Erindi sem Á.Í. flutti á
"aquaculture" þingi í
Amsterdam vorið 1987.

SALMON RANCHING

A WORLD REVIEW

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VEIÐIMÁLASTOFNUN
Fiskeldisdeild

104

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Hafbeit
- Hafbeit almennt
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- Hafbeit í öðrum löndum

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Salmon Ranching
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Salmon ranching: A world review.

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ABSTRACT

The classification of salmon ranching within the field of aquaculture and how it can be distinguished from public enhancement practices on genetic and biological grounds are discussed. The term ranching is most commonly applied to migratory species but can be expanded to include extensive farming of sedentary species such as molluscs.

The review provides a brief historical account of salmon ranching in the Pacific and the Atlantic, emphasizing major technological innovations. The biological principles underlying the concept of ranching are discussed also, primarily the principle of homing, as are the various biological and political factors constraining ranching, including the capacity of marine waters to grow salmon, conflict with conservation of natural stocks and alternative harvest strategies.

The possibilities of improving ranching performance through selective breeding and manipulation of the rearing cycle are great. For example, a successful zero-age smolt program has been in operation with coho salmon in the U.S. and seems to hold promise for other salmonids.

A survey of the literature on salmon ranching seems to indicate that the most profitable commercial operations are those using species with a short freshwater rearing period, such as pink and chum salmon. These operations occur mostly in Japan, U.S.S.R. and Alaska and support large scale commercial fisheries.

Publicly operated ranching programs in the Pacific which are based on chinook and coho salmon would probably not be economical if they supported only a commercial fishery. There is a sizable sports fishery for these species but it is difficult to evaluate in monetary terms. It seems likely that these public operations are economical at least in years with reasonable sea survival. Most of the public ranching efforts with Atlantic salmon are marginal in an economic sense, with the exception of operations in the Baltic region which are quite profitable but subject to a lot of international complications. In Iceland there is a high demand for smolts which makes ranching non-profitable at the present time compared to the sale of smolts. Assuming a lower smolt price, the Icelandic operations should be profitable.

In most countries, salmon ranching operations interact seriously with wild stocks, especially where the ranched salmon are primarily harvested in mixed stock fisheries. This is a logical consequence of the fact that ranched populations can stand a higher rate of harvest than wild populations. In most cases the only possible solutions require a switch to terminal fisheries and associated stock based management of the resource.

INTRODUCTION

During the last 20 years there has been a great increase in the farming of fish and other aquatic animals. This is partly due to the fact that most wild fish stocks are being harvested at maximum capacity or have been overharvested. Aquaculture production is expanding most rapidly in the developing countries, where the primary emphasis is on inexpensive methods to produce fish protein to feed a rapidly growing human population. In the industrial countries, which are mostly in the temperate zone, highly technical rearing methods have received major emphasis. The primary goal has been to supply international fish markets with relatively high priced aquaculture products. Industrial-scale production is limited to relatively few species, primarily salmon, trout, catfish, sturgeon, shrimp, and several types of molluscs.

Aquaculture in its simplest form has been carried out for at least 3000 years. The earliest records are from China but there is evidence of aquaculture activity in Europe during the middle ages (Ackefors et al. 1986). This usually involved stocking of fish in ponds or enclosures without any type of feeding. This type of farming is still practiced in many localities where productivity of natural food is high and is referred to as "extensive aquaculture". A good example of this is the valliculture of eel in Italy, which involves stocking imported or locally caught elvers into estuarine lagoons where they grow to market size on natural food.

In more recently developed programs, known as "intensive aquaculture", the fish farmer takes the fish through all the stages from egg to adult, using modern rearing techniques, and artificial diets. A good example is the salmon farming industry in Norway. Since the fish are fed a high protein diet, the end product is usually expensive.

Ranching is a term most often applied to salmon released as juveniles into natural waters, where they grow to market size on natural foods. The feeding areas can be either a large lake or the ocean. The similarities between ranching and extensive aquaculture rearing are obvious, with the main difference being that ranched animals are free to migrate to feeding areas which lie well beyond the zone of release. Harvesting can occur in the open water or when maturing fish migrate back to the release location.

Ranching of salmon, and possibly other species exhibiting a strong homing instinct, can be a very sound method of aquacultural production, both in financial and ecological terms. Thorpe (1982) pointed out that intensive rearing of salmon is costly since the species is high in the food web (carnivore) and requires high grade fish protein in the diet to achieve optimum growth; such captive rearing yields only about 10% of the protein consumed. Thus the product must have a high wholesale value for intensive rearing to be economically viable.

The term ranching is primarily applicable to the following classes of aquatic organisms:

1. Migratory species, usually-anadromous, which can be harvested at or near the point of release on their return spawning migration. The most important species in this class are salmonids (Salmo,Salvelinus, Oncorhynchus) and sturgeon.

2. Stationary species, which reside on the ocean bottom, or attached to artificial underwater structures, within a special zone where they can be harvested. Due to the nature of this species class, some stock management and adjustment of growing conditions are possible although feeding is entirely natural. Oyster and mussel culture are typical examples.

3. Marine species, where recruitment of juveniles is limiting production of harvestable stocks. It is possible that this condition exists for various species of groundfish such as cod and flatfish. Advanced techniques for the mass production of juveniles of several marine species exists today. However, the potential for ranching of these species has not been developed.

The term ranching is commonly used as a synonym for enhancement within management agencies in Europe and the United States. In a narrower sense, ranching can be defined as an aquaculture practice, intended primarily for the production of a commercial product. Under this definition, selective breeding and other genetic practices typical of animal husbandry can be used to reduce production costs, quality of harvested product, and survival to maturing adults. The primary distinction, then, between enhanced and ranched stocks is the opportunity for genetic manipulation.

The report considers stocking and ranching from an aquaculture viewpoint. Emphasis is placed on Pacific salmon in North America and Asia and Atlantic salmon in North America and Europe. The ultimate goal of ranching is to utilize fully the carrying capacity of the environment into which juveniles are released. Instances where selective breeding has or can be used to improve performance will receive emphasis. There are many instances where wild salmon runs have been eliminated as a result of hydroelectric schemes, pollution or other man made changes. In some cases the losses have been mitigated with ranching technologies and these will be reviewed briefly. Enhancement of wild populations frequently involve release of fry and parr into fresh water nursery areas in addition to smolts. Juveniles used for enhancement should typically be from the local stock to maintain the genetic composition of the population in question (Saunders 1981, Verspoor 1986, Cross et al. 1983, Thorpe 1986, Stahl 1983, Jessop 1976, Ritter 1975, Wilkins 1985). These instances will not be discussed.

INSTITUTIONAL STRUCTURES

Ranching can be divided into three categories: a) public ranching, where fish are harvested as a public resource, generally on the open ocean; b) private ranching, where fish are harvested as a private resource in freshwater or a land based site; and c) cooperative ranching where salmon fishermen are actively propagating the resource through ranching.

Public ranching is a common form of ranching in which government operated hatcheries release large numbers of salmon smolts for harvest at sea by the traditional commercial and sport fisheries. In some cases the hatcheries function to remedy a reduction or loss of wild stocks due to man's activities and in other cases to enhance the commercial and sport fisheries. A very high proportion of these fish are harvested in the ocean, often at the cost of depleting wild stocks. This type of enhancement has been conducted in the U.S. Pacific northwest for decades. These public ranching programs are practiced extensively in the U.S., U.S.S.R., Canada, Sweden and Ireland, to mention a few.

Ranching by private entities would, in most instances, assume that the organization releasing the fish had the prime right to harvest them at or near the location of release. This in turn assumes that fish return to the site of release, the typical behavior for salmonids and other anadromous species. Harvest of anadromous species at or close to the source of juvenile production is considered the most rational and economical method of management. However, these prerequisites for private ranching are met at only a few localities in the world: most appropriate localities also support coastal or high seas fisheries. Although economic incentives for private ranching are reduced by oceanic fishing on mixed stocks, private companies have invested in ranching in the United States. The state of Oregon has allowed private firms to participate since 1971 (Lannan 1980) and one firm has operated in California since 1968. The only salmon producing country which has no near-shore fishery and manages its resource entirely on a stock by stock basis is Iceland; salmon fishing in contiguous marine waters has been forbidden for over 50 years. Several private ranching stations are operating in that country.

The last category of ranching is the one performed by fisherman's cooperatives or corporations where a large fraction of the harvest is taken in the sea. In recent years, a share of public type of ranching has been performed by interest groups such as fisherman's cooperatives, Indian tribes, and various other non-profit organizations. Since the fish released by these groups are normally harvested in the open ocean with conventional fishing gear, and since no individual corporation is dependent on profit from the operation, the operation of these programs differs little from public ranching. Alaska has allowed non-profit corporations to ranch salmon since 1974 (McNeil 1980). In 1986, Japan had 270 salmon hatcheries operating as private entities(Nasaka,in press), and the U.S.S.R. operates salmon hatcheries through state-owned corporations.

HISTORY OF RANCHING

The Pacific

Salmon ranching in the Pacific dates back to 1872 when the U.S. Fish Commission established a hatchery on the McCloud river in California (McNeil 1980). However, subsequent technological developments have been more pronounced in the states of Oregon and Washington.

Initial salmon ranching efforts were directed toward the enhancement of depleted stocks or mitigation for habitat loss. Early development was slow and nearly all operations were based on the release of young fry. Although experimental feeding of fry started early the major breakthroughs in feeding technology came after 1950. In 1960, 72 million fingerlings and smolts were released by the State of Washington (Donaldson 1980) but by 1977 this number increased to 160 million. The fish released in 1977 were also larger due to improved diets and the greater ocean survival of larger smolts. As a result, the output by weight increased tenfold from 1960 to 1977 (Donaldson 1980). Diets, including the Oregon moist pellet, had been improved substantially by the late 1970's. Washington and Oregon were the leading states in salmon husbandry and these early developments in the Pacific Northwest laid the foundation for salmon ranching using large, intensively reared smolts. These early efforts were all done with Pacific salmon (Oncorhynchus sp.), primarily chinook and coho, but the rearing of steelhead trout (Salmo gairdneri), a sea run variety of rainbow trout, also started very early.

As was pointed out earlier, private ranching of salmon depends on the precise return of salmon to the point of release. There is no doubt that no single operation has had a greater influence on the early development of private sea ranching than the salmon holding pond at the School of Fisheries in Seattle, Washington. The pond built, by Dr. Lauren Donaldson in the late 1950's, was equipped with a small salmon ladder and supplied with lake water pumped from a nearby ship canal. Donaldson's experiments demonstrated unquestionably, how effectively salmon home to the point of release.

A private company, Oregon Aqua-Foods, constructed a salmon ranching facility at Newport, Oregon in 1972 for the rearing of salmon in saltwater ponds(Commercial Fish Farmer 1977).The company was purchased by the Weyerhaeuser Company in 1975, and the saltwater facility was expanded to operate as a salmon release/recapture facility. Maturing salmon have successfully returned to the saltwater ponds and the rate of straying has not been greater than one might anticipate with releases from freshwater sites (McNeil pers.comm.). Currently, a number of firms are in operation along the Oregon coast as are a not-for-profit corporations in Alaska.

The Atlantic

Artificial fertilization methods were first reported by Jacobi (1763) but it took many years before propagation of Atlantic salmon (Salmo salar L.) became a practical procedure. European hatcheries started planting sac fry into streams in the late 1800's with little success until methods for feeding fry were developed. Rearing of salmon to parr size began in Sweden around 1930 and Atlantic salmon smolts were first produced in Sweden about 1950 under the leadership of Dr. Börje Carlin of the Swedish Salmon Research Institute (Larsson 1980). Smolt production had increased to over half a million annually by 1960.

Subsequently, two Atlantic salmon research stations were built in the early 1960's, one at Furnace on the Burrishoole river in Ireland and operated by the Salmon Research Trust (Piggins 1980)and the other at the Kollafjördur Experimental Fish Farm in Iceland, operated by the Institute of Freshwater Fisheries (Gudjonsson 1973). The Salmon Research Trust facility has contributed greatly to the understanding of Atlantic salmon ranching whereas the Icelandic facility, which has been dependent financially on ranching income, must be considered the pioneer of private salmon ranching in Europe.

Other research stations have been established. Long term genetic research was started at the North Atlantic Salmon Research Center in Canada in 1974. Their objectives included selective breeding for strains of salmon suitable for salmon ranching and cage rearing (Saunders 1982). Salmon ranching research has been an important activity at the Faroese research station at Air since 1976 (Reinert 1982) and a research station at Ims in south-western Norway also has been involved with research on ranching of Atlantic salmon and other salmonid species since 1978 (Hansen 1982). More recently an experimental salmon ranch was established by the Department for Agriculture and Fisheries for Scotland at the mouth of the River Lussa in south western Scotland (Thorpe 1982).

HOMING AND IMPRINTING

Salmon ranching relies on the ability of salmon to return to release sites from the feeding grounds in distant oceanic areas. This ability is best demonstrated by Pacific salmon (Oncorhynchus sp.) which in some cases may travel, on feeding migrations, from Asiatic to North American waters, and vice versa, a distance of several thousand nautical miles. Atlantic salmon (Salmo salar) undertake similar long migrations in the North Atlantic.

Many theories have been advanced to explain this navigational ability of salmonids. In principle, it is very difficult to explain the migratory behavior of salmon with a single theory. It has been known for a long time that salmon use their sense of smell to identify the home stream (Harden Jones 1968). The ability to home across vast expanses of oceanic areas is more difficult to explain. Theories proposed include orientation to the sun and other celestial bodies, oceanic currents, magnetic anomalies and chemical as well as physical characteristics of water masses. Royce and Hartt (1968) concluded that high seas migrations of salmon could not be performed by random drift and advocated electromagnetic cues from oceanic currents. They suggested that the responses to those cues must be inherited and not memorized, except for the final location of the home stream.

It has been shown repeatedly that transplanted salmon can be imprinted to return to the place of release rather than to the stream or hatchery where they were reared, even if the two locations are in close proximity (Hasler 1966, Harden Jones 1967, Isaksson and Oskarsson 1985). This behaviour has been used extensively in private salmon ranching operations in the United States and Iceland where salmon are released from fresh and saltwater sites which are remote from rearing stations (Cummings 1982, Isaksson and Oskarsson 1985).

The exact mechanism of imprinting is not well known. It is fairly well established that the salmon imprint to and recognize the chemical components of the home stream or release site using olfactory cues, but many authors suggest that imprinting mechanisms may be operating far beyond the estuary. Harden Jones proposed a sequential imprinting system for salmon, analogous to the recording of a magnetic tape, during the outward migration and playing it backwards during the return journey. Hansen et al. (1987) suggested a similar mechanism and Hartt and Dell (1986), after finding that Pacific salmon smolts travel along the west coast of North America towards the Bering sea, suggested that they might be imprinting to some sensory cues which they use during the return journey. Theories have been put forward in which stock are presumed to release pheromones which can only be recognized by other members of a given stock (Nordeng 1977, Stabell 1984). These theories are speculative and do not explain homing response in situations where release sites are devoid of salmon of the same species or stock.

SELECTIVE BREEDING

Until very recently, very little emphasis has been placed on genetic selection in ranching. This may be partly due to the fact that major emphasis was on improvement in the area of husbandry, and partly because the influence of genetics on survival and fitness has been poorly understood. Some experts have thus considered it prudent to refrain from systematic selection (McNeil 1975). However, much has been learned about the genetics of salmon within the last decade, particularly from efforts by the Norwegian salmon rearing industry. People are thus more confident embarking on a program to study the heritability of factors important to salmon ranching (Gjedrem 1986). Although genetic selection is a fairly new concept in ocean ranching, some very successful selection programs have been executed especially with Pacific salmon. Hines (1976) reports increased return rates and fecundity in chinook and coho salmon in a selection program directed by Dr.Lauren Donaldson at the University of Washington in Seattle during the sixties. A cooperative genetics program, which aims at improving performance in salmon ranching, is being started at the Kollafjorour Experimental Fish Farm in Iceland, based on the vast experience obtained in research for Norwegian cage culture.

Saunders and Bailey (1980) list the factors most likely to be of importance in a genetic selection program with Atlantic salmon: fecundity; survival in hatchery; growth rate in hatchery; seaward migration; survival in the sea; growth rate in the sea; age at sexual maturity; migratory behaviour; homing; seasonal return pattern; disease resistance; fish appearance and flesh quality, including colour. Several of these factors such as fecundity, freshwater and seawater growth rates, age at sexual maturity and disease resistance have already been shown to have a genetic basis in the salmon farming operations in Norway (Kinghorn 1983). Gjedrem (1986) concluded that the factors of greatest economic importance in ranching which probably could be improved through selection were seawater growth, age at maturity, and percent return. For example, experiments in Sweden, using full sib families, showed significant difference between families in recapture rate (Carlin 1969) which indicates a possible genetic contribution to survival and homing. Timing of seaward migration and time of return are probably influenced by genetic as well as environmental factors.

There is some evidence that navigational abilities and migratory behaviour have a genetic as well as an environmental basis. It seems likely that salmon, with its extensive oceanic migrations have some genetic responses to environmental stimuli during the migration. Canadian experiments have indicated that the return rate of transplanted salmon decreases with increased distance from the home stream (Ritter 1975). Icelandic experience, however, indicates that homing of transplanted stocks can be quite comparable and accurate within a relatively large area (Isaksson and Oskarsson 1986). It should, however, be pointed out that the area in question was much smaller in the Icelandic than in the Canadian experiment.

Oceanic migratory patterns can vary considerably among stocks. For example, some stocks of Atlantic salmon from Canada stay inshore and do not contribute to catches off Greenland (Jessop 1976). In the Baltic, Finnish workers have plans to release stocks from the Soviet river Neva since they do not migrate very far and thus contribute little to foreign catches (Sumari and Toivonen 1982).

HUSBANDRY

A salmon rancher exercises control over his fish only while they are in the hatchery or at the time of release. Once in the sea, ranched salmon are subject to mortality from natural factors and from fishing. Ocean fisheries, foreign and domestic, can be dealt with through political channels, whereas oceanic conditions affecting survival cannot be controlled. However, there are various indirect methods of improving ocean survival by producing high quality smolts, if possible at low cost. To date, emphasis has been placed on time and size at release to insure a successful return.

Size at Release

At this point it may be useful to look at the size of artificially produced smolts of various salmonids used for salmon ranching. Typical smolt sizes, arranged in order of increasing size are: pink salmon (Oncorhynchus gorbuscha), 0,5 to 1.0 grams; chum salmon (Oncorhynchus keta), 0,5 to 1.0 grams; chinook salmon (Oncorhynchus tshawytscha), 4 to 40 grams; coho salmon (Oncorhynchus kisutch), 25 to 30 grams; and atlantic salmon (Salmo salar), 30 to 50 grams. Economically successful ranching programs with pink and chum salmon in Japan, U.S.S.R., Alaska, and Canada are due in part to the low cost of releasing small smolts. With species released at larger sizes, considerable effort has been put into optimization of the rearing scheme because of the longer rearing cycle. The most concentrated effort has been on coho and chinook salmon, the most successful species in salmon ranching operations in North America south of Alaska.

Donaldson and Joyner (1983) reported that by controlling temperature during hatching and rearing, the growth of coho could be accelerated to produce smolts in six months instead of the conventional eighteen months. This pioneering work has been put into practice in private salmon ranching operations in Oregon which rely heavily on the release of coho salmon (Severson 1982).

Although Atlantic salmon smolts are generally somewhat larger at release than coho, the rearing cycle and life history similarities of the two species warrant optimism regarding the potential of acceleration programs with Atlantic salmon. Experimental programs to accelerate the development of Atlantic salmon have been undertaken in Iceland, using geothermal energy

(Isaksson 1985) and a limited quantity of smolts has been produced in seven months. Returns have been poor possibly because the time of release has lagged behind conventional release times by at least one month. Further acceleration could potentially be obtained by advancing the maturation of adults and by increasing growth rate in freshwater through selective breeding.

Various other methods could be used to increase economic return in ranching. In temperate latitudes,part of the smolt production can take place in cages on freshwater lakes to enhance growth. This method has been used for some time in Norway and in Iceland there are plans to utilize geothermal upwelling in a lake for cage production. These methods reduce investment in expensive storage ponds and could reduce smolt production costs considerably.

Release Techniques

Ranching experience in various countries has shown that release techniques have a major influence on survival of ranched salmon. In Iceland smolts released from adaptation ponds or sea cages close to estuaries have double the return rate when compared with smolts released directly into streams. These estuarine releases seem to affect the upstream migratory behaviour of returning fish, since the ranched salmon tend to stay in the lower reaches and do not enter the salmon sport fishery in up-stream sections of the river.

In the U.S. Pacific Northwest, a delayed release technique of releasing large smolts in July or August instead of the conventional April-May period resulted in increased contribution of hatchery smolts to coastal fisheries, indicating improved survival and shorter overall migration (Novotny 1980). Similar experiments with the delayed release of Atlantic salmon at estuarine sites in the Baltic have produced up to a five-fold increase in survival compared to standard river releases of smolts (Ericsson 1985). Delayed releases of large smolts in Iceland have not brought about significant increase in returns, and in some cases lower returns, than for conventional release programs.

FACTORS CONSTRAINING RANCHING

It is clear that salmon ranching is affected by various external factors, some of which have already been mentioned. For the purpose of review, it is useful to divide the discussion into two sections. One deals with ecological constraints which are set by various physical and biological factors and often beyond control. The other considers political constraints such as intercepting fisheries, land and stream ownership and ranching permits, all of which are subject to laws, treaties and negotiations.

Ecological Constraints

Smolt production: There are various factors associated with the rearing of smolts which could affect ranching performance. One can, for example, ask how many smolts could be produced in any one location without degradation of smolt quality and increased financial risk due to serious disease out-breaks. This latter point is closely linked to the fact that authorities might revoke, temporarily the ranching permit if a disease was considered dangerous to wild stocks in the vicinity. These factors are of special importance to private salmon ranching operations producing relatively large smolts such as those in Iceland. As smolt quality and disease occurrence is usually inversely related to rearing period, the species with a relatively short rearing time would have a clear advantage.

Carrying capacity of estuarine and oceanic areas: The Pacific Ocean has historically been the greatest producer of salmon with over 500 thousand metric tonnes being landed in 1984 (FAO 1986) compared with less than 10,000 tonnes of Atlantic salmon landed in the Atlantic, excluding intensive salmon farming operations. It is not surprising that the first concerns about overgrazing have come from the Pacific.

It has been assumed that the Pacific Ocean could at least support as many salmon as it did before modern man's intervention in the fishery. Walters et al. (1978) suggested that the yearly production had been at least twice that experienced in recent times. This indicates that there is still room for increased the salmon production, although there are concerns of overgrazing in isolated areas.

In recent years, there has been a history of increasing chinook and coho releases in the Columbia river watershed being associated with declining adult returns (Fraidenburg pers.comm.). However, it is not clear whether these observations are associated with bottlenecks in the estuaries during smolt migration or with fluctuations in the oceanic environment itself.

A related phenomenon is a situation which occurred in the feeding areas of coho off the Oregon coast from 1977 through 1984 (Salmon News 1983). In 1977 the coho returns dropped drastically and did not show a significant recovery until 1985 (Salmon News 1986). This situation has been blamed on a phenomenon called "El Nino" which expresses itself in abnormally warm seawater temperatures during the summer months as a result of poor upwelling of nutrient-rich cool bottom water. This upwelling has been shown to be of vital importance for coho smolt survival (Salmon News 1985). In addition to affecting the early survival of smolts the elevated sea-temperatures are believed to have resulted in the death of adult salmon before they could enter freshwater to spawn (Salmon News 1983).

The roots of this phenomenon are of major importance and may possibly be related to cyclical changes in the oceanography of the Pacific. Periodically there is an increase in the flow of warm tropical water towards South America. If these currents are strong enough they move north along the coast of America and override the normal colder coastal currents A similar situation probably reduced coho catches in the late 1950's, indicating that this could be a recurring event (Oregon Dept. Fish and Wildlife 1983).

Very little is known about the grazing capacity of the Atlantic Ocean. Thorpe (1980) theorized that the Atlantic probably supported 40 million more salmon in the 17 hundreds than it does today, due to poor fishery management and loss of nursery areas in major rivers in Western Europe during the last two centuries. Therefore, it seems unlikely that grazing conditions are a major limiting factor in the Atlantic. It is more likely that the serious bottlenecks are in the rivers and shallow coastal areas close to the point of release where suitable prey animals may be scarce and concentration of smolts high during the limited time of initial seaward migration. Once in the sea one can, however, speculate that there is a conflict with other pelagic species which have taken over the niche left vacant by the salmon.

Just as warm oceanic conditions have been observed to reduce survival in the Pacific (El Nino), there is evidence that too high an inflow of cold polar currents can reduce survival of salmon in the Atlantic. These conditions are very pronounced in Northern Iceland which is on the border of cold currents flowing south along the east coast of Greenland and the warm Irminger current which warms the southern coast of the country and mixes with the cold currents off the north coast. The relative strength of these currents is variable and periodically the nutrient rich boundaries are driven southward with serious ecological consequences in the northerly areas. These shifts in condition seem to last for only a few years. One such period occurred in Iceland from 1965-70, resulting in a major reduction in wild salmon abundance in north coast streams (Scarnecchia 1984). A similar condition was observed from 1979 through 1983, resulting in another collapse of north coast salmon stocks. There was a simultaneous reduction in the growth and abundance of cod and other food fish in the same area and a reduction in primary productivity of the sea water was observed (Malmberg 1986).

During this second period (1979-83) there was a great increase in the ocean salmon fishery off the Faroe islands and the large salmon which sustain the fishery were caught relatively far south. In recent years, after the sea conditions reverted to normal, the major fishing grounds are farther north, indicating that the salmon are responding to the oceanographic changes.

It should be pointed out that the dominance of cold currents off the North Icelandic coast has a pronounced effect on the climate in that area, which in turn affects the freshwater production of salmon smolts and possibly their seaward migratory behaviour, and could be a major contributor to the observed reduction in wild salmon abundance. Although this effect on smolt production could be avoided in a salmon ranching operation, it has become quite clear that salmon ranching operations in that area will have to endure considerably lower return rates than those in southern Iceland.

It seems likely that similar cold water conditions may occur in the Davis strait between Labrador and Greenland where cold currents are very prominent. This situation is, on the other hand, less likely along the Norwegian coast, since the temperate Gulf stream affects that area quite far north. Cold conditions are also known to affect salmon production in the northernmost areas of the Pacific.

Conflict with wild stocks: It is widely accepted that salmon populations can be divided into subgroups called "races" or "stocks", based on their stream of origin. There is evidence that the release of hatchery smolts from a ranching station over a few generations creates a specific ranching strain which probably differs genetically from the wild stocks in the neighboring streams. Although these potential differences have not been quantified it unavoidably raises the question of whether the straying of ranched salmon into the neighboring streams would have a detrimental effect on the genetic make-up of wild stocks through interbreeding.

Wilkins (1985) concluded that the mixing of hatchery reared salmon with natural stocks in a stream could upset the genetic make-up of a wild stock and possibly reduce its homing precision. However, this could be minimized by using hatchery stocks from the same area for stocking. He furthermore pointed out that some rivers in Ireland, such as the Shannon where salmon have been propagated for many years, have had very little straying of the hatchery stocks. This conclusion agrees well with the Icelandic ranching experience (Isaksson and Oskarsson 1985).

Gordon (1982), in a discussion of the theory of genetic contamination, concluded that it was extremely difficult to confirm the hypothesis as no one had been able to compare one population's genotype with another. He also pointed out that countertheories regard straying of salmon as a natural and beneficial phenomenon which enriches the gene pool of populations with new genetic material and reduces effects of inbreeding.

Mahnken et al. (1983) concluded that the north Pacific rim nations had developed their ranching programs to such an extent that it would be hazardous to rely heavily on wild stocks for fishery production even if they could be rehabilitated, especially considering present harvest demands. A similar view would probably be taken by many countries in the Baltic where fishery production is largely dependent on hatchery stocks and natural stocks have reached very low levels.

In Iceland where wild stocks are still predominant and only terminal fisheries are operating, it seems quite prudent to operate large ranching station in certain areas distant from the major salmon producing river systems to minimize straying and mixing with wild stocks. Salmon streams could also be enhanced using parr or smolts originating from stocks native to the stream in question. Sensible coordination and management could thus minimize the potential negative effects of ranching on wild stocks.

Where ranched salmon are harvested in a mixed stock fishery composed of both ranched and wild stocks, overharvest of wild stocks could be a serious problem. This is because ranched stocks can typically support much higher fishing rates than wild stocks. In an attempt to correct the problem in the U.S. Pacific northwest, the harvest rate in designated areas is being restricted to the capacity of the least productive stocks. Over-fishing of wild stocks has been a problem in Pacific salmon management for decades. An analogous situation exists for many mixed stock fisheries of Atlantic salmon where small wild stocks are heavily overfished at harvest levels appropriate for the largest stocks. Such a situation exist in many Norwegian, Scottish and Irish fisheries and can only be corrected by imposing terminal fisheries close to estuaries or by controlling mixed stock fisheries at levels appropriate for the most restrictive component.

Since most countries harvest salmon in the open ocean, over fishing is a universal problem in the Pacific and the Atlantic alike and it is safe to say that Iceland is the only country in the northern hemisphere that entirely relies on a freshwater, terminal salmon fishery. This situation provides unique opportunities for salmon ranching without the threat of overfishing wild stocks.

An additional and potential problem associated with salmon ranching is the threat of spreading disease to nearby river systems if the hatchery fish become resistant carriers. This problem requires constant veterinarian inspection and high health standards within smolt production facilities.

Pollution: Unlike many other forms of aquaculture such as cage rearing, ranching causes only minimal potential for water pollution from waste food and fecal material, since biological by-products are generated only during the smolt production phase. Unchecked pollution from industry and municipalities may, however, become a threat to salmon ranching, especially in inland seas such as the Baltic. Where the great oceans are concerned, it seems likely that industrial pollution might affect smolts in the bays and fjords before they reach the ocean. It should be borne in mind that the effect of pollution may not necessarily mean death for the salmon but the feeding fish could possibly become contaminated with heavy metals, pesticides or radioactive chemicals, which could render them unfit for human consumption. This type of pollution can therefore have disastrous effects on the whole food-chain in the ocean.

Political Constraints

A number of political questions have a direct impact on considerations of salmon ranching. There are concerns which relate to the impact of salmon ranching on wild stocks, questions regarding resource conservation and private ranching for profit, and implications of both national and international law which affect private as well as public ranching.

Private ranching: The most recent addition to the ranching programs in the Pacific has been the operations of release/recapture sites by large corporations where they plan to harvest millions of salmon and make a profit despite a heavy oceanic fishery. These operations are referred to as private ranching for the purposes of this review. The introduction of this type of salmon ranching in the U.S. Pacific Northwest has aroused major objections, primarily from commercial fishermen and environmentalist, based primarily on socioeconomic concerns. The primary objections are (Berg 1981): large private corporations should not be allowed to send feeding salmon into public waters for private profit; there is fear that the ranching industry will be marketing salmon of inferior quality to those caught in the sea; the commercial fishermen fear that the salmon ranchers will flood the market with fish bred to avoid conventional fishing gear; and there is concern that the ranching industry, once established, will use political pressure to limit commercial fishing.

From the viewpoint that a terminal fishery is the most sensible way of managing salmon stocks, only the first objection seems to be valid. However, considering that salmon in the Pacific Northwest go to feed within the jurisdiction of other states and countries adds weight to these objections. This matter is further confused by issues like the right of Washington Indian tribes to catch half of the fish passing through their traditional fishing grounds. For those and other reasons private salmon ranching has been legalized only in Oregon and California.

Terminal fisheries by sport and commercial gear are common all along the coast from California to Alaska, in addition to heavy mixed stock fisheries. Private salmon ranchers are similarly operating in a terminal fishery after the offshore commercial and sport fisheries have taken their toll. From a salmon conservation viewpoint these private operations are thus very sensible and in addition, provide salmon for the public. The only concern might be their possible genetic effects on nearby wild stocks. On the other hand, any development towards terminal fishing would be a great boon for wild stocks and save a lot of fuel and energy since "the fish are coming home anyway".

Land and stream ownership: One aspect that limits the possibilities of salmon ranching in many countries is land and stream ownership. In Iceland, and some other countries in Europe, streams can be privately owned and can be used for private ranching. In the United States and Canada the streams are public property by law and can not be utilized for such purposes, unless a government permit is issued for the specific purpose of ranching. Often ranchers must create their own stream by pumping seawater, as has been done at facilities in Oregon. This in turn has had some curious implications for the homing of the salmon, which probably would not occur if freshwater was used.

The stream ownership issue raises interesting questions regarding the utilization of natural resources. It seems that the interpretation of the U.S. laws of public ownership has granted the government the right to build numerous dams on most major streams without proper consideration for the salmon resources at stake. The stream owners in Iceland have, on the other hand, opposed some hydroelectric schemes with the result that the salmon have always had a fair representation. Fortunately, the Icelanders have had some large non-productive glacial streams to generate hydroelectric power so neither party has been hurt by this arrangement.

Distant salmon fisheries: The final political issue discussed here is the distant sea fishery for salmon, where in many cases nations without salmon streams or ranching operations are catching salmon within their jurisdiction. Prime examples of this in the Atlantic are the West Greenland fishery which is harvesting salmon originating from Europe and North America, the Faroese fishery catching salmon from Norway, Britain and Ireland, and finally the Baltic fishery where Poles, Germans and Danes are catching salmon mostly produced in Swedish and Finnish hatcheries. The situation in the Pacific is even more complex. The main problem involves the allocation of transboundary migrants among the producing and non-producing countries.

These situations are unavoidable due to the extensive migrations of salmon and the fact that international law has given those non-producing nations some right if the salmon are feeding off their coast; the so called grazing fee principle. This entitles these nations to a certain share of the salmon which are foraging on fish living within that country's jurisdiction. However, the size of the share is an arbitrary thing, and many countries do not recognize grazing fee principle.

Oceanic fisheries for salmon will probably be in operation as long as they are profitable. Therefore, it is very important to regulate the fishery on some kind of principle which will require international negotiation and cooperation.

CURRENT PRODUCTION AND POTENTIAL

Pacific Salmon

There is no doubt that the most economical salmon ranching programs today are those based on chum and pink salmon, species which can be released at a size of less than one gram with reasonably good ocean survival. These programs, which account for the largest ranching production of Pacific salmon, are carried out primarily in Japan, U.S.S.R., Alaska and Canada.

Fig. 1 shows the releases of chum and pink in the Pacific from 1974 to 1986. It is evident that Japan and the U.S.S.R. are by far the largest producers of these species, each releasing almost 2 billion fish annually. The Japanese releases are primarily chum, whereas the Soviet releases are composed of equal numbers of each species. Alaska released almost 800 million fish in 1986, with pinks exceeding chum by a considerable margin.

The number of chum and pink salmon returning from fry releases in Japan and Alaska are shown in Fig. 2. Almost 50 million chum salmon are taken in a trap net fishery operated in Japanese coastal waters. This amounts to a return rate of 2-3% which is quite profitable for the species. It is estimated that each kilogram of chum fry released generates about 80 kilograms of adult salmon (McNeil 1984). The results from Alaskan releases seem to be quite comparable, only on a smaller scale. Return figures for the U.S.S.R. fisheries are not available but should be comparable to the other two countries.

Japan: Of all countries, Japan is the most dependent on salmon ranching to support its salmon fisheries. Fig. 3 shows the trends in the inshore and high seas catches of the Japanese fisheries during the last 10 years. The inshore catch, which is taken entirely in trap nets, is almost exclusively ranched chum salmon. This amounts to well over 80% of the total Japanese catch of almost 200 thousand metric tonnes.

The Japanese depend on annual quotas granted by the Soviet Union for its high seas salmon catch. This was reduced to 42 thousand tonnes in 1978 following the establishment of the 200 mile fishing zone by the Soviet Union and has stabilized at approximately 40 thousand tonnes (N.M.F.S. 1984).

The Japanese ranching program has been exceptionally successful during the past decade. Salmon returns have increased steadily as a result of expanded releases and improved release methods (Kobayashi 1980). The releases are performed by government hatcheries and by private hatcheries which lease fishing rights from the government. It is estimated that the Japanese ranching programs are providing three to five times as many salmon as were ever caught historically in Japanese waters which demonstrates the success of the programs.

U.S.S.R.: The Soviet Union is releasing almost as many pink and chum as the Japanese. The planned releases from the far eastern hatcheries were about 2 billion fry in 1985 (Konovalov 1980). By 1990 this figure is expected to be in excess of 3 billion fry. The Soviets plan to combine the rearing process with natural reproduction and thus, try to strengthen the adaptive capabilities of the salmon stocks. This is quite important as the Soviet Union, unlike Japan, has considerable natural spawning areas in operation.

Alaska: As seen in Fig. 1, Alaska released over 700 million pink and chum fry in 1986 (Hansen 1986). These were released by 19 state operated hatcheries and 17 private hatcheries operated as nonprofit organizations which are entitled to the salmon once they enter a special harvest zone in coastal waters (McNeil 1984). It is estimated that these ranching programs contributed over 13 million salmon to the Alaskan fisheries in 1986 (Hansen 1986). This is probably close to 25% of all salmon landed in the State of Alaska.

Alaska is one of few states around the Pacific rim that has a successful hatchery program with sockeye salmon. Sockeye are very susceptible to viral diseases, primarily IHN, which occurs in sockeyes in nature and is exacerbated in hatcheries. Alaskan technicians have learned to "farm" around this disease and over 70 million sockeye smolts were released in 1986 (Hansen 1986).

The Pacific Northwest and Canada: Coho and chinook salmon, which are released at sizes ranging from 5 to 30 grams, form the backbone of the public ranching programs in the Pacific Northwest. These species occur naturally in North America from Western Alaska to California but the greatest abundance of coho is from Southeast Alaska to Oregon with chinook abundant down to California. These species also occur in considerable quantities in Asia but are not artificially propagated and thus not discussed here.

Coho salmon catches are double those for chinook with annual North American catches of 7-8 million coho and 3-4 million chinook observed in recent years (Mahnken et al.1983). However, this difference is not so pronounced on a weight basis since chinook are considerably larger. Since chinook are also more valuable on the market, it is not surprising that the overall ranching effort has been even greater than for coho.

Fig. 4 shows the numbers of coho and chinook smolts released by public hatcheries in the U.S.A. and Canada for the last 10 years. It is evident that the ranching efforts in Canada have been smaller than in the U.S.A., possibly because natural river systems in British Columbia are still producing considerable quantities of salmon, Enhancement efforts are, however, increasing considerably in British Columbia. Canada also releases considerable quantities of sockeye salmon from hatcheries and spawning channels.

Total releases of chinook by the U.S.A. are close to 250 million smolts, mostly from hatcheries in Washington and Oregon. Although this quantity in terms of numbers of fish is only 12% of the Japanese releases of chum, the chinook releases exceed chum releases in terms of weight, since the release size of chinook exceeds 4 grams compared to 1 gram for the chum. The same is true for the 200 million coho smolts released by the U.S.A. in recent years. The total releases by U.S. hatcheries probably amount to almost 7000 tonnes of chinook and coho smolts alone, which is close to half of total salmon releases around the Pacific rim.

Due to the larger size of chinook and coho smolts, the economics of the hatchery releases are much more questionable than the chum and pink releases by Japan, the Soviet union and Alaska. Some claim that these ranching programs are heavily subsidized by the taxpayers. It should, however, be kept in mind that these species support a considerable sports fishery, which is difficult to evaluate in monetary terms.

The economics are further confounded by the extensive migration of those species which exposes them to harvest by various states and countries that do not release the smolts. For example, Canadians are harvesting about 30% of the chinook salmon bound for the Columbia River in the U.S. and U.S. fishermen are similarly intercepting salmon bound for the Fraser River in Canada. The management of these salmon stocks is thus a continuous political struggle which has done little good for the salmon resource as a whole, especially the dwindling wild populations which should be managed at the stock level.

Under normal circumstances the total return rates of hatchery chinook and coho would be in the order of 2-8% including the oceanic fishery. It seems likely that these could be increased considerably through improved release techniques as Bilton (1980) reported 43% return rates for 25 gram coho released in late June.

One interesting aspect of salmon ranching in the Pacific Northwest is private ranching, which has only been legalized in Oregon and California. These private companies are hoping to make a profit from smolt releases in spite of a sea fishery which catches a high percentage of the returning fish. Ten private ranches are now releasing fish in Oregon, consisting of over 70% coho, the easiest species to rear, and considerable quantities of chinook (Cummings 1985). Chum salmon have also been released on an experimental scale, but the programs have suffered from the limited quantity of local genetic material which has forced ranchers to use distant stocks from Washington and USSR. Judging from the recent difficulties encountered with coho ranching in Oregon as a result of "El Nino" it seems likely that ranching of chum in Oregon may be difficult in some years since that state is on the borderline of the distribution of the species.

Fig. 5 shows the coho releases of the private ranches in Oregon compared to the total releases by public hatcheries in the U.S.A.. It is evident that the private releases are still fairly insignificant (<6.0 %) compared to releases by public hatcheries. The average survival for the 1978 - 83 releases from private operators was about 1.3 percent returning to the release site (Cummings 1985). Recent returns to private Oregon ranches (1985 and 86) have been reported in the range of 4-6% for both coho and chinook (Gall pers.comm.). This is getting close to the returns experienced before El Nino started affecting the industry in 1977. These improved survival figures restore the belief that private salmon ranching with pacific salmon can be carried out as an economical venture. However, considering the small fraction of the returning salmon that ever reach the salmon ranch it is evident that the industry can not tolerate many down-periods such as the one experienced in the last 10 years.

In addition to the extensive ranching of coho in the Pacific, this species has been successfully transplanted to the Great Lakes where it supports a sizable sports fishery.

Other countries in the Pacific: Pacific salmon have been introduced to several countries in the Southern hemisphere, primarily New Zealand and Southern Chile. Chinook salmon were introduced to New Zealand in the early part of this century. There are now modest self-sustaining populations. There is some experimental ocean ranching of this species being carried out as well as confinement rearing to market size in fresh and seawater (McDowall 1985).

Numerous attempts were made to introduce Pacific and Atlantic salmon into Chile in the early part of this century. The first serious efforts to introduce salmon for ranching were done in the late sixties, when 180,000 coho eggs were shipped from Oregon and Washington (Joyner 1980). The resulting releases were not successful and subsequent experiments with coho have not raised optimism. However, sea cage rearing of coho is a very profitable business in Chile today (Brown 1986).

Experiments with chinook salmon in Chile have yielded some returns which indicate that a broodstock might be built up with time (Lindbergh 1982). Commercial ranching of this species is not yet viable.

Atlantic Salmon

Ranching in the Atlantic differs from the Pacific ranching operations in many respects. First and foremost there is only one species involved, the Atlantic salmon (Salmo salar), compared to 6 species of Pacific salmon (Oncorhynchus sp.). These salmonids differ considerably since the Atlantic salmon is more related taxonomically to the Salmo trout species than to Pacific salmon. It does not always die after spawning as does its Pacific cousin and has somewhat different habitat requirements in freshwater.

The ranching of Atlantic salmon can be considered only to be on a pilot scale compared to the extensive ranching operations in the Pacific. Fig. 6 shows the extent of Atlantic salmon ranching programs compared to coho and chinook, the two Pacific species with similar life history patterns. The number of Atlantic salmon smolts released amounts to only about 1.5% of the number of coho and chinook smolts released in the Pacific. However, on a weight basis, however, this amounts to 4% of total biomass output since Atlantic salmon smolts are considerably larger.

In accordance with our earlier definition of ranching, most of the programs in the Atlantic and the Baltic are considered public. Only the programs in Iceland are entirely ranching for profit by private concerns. Fig. 7 shows the releases of reared smolts in the major ranching programs in the Atlantic and the Baltic and the expected average return rates, including oceanic

fisheries. The ranching effort varies considerably between countries as do the economic returns. It should be pointed out that the return rates presented are rough averages for all releases but
all countries have individual groups of tagged smolts which perform considerably better.

The figures reveal great differences in ranching potential between the Baltic and the Atlantic. The average returns from Baltic releases are over 15%, whereas returns from the releases into the Atlantic are frequently less than a third of that. Part of the explanation must lie in the low salinities of the Baltic (<10 o/loo) compared to the Atlantic (30 o/loo) which eases the stress on smolts during their transition from fresh to salt water. Other important factors may be different predator as well as prey fauna favoring the Baltic region. Furthermore, Baltic salmon are caught predominantly on the feeding grounds whereas other Atlantic salmon stocks are exploited to a greater extent on their spawning migration.

U.S.A. and Canada: The ranching programs in the United States and Canada have very different objectives. The United States is releasing primarily smolts in an effort to restore salmon runs to rivers which have been practically devoid of salmon for decades. In many cases this has necessitated bringing in new stocks to build up the runs. The U.S.A. released over 1.2 million smolts in 1985 (Fig. 7) , primarily into rivers in the State of Maine (Rago et al.1987). These smolts migrate up the coast of Canada and partly into Greenlandic waters. They are intercepted by both the West Greenland fishery and coastal fisheries off Canada. However, no fisheries are allowed within U.S. coastal waters. The return rates of these fish have been very low, with many of the returns coming from the interceptory fisheries, a factor which has aroused considerable controversy.

As in the U.S.A., the Canadian releases are primarily done by public hatcheries. The hatcheries have in most cases been built to alleviate the effects of daming major salmon streams or where serious degradation of freshwater habitat has taken place. Thus salmon originating from government hatcheries are released only into streams where the need for artificial propagation has been identified (Ritter et al.1980).

The returns from Canadian smolt releases are fairly low, probably below the level of economic return. Considering that the released fish are also being harvested in the Greenlandic fishery, it seems unlikely that Canada will expand its public ranching program in the near future, at least not beyond that necessary for resource development.

Scotland, Ireland and Norway: These three countries are the major producers of wild Atlantic salmon and their combined home-water catches comprise over 70% of the world catch of Atlantic salmon. However, their salmon ranching programs differ considerably. Apart from a small experimental salmon ranching operation near Campeltown in Argyll there is very little salmon ranching activity in Scotland. There are no public production facilities and privately produced smolts have been in very high demand for the growing cage-rearing industry. Private ranching is not viable due to the heavy sea fisheries off the Scottish coast and laws governing freshwater use, which are not supportive of a ranching industry (Thorpe 1980). Therefore, salmon ranching in Scotland will grow very slowly.

The present releases in Ireland exceed 1.2 million smolts (Fig.7) of which over a million are produced by four large rearing stations owned and operated by the Electrical Supply Board. This board is charged with the preservation of fisheries which are affected by hydroelectric developments instigated by the Board (Central Fisheries Board 1986).

Browne (1984) has estimated the contribution of hatchery smolts to the Irish national catch in 1981-1983. He found that the returns from various groups of microtagged smolts were low, ranging from 0.2 to 5.0%. He concluded that little benefit was accruing from the hatchery programs but there were indications that smolts released under carefully supervised optimal conditions were contributing enough to the fisheries to justify production costs. This is supported by the fact that the Salmon Research Trust experimental operation in Northwest Ireland has consistently shown return rates of hatchery smolts of well over 8 percent to the drift net fisheries (Piggins et al. 1985).

Piggins (1980) concluded that ranching by private concerns was not possible in Ireland as a result of a heavy drift net fishery which takes over 80% of returning adults. There is also a restriction on river mouth traps in existing legislation which precludes the culling of total runs. However, it seems likely that there will be an expansion in the public ranching sector, especially if the offshore drift net fisheries are brought under control.

Public ranching in Norway has been on a small scale, and private ranching is non-existent. The State Experimental Station at Ims has done research related to salmon ranching on an experimental basis. Recent information from the station suggests that survival of hatchery smolts ranges from 5 to 15% considering non-reporting of smolt tags from commercial fishermen (Hansen et al. 1986). Returns of wild smolts in the same system are higher. Hansen et al. (1988) concluded that the yield of hatchery smolts from Ims was 200-250 kg per 1000 smolts released at the station, which would be socio-economical for Norway. They also concluded that salmon ranching as a private enterprise would not be profitable.

In Norway there are several public smolt production facilities which are releasing about 400 thousand smolts annually into various streams. There are however no private releases since the smolt producers have not been able to satisfy the demand for smolts from the exploding cage- rearing industry. Numerous smolt stations are being built to meet this demand.

The Directorate for Wildlife Management has suggested a major release program to explore salmon ranching possibilities in Norway, with an emphasis on the interaction of ranched salmon with wild populations(Working group on ranching 1983)

The Baltic countries: As mentioned previously, the Swedish paved the way for smolt production in Europe under the direction of Dr. Börje Carlin in the 1950's. Numerous smolt stations were built by Swedish power companies as mitigation for the loss of freswater habitat. Smolt releases reached over 0.5 million by 1960 (Eskelinen et al 1987).

Fig. 8 shows the degradation of natural smolt production in the Baltic and the subsequent increase in compensatory smolt releases. It is quite clear that natural reproduction has been entirely replaced by artificial propagation in that region. The present releases are about 4.5 million smolts, fairly evenly shared by Sweden and Finland (Fig. 7). These releases consist of mostly fairly large (50 g) two year smolts.

Fig. 9 shows the increases in catches since the 1950's and how the sea fisheries have almost completely replaced river and coastal fisheries in recent years. The consequences are that the smolt producing countries are catching less than half of the 4000 tonnes caught in the Baltic.

Comparing the data in Figs. 8 and 9, it seems clear that the public ranching programs are providing as many kilograms of salmon per smolt released in the 1980's as the naturally produced smolts did in the 1950's. This shows the effectiveness of the ranching programs, although it may also be due to greater fishing effort in recent years since conservation of wild stocks is no longer a major issue.

As mentioned earlier, the normal return rates from the Baltic fisheries of river released salmon are 10-15 % or approximately 500 kilograms per 1000 smolts released. Cage releases of normal sized smolts (60 g.) have resulted in a doubling of that amount and some delayed releases of 100-300 g smolts have given 2500 to 3000 kilograms per 1000 smolts. These results seem to indicate that the future of Baltic sea ranching is bright provided that the countries involved can work out methods for sharing the smolt production costs.

Iceland: Compared to other countries in the North Atlantic, Iceland is in a unique position with respect to salmon ranching. Sea fisheries of salmon have been forbidden for over 50 years and only terminal fisheries in the streams are allowed. Thus, salmon are managed on a stock basis and the danger of overfishing has been almost eliminated. Since the owners of the surrounding land also own and exploit the streams, it is possible to establish salmon ranching operations in many areas, both to enhance sport fisheries as well as to harvest salmon for the market.

Private salmon ranching has been a growing industry in Icelan in recent years. Fig. 10 shows the trends in salmon catches in Iceland since the 1950's. Although the salmon catches are relatively modest (<300 tons), it is quite clear that ranching is beginning to contribute a sizable proportion of the total catch (25%). Therefore, it may be only a matter of a few years before ranched production exceeds that from the net and sport fisheries. Due to the immense value of the sport fishery, it is quite important to guide the ranching industry in a way that prevents major conflicts with natural salmon stocks. This should be possible in Iceland since natural salmon production is restricted to fairly concentrated areas.

The oldest salmon ranching operation in Iceland is Kollafjördur Experimental Fish Farm, located near the city of Reykjavik, which has been in operation since 1963 and has done pioneering work on smolt quality and ranching potential in Southwestern Iceland. The return rates for different release groups from 1963 through 1982 are shown in Fig. 11. There has been great variation in return rates between years, but experience in recent years seems to indicate that an average return rate of 7% could be expected for the west and south coasts of Iceland. Return rates for the north coast would be considerably lower especially during adverse oceanographic periods.

Fig. 12 shows the main salmon ranching operations in Iceland. Most of the larger operations are in the south west, some of them attached to rearing stations but also several that are only release sites. Experience has shown that salmon smolts can be transported considerable distances from their stream of origin without reduction in homing and return rate.

Iceland has, in some respects, favourable conditions for smolt production. Most rearing stations use fairly sterile well water for rearing which reduces the risk of disease. However, the water must be heated from 4oC to 12oC using geothermal energy which is costly since most of the intense rearing must take place indoors to avoid heat loss. The present production of smolts is 2.5 million and it has been estimated that the smolt production capacity is almost 15 million smolts (Helgason 1986). Only 20% of the present production is being used for ranching due to a great demand for smolts from local and foreign cage-rearing operations.

Salmon ranching for international markets is not viable in Iceland as long as smolt prices exceed $2.00 U.S. Howver, increased supply will lower prices in the near future but ranching to enhance fisheries in mediocre salmon streams is already profitable and should increase considerably.

ACKNOWLEDGMENTS

The author wishes to thank Graham Gall, Peter Bergman, Michael Fraidenburg, William Hopley and Conrad Mahnken for critical review of the manuscript.

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Figure 1.

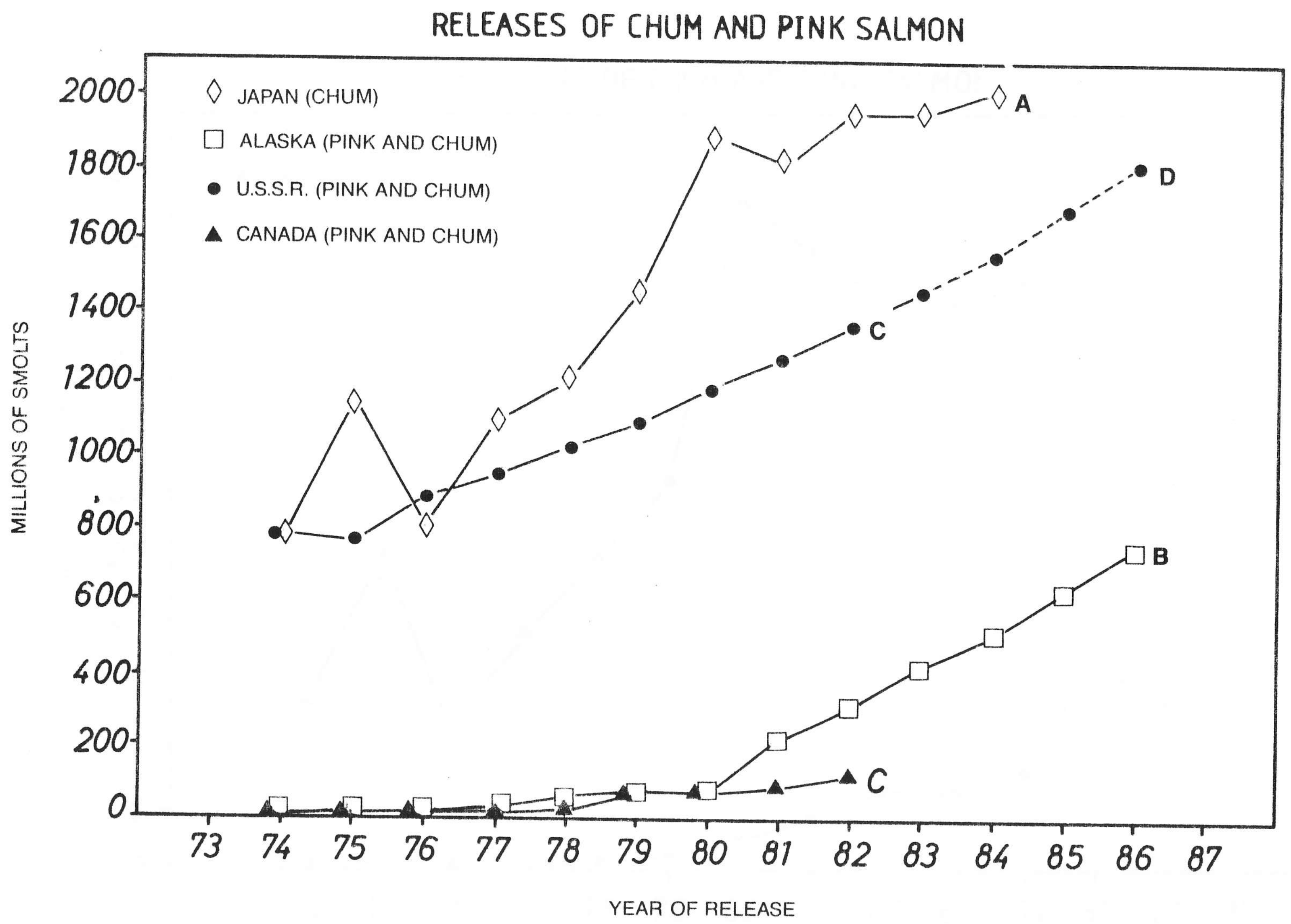

Fig. 1. Releases of pink and chum salmon in the North Pacific.
A: National Marine Fisheries Service, 1984
B: Hansen J. A., 1986
C: Mahnken et al., 1983
D: Planned releases, Konovalov 1980

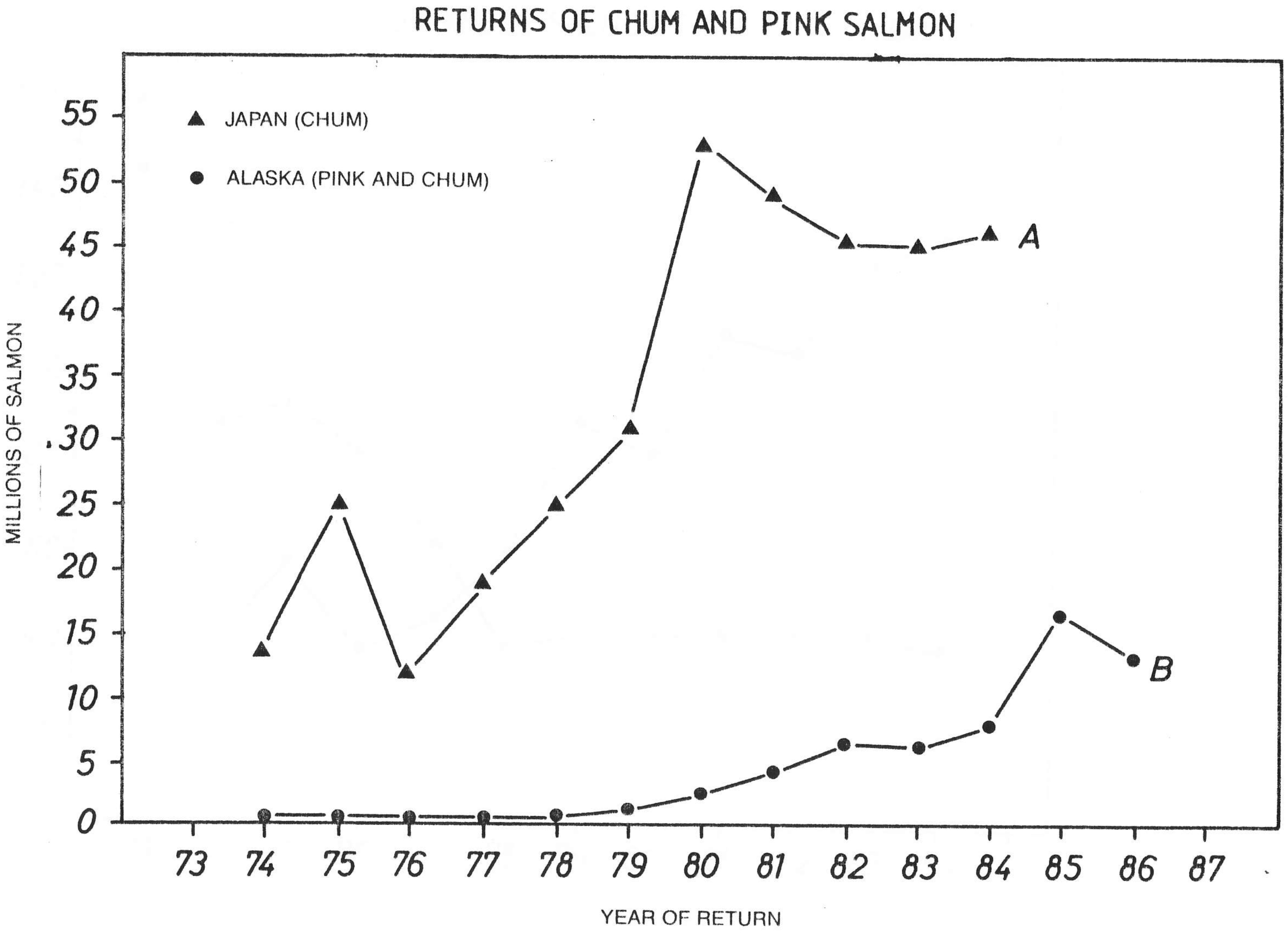

Fig. 2 Returns of pink and chum salmon released in Japan and Alaska.
A: National Marine Fisheries Service, 1984
B: Hansen J. A. 1986

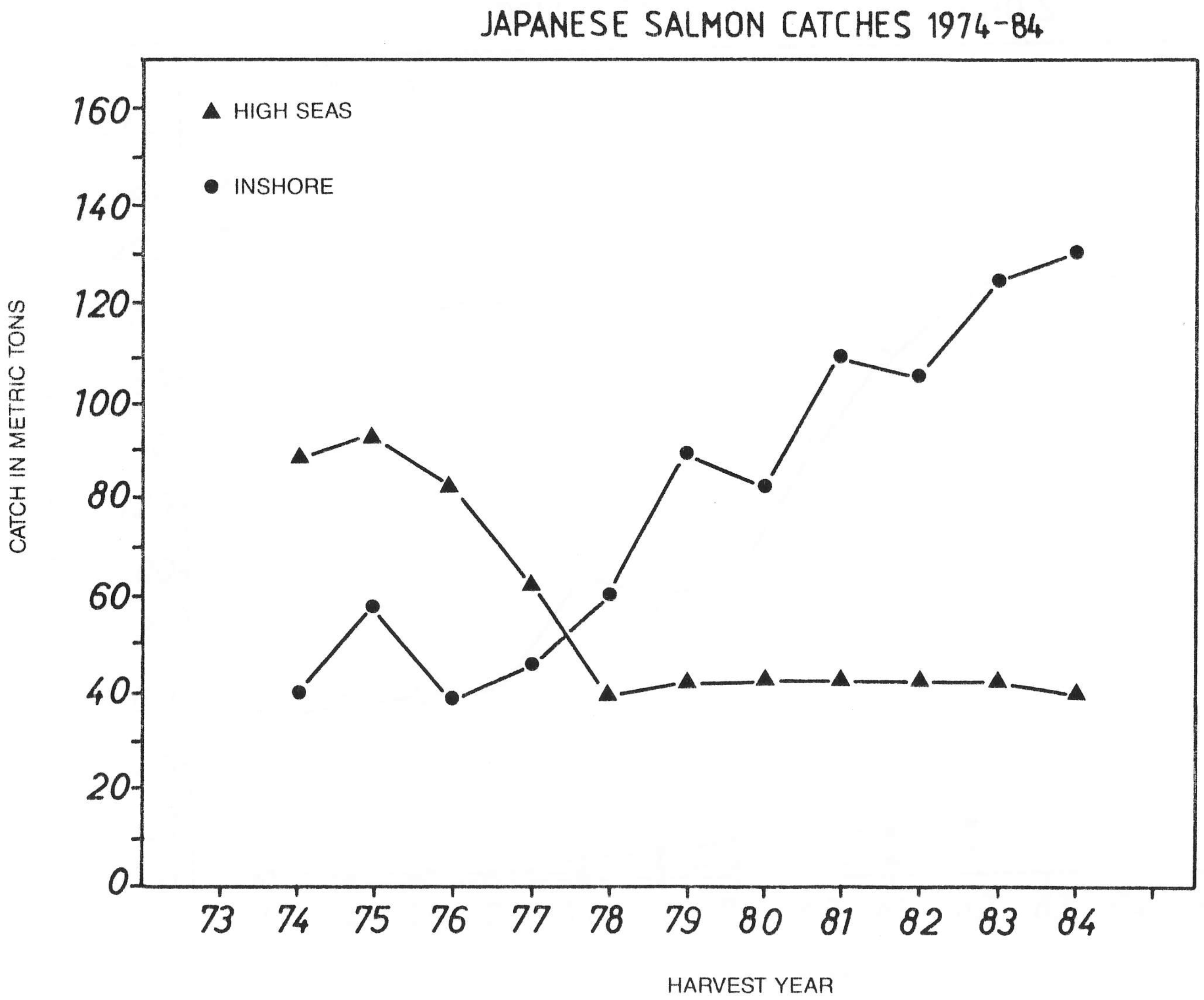

Fig. 3 High seas and inshore catches of salmon by Japanese fishermen 1974—84. The inshore catch is mostly composed of ranched chum salmon (National Marine Fisheries Service 1984).

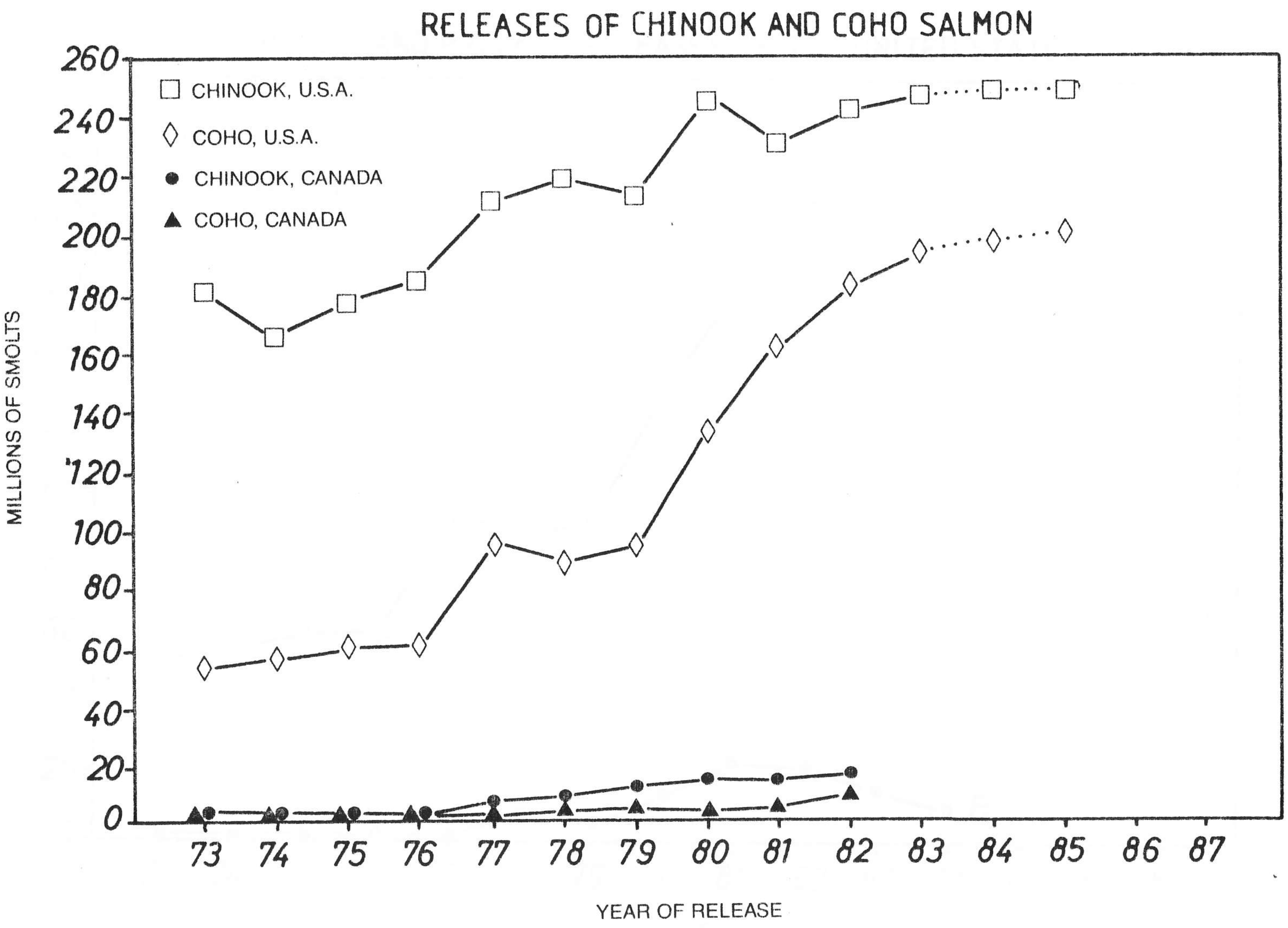

Fig. 4 Releases of chinook and coho smolts in U.S.A. and Canada (Mahnken et al. 1983).

Figure 5.

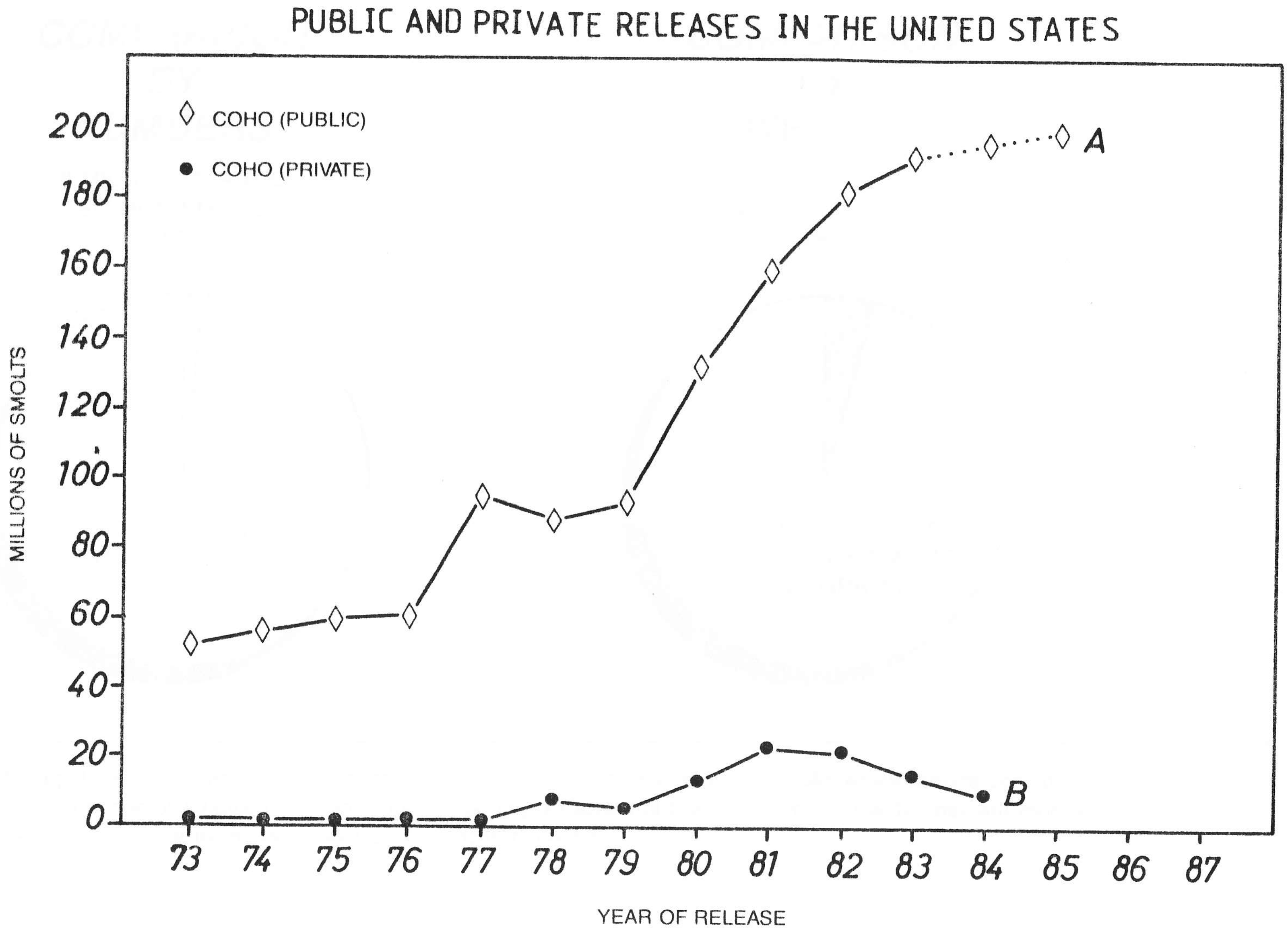

Fig. 5. Releases of coho from public and private hatcheries in the United States from 1973 through 1984.
A: Mahnken et al. 1983
B: Cummings 1985

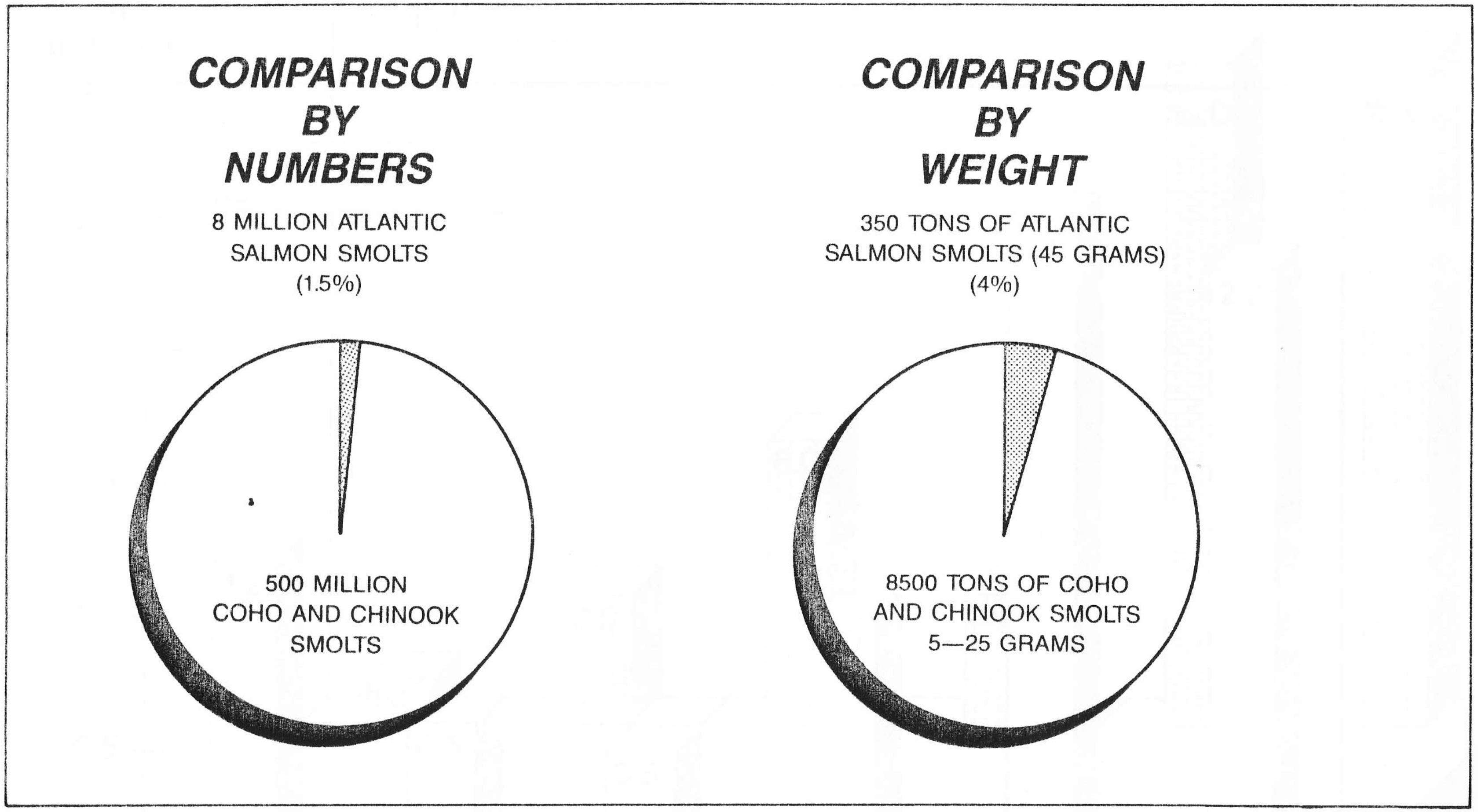

Fig. 6 Comparison of magnitude of the ranching programs in the Pacific and the Atlantic using smolts which require considerable rearing. Although the scope of Atlantic ranching programs is only a fraction of the activity in the Pacific they are more pronounced on a weight basis due to the large size of the smolts released.

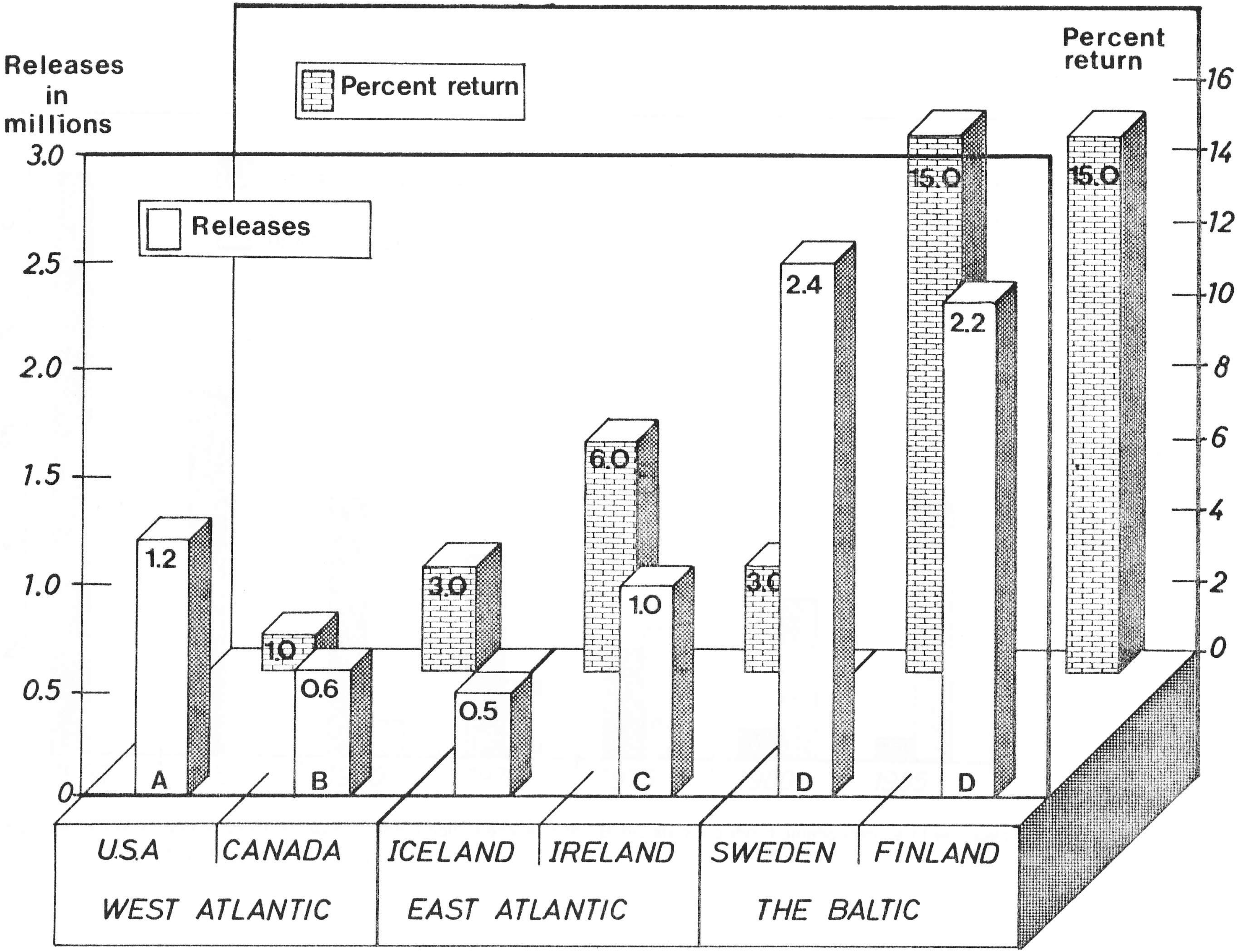

Fig. 7. *Releases in 1985 in the major enhancement and ranching programs in the Atlantic and Baltic and frequent return rates in previous years. The return rates are mostly from sea fisheries,*

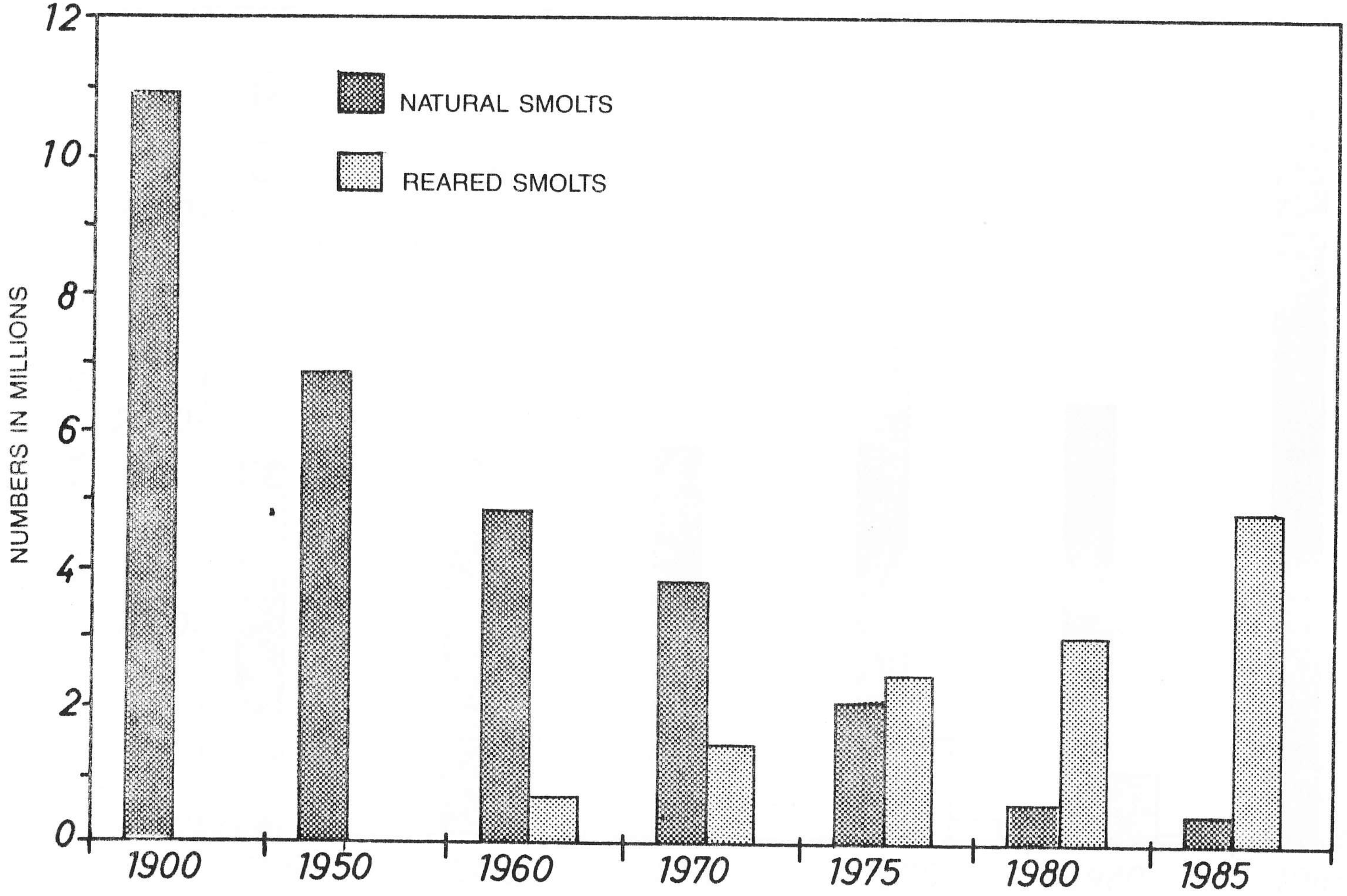

Fig. 8. Long time trends in natural smolt production and smolt releases in the Baltic showing the dramatic decline of wild salmon populations (Data from Eskelinen et al. 1987).

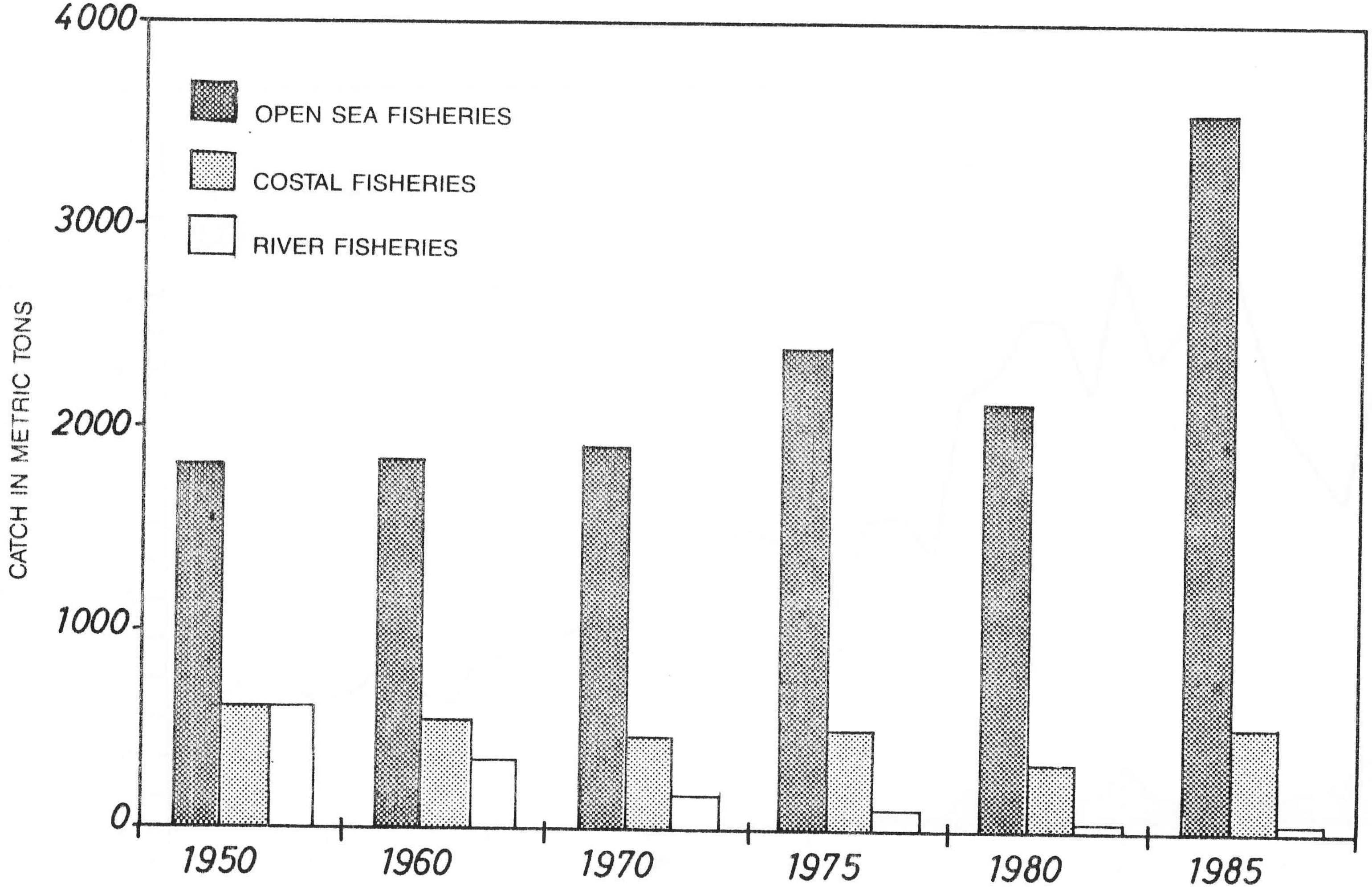

Fig. 9. Trends in salmon catches in the Baltic and divisions into open sea, costal and riverine catches (Data from Eskelinen et al. 1987).

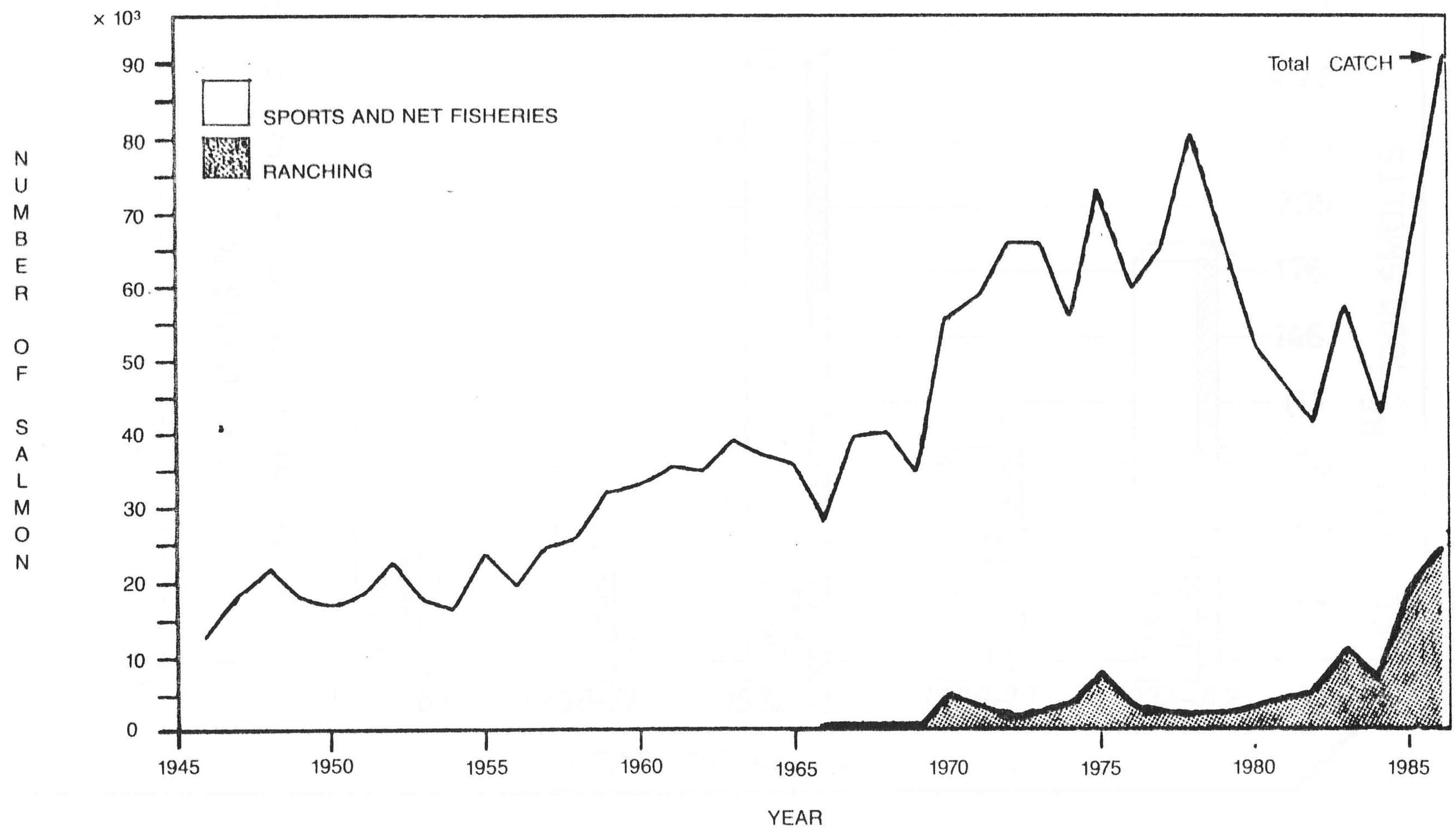

Fig. 10. Salmon catches in Iceland 1946—86, showing the increased contribution of salmon ranching in recent years.

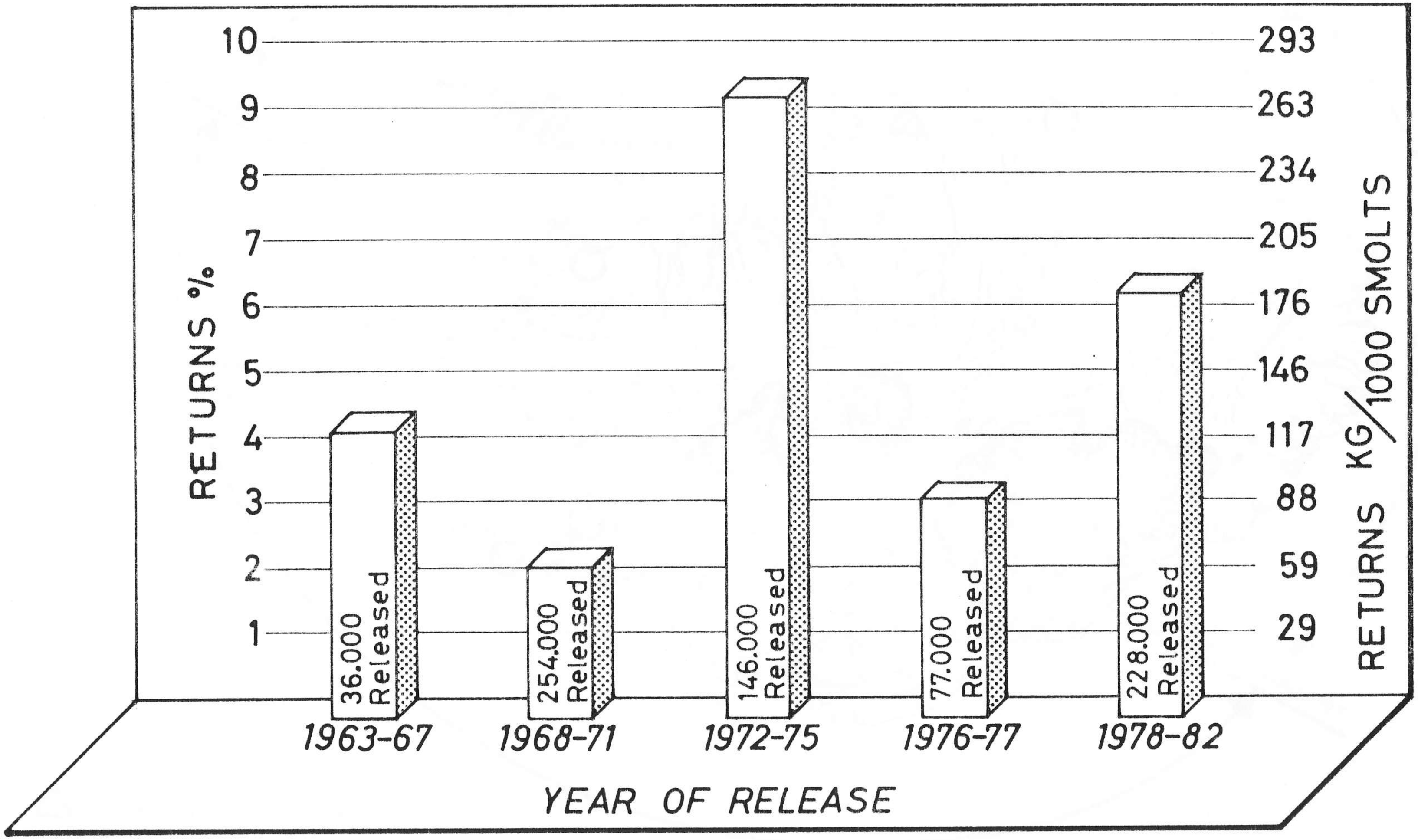

Fig. 11. Total releases and returns to the Kollafjörður Experimental Fish Farm from 1963 to 1982, combining years with similar rearing practices and release techniques (Isaksson 1987).

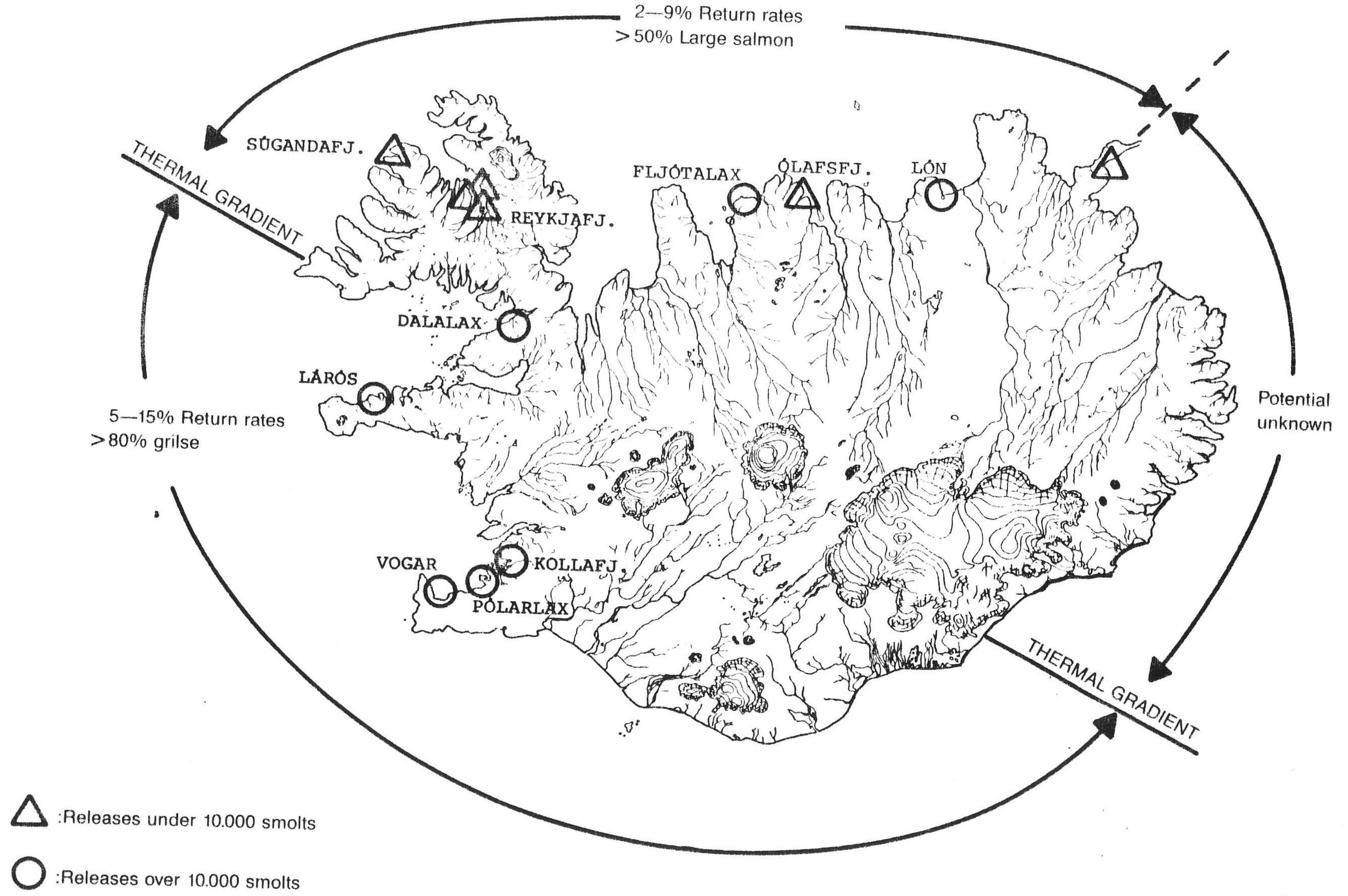

Fig. 12. The major salmon ranching facilities in Iceland. Also shown is an estimate of the salmon ranching potential in various parts of Iceland (Isaksson 1987).