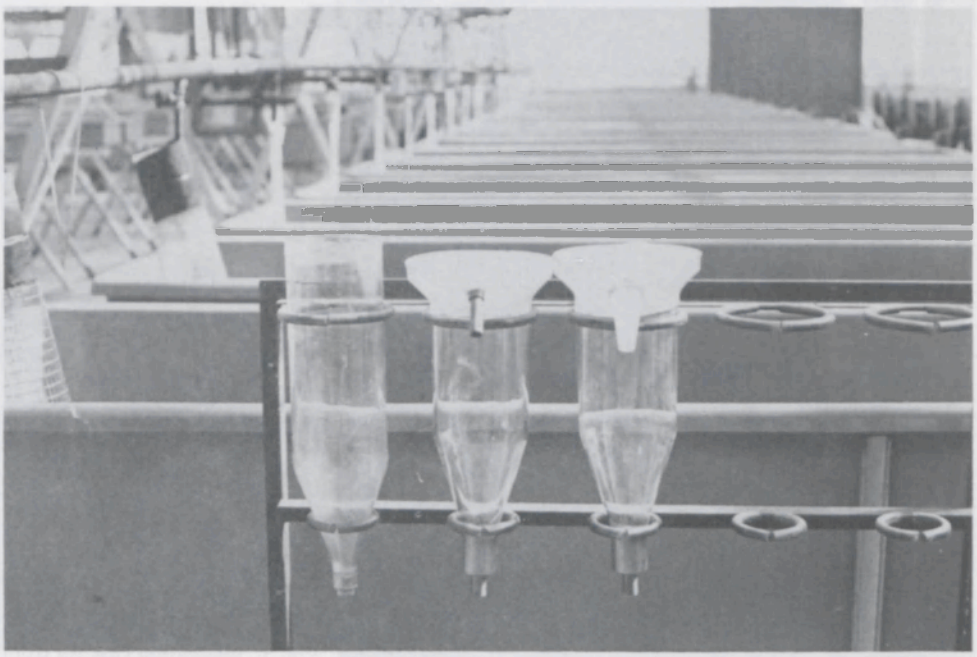


Fig. 3. Zugerglasses for incubation of eggs.

VALOV and RUBZOV, 1972). This result has not been confirmed in our experiments.

Stickyness cannot be removed from the eggs of European catfish. Therefore the eggs are spread as well as possible in a monolayer over the inset-trays of a Californian trough. Then they are bathed for 20 sec. in a 30 ppm. Malachite green solution to prevent fungus infection to which these eggs are very sensitive.

With artificial fertilization very good results can be obtained. For carp for instance we recorded fertilization rates up to 99%, for European catfish to about 80%.

Fertilization rate, however, can vary widely even among fish of the same population. In this respect time of stripping is important, but also environmental circumstances might be of influence.

In recent years especially for salmonids there is increasingly more literature to suggest a negative influence of pesticides on either fertilization rate or on the early stages of embryonal development. This was shown for rainbow trout by HOPKINS,

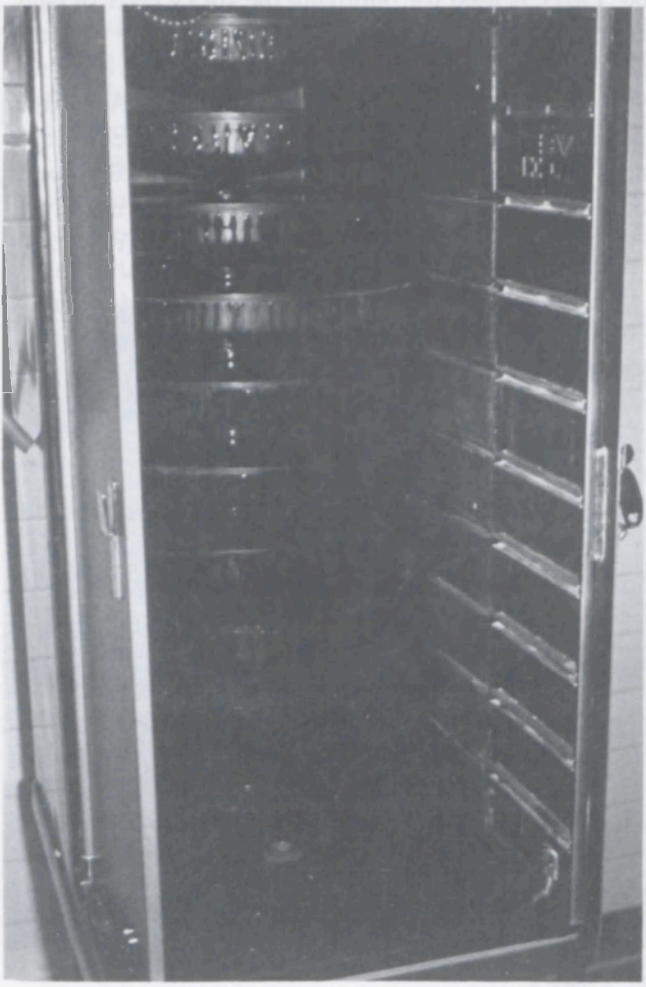


Fig. 4. Incubation case for trout eggs.

SOLLY and RITCHIE (1969) and by DACRE and SCOTT (1971); for coho salmon *(Oncorhynchus kisutch)* by WILLFORD, SILLS and WHEALDON (1969); for lake trout *(Salvelinus namaycush)* by BURDICK et al. (1964); and for pike by HUISMAN, KOEMAN and WOLFF (1972). It was not only recorded in natural waters but also in hatchery management by CUERRIER, KEITH and STONE (1967).

2.3. *Incubation*

After fertilization eggs can be incubated. Many different incubators are in use: jars for trout eggs, for instance, have been described by BUSS and FOX (1961), Zuger-glasses (Fig. 3) for pike and carp eggs by WOYNAROWICH (1962), for trout by BOHL (1969) and for grass carp *(Ctenopharyngodon idella)* by ANTALFI and TÖLG (1971). For trout Californian troughs as well as incubation cases are being used (Fig. 4).

For pike eggs we have developed a coneshaped jar, with a top angle of 36° which has given good results. The advantage of this Dutch type of jar is that dead eggs collect at the periphery and they can be siphoned of very easily (Fig. 5).

Incubation time differs widely among fish species and, of course, it is temperature dependent. Embryonal development takes a certain amount of day-degrees. But also this total amount of day-degrees is dependent on temperature as WILLEMSEN (1959) showed for pike.

During incubation the sensitivity of the eggs varies widely. The deformation due to pressure was examined for pike eggs by SCHÄPERCLAUS (1940). It is high during the

Fig. 5. Incubation jars for pike eggs.

first stages, least about one day after fertilization and increases again at the end of the embryonal development. Bumping sensitivity is low for freshly fertilized pike eggs according to LINDROTH (1946), increasing during the first stages and decreasing already after 50% development.

Therefore freshly fertilized eggs or eyed eggs can easily be shipped, as then the risk of mechanical damage is rather low.

During incubation oxygen supply is of great importance. LINDROTH (1966) showed for pike eggs that oxygen consumption increases 10 times during incubation.

Eggs are usually treated for prevention or curation of diseases in hatchery procedures. A variety of chemicals are available for this purpose (malachite green, methylene blue, Masoten, formalin, acriflavine, Wescodyne and so on). Obviously prophylactic treatment should be the first and main objective. Apart from treatments of eggs, all equipment should be carefully sterilized, for instance in quaternary ammonium products such as benzalkonium or iodine complexes such as PVP-iodine (Wescodyne).

With an automatic dosing apparatus connected to the water supply, it is easy to give continuously an amount of therapeutics in a rather accurate concentration for a desired period of time.

Fig. 6. Hatching of pike.

2.4. *Hatching of eggs*

At the end of development eggs hatch (Figs. 6 and 7). Normally it takes some hours or even days before all eggs have hatched. Usually hatching takes place in the incubator that was used.

With respect to the influence of some environmental factors, LINDROTH (1946) postulated that birth of fishes is not a sharply fixed stage of their development. He was able to induce a premature birth at about 80% of normal development by an artificial lack of oxygen. LILLELUND (1967) showed for pike that, when incubation took place at low temperatures, birth occurred in a more advanced morphological stage, the larvae being bigger than normal. This phenomenon has also been observed in rainbow trout and some coregonids. A reason for this phenomenon might be the higher oxygen pressure at low temperature or the low activity of the embryo or a slower weakening of the egg shell.

Hatching can be accelerated by increasing the temperature (WILLEMSEN, 1959).

According to these data a successful hatching procedure, empirically described by SORENSEN, BUSS and BRADFORD (1966) is applied at the hatcheries of the Organization for Improvement of Inland Fisheries in the Netherlands. For pike 1 litre of fully developed pike eggs are placed in a pan filled with 8 to 9 litres of water and placed in a heated room, so that during 1 to 2 hours the temperature rises to about 17°C (normal incubation temperature 10–12°C).

Oxygen saturation drops from about 90% to 25%. With this procedure all eggs hatch within 60–120 minutes, whereas normally it takes more than 6 hours.

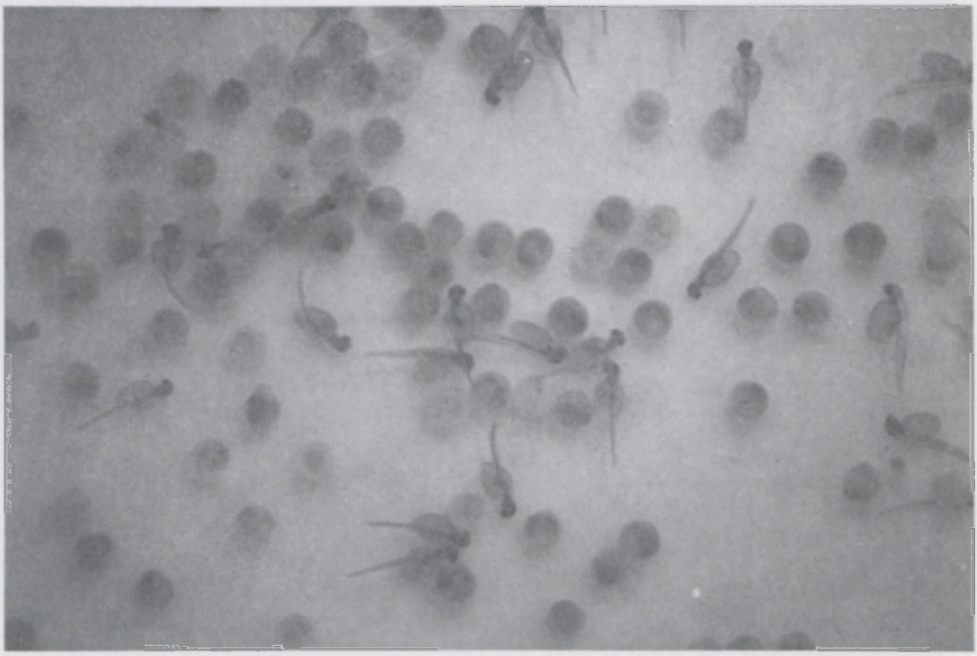


Fig. 7. Hatching of rainbow trout.

3. Nursery operations

Nursery operations are defined here as operations from the stage of hatching to the stage of free-swimming and feeding fry.

3.1. *Larval rearing*

After hatching it is important to separate the larvae from egg shells and dead eggs so that fungal infection is reduced. As the specific gravity of egg shells is very low, they can easily be removed from the incubation jars by the water flow. This method is used in carp and grass carp culture in Yugoslavia and Hungary (Antalfi and Tölg, 1971).

After hatching most fry (pike, carp, grass carp) prefer to attach themselves to several kinds of material (wood, plants, textiles, etc.), during the stage of yolk sac absorption. During this stage it is easy to siphon off dead eggs and egg shells from the bottom of the basin, the inset tray or the trough.

In our opinion the easiest and most successful method to get 'clean' fry is by using a sieve with mesh of a size that allows the larvae to pass through but retains the dead eggs. Greenberg (1966) described such a sieve for trout eggs. Most of the egg shells can be removed in this way as well.

The hanging stage may be passed in the incubator itself, in jars, troughs or in swimming cages, specially designed for this purpose, as for instance described for grass carp by Antalfi and Tölg (1971).

For pike this hanging stage takes rather a long time (about 8 days at 12°C). Then it is especially advantageous to keep the larvae in a clean environment. Therefore, after hatching, pike larvae are mostly conveyed into the insettrays of a Californian trough to pass the hanging stage, at the hatcheries of the already mentioned Organization.

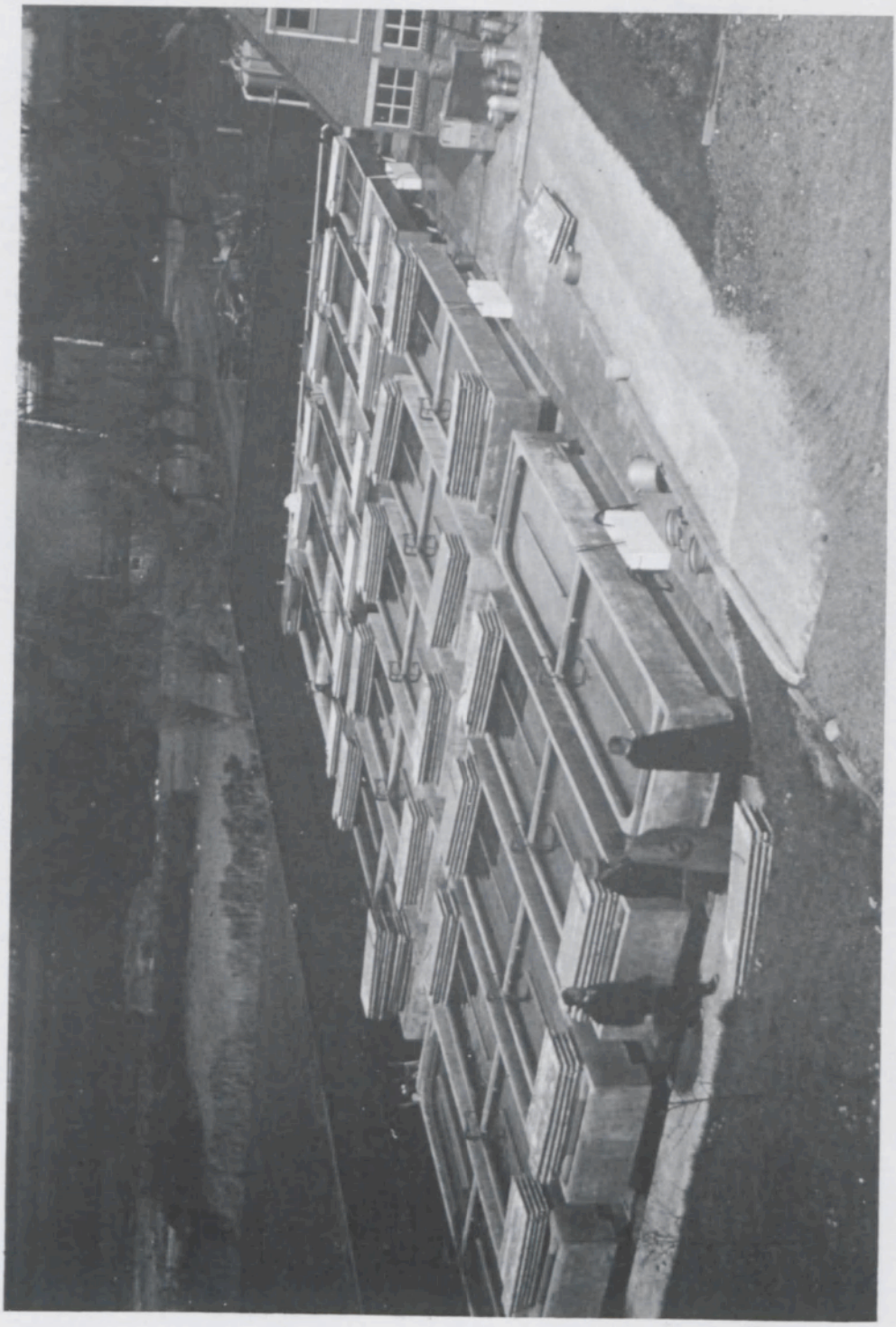
According to Frost and Kipling (1967) the advantages of hanging under natural conditions are that the fry are free from the sludge, more protected against predators and have a better oxygen supply.

The publication of Hiner (1961) showed that hanging is not strictly necessary for pike larvae. He kept the larvae in the jars until the free-swimming stage.

Formerly in the Netherlands aquatic plants such as *Stratiotes aloides* were used as hanging material, but these have the disadvantage of pollution. So far we have gained the best results with a framework of rough wood and with textiles such as cheese-cloth. Under our circumstances trout and European catfish pass their larval stage in the inset trays of Californian troughs without any hanging material.

During the larval stage the biggest danger arises from fungal infections which are easily controlled or better prevented by the chemicals already mentioned.

Fig. 8. Concrete rectangular tanks at the pike hatchery 'Nieuw Vennep' of the Organization for Improvement of Inland Fisheries.



After the yolk sac has been largely consumed the larvae start to fill the air bladder. BRAUM (1964) observed that pike larvae swim frequently to the water surface for air intake, each intake taking 20–30 seconds. After about one day fully hydrostatic adjustment was obtained and tail and fins started to vibrate and the time had come to start feeding.

3.2. *Rearing of fry*

It is quite usual to start feeding in the equipment used for the larval stage, but after a few days the fry is transported to aquaria, tanks or ponds.

In a hatchery most fry will be cultured in tanks of various shape and material such as rectangular, circular, concrete, fibre-glass, etc. (Figs. 8 and 9).

In the Netherlands we use rectangular tanks of concrete for pike, as well as rectangular and circular tanks of fibre-glass. The fibre-glass tanks are also used for trout, grass carp, carp and European catfish.

But apart from equipment, the rearing of fry is completely dependent on food supply and maintaining hygienic conditions.

Although in recent years 'dry completes' (pelleted food) have become increasingly important, in feeding very young fishes there is the difficulty of the right particle size, especially for the tiny cyprinids. On the other hand predator fish such as pike refuse pelleted food.

GRAFF (1968) showed it was possible to raise pike fry on pellets to some extent. We were also able to raise a very small amount of pike from fry to a length of about 25 cm with pellets. But till now it has not been possible to do this on production scale.

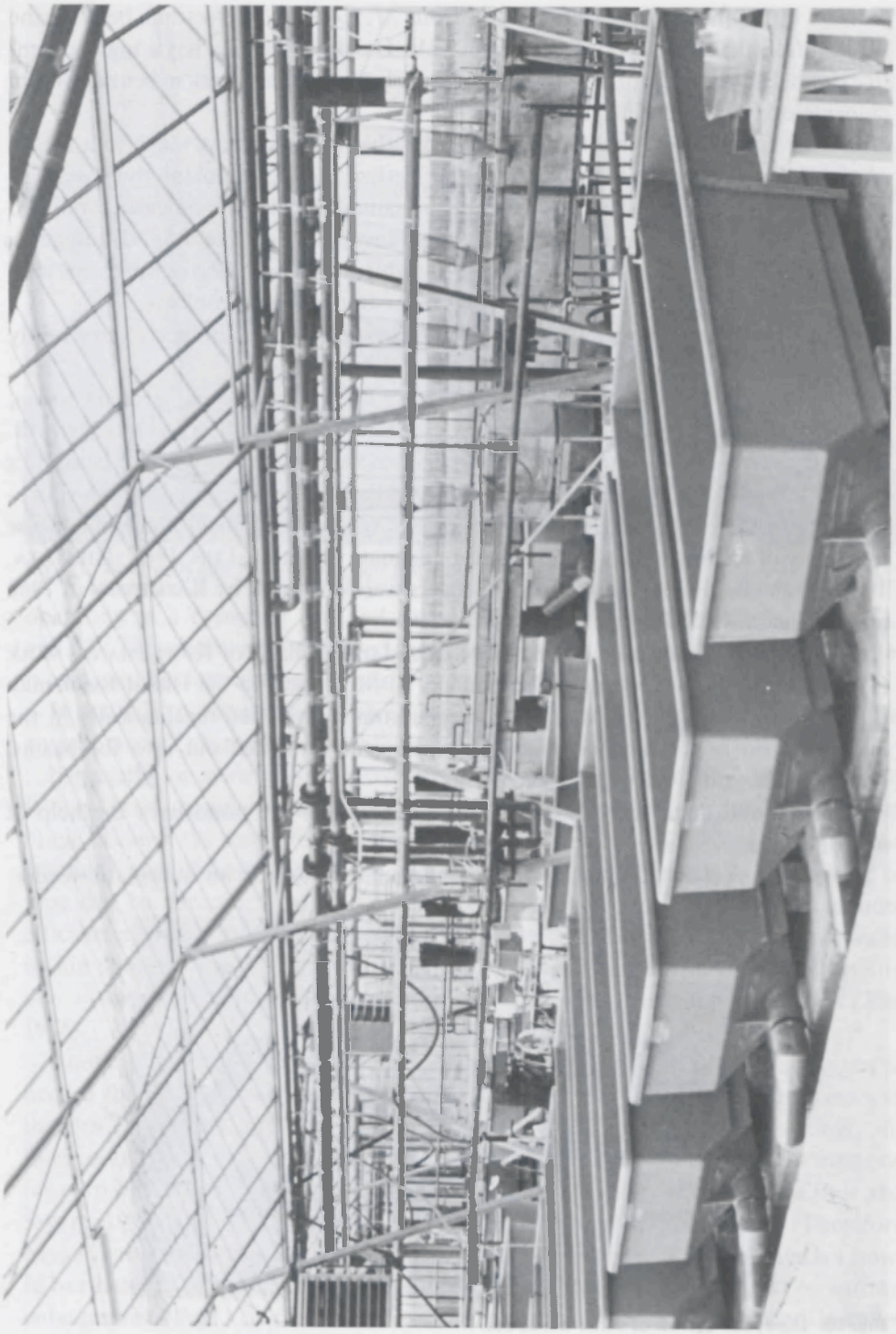
There is no difficulty to start feeding either trout or European catfish with very small pelleted particles, but for pike and carp it is not yet possible.

During the last few years we have tried two different types of biological structures for carp e.g. hard-boiled egg yolk and homogenate of cow liver. Furthermore we tried *Artemia salina* and small zoo plankton (HUISMAN, 1974).

Artemia salina proved to be a very good starter, as was also shown by KOSSMANN (1970) and by LJUDSKANOVA and JOSHER (1972). According to our experience the best results are obtained by feeding egg yolk only for the first day, afterwards *Artemia salina* up to a mean weight of 20 mg and then steadily replacing *Artemia salina* by a fine-sieved trout starter. This process is carried out in 100 l aquaria till the fry (up to 40 000 per aquarium) have reached a weight of 60–100 mg. Then they are conveyed into circular tanks. In practice it was worthwhile to give some zoo plankton in addition to the pellet.

With this procedure an average weight of about 2 g can be obtained in 6–7 weeks at an average temperature of 23°C.

Fig. 9. Interior with fibre-glass tanks. Hatchery house at the pond farm 'Lelystad' of the Organization for Improvement of Inland Fisheries.



Most difficulties in this culture arise from *Myxobacteria* infections because the water intake of the hatchery comes from Lake IJsselmeer, which has a high content of extremely fine silt. For prevention the fish are bathed twice a week in benzalkonium chloride or Furanace (GHITTINO, 1970).

In pike culture zoo plankton is given from the free-swimming stage to a length of about 4 cm (a length that is used in the Netherlands for stocking purposes).

When pike and trout fry are present at the same time, it costs no extra labour to feed trout with the bigger zoo plankton, that is unsuitable for pike. It is advantageous to do so, because feeding with starter pellets easily leads to pollution of the basins with fine food stuff, inducing gill damage and other undesirable problems.

In the last years spawning of European catfish has been induced successfully (HUISMAN, 1973).

Some different types of food were used for the fry (plankton, *Artemia salina*, pellet). Starting with very fine pelleted particles at once gave the best results in growth. At 23 °C an average weight of 3.7 g was reached in 9 weeks, the biggest fish being 12 g (Fig. 10). During the last few years feeding techniques have progressed with the introduction of automatic and demand feeders. This type of equipment is useful because frequency of feeding is very important for adequate growth (LÜHR, 1967; ISHIWATA, 1969; HUISMAN, 1970). Many types of feeders were discussed by RASMUSSEN in 1968 and by BERKA in 1973.

Feeding of plankton can also be automatized on the basis of KRIEGSMANNS work (1952) and this is carried out at the hatchery of Mr. Koch on the Isle of Reichenau in the Lake Bodensee (Germany). Here plankton is densified mechanically in the lake, pumped to the hatchery, densified again and streamed out into the basins, all these operations being automatized.

On the pond farm 'Lelystad' plankton is caught in the pond with the help of nets (Fig. 11).

Pellets are mostly administered with a demand feeder or an automatic feeder,

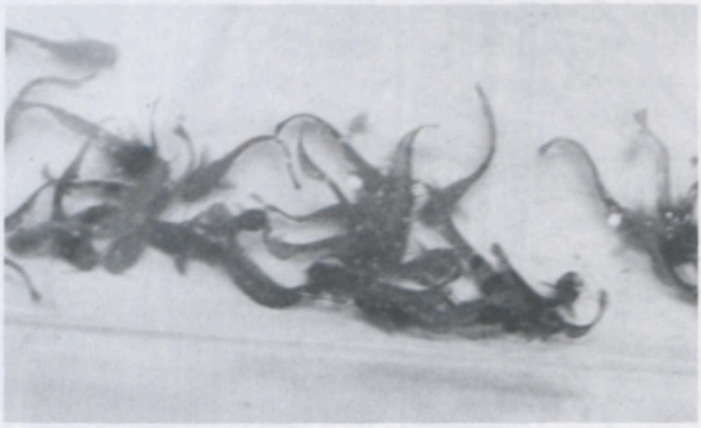


Fig. 10. European catfish of some weeks old.

Fig. 11. Boat with nets for catching zoo plankton.

operating as a conveyor belt and called 'Scharflinger automatic feeder' (Figs. 12 and 13). These two types give good results with carp, grass carp and trout. The latter is also suitable for European catfish.

In artificial propagation of fish environmental control is highly important. Some environmental characteristics will be briefly discussed.

Especially for growing young fish an optimum range of temperature is desirable. It may be worthwhile to maintain a relatively high temperature within this optimum range because the scope for activity (the arithmetric difference between active and standard metabolism) increases with temperature, so that more food per unit of time can be consumed. Moreover the conversion of food into fish flesh is more efficient at higher temperatures (Figs. 14A and B). This is, of course, only valid within species – specific ranges of temperature. This increase in scope for activity due to the rise in temperature, however, decreases with increasing fish weight (JOB, 1955).

Another important environmental factor is the oxygen supply. As oxygen is needed for standard metabolism as well as for the internal production processes in the fish (Figs. 15A and B), the environmental oxygen concentration strongly influences the conversion efficiency of food into fish flesh. This was shown, for instance, for carp by CHIBA (1965) and HUISMAN (1970) (Fig. 16), for pike by ADELMAN and SMITH (1970) and for rainbow trout by LARMOYEUX and PIPER (1973). Therefore oxygen saturated water is essential. Many types of aerators are on the market now. In our hatcheries two methods of aeration are used, the first being based on surface enlargement (Fig. 17), the second on overpressure. The second method is called

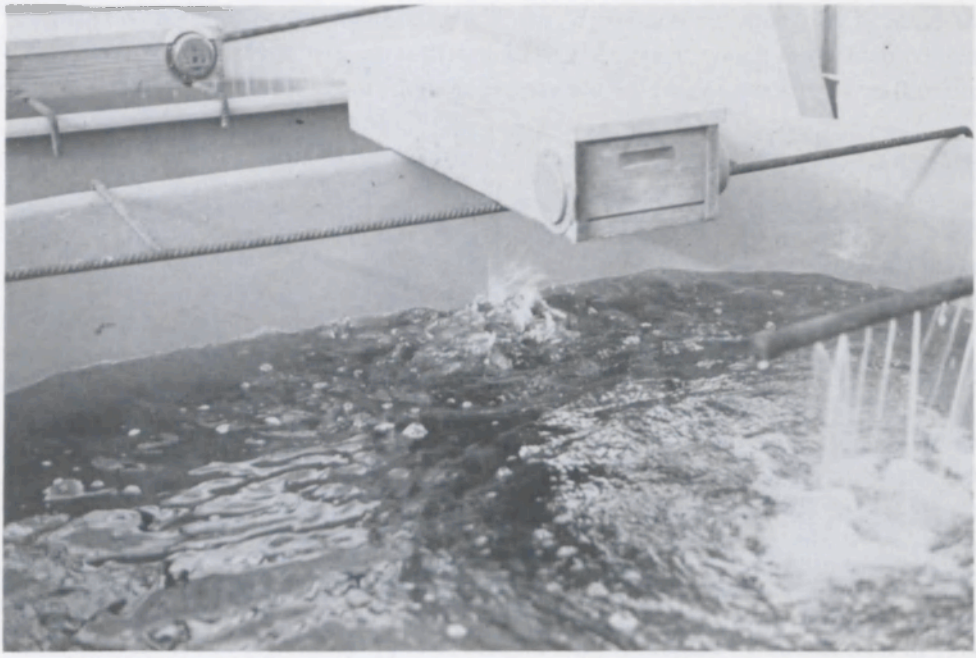


Fig. 12. 'Scharflinger' automatic feeder.

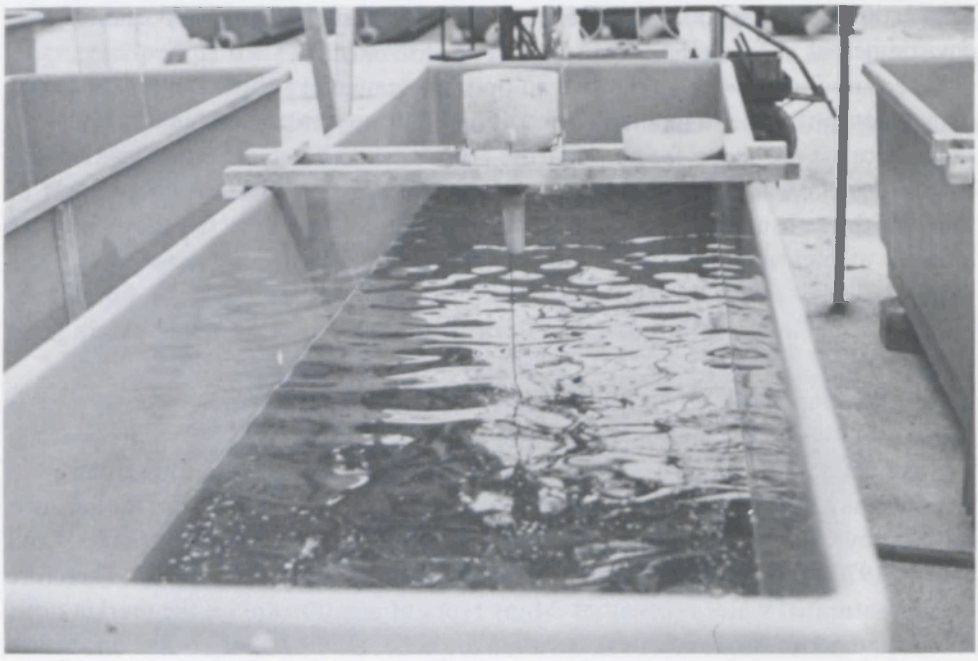


Fig. 13. Demand feeder.

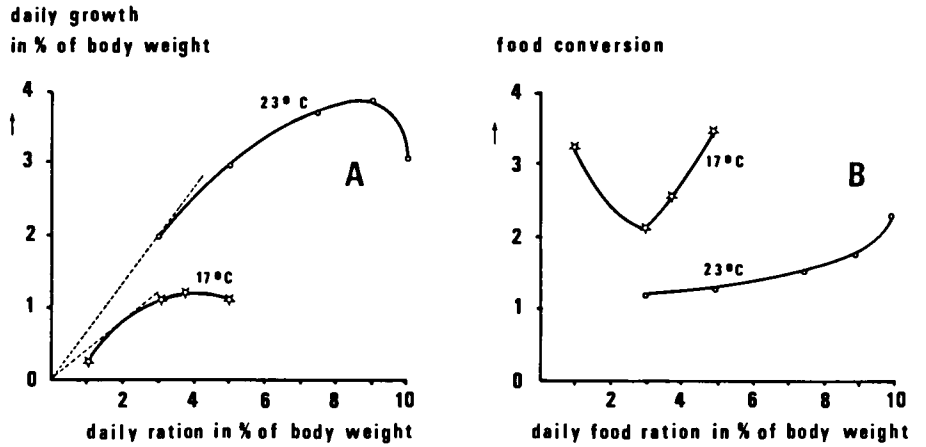


Fig. 14. Relation between growth and food ration (A) and conversion and food ration (B) at 17°C and 23°C for carp weighing 50–80 grammes.

U-tube oxygenation and has a high efficiency, being very economical as was shown by SPEECE (1969).

For incubation and larval rearing it has already been mentioned that prevention and curation of infections are of primary importance. Apart from the use of therapeutics other measures can be taken, such as sterilization of the water either by ultra-violet rays as described by BURROWS and COMBS (1968) or by ozonization. The latter method is in operation at the hatchery on the Isle of Reichenau. For

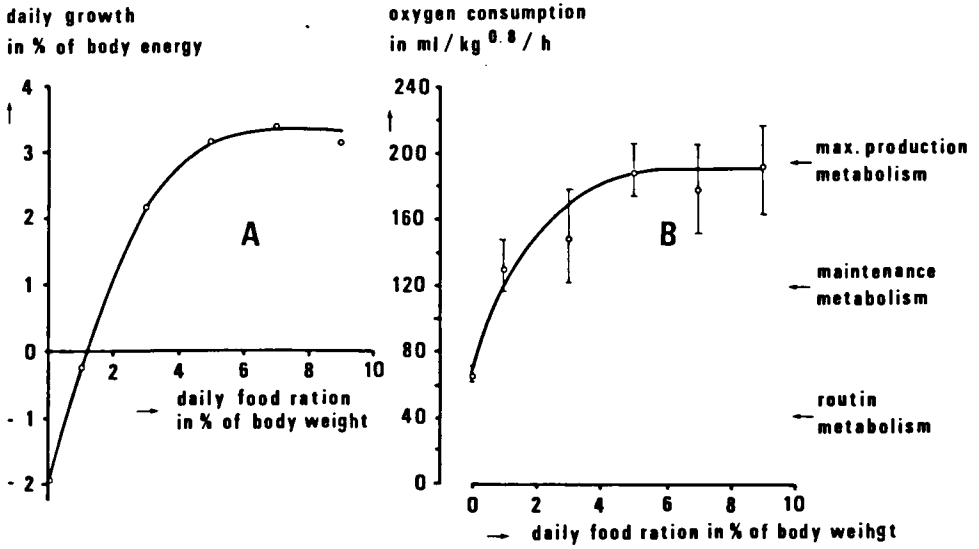


Fig. 15. Correlation between food ration and growth (A) and food ration and oxygen consumption (B) for carp of 50 grammes at 23°C.

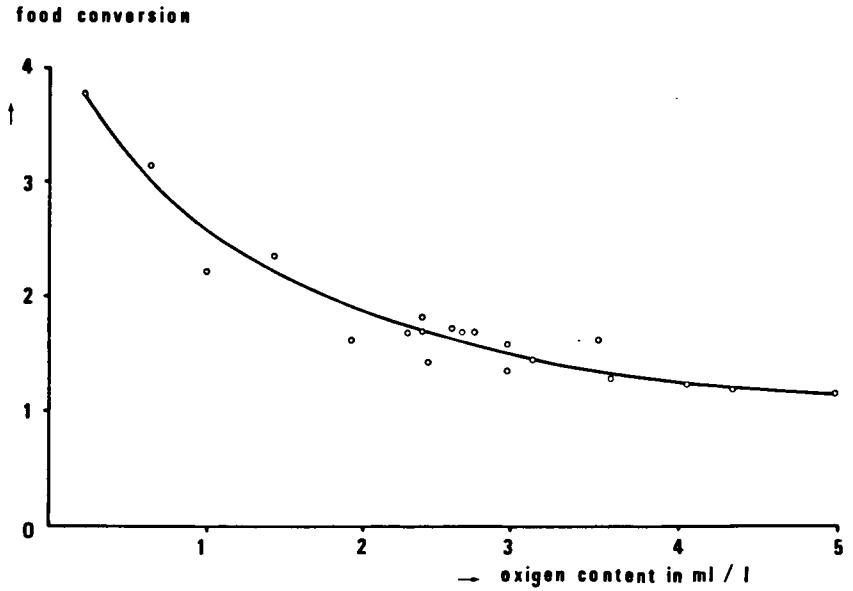


Fig. 16. Relation between food conversion and oxygen content of the water.

economical reasons sterilization of water may be combined with recirculation systems, sterilizing the small fresh water supply as BURROWS and COMBS did.

Water can be recycled for two reasons, viz. prevention of diseases or economy. The latter reason is important when water is scarce or when processing of water (pumping, filtering, heating, sterilization) forms a great part of the production costs.

Up to now recirculation as described by MESKE (1967, 1968), BURROWS and COMBS (1968), WOHLFAHRT, LAHMAN and MOAV (1971) is mostly limited to small experimental plants or to rather expensive fish species.

4. ABSTRACT

In this article attention was paid to the operations applied in the artificial propagation of fish during the first part of their life cycle. These operations such as collection of sexual products, fertilization, incubation, hatching, larval rearing and rearing of fry were dealt with from a practical point of view.

As the control of environmental characteristics is of importance for these propagation methods, the influence of some environmental factors was discussed on the basis of literature cited and our own experience, mostly collected at the pond farms and hatcheries of the Organization for Improvement of Inland Fisheries in Holland.

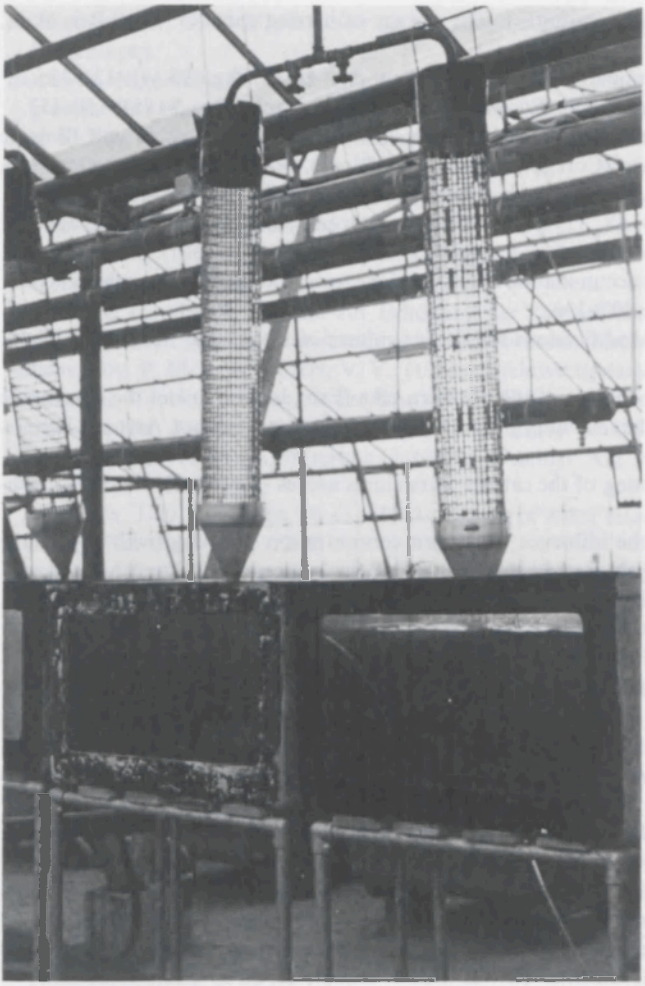


Fig. 17. Aëration by surface enlargement.

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THE AFRICAN CATFISH, *CLARIAS LAZERA* (C.&V.), A NEW POSSIBILITY FOR FISH CULTURE IN TROPICAL REGIONS?

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1. INTRODUCTION

The African catfish *Clarias lazera*, (C. & V.) has a somewhat mysterious reputation. The people of Central Africa often consider this species, which can grow to a maximum length of at least 130 cm, as a voracious predator. However the fact that this fish can be easily caught by angling using toilet soap as a bait weakens this reputation. In the literature Clarias species are described as animals ranging from harmless microphages to piscivores (CORBET, 1961; MUNRO, 1967).

The opinion that African Clarias species probably have more euryphagous habits is shared by MUNRO (1967) who stated that *C. gariepinus*, Burch. becomes more harmless with increasing size: 'Diptera, particularly chironomid pupae, predominate in the diet of the smallest group but become progressively less important with increasing size. Zooplankton becomes more important with increasing size and predominates in the diet of the largest fishes. The greater importance of zooplankton in the diet of large fishes is believed to result from two morphological features of the larger *C. gariepinus*. The size of the gape increases and at the same time the number of gill-rakers increases (JUBB, 1961), presumably resulting in more efficient filter feeding'.

The small teeth on the jaws and inside the mouth indicate that small invertebrates and plant material can be eaten. This diet was found for *C. senegalensis* (C. & V.) *(C. lazera)* by THOMAS (1966). Support for the idea that the African Clarias species are not so voracious as most people think comes also from physiological research. BIEDENBACH (1973) found that the bottom-dwelling American catfish *Ictalurus nebulosus* has a body surface containing structures resembling mammalian taste buds and suggests that this fish recognized food mainly by touch via barbels and skin. The African species *Clarias anguilloides* (probably *C. anguillaris*, L.) was found to respond to low-frequency pulses, perceived by the same sense organs. The significance of this remarkable sensitivity was sought in the ability of the fish to detect action potentials of predators or prey passing by (LISSMAN and MACHIN, 1963).

At this stage Clarias species are probably best described as clumsy piscivores

which also exploit aquatic and terrestrial invertebrates as auxiliary or emergency food. A true picture of its food habits can only be obtained through further and more intensive study (GROENEWALD, 1964).

A second remarkable aspect of *C. lazera*, which has given this fish a particular fame is its ability to practise aquatic and aerial respiration. Its amphibious way of life (JOHNELS, 1957) and its ability to resist adverse conditions such as dryness have caught the imagination of many authors. WELMAN (1948) on a bright moonlight night observed a school of 30 *C. lazera* cross from an isolated swamp to a river. To quote him:

'The shoal, which contained at least 30 fish, ranging from 1 to 2 feet in length, was led by an exceptionally large specimen fully 3 feet long and of a distinctly lighter colour than the others. They wriggled through the grass with snake-like movements, from time to time uttering low grunts and croaks as the air was expelled from their swim-bladders or possibly from the lunglike reservoirs these fish possess. Moving in a close column three or four fish abreast, those behind often overtook or crawled past or over those immediately in front, but none ever overtook the leader. The ground over which they passed, though slightly boggy, was entirely free of surface water, the short grass, still slighty wet from the evening's rain, alone serving to keep their skins moist. It was difficult to estimate their actual speed, as individuals paused frequently to wave their barbels at passing companions, and several times the whole column stopped for a few moments, but they took nearly an hour to cross the 200 yards to the backwater. On reaching it, the large fish in the front led the shoal into the fringing sedges where they soon disappeared from view.'

The organs which make aerial respiration possible are situated on the second and fourth branchial arcs. They are cauliflower-like structures, which are supported by cartilage and covered by a tissue resembling gill lamellae, which can absorb atmospheric air (MARLIER, 1938; MOUSSA, 1956). *C. lazera* can survive in water saturated air without air breathing. Reduction in the oxygen content of the water results in the fish frequenting the surface of the water to meet its oxygen requirements (MOUSSA, 1957; ABDEL MAGID, 1971). BEADLE (1932) gave an evolutionnary explanation for the amphibious way of life of *C. lazera*. He believed that poorly oxygenated swamps were probably very widespread in Africa before the formation of the Rift Valleys and that aerial respiration may have evolved in adaptation to life in these swamps. In modern conditions Clarias has gained access to poorly-oxygenated as well as to well-oxygenated waters but retains the habit of aerial respiration.

Three adaptations of this species to its natural environment make it interesting for fish culture: its hardiness, its ability to feed also on food from vegetal origin and its ability to live in poorly oxygenated water. The species *C. lazera* was chosen recently as a new species for fish culture. The object of this paper is to summarize and discuss the progress in research on systematics and some particular topics of fish culture management.

2. SYSTEMATICS

The systematic position of *C. lazera* with respect to the other large African species e.g. *C. anguillaris*, *C. senegalensis*, *C. mossambicus* and *C. gariepinus* is not clear. BOULENGER (1915) used the form of vomerine teeth, the ratio vomerine/premaxillary teeth band and the number of gill-rakers to discriminate between these 5 species:

a. Vomerine teeth mostly pointed or granular-subconical, forming a band which is not broader than the band of premaxillary teeth; distance between occipital process and dorsal fin 3½ to 7 times in length of head. 20–27 gill-rakers on anterior arch; distance between dorsal and caudal 1–2½ diameters of eye . . . . . *C. anguillaris*, L.
25 (in very young)-80 gill-rakers on anterior arch; distance between dorsal and caudal 1½–2 diameters of eye . . . . . *C. gariepinus*, Burch.
b. Vomerine teeth all or mostly granular, forming a crescentic band with or without posterior process.
30–40 gill-rakers an anterior arch; band of vomerine teeth as broad as or a little narrower than band of premaxillary teeth; head not more than 1⅔ times as long as broad, 4–7 times its distance from dorsal . . . . . *C. senegalensis*, C. & V.
25 (in very young)-100 gill-rakers on anterior arch; band of vomerine teeth nearly 1 to 1½ times as broad as premaxillary band; head not more than 1⅔ times as long as broad, 4–7 times its distance from dorsal . . . . . .*C. mossambicus*, Peters.
35 (in very young)-135 gill-rakers on anterior arch; band of vomerine teeth 1⅓ to 2½ times width of premaxillary band; head not more than 1⅔ times as long as broad, 4–7 times its distance from dorsal. . . . . *C. lazera*, C. & V.

DAVID (1935) systematically revised the genus Clarias and used similar differential features for the 5 species concerned:
a. 20–27 gill-rakers, vomerine teeth conical, except the posterior ones, which can be granular, maxillar barbel ⅗–⅚ length of head . . . . . *C. anguillaris*, L.
b. 25–135 gill-rakers, maxillar barbel ½–1 length of head, vomerine teeth mostly granular:
35–135 gill-rakers, band of vomerine teeth 1½–2½ times width premaxillary band . . . . . *C. lazera*, C. & V.
25–100 gill-rakers, band of vomerine teeth 1–1½ times width premaxillary band . . . . . *C. mossambicus*, P.
25–80 gill-rakers, band of vomerine teeth smaller than premaxillary band . . . . . *C. gariepinus*, Burch
30–40 gill-rakers, band of vomerine teeth as broad or smaller than premaxillary band . . . . . *C. senegalensis*, C. & V.

Many determinations (probably based on these two keys) for the above mentioned species, from different parts of Africa, are listed below (Table 1). Some authors have had difficulties in determining these closely related Clarias species.

Table 1. Review of literature on distribution of the largest Clarias spp. in Africa.

Rivers/Lakes/Country	Species	Author
Nile, Lake Victoria, Chad basin	*C. anguillaris*	BOULENGER, 1915
Natal, Orange river, Transvaal, Rhodesia, Mosambique, Katanga, Angola	*C. gariepinus*	BOULENGER, 1915
Senegal, Gambia, Niger	*C. senegalensis*	BOULENGER, 1915
Abyssinia, Lake Victoria to Lake Tanganyika, Zambezi	*C. mossambicus*	BOULENGER, 1915
Syria, Nile, Senegal to Congo	*C. lazera*	BOULENGER, 1915
Biskra (Atlas mountains)	*C. lazera*	PELLEGRIN, 1921
Lake Rudolf	*C. lazera*	BEADLE, 1932
Lake Nyassa (Malawi)	*C. mossambicus*	WORTHINGTON, 1933
Lake Tanganyika, Lake Kivu	*C. mossambicus*	POLL, 1939
Upper Niger	*C. senegalensis*	DAGET, 1954
	C. anguillaris	DAGET, 1954
	C. lazera	DAGET, 1954
Gambia (Bansang)	*C. senegalensis*	JOHNELS, 1954
	C. lazera	JOHNELS, 1954
Lake Victoria	*C. mossambicus*	GREENWOOD, 1955
Lake Edward	*C. lazera*	CURRY-LINDAHL, 1956
Kariba area	*C. mossambicus*	JACKSON, 1961
Lake Victoria	*C. mossambicus*	CORBET, 1961
Chad	*C. lazera*	BLACHE and MITON, 1962
	C. anguillaris	BLACHE and MITON, 1962
Zaire river	*C. lazera*	GOSSE, 1963
Orange river	*C. gariepinus*	GROENEWALD, 1964
Lake Nunguna	*C. senegalensis*	THOMAS, 1966
Zambezi	*C. mossambicus*	HARDING, 1966
Lake Nkugute	*C. lazera*	BEADLE, 1966
Nigeria	*C. lazera*	MILLS, 1966
	C. senegalensis	MILLS, 1966
Lake Mcllwaine	*C. gariepinus*	MUNRO, 1967
Lake Victoria	*C. mossambicus*	GEE and GILBERT, 1967
Nigeria, Kanji dam	*C. lazera*	REED, 1967
	C. anguillaris	REED, 1967
Rhodesia (Mazoe)	*C. gariepinus*	HOLL, 1968
Lake George	*C. lazera*	DUNN, 1972
Lake Edward	*C. lazera*	DUNN, 1972
Lake Kariba	*C. gariepinus*	BALON, 1972
Lake Tana	*C. mossambicus*	BEADLE, 1974
Lake Chilwa	*C. mossambicus*	BEADLE, 1974
Olifants river	*C. gariepinus*	VAN DER WAAL, 1974

In Nigeria (MILLS, 1966) the fish which has been described as *C. lazera* has a number of features which *C. senegalensis* also exhibits. The number of gill-rakers on the first branchial arch, however, seems to preclude *C. senegalensis*, and the fish is either a local variant of *C. lazera*, or a hybrid from which *C. lazera* and *C. senegalensis*

have arisen. JOCQUÉ (personal communication to MICHA, J. C., 1975) obtained in Ivory-Coast hybrids from *C. lazera* and *C. senegalensis*. THYS VAN DEN AUDENAERDE (personal communication) systematically revised the West African Clarias species and found that the species *C. anguillaris*, L. and the species *C. senegalensis* C.&V. are not separate species. *C. senegalensis* should be considered as *C. anguillaris*. The species studied by THOMAS (1966) and determined as *C. senegalensis* should be considered as *C. lazera* as the number of gill-rakers increases with body length (see Fig. 6, p. 487, THOMAS, 1966).

There are similar problems with the relationships between *C. gariepinus* and *C. mossambicus*. JUBB (1961) suggested that the fish *C. mossambicus*, determined by CORBET (1961) for Lake Victoria, is synonymous with *C. gariepinus*.

The same possibility was suggested by GREENWOOD (personal communication to ALEXANDER, 1965) for the species *C. mossambicus* and *C. gariepinus* in general. In recent publications dealing with the inland waters of Central Africa, however, both species names are still found (BEADLE, 1974 using *C. mossambicus* only, LOWE – MCCONNELL, 1975 using *C. mossambicus* as *C. gariepinus* as well and BALON and COCHE, 1974 using only *C. gariepinus*).

A map of the geographical distribution of the 5 species concerned has been drawn. The data of Table 1 have been used for this purpose, with the exception of those

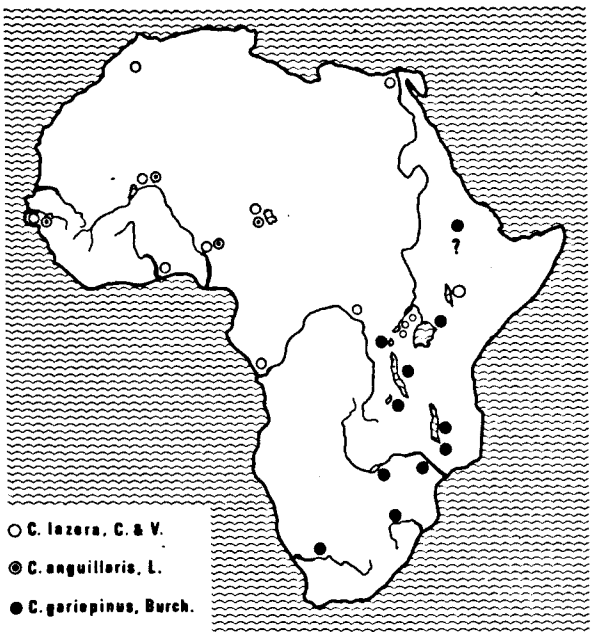

Fig. 1. Geographical distribution of the largest African Clarias species, *C. anguillaris*, *C. gariepinus*, *C. senegalensis*, C. *mossambicus* and *C. lazera* (Table 1). The species *C. anguillaris* and *C. senegalensis*, and the species *C. gariepinus* and *C. mossambicus* have been lumped together as *C. anguillaris* and *C. gariepinus*, respectively. (For explanation see text).

given by BOULENGER (1915) from which the origin could not be traced. The species *C. anguillaris* and *C. senegalensis* are lumped together as *C. anguillaris*; and the species *C. gariepinus* and *C. mossambicus* are lumped together as *C. gariepinus* (Fig. 1).

The distribution of the three species concerned, based on the assumption that *C. senegalensis* and *C. mossambicus* are no longer valid species, could be: *C. anguillaris*, from Lake Chad to the South West part of Africa. *C. lazera*, North and Central Africa. The presence in Central Africa is limited to the Zaire river, Lake Idi Amin (Edward), Lake Moboetoe (Albert), Lake Rudolf. *C. gariepinus*, Central and South Africa. The presence in Central Africa is limited to Lake Victoria, Lake Kivu and Lake Tanganyika. The observation of *C. mossambicus (C. gariepinus)* in Lake Tana mentioned by BEADLE (1974) does not fit in the whole distribution pattern of *C. gariepinus* and must be considered as doubtful.

3. FISH CULTURE MANAGEMENT

3.1. *Breeding cycles*

Knowledge about breeding cycles and spawning habits of African fish in their natural habitat is in general scarce. From the few observations available on Clarias species, the study of THOMAS (1966) on *C. senegalensis* C. & V. (should be *C. lazera* C. & V. according to THIJS VAN DEN AUDENAERDE pers. commun.) is probably the most complete. Up to 20 Clarias specimens per month were collected from Nunguna lake in Ghana from March 1959 to February 1960 and dissected to determine the sex and the maturation state of the gonads. The data showed that fish became sexually mature from ± 32 cm and onwards during the period of March to April. These fish left the lake and moved upstream to spawn in April and early May in flooded areas of the river. Immature specimens below 32 cm also migrated from the lake upstream. Shortly after spawning the spent fish returned from the flooded areas to the lake. During May to September no fish below 30 cm were captured in the lake because they had all moved upstream. In September when the stream was drying up the immature fish and the 0 + year class produced from the eggs laid in April and early May migrated to the lake. From this study, which does not have the pretention to be a population study, the assumption can be made that females from *C. senegalensis (C. lazera)* probably need two years to mature. EL BOLOCK's (1972) data from growth checks in vertebrae of *C. lazera* for determining age and growth in a semi-natural inland water in Egypt, suggest that females reach the length of 32 cm after 2 to 3 years with a corresponding weight of 200 to 300 grams. Under pond conditions males and females mature after ± 7 months when they have attained a weight of 200 to 300 grams (MICHA, 1975). With the information from these three sources, it can be assumed that *C. lazera* under natural conditions usually matures after two years at a length of about 32 cm and a weight of about 250 grams.

It seems that the internal gonadal maturation rhythm for Clarias species differs from region to region. In Egypt (the Nile, NAWAR, 1959; NAWAR and YOAKIM, 1962) and in Central African Republic (Ubangui river, MICHA, 1974) the breeding cycle of *C. lazera* starts in July and ends in September. In Uganda (Lake Victoria, GREENWOOD, 1955) *C. mossambicus (C. gariepinus)* spawns in March and April while in Rhodesia (Mazoe, HOLL, 1968) *C. gariepinus* does it in December to February. Hence these Clarias species have in common that they spawn once a year. Most authors mentioned that spawning starts with the onset of the rainy season and that it happens in flooded areas.

3.2. *Spawning*

The spawning habits under natural conditions have been studied by GREENWOOD (1955, 1956) for *C. mossambicus (C. gariepinus)* and by HOLL (1966, 1968) for *C. gariepinus* and under artificial conditions by MICHA (1975) for *C. lazera* (in ponds) and by VAN DER WAAL (1974) for *C. gariepinus* (in aquaria). Their observations underline that a stimulus of flood water or a rising water level (in ponds) is necessary to induce spawning. During courtship, which can last several hours to one day, eggs and sperm are ejected in 15 to 50 batches, with intervals ranging from 2 to 15 minutes (VAN DER WAAL, 1974). Spawning occurred at temperatures of 17°C and higher. The fertilized eggs were distributed over a wide area and stuck to flooded sedges and grass.

3.3. *Artificially induced breeding*

The above described breeding cycle and spawning behaviour of *C. lazera* has caused problems in breeding this fish in ponds. The breeding stock used in experiments by MICHA (1975) in Bangui (Central African Republic) by DE KIMPE (DE KIMPE and MICHA, 1974) and by PHAM (1975) in Ivory Coast and by HOGENDOORN and WIEME (1975) in the Cameroons all originated from a wild population of the Ubangui river (MICHA, 1974). The fish matured under pond conditions after 7–10 months during July till October thus corresponding with the natural reproduction cycle which they obviously had retained. In the three countries mentioned some females matured during other periods of the year but in general artificially induced breeding out of the natural season was difficult because egg batches were small or eggs were not fertile. Therefore MICHA (1975) doubted whether females, which developed ripe eggs out of the natural season, really had reached pre-reproductive maturity. Experiments with *C. lazera* on the important question of how to obtain mature fish which spawn out of the natural reproduction cycle are still lacking and thus the mechanism which regulates maturation of oocytes and spermatozoïdes in the pre-spawning period is still unknown. During the reproduction season of *C. lazera* in ponds it is also difficult to decide whether a male or a female is ripe or not. The manual pressure on the belly of the female and the appearance of eggs does not seem a good criterion. It is believed that pressure on the abdominal part of the belly

of the female, which results in the appearance of a peripherical germinal vesicle could be reliable (MICHA, 1975). Males must be selected on the basis of aggressiveness as attempts to discharge milt by hand remained unsuccessful.

Three techniques have been generally used to induce spawning:

a. Natural reproduction in ponds

Mature genitors were stocked in ponds which were filled partly after draining. A few hours later the level was raised up to 30 to 40 cm. Spawning occurred during the night and generally rapidly. The percentage of successful spawning was high but the number of fingerlings obtained was low due to cannibalism between the young fishes and possible predation by frogs. *C. lazera* has the disadvantage for fish culture that it does not practise parental care for fry as Asiatic Clarias species do.

b. Artificially induced reproduction in cement containers

The principle of this technique is to force spawning by hormonal treatment within one day. The delicate point is the choice of male as the criterion of aggressiveness for a male being mature or not remains uncertain. The females were injected with Des Oxy Corticosterone Acetate (DOCA) a hormone which has no effect on egg maturation but acts as a stimulus for ovulation (MICHA, 1975). The dose was about 5 mg DOCA per 100 gram weight of fish. Smaller amounts do not affect ovulation, higher doses can be mortal. The dose was given intraperitonially in one single injection. Injected females and selected males were placed separately in tanks for 10 hours. In the evening a male and a female were placed together in a cement container and spawning occurred during the night. A disadvantage of the method is that the couples often injure each other sometimes ending in the death of one of the genitors. An advantage is that spawning occurs in most cases at a fixed time, about 10–16 hours after injection and that spawning is more complete than under natural conditions. The eggs can be collected easily afterwards and their development can be followed (DE KIMPE and MICHA, 1974; PHAM, 1975).

c. Artificially induced reproduction followed by stripping

Female and male genitors were injected with DOCA (5 mg/100 g) in the morning to ensure ovulation of the female and ripe sperm from the male in the evening. Females could be easily handstripped after 10 hours. Males cannot be handstripped in this manner because of the anatomy of the seminal vesicle of *C. lazera*. It is a paired structure situated behind the testis. Dorsolaterally from each vesicle arise about 20 fingerlike lobes (NAWAR, 1959). Pressure on the male abdomen probably conducts the milt into these lateral lobes instead of towards the genital opening. Hence males had to be killed and sperm collected directly from the vesicles. Hormone injection increased the yield of the milt from 2 to 3 droplets to 10 droplets per testis. Eggs and milt were collected and mixed to effectuate fertilization.

The method was applied in experiments carried out in the Cameroons (HOGENDOORN, 1976, Personal communication).

3.4. *Fecundity*

The fecundity in a natural population of *C. lazera* was estimated at 10000–160000 eggs for females ranging from 200–600 grams (178 specimens examined, NAWAR and YOAKIM, 1962). Under pond conditions these numbers were 10000–120000 eggs for females ranging from 200–700 grams (20 specimens examined), and the weight of the eggs per female correspond with ± 10% of the body weight (HOGENDOORN, 1976, Personal communication).

3.5. *Raising fish*

The rearing of larvae of *C. lazera* was studied by DE KIMPE and MICHA (1974). At 26°C hatching occurs 24 hours after fertilization. The larvae are very small and weigh roughly 1 mg. They start feeding when they are 3 days old, resorption of yolk is completed after 6 days. Larvae of 3 to 6 days old were transferred to ponds which were slightly fertilized with organic matter or poultry dung. At this age the larvae must encounter adaequate food to have a chance of surviving. The larvae were stocked at densities of 1000–2000 ind./are and fed on natural pond food for two to three weeks. After three weeks the fry had reached a weight of about 10 grams and could be given pelleted feeds.

Experiments on the growth of *C. lazera* have been done by HASTINGS (1973), DE KIMPE and MICHA (1974) and MICHA (1975). Working with fingerlings from about 9 grams, HASTINGS (1973) tried to get information on the growth of *C. lazera* using locally available vegetal and animal byproducts such as brewery waste, corn bran, rice bran, cotton cake, sesame cake and bonemeal. The experiments from HASTINGS (1973) and from DE KIMPE and MICHA (1974) were carried out at the station Landjia near Bangui (Central African Republic). The fingerlings were stocked at densities of 1/m², 2/m² up to 10/m² and given pelleted feeds prepared according to the feed composition in Table 2 or with feeds which contained the same products plus some fishmeal and dried cow blood. The feeds were distributed once or twice per day in amounts ranging between 2.5 and 10.3% of total fish weight present. The feeds were administered by hand as the application of demand feeders by *C. lazera* remained unsuccessful under the conditions used. The experiments were carried out in ponds which did not exceed the size of 32 ares. Best results in kg/ha were in general obtained at stocking rates of 2 ind./m². The relative food conversion of *C. lazera* stocked at 2 ind./m² in a pond of 3.7 ares and fed on pelleted feed containing mainly vegetal ingredients (Table 2) was rather favourable, resulting in values of 0.7–3.6 for fish growing from 9.5 to 603 grams. These values should be interpreted, however, with caution as data on the natural production of the pond, the mortality rate due to cannibalism, the immigration of fish from other ponds (over land) are lacking. From the original data of HASTINGS (1973) a growth curve has been drawn in Fig. 2. This growth curve should be considered as very promising for fish culture. Under the conditions mentioned above a yield of 12786 kg/ha/year can be obtained when the fish is harvested after 86 days.

Table 2. Composition of feed for *C. lazera* fingerlings based on vegetal and animal byproducts in Bangui (Central African Republic) (Modified after HASTINGS, 1973).

Products	Total dry matter (%)	Chemical composition of dry matter					In feed (%)
		N-free extract (%)	Lipids (%)	Total nitrogen (%)	Cellulose (%)	Minerals (%)	
Brewery waste	50.0	46.4	7.8	22.8	18.8	4.2	15
Corn bran	87.7	59.7	3.8	14.4	14.5	7.5	15
Rice bran	88.4	56.9	3.8	8.7	22.6	8.0	15
Cotton cake	93.1	28.5	7.4	47.3	9.6	5.4	45
Sesame cake*	94.4	14.4	53.0	22.1	4.8	5.7	7.75
Bonemeal*	91.9		7.1	52.1		40.8	2
Concentrated vitamins							0.25

* after MORRISON, 1959.

The conditions (initial weight of fingerlings, size of ponds etc.) of the experiments from HASTINGS (1973) were more or less maintained by DE KIMPE and MICHA (1974). The influence of vegetal protein (30%) and animal protein (30%) in the pelleted feeds on the growth of *C. lazera* was determined. The constructed growth curves of DE KIMPE and MICHA (1974) which refer to a period of 6 months for the experiment with animal protein and which refer to a period of 8 months for the experiment with vegetal protein, have the same shape as the growth curve represented in Fig. 2. The linear part of the growth curve obtained for vegetal proteins is steeper than the one obtained for animal proteins.The absence, however, of qualitative and quantitative data on the food composition do not permit a general conclusion on the observed difference in growth.

An investigation on appropriate diets for *C. lazera* in Egypt (IMAM et al., 1970) gives results which differ from the previous ones. An animal protein diet with fish meat (91.87%) gave a higher growth rate than vegetal protein diets with rice bran (14.44%) or vegetables (25.07%). As quantitative data on the ingredients of the feed added are lacking too (IMAM et al., 1970) and as the growth in general (from 13.9 to 40.8 grams in 6 months) was very low in this investigation, comparisons with data from DE KIMPE and MICHA (1974) are difficult.

A more interesting point emerging from DE KIMPE and MICHA's work (1974) is the difference found between growth of males and females. After four months of rearing, males had attained a mean weight of 427 grams and females a mean weight of 292 grams, being a difference of 33% of the males mean weight. A similar phenomenon was observed in the growth pattern of *C. lazera* in a semi-natural water in Egypt (EL BOLOCK, 1972). The mean weight of males and females after two years was 207.3 grams and 187.9 grams, respectively. This general trend in weight difference

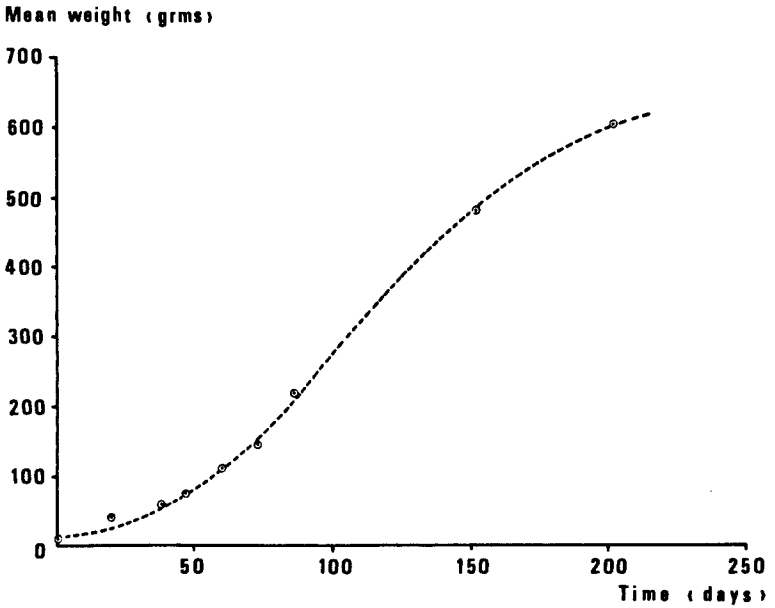

Fig. 2. Growth curve of *C. lazera* in a pond of 3.7 are, stocked at a density of 2 ind./m² and fed on pelleted feed (Table 2).

between the sexes was also found in the consecutive years of growth up to an age of 6 years. The possibility of rearing only *C. lazera* males should, therefore, be considered in fish culture.

4. Discussion

4.1. *Systematics*

Colour patterns, such as the presence or absence of a dark band along the lateral surface of the head or a spot on the caudal penduncle (Fig. 3) have been used for determining Clarias species. Often these characteristics did not match the criteria of Clarias species. The occurrence of hybrids e.g. of *C. lazera* and *C. senegalensis* in nature and in culture has, therefore, often been suggested. Present knowledge (Thijs van den Audenaerde, 1976, Personal communication) shows that colour patterns are not reliable criteria for determining Clarias species and that the morphological characteristics such as vomerine teeth, the ratio of vomerine/premaxillary teeth band and the number of gill-rakers are suitable to determine the three Clarias species *C. anguillaris*, *C. gariepinus* and *C. lazera* that have been maintained.

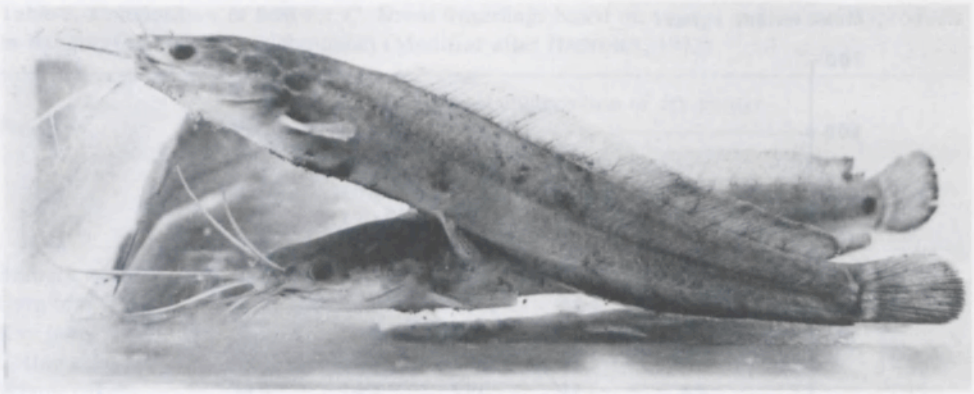

Fig. 3. Fingerlings of *C. lazera*, originating from a wild population of Ubangui river (Central African Republic), reared at Wageningen University. Colour patterns such as the presence or absence of a spot on the caudal peduncle are not reliable criteria for distinguishing different species of the genus Clarias.

4.2. *Fish culture management*

Clarias species, living under natural conditions normally spawn once a year with the onset of major rainfall. Under pond conditions this breeding rhythm is more or less maintained. The internal gonadal maturation cycle of Clarias species can be arbitrarily divided into a long post-spawning period characterized by flat empty gonads in a non-secretory condition (NAWAR, 1959) and recovering afterwards; a pre-spawning period characterized by nearly ripe gonads whose development can remain arrested for a considerable length of time (HOLL, 1966, 1968) and a breeding period, characterized by ripe gonads, preceding spawning.

The post-spawning period: until now no experiments have been done on the mechanisms of *C. lazera* that regulate maturation of oocytes and spermatozoides (DE KIMPE and MICHA, 1974; PHAM, 1975; HOGENDOORN and WIEME, 1975). It is particularly important in fish culture management to know how these mechanisms work. Photoperiodicity could be a factor because SUNDARARAJ and SEGHAL (1970) found that the ovaries of the tropical catfish *Heteropneustes fossilis* significantly increased in weight in the post-spawning period when the fish were exposed to a decreasing daylength followed by an increasing daylength program. Also in nature, ovarian recrudescence occurs if daylength is increased from 12 to 14 hours. The hormonal background of the mechanism will not be discussed here as it is beyond the scope of this paper.

The pre-spawning and breeding period: many observations and experiments have been done on natural and artificially induced spawning. Sampling of gonads of *C. gariepinus* in the water of the Mazoe dam (Rhodesia) indicated that this species gets ready to spawn in October to November. Spawning runs have been noticed much later. In one year, which was characterized by very late rains, spawning occurred even in February (HOLL, 1968). Spawning may thus be delayed for a long time.

In pond culture mature fish were also found throughout a considerably long period. In Bangui (Central African Republic) maturity lasted from July till October (DE KIMPE and MICHA, 1974). Females with ripe eggs in this period, however, often did not spawn or yield viable eggs after stripping. This observation indicates that the spawning phase was obviously not attained.

An experiment with *C. batrachus* in India on testing the potency of homoplastic pituitary suspensions on ripe females calls attention to the same problem. The experiments were done during June–November, covering pre-spawning, breeding and post-spawning. The fish used were all mature, corresponding with Stage 5 of the international scale of maturity. During June, females were injected with one pituitary gland every day for 5 days but they did not spawn or yield viable eggs after stripping. However, from the end of July onwards, mature females yielded viable eggs uniformly on injection. Up to the end of November more than 40 experiments were done, most of them being successful (RAMASWAMI and SUNDARARAJ, 1957).

Thus with the present information it can be assumed that:

a. Photoperiodicity influences the first phase of gametogenesis; there is no evidence that this factor also controls the last phase of ripening of eggs and sperm.
b. Females and males, with sexual organs filling the whole ventral cavity and giving the impression of ripeness (ovary with developed eggs, testis with milt), still need a month or more to reach the spawning phase. Pressure on the abdominal part of the belly of the female, which results in the appearance of a peripheric germinal vesicle could be a better morphological criterion for ripeness (MICHA, 1975).
c. Females and males that have attained the spawning phase can delay spawning for a long time.
d. A rise in water level, which occurs in nature with the onset of the heavy rains, is a final stimulus to spawn.

The rising of the water level as a stimulus to spawn can be replaced by a hormonal injection (DE KIMPE and MICHA, 1974; MICHA, 1975). This second method for obtaining eggs is less laborious and is for this reason preferable in culturing *C. lazera*. Tests with homoplastic or heteroplastic pituitary suspensions and DOCA have been successful whereas HCG and LH gave negative results (DE KIMPE and MICHA, 1974; MICHA, 1975; PHAM, 1975; HOGENDOORN and WIEME, 1975) (Table 3). These experiments on artificially induced breeding, which have been done by these workers in Central African Republic, Ivory Coast and the Cameroons were carried out with the aim to find quickly an effective inducing agent that could make consecutive larval, fry and fingerling rearing possible. Hence the results obtained with DOCA, pituitaries etc. were not compared with those of controls.

In Aziatic countries (India, Thailand, Phillipines) the species *C. batrachus* and *C. macrocephalus* like *C. lazera* also spawn in the rainy season in flooded areas like paddy fields. These species practice parental care; the males take care of the redds and eggs. Breeding has been artificially induced with homoplastic and heteroplastic

Table 3. Summary of experiments on artificially induced breeding of Clarias species. (The data of control animals are mentioned in the text).

Species	Country	Males		Females		Treatment		Response		Reference
		number	weight (grams)	number	weight (grams)	agent injected	total dose	spawning	% of fertile eggs	
C. lazera	Central African Republic	–	–	–	–	homoplastic pituitary	–	good	–	DE KIMPE and MICHA, 1974
		–	–	–	–	heteroplastic pituitary	–	reasonable	–	
		–	–	–	–	H.C.G.	–	none	–	
		–	–	–	–	L.H.	–	none	–	
		–	–	52	400–3400	DOCA**	± 5 mg/ 100 g	poor – good*	0–70	
C. lazera	Ivory Coast	13	480–1110	13	295–1075	DOCA**	± 5 mg/ 100 g	poor – good*	0–77	PHAM, 1975
C. lazera	The Cameroons	9	–	9	–	DOCA	± 5 mg/ 100 g	good	–	HOGENDOORN and WIEME, 1975
C. batrachus	India	–	–	–	173–178	homoplastic pituitary	5♀ glands/ fish	none*	–	RASMASWAMI and SUNDARARAJ, 1957
		–	–	–	145–330	homoplastic pituitary	4♀ glands/ fish	poor-good*	–	
		–	–	2	198, 209	homoplastic pituitary	4♂ glands/ fish	none	–	
		–	–	2	–	P.M.S.	–	none	–	
		–	–	4	110–183	H.C.G.	375–500 IU/fish	none*	–	
		–	–	6	183–228	H.C.G.	250–300 IU/fish	good	–	

C. batrachus	India	–	75–200	–	75–200	homoplastic pituitary	13–30 mg/kg	good	77–99	DEVARAJ et al., 1972
		–	75–200	–	75–200	heteroplastic pituitary	13–30 mg/kg	good	77–99	
C. batrachus	India	–	–	–	–	homoplastic pituitary	4 glands/fish	good	–	KHAN, 1972
		–	–	–	–	heteroplastic pituitary	100–150 mg/kg	good	–	
C. macrocephalus	Thailand	6	–	6	100–187	homoplastic pituitary	0.0013/fish	none	–	TONGSANGA, A. et al., 1963
		6	–	6	100–168	homoplastic pituitary	0.0026 g/fish	good	–	
		6	–	6	102–169	homoplastic pituitary	0.0039 g/fish	good	–	
C. macrocephalus	Philippines	39	120–200	39	120–200	homoplastic pituitary	0.5–1.5 glands/fish	poor-good*	0–98	CARREON, J. A. et al., 1973
		10	120–200	10	120–200	homoplastic pituitary + H.C.G.	0.5–1.5 glands/fish + 50 IU/fish	poor	0	
		8	120–200	8	120–200	H.C.G.	50–250 IU/ fish	poor	0–44	

* Variability in spawning results can probably explained by differences in maturation of the test animals.

** Concerns experiments carried out in cement containers. Males were in general not injected with DOCA.

pituitaries and HCG for *C. batrachus* (RAMASWAMI and SUNDARARAJ, 1957; DEVARAJ et al., 1972; KHAN, 1974) as for *C. macrocephalus* (TONGSANGA et al., 1963; CARREON et al., 1973). The technique has had no substantial commercial application in culturing these two species. The only source of stocking material for the fish farmer in these Aziatic countries is immature fish captured during the harvest of wild fish. In Thailand for instance stocking of immature fish happens only once a year during the breeding season between November and January (SIDTHIMUNKA et al., 1966; SIDTHIMUNKA, 1973; KLOKE and POTAROS, 1975). Hence experiments on artificially induced breeding with *C. batrachus* and *C. macrocephalus* are mainly carried out by Universities who are more interested in the specific hormonal aspects of the technique than of its application in fish culture. Some additional information from the two Aziatic species examined could also be valid for *C. lazera*. Unlike *Heteropneustes fossilis*, the pituitary of *C. batrachus* males appeared to be as potent as that of females in artificially induced breeding experiments (RAMASWAMI and SUNDARARAJ, 1957).

TONGSANGA et al. (1963) studied the amount of pituitary needed to artificially induced breeding in *C. macrocephalus*. Amounts of 0.0026 and 0.0039 grams pituitary gland/fish gave better results than the lowest dose of 0.0013 gram/fish (Table 4).

When the results on artificially induced breeding with hormonal agents obtained with *C. lazera* are compared with those obtained with *C. batrachus* and *C. macrocephalus*, some preliminary conclusions can be drawn. HCG has been proved to be a good inducing agent for *C. batrachus* (RAMASWAMI and SUNDARARAJ, 1957) and for *C. macrocephalus* (CARREON et al., 1976) whereas the results obtained for *C. lazera* were negative (MICHA, 1975) (Table 4). Pituitary homogenates for the three species concerned gave positive results whereas DOCA was found to be successful for *C. lazera* (DE KIMPE and MICHA, 1974) and *C. macrocephalus* (CARREON et al., 1976). In Clarias culture DOCA should be used rather than pituitary homogenates as the loss of donors necessary for the second method is often undesirable. The specific action of this steroid has been recently established for the tropical catfish *Heteropneustes fossilis*. DOCA like some other steroids affected the maturation of yolky primary oocytes in vitro as well as in vivo (GOSWAMI and SUNDARARAJ, 1974). It is therefore suggested that the influence of light periodicity (SUNDARARAJ and SEHGAL, 1970) and the influence of DOCA treatment on egg maturation should be tested in *C. lazera* to try to get mature fish throughout the year.

Larval rearing up to fry in ponds remains a difficult problem in *C. lazera*. The predation by frogs and cannibalism have been mentioned as possible reasons for high mortality. The alternative possibilities of rearing fry in hatcheries by supplying zooplankton followed by pelleted feed up to a mean fish weight of 10–50 grams should be considered.

Fingerling rearing and production in terms of kg/ha/year from *C. lazera* (HASTINGS, 1973; EL BOLOCK, 1975) is now compared with the results obtained with *C. batrachus* in Thailand (KLOKE and POTAROS, 1975). For some information on the

conditions used and the techniques applied, a summary of their report is given first: The stocking rates recommended by the Thai Department of Fisheries is 60–100 fingerlings of 3–5 cm per m^2 but because of fingerling mortality many farmers stock at rates as high as 200 fingerlings per m^2 hoping to compensate for the high mortality (up to 70%) that is often experienced. The catfish industry relies on the cheap and abundant supply of trash fish available at low cost from Thailand's large trawling fleets for the main feed in catfish culture. The trash fish is mixed with rice bran in a ratio of about 10:1 kg weight and put through a grinder to form a sticky paste. After the first two months of culture the proportion of rice bran may be increased to as much as two parts and one part of cooked broken rice will be added, increasing to as much as two parts by the fourth month. Farmers have found that more than 0.5 kg of feed per day (m^2) of pond area will result in pond pollution and heavy mortality. The first crop is harvested after 3–4 months during July and August when the market for the crop is good. By this time the fish will have attained a size of 25–30 cm and a weight of 200–300 grams, ideal for the local market. Fingerlings stocked between July and September are harvested (a second time) between February and April after a culture period of 5–6 months. Fish in this crop may grow to 35–40 cm and 400–450 grams, also an acceptable size, particularly for the Bangkok market. Average production with trash fish and rice and rice bran as a feed in intensive culture is 209 tons/ha/year in two crops. Average relative conversion is 4.1.

Although it is difficult to compare the results obtained with *C. lazera* in Africa with those obtained with *C. batrachus* in Asia because of different stocking rates and differences in climatic and pond conditions, an attempt has been made in Table 4. The growth of fingerlings (9 grams) to a marketable weight (200 grams) in the Central African Republic (HASTINGS, 1973) and in Egypt (EL BOLOCK, 1975) from the point of view of food conversion have been shown to be satisfactory. The production expressed in kg/ha/year, however, in both African countries is low, compared with that in Thailand where stocking densities are very high, the feed used contains a high percentage of animal protein, the conversion rate is relatively low and the production expressed in kg/ha/year is very high. It would be interesting, therefore, to culture *C. lazera* in a future experiment in the same high densities (100 ind./m^2) with a pelleted vegetal feed (HASTINGS, 1973) to compare conversion rates and production under such conditions with those from *C. batrachus* with trash fish.

The promising progress of *C. lazera* culture can be demonstrated best by quoting what was known about this species a few years ago (BARDACH, RYTHER and MCLARNEY, 1972). In a list of African freshwater fishes used in practical or experimental fish culture, these authors give the following characteristics for Clarias spp., including *C. lazera*. Range: all of Africa; cultured on a subsistence basis in the Congo and Rwanda; suggested for culture in the Cameroons. Food habits: any sort of animal matter; some species at least, accept plant matter; very voracious. Propagation: *C. mossambicus* eggs have been artificially fertilized; otherwise not bred in captivity; spawning usually takes place in temporary waters after rains.

Table 4. Survey of conditions and production in Clarias spp. culture in Africa and Asia.

Country	Species	Mean pond size used (m^2)	Maximum number stocked per ha	Feed		Number of crops per pond per year	Fish produced kg/ha/year	References
				Composition	Relative conversion			
Central African Republic	*C. lazera*	320	20000	Vegetal byproducts (97.5%) bonemeal (2.5%)	0.7–3.6	4	12786	HASTINGS, 1973
Egypt	*C. lazera*	926	26000	chicken offall, rice bran, animal blood	3.2	1–2	7833	EL BOLOCK, 1975
Thailand	*C. batrachus*	200–1000	2000000	Trash fish (80%), rice bran and rice (20%)	4.1	2	209000	KLOKE AND POTAROS, 1975

Apart from the expansion of research, in particular with *C. lazera*, it must be stressed that especially in the field of feeds and feeding there is still a need for additional experiments on food formulation and conversion efficiency to give more accurate information on the food requirements of Clarias species.

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