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SEA RANCHING OF COHO SALMON IN THE KERGUELEN ISLANDS (TAAF)

by

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ABSTRACT

The Kerguelen Islands (Subantarctica) are located just South of the Antarctic convergence and thus are bathed by the cold Antarctic waters. Since 1978, a small acclimatized coho salmon population has been self sustaining in a river.

In order to examine the biological feasibility of exploiting this species by the sea ranching technique, a pilot project was initiated in 1984. Coho eggs imported from the state of Washington (USA) after 15 to 22 days of transportation were raised in a recirculating incubation system up to the feeding stage ; fry were then placed in swedish circular tanks for a short time and transferred as soon as possible in floating cages on a lake and released as smolts after about ten-month rearing. First returns were observed in 1987 and since then the progeny of returning adults has been reared alternately each year with imported eggs.

For the first time, the biological feasibility of sea ranching coho salmon in true Antarctic waters was demonstrated. However, in spite of statutory and environmental advantages, the economical feasibility seemed jeopardized by logistic costs and the present evolution of salmon market.

RESUME

Les Iles Kerguelen (Terres Australes et Antarctiques Françaises) sont situées dans l'Océan Indien légèrement au Sud de la Convergence Antarctique et sont donc baignées par les eaux froides de l'Océan Antarctique. Depuis 1978, une petite population de saumon coho a été acclimatée dans un réseau hydrographique vierge de poissons, et s'y maintient par la seule reproduction naturelle.

Afin de tester la faisabilité biologique de l'exploitation de cette espèce par la technique du pacage marin, un projet pilote a été élaboré en 1984. Les oeufs de saumon coho sont importés de l'état de Washington (USA) et après 15 à 22 jours de transport aérien et maritime, ils sont élevés dans un système d'incubation en circuit fermé jusqu'au premier nourrissage ; ils sont alors placés dans des bacs d'alevinage de type suédois et transférés le plus tôt possible dans des cages flottantes sur un lac où ils seront élevés pendant une dizaine de mois jusqu'à la smoltification. Les premiers retours de saumons issus des smolts lâchés à partir de la fin de l'année 1984 ont été observés à partir de 1987 et depuis lors la descendance des saumons de retour est élevée annuellement en alternance avec les cohortes d'oeufs importés des USA.

La faisabilité biologique du pacage marin de saumons coho est démontrée pour la première fois dans les eaux antarctiques, mais en dépit d'atouts d'ordre réglementaire et environnemental, la rentabilité économique de cette spéculation paraît compromise par les coûts logistiques actuels élevés et l'évolution à court et moyen terme du marché mondial du saumon.

1 - INTRODUCTION

Except natural production, Ocean ranching is the most economical method of producing Salmonids with low costs of investment and functioning, provided that the fish can be efficiently harvested. The proposal of indirectly exploiting the enormous abundance of krill in the Antarctic ocean by the way of salmon ranching was made in the early seventies (Joyner *and al.*, 1974). This is one of the reasons why salmon ranching was retained when the French authorities looked for different ways of developing the economy of the Kerguelen Islands (TAAF) as it was done for the Falkland Islands at the same period (Shackleton, 1982 ; Anon, 1984). Thus a pilot project, financed jointly by the authorities (Mission de Recherche des TAAF) and a private fishing company operating around Kerguelen (SAPMER) was initiated in 1983 to explore the biological and economical feasibility of salmon ranching (Davaine, 1989).

2 - MATERIAL AND METHODS

2.1 Environmental conditions

The Kerguelen Islands are located just south of the Antarctic Convergence (Fig. 1) and are bathed by the cold Antarctic waters (sea surface temperature between 0.5 and 5°C).

The archipelago is of volcanic origin with a main island of 6 000 km^2 partially covered with an ice cap on its western part. Melting of the glaciers has left a multitude of small U-shaped valleys with lakes, swift flowing rivers and waterfalls. Catchment areas are between 30 and 100 km^2 and rivers between 5 and 20 km long. Climate is of the subantarctic type (Duchêne, 1989), temperate cold (mean annual air temperature 4.4°C at sea level) with very strong winds (mean annual speed 9.6 m/s, maximum 80 m/s) and regular rainfalls (817 mm in 222 days).

Thus the variations of water temperature in rivers and lakes are moderate and the ionic concentrations low and under the oceanic influence.

2.2 Fish populations

Owing to their geographic isolation and the surrounding Antarctic ocean, the freshwaters in Kerguelen islands are virgin of fish. Two salmonid species, brown trout (*Salmo trutta* L.) and brook trout (*Salvelinus fontinalis* Mitchill) were successfully acclimatized, and gave rise to populations of resident trout, migratory sea trout and lake trout according to the biotas they colonized. Attempts with atlantic salmon (*Salmo salar* L.) failed to establish migratory stocks and led to precarious maintenance of landlocked populations. Only a small migratory coho salmon population (*Oncorhynchus kisutch* Walbaum) is self sustaining in a river since its introduction (Davaine, Beall, 1982 ; Davaine, 1989).

2.3 The "Aquasaumon" project

This pilot project has been described by Davaine (1989). The adopted strategy was to place ourselves right in the best conditions, as revealed by comparable experiments in the Southern Hemisphere, to reduce the number of tests and the cost of operation.

Thus the salmon species choosen were coho and chinook (*Oncorhynchus tshawytscha* Walbaum) for their adaptive plasticity relating to transplantation experiments in the Southern Hemisphere (Waugh, 1980 ; Lindbergh and al., 1981, 1982 ; Scott, 1985) and for relative easiness of rearing.

As there is no suitable site in the vicinity of the permanent base, the rearing facilities were settled 40 km in the West on the very short outlet of a lake situated close to the end of a small fjord (Fig. 1 and 2). This site can be reached only by boat when the weather is propitious, and the small resident staff lives in relative isolation during the wintering.

Because of the ship date of departure from La Réunion Island (first days of December) we met with difficulties in obtaining salmon eggs at the right stage to be transported for a long time. This is the reason why we imported exclusively coho eggs, with the exception of December 1986 when both coho and chinook were available.

The eggs are sent in styrofoam boxes by plane from Washington State (USA) to Paris where they are cleaned. The boxes are refilled with ice and sent by plane to La Réunion Island (Indian Ocean) with the staff of the next missions to the subantarctic islands. Then 12 more days are necessary for the ship to reach the Kerguelen Islands. During the crossing the ova are maintained at 2°C under dripping ice to delay hatching and cleaned every day to remove and count dead eggs. As a whole the transportation lasts 15 to 22 days depending on the time allowed for the scheduled stops.

In Kerguelen the ova are raised in two recirculating incubation systems to prevent harmfull temperature variations during Southern summer and accelerate their developement. As soon as the fry reach the feeding and swimming stage they are placed into swedish circular tanks (2 m diameter) and fed continuously dry feed with additional drifting zooplankton. After one or two weeks, they are transferred in floating net pens on Lake Armor in the most sheltered place. Rearing in the lake lasts 10 or 11 months until smoltification at the end of december ; parrs are fed chopped Antarctic fish with additonal dry feed and vitamins. Salinity conditioning is made in 100 m^3 circular tanks fed with fresh and sea water. Smolts are released directly from the tanks into the lake outlet 40 m from the sea.

The returning salmon are stopped by a fence across the outlet and directed to a fish ladder ending in a trap. They are maintained in holding tanks until spawning.

A second raft in the fjord is used for delayed release of smolts and testing of intensive rearing up to the adult stage.

Every day the dead fish are picked up and counted ; every month the fish of each pen are weighed to check ration adjustments and three samples of 100 individuals are taken at random and individually measured and weighed for growth studies.

Age of returning adults is determined by scale reading helped by the comparison with scales taken out of the smolts before release. Fin clipping provides validation for some returning marked fish.

3 - RESULTS

3.1 Smolt production

3.1.1 Survival

Survival during transportation is good (Table 1) ; mortalities fluctuate between 0.3 and 1.6 % with the exception of december 1985 when rough handling and frost exposure before departure of the plane in the USA killed 19.6 % of the eggs and caused delayed losses till the end of yolk absorption.

The incubation phase lasts 31 to 49 days from arrival in Kerguelen to the end of yolk absorption ; mortalities occur particularly at hatching and are comprised normally between 5.1 and 13.1 %, but in January 1987 and 1988 an accidental power cut in the recirculating units provoked the death by anoxia of 36.8 and 64.8 % of the larvae.

Passage in the fry tanks is very short (3 to 19 days) with mortalities between 0.1 and 2.5 %.

Rearing in lake pens lasts 292 to 353 days with mortalities between 1.3 and 13.6 %. In 1990, poor quality dry feed led to heavy losses (27.3 %) stopped by adding extra vitamins in the food.

In addition to these mortalities many fish disappear from the cages (6.3 to 42.1 %) ; very few dead fish escape attention of the staff collecting mortalities, some are caught by predatory birds (penguins, cormorants, seagulls ...) but the majority gets away through holes in the nets that are not immediately detected ; 83.9 % of the only chinook cohort escaped through a large tear in the net during a long storm.

Depending of the year and the different mishaps the net cohort survival to one-year old smolts from imported eggs is between 15.6 and 73.3 %.

Rearing of native cohorts born from returning adults gives approximately the same results (Table 1) ; mortalities are heavier during incubation and in fry tanks but this is natural as these phases last a much longer time during winter and considering that incubation is taken as a whole. Most of the losses occur before the eyed stage because of fungus attacks in spawns of overripe females and lack of experience from the wintering staff.

The unique experiment with fall chinook seemed promising until tearing of the net but the smoltifying parrs were too small in July to survive efficiently in cold (1°C) and high salinity water (34,4 °/°°).

3.1.2 Growth

Fry are transferred in lake pens around mid-February ; at that time, lake temperature is highest and growth must be optimum to allow the parrs a good winter survival when temperature falls sharply in April. Figure 3 shows that specific growth rate (SGR) decreases sooner than temperature and never recovers its initial value (around 4 %) though remaining always positive. At the same time, the food conversion ratio (ICC) rises as the fish are overfed to optimize growth, and decreases at a more reasonable level as the ration is progressively adapted to the fish appetite and every day changes in weather conditions.

Annual growth of the coho parr improved during the first years (1984 to 1986) owing to better knowledge of local constraints and fish requirements though the wintering staff changes each year (students accomplishing their military service), but now annual temperature is the decisive factor as shown in figure 4 and 5 where 1988 is the coldest year and 1987 the warmest.

Native cohorts have better growth because of a longer rearing period including the whole summer of their first year (Fig. 6 and 7); in addition the "89a" cohort (eggs spawned in winter 1989, parrs reared during 1990) benefited from its very low rearing density screening the temperature effect.

Rearing experiments show that population density has a strong effect upon growth whereas two different diets, chopped Antarctic fish with additional pellets versus dry feed only, have not.

3.1.3 Smolting

Signs of smoltification appear in November and by the end of December fish are ready to enter the sea. The proportion of smolts depends on fish size and varies from 85 % the two first years to 99 % now ; remaining parrs are mostly fish showing physical malformations.

Starting from around 10 g the first year, smolts weight is now comprised between 10 and 20 g for imported cohorts and between 20 and 30 g (up to 55 g) for native cohorts.

Different release techniques have been tested to reduce bird predation : directly in the lake, at night from the tanks in the outlet covered with nets, during spring tides, directly from sea net pens.

Delayed releases were used for 1986 and 1989 cohorts in order to shorten migration range and increase survival.

3.2 Returning adults

3.2.1 Composition

The first returns of coho salmon were registered in 1987, and every year since that year. Fish enter the lake outlet from March to July (the majority in April and May) and swim up the salmon ladder up to the trap or are caught by electrofishing downstream from the fence. Numbers and composition are given in table 2. There was a dramatic fall of the returns in 1989 following the most severe winter of all these years in 1988.

In 1987, most of the fish were 2+ (cohort 1985) with 60 % 2-year smolts and 40 % 1-year smolts ; the few 3+ fish (cohort 1984) were all 2-year smolts ; two salmon (cohort 1986) came back as jacks three months after release.

In 1988, half of the fish were 3+ (cohort 1985) with 88 % 2-year smolts and 12 % 1-year smolts ; the other half were 2+ (cohort 1986) all 1-year smolts ; three salmons were 4+ (cohort 1984) 2-year smolts and eight returned as jacks (cohort 1987).

All of the few salmon that came back in 1989 were 2+ (cohort 1987) 1-year smolt.

In 1990, nearly all the salmon were 2+ (cohorts 1987A and 1988) 1-year smolt ; one fish returned as jack (1988A).

As the size of smolts increases with rearing improvements, it seems that all the fish released migrate frankly as one year smolts without spending one more year in freshwater (like cohorts 1984 and partly 1985) and return massively after two summers at sea (15-16 months) as 2+ salmons.

Since 1987, the mean size of returning coho salmon increased significantly (Table 3) and with the exception of jacks they reach a decent market size for this species.

3.2.2 Growth

Back calculated fork-lengths by the Fraser-Lee method are presented in Table 4 and the corresponding calculated weights in Table 5. Individual growth has increased since the first cohorts, length gain passing from 15 cm to 22 cm during the first summer at sea, and from 15 cm to 24 and 28 cm during the second one. The initial advantage in size of the native cohort (coho 1987A) does not seem to be maintained after two summers at sea.

This growth can be considered as fair, taking into account the low temperature of the sea around Kerguelen, and well above that of acclimatized sea trout.

The biggest of the few returning chinook salmon measured 87 cm and weighed 9 200 g.

3.2.3 Return rates

There is a possibility that ascending salmon might have jumped over the fence during spates before 1990 and the construction of a flow-regulation dam ; this has been demonstrated by the presence of wild coho fry in the inlet of the lake since 1988. Nevertheless the salmon checked at the fence make up almost all of the ascending fish. Straying can't be discarded too, but most of the neighbouring rivers are too small or inaccessible.

The return rate of each cohort (Table 6) had to be considered as a whole as many of the fin clipped smolts could not be undoubtedly identified when captured as adults. When identification and cross checking was possible it appeared that batches of marked fish had a very bad return rate and that the bulk of returning fish were issued from unmarked smolts as transportation and handling of smolts proved very unsatisfactory.

Except cohort 1984 which was raised in bad conditions, the following cohorts 1985 and 1986 showed promising return rates (8.4 and 5.5 °/°°) in the context of a very distant transplantation out of the species range.

But the weak returns of 1988 and 1989 have masked the potential of cohorts 1987, 1988 and especially the second generation cohort 1987A that should have presented better return rates as in most acclimatization experiments. This could be explained partly by the exceptionnally cold winter in 1988 provoking the death of the salmon in the open sea, or by poor smolt stamina following bad quality feeding and deficiency disease.

4 - DISCUSSION AND CONCLUSION

There have been numerous attempts at transferring salmonids from the Northern to the Southern Hemisphere since the end of the 19th century (Thorpe, 1980). In most cases acclimatization of sedentary species, or sedentary forms of anadromous species, was successful when environmental conditions met with the fish requirements ; on the contrary, attempts with migratory forms usually failed. In south America (Joyner, 1980), Falkland Islands (Arrowsmith and Pentelow, 1965), Kerguelen Islands (Davaine and Beall, 1982 ; Davaine, 1989), Australia and Tasmania (Mac Crimmon and Marshall, 1968), New Zealand (Stewart, 1980 ; Waugh, 1980 ; Scott, 1985) introduced brown trout, rainbow trout or brook trout developped natural populations perfectly adapted to their new environment. Brown trout even presented migratory populations remaining on the continental shelf . On the other hand, Atlantic salmon failed to develop migratory stocks and remained landlocked when acclimatized. For many years, the only successful transplant of a salmon species was that of chinook in New Zealand.

Among the numerous hypotheses put forward to explain this state of fact, the gyre theory proposed by Stewart (1980) condemns salmon introductions in the Southern Hemisphere for they would not find the gyres that guide them during their migration in the

Northern Hemisphere. The assumption formulated by Scott (1985) says "The probatility of establishment of a complete migratory pattern is inversely proportional to the distance of migration of the parent stock".

These statements are in agreement with the results of salmon ranching experiments in South Chile (Lindbergh and al., 1981 ; Lindbergh and Brown, 1982) when short range or diversified migration pattern species like chinook or coho returned to the ranch and long range migratory species like chum failed to return.

Thus in the Southern Hemisphere, genetic variability with respect to migration distance appears to be the condition for success of acclimatization of anadromous stocks that will develop from the more coastal individuals. Greater Increased length of migration increases reliance on a more complex fail safe series more subject to disruption (Scott, 1985) in a completely different marine environment.

The Kerguelen sea-ranching experiment gave interesting return rates with first generation coho salmon (8.4 and 5.5 °/°°) compared with the results of DOMSEA and SALMONES ANTARCTICA in Chile with the same species (0.1 to 1.2 °/°° ; Lindbergh and Brown, 1982). In spite of logistic difficulties smolt rearing can be carried out satisfactorily and production costs reduced by feeding the parrs with wastes of industrial fishing around Kerguelen (filleting Antarctic fish produces 50 to 60 % wastes). Emigrating smolts seem to cope with bird and marine mammal predation and find suitable feeding grounds around the shore where Antarctic fish spend their first year and planktonic and benthic crustacea are very abundant ; later on they can remain on a continental shelf of more than 100 000 km^2 densely populated with fish (Duhamel, 1989).

However, the last returns and particularly the second generation returns, instead of showing a significant increase as usual, are much lower owing to exceptional cold related to unpredictable convergence displacements and/or fish pathology and handling stress.

It is too soon to form a final opinion as to whether the economical feasibility of sea ranching coho exists in the Kerguelen Islands, without knowing the actual possibilities of second generation acclimatized fish ; nevertheless the present evolution of salmon market does not incite to unconditional optimism.

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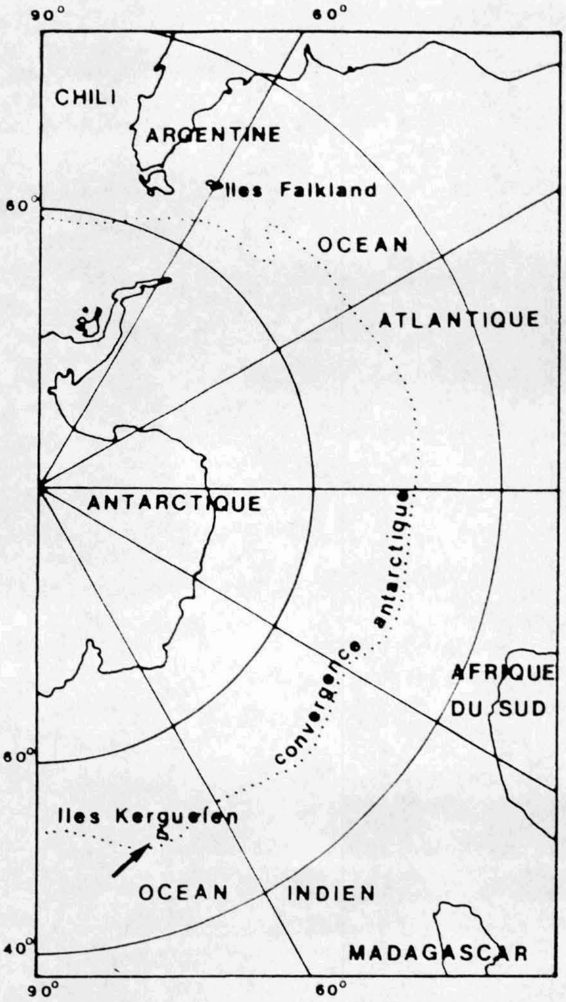
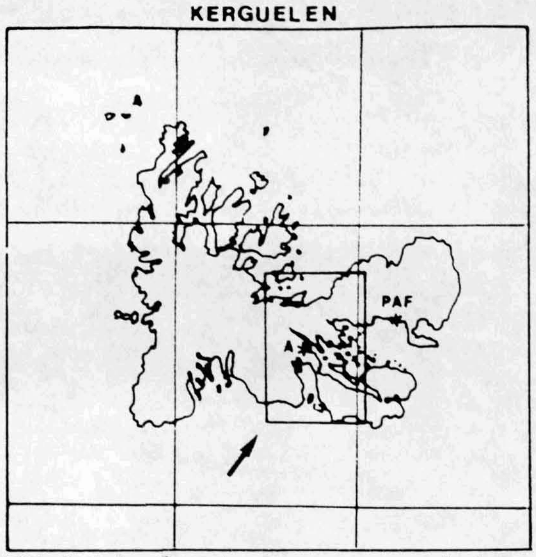
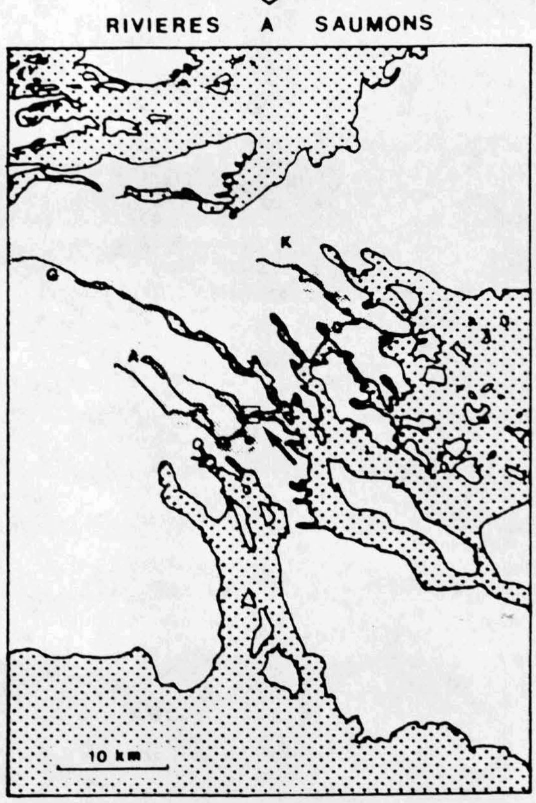
Figure 1 - Geographic situation of ARMOR sea ranching base

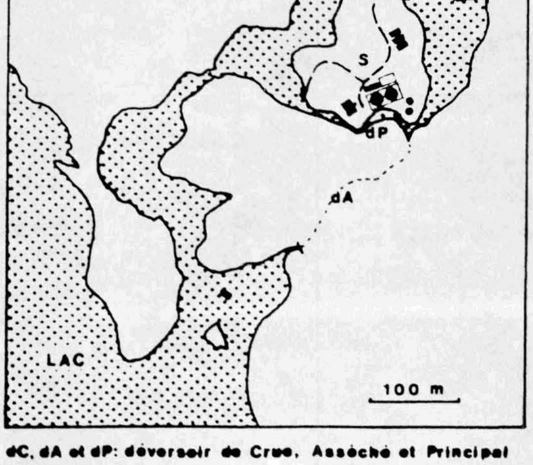




PAF: Port Aux Français A: Armor



-K: Korrigans — Salmo salar
-G: Grisanche — Oncorhynchus kisutch
-A: Armor — Salmo salar
Oncorhynchus kisutch
Oncorhynchus tshawytscha



dC, dA et dP: déversoir de Crue, Asséché et Principal
S: Salmoniculture

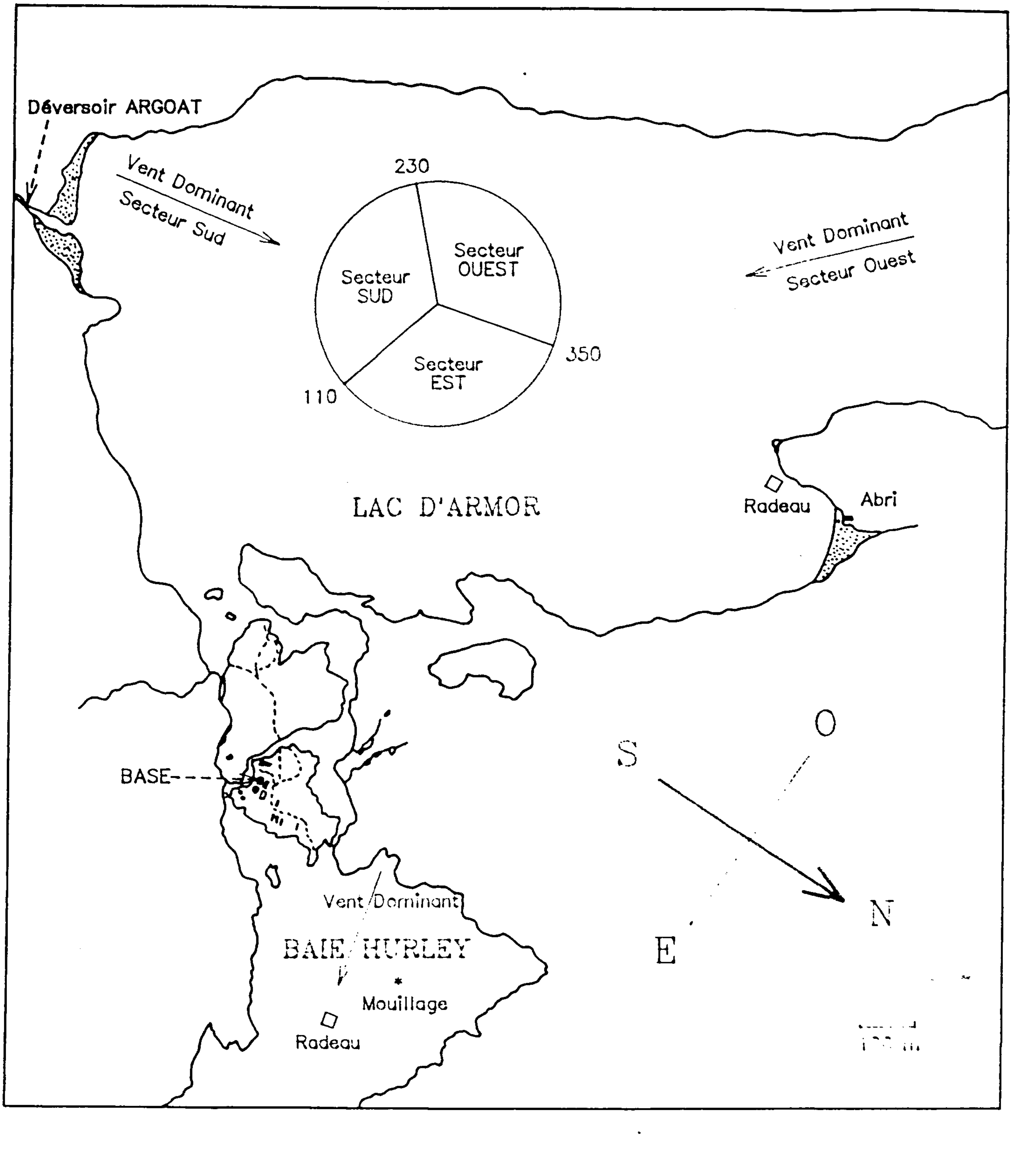
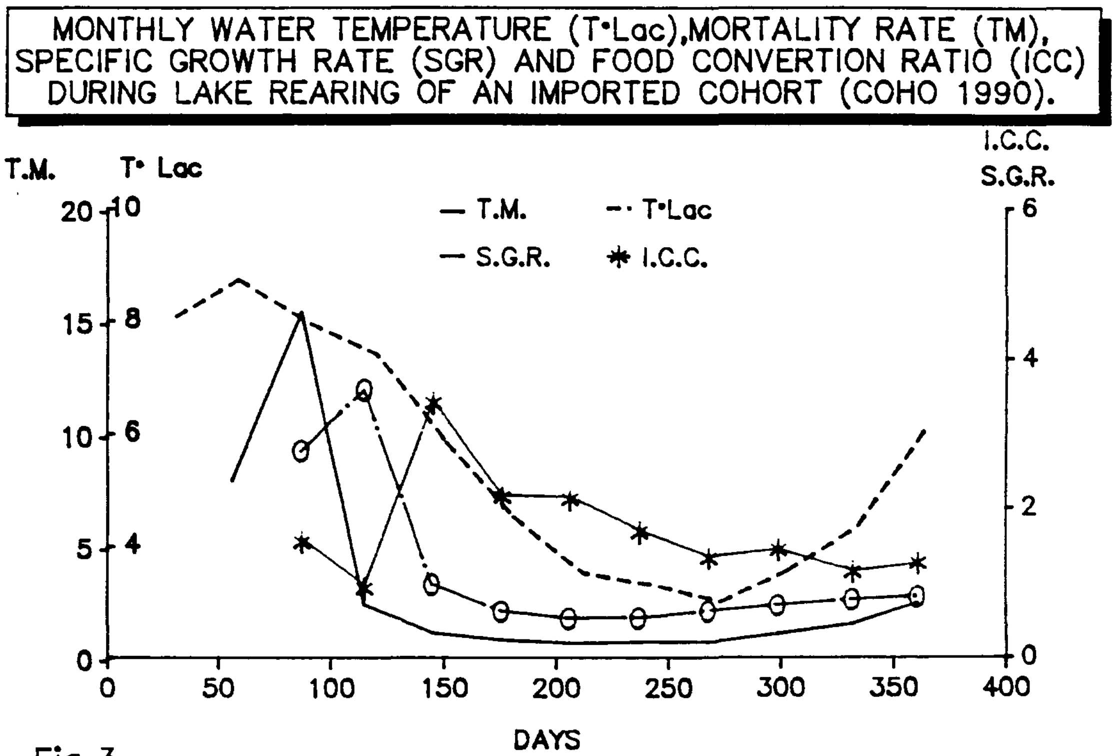


Figure 2 - Sea ranching base, rearing facilities.


MONTHLY WATER TEMPERATURE (T•Lac),MORTALITY RATE (TM),
SPECIFIC GROWTH RATE (SGR) AND FOOD CONVERTION RATIO (ICC)
DURING LAKE REARING OF AN IMPORTED COHORT (COHO 1990).
T.M.
T• Lac
I.C.C.
S.G.R.
T.M.
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S.G.R.
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Fig 3

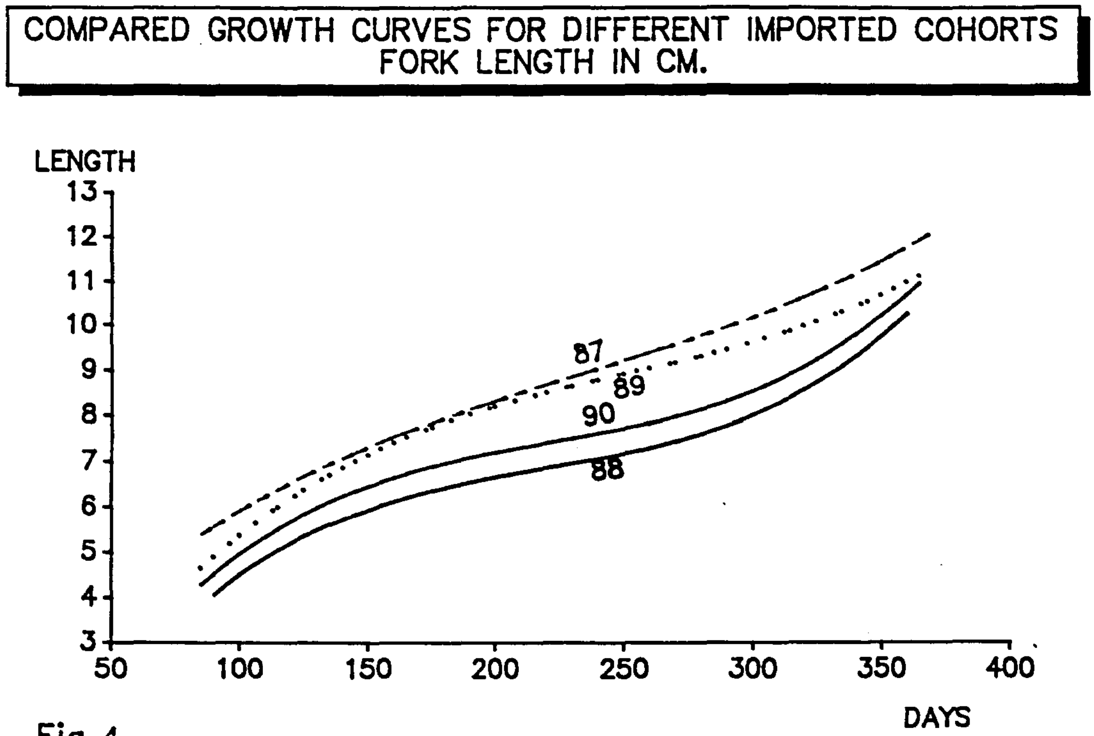
COMPARED GROWTH CURVES FOR DIFFERENT IMPORTED COHORTS
FORK LENGTH IN CM.
LENGTH
13
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Fig 4

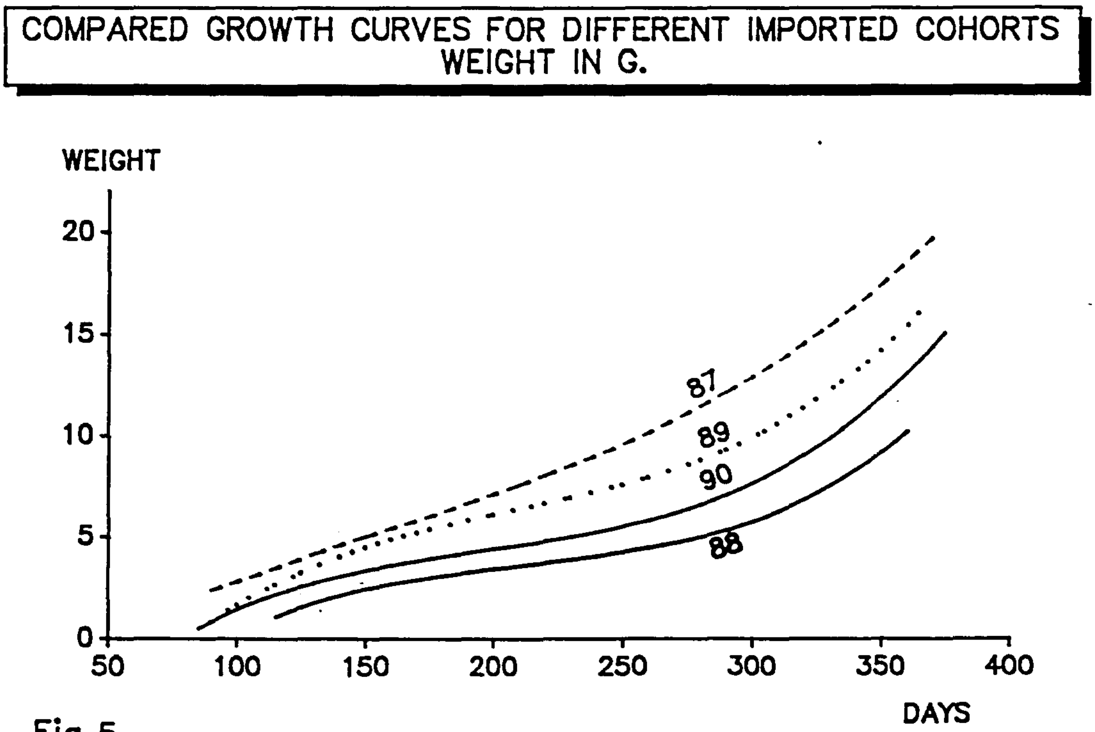
COMPARED GROWTH CURVES FOR DIFFERENT IMPORTED COHORTS
WEIGHT IN G.
WEIGHT
20
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Fig 5

COMPARED GROWTH CURVES FOR DIFFERENT ACCLIMATIZED COHORTS
FORK LENGTH IN CM.

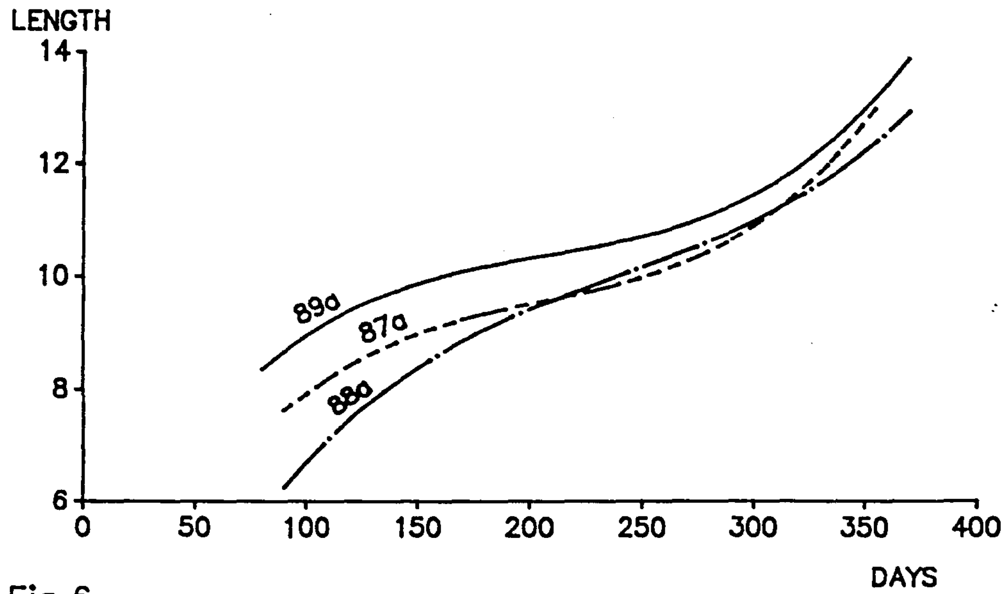

Fig 6

COMPARED GROWTH CURVES FOR DIFFERENT ACCLIMATIZED COHORTS
WEIGHT IN G.

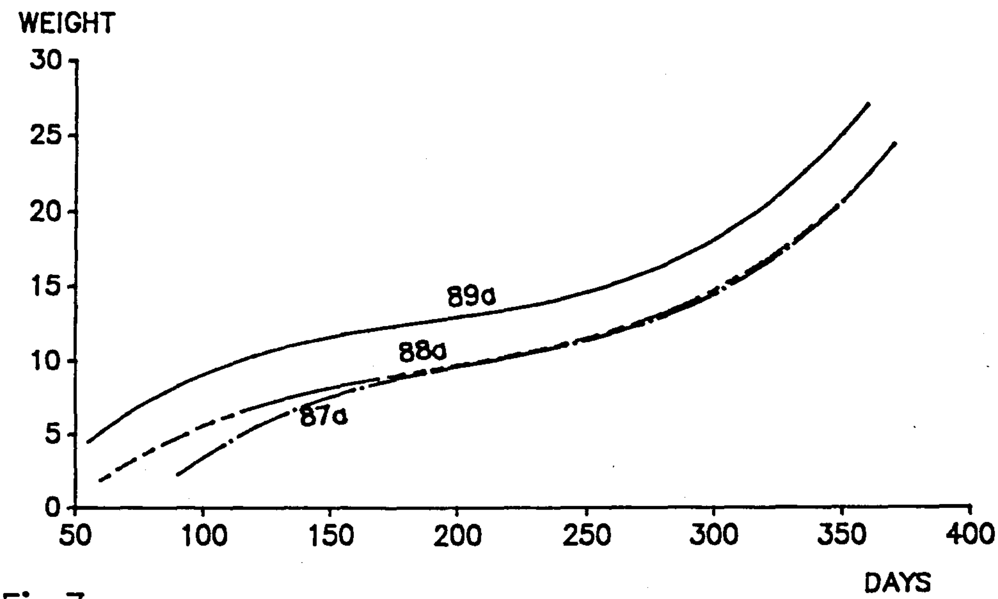

Fig 7

Table 1 - Mean mortalities in % of the initial number of eggs (heavy accidental mortalities withdrawn)

		% Mortality				% missing (escaped)	% survival 1 year smolt (theoretical)
		Ship Transport	Incubation	Fry tanks	Lake pens		
COHO Imported cohorts 1984 to 1990	mean	0.9	8.2	1.0	7.5	22.1	60.3
	optimum	0.3	5.1	0.1	1.3	6.3	86.9
CHINOOK Imported cohort 1987		1.0	6.2	0.6	1.7	83.9	6.6
COHO Native cohorts 1987 to 1989	mean		26.1	8.9	8.8	16.3	39.9
	optimum		16.7	2.4	1.3	4.4	75.2

Table 2 - Yearly number and composition of returning coho salmon (native cohorts 1987A, 1988A, born in 1987 and 1988 are raised with the imported cohort of the following year 1988 and 1989 and released at the same time : january 1989 , january 1990).

COHORT	YEAR OF RETURN				DATE OF RELEASE
	1987	1988	1989	1990	
COHO 1984	4.44 %	1.03 %			Jan. 1985
COHO 1985	94.97 %	51.03 %			Jan. 1986
COHO 1986	0.59 %	45.55 %			Jan. 1987
COHO 1987		2.74 %	100 %		Jan. 1988
COHO 1987A				63.64 %	Jan. 1989
COHO 1988				33.33 %	Jan. 1989
COHO 1988A				3.03 %	Jan. 1990
NUMBER	338	292	6	33	

Table 3 - Size of coho salmon captured each year (mean and confidence limits P.0.99)

YEAR	FORK LENGTH (CM)			WEIGHT (G)		
	MEAN	RANGE		MEAN	RANGE	
1987	40.9 ± 1.2	25.0	62.0	896 ± 84	150	2600
1988	51.8 ± 0.5	25.0	75.0	1668 ± 65	150	5100
1989	47.0 ± 5.3	34.0	51.8	1323 ± 342	500	1600
1990	58.4 ± 3.1	22.7	75.0	2602 ± 365	127	5800

Table 4 - Mean backcalculated fork-lengths in cm for each cohort (the first winter happens about 6 months after hatching for imported cohorts)

COHORT (NB)	SMOLT AGE	WINTERS					SMOLT SIZE
		1	2	3	4	5	
IMPORTED							
COHO 1984 (18)	2	6.5	16.3	31.8	46.0	57.8	
COHO 1985 (470)	1	5.7	27.1	44.4	56.8		11.7
	2	5.7	16.4	36.5	51.4		17.4
COHO 1986 (135)	1	6.0	35.5	51.3			13.5
COHO 1988 (11)	1	7.7	32.9	60.7			10.1
NATIVE							
COHO 1987A (21)	1	9.2	35.4	59.1			13.5

Table 5 - Mean weight in g calculated from backcalculated lengths by means of weight/length relations for each cohort and smolt age

COHORT	SMOLT AGE	WINTERS					SMOLT SIZE
		1	2	3	4	5	
IMPORTED							
COHO 1984	2	3	48	357	1086	2162	
COHO 1985	1	2	238	1255	2321		17.6
	2	2	51	490	1570		58
COHO 1986	1	2.3	536	1650			27
COHO 1988	1	4.9	406	2611			11.2
NATIVE							
COHO 1987A	1	8.5	507	2408			27

Table 6 - Smolt releases of different origins and global return rates to date

COHORT	ORIGIN	SMOLTS		GLOBAL RETURN RATES
		PRODUCED	RELEASED	
IMPORTED				
COHO 1984	Puyallup River	31 000	23 453	0.8 °/°°
COHO 1985	Soleduck River	73 000	55 730	8.4 °/°°
COHO 1986	College Fisheries Seattle	32 000	24 677	5.5 °/°°
COHO 1987	Willapa River	24 000	18 180	0.4 °/°°
COHO 1988	Fish Pro Inc.	37 000	32 197	0.3 °/°°
COHO 1989	Soleduck River	41 000	40 421	
COHO 1990	Green River	59 000	43 517	
CHINOOK 1987	College Fisheries Seattle	112 000	105 000	< 0.1 °/°°
NATIVE				
COHO 1987 A	Soleduck x Puyallup	38 000	33 792	0.6 °/°°
COHO 1988 A	Soleduck x Seattle	65 000	63 120	
COHO 1989 A	Willapa	2 200	0	