A Successful Transplant of Pacific Salmon to Chile

JON M. LINDBERGH
Consultant to Fundacion Chile
Via Sur-Parque Institucional 6651
Santiago, Chile

INTRODUCTION

Annual worldwide fisheries production reached about 70 million metric tons in 1970. In spite of intense effort and advanced techniques, production has not continued to increase. We seem, in practical terms, to have found the optimum sustained yield. Still, one hears of huge new marine food resources yet to be developed in the world's oceans. These food sources exist, to be sure, but most of them are in forms expensive to extract and difficult to utilize, such as Antarctic krill, pelagic crabs, and small low value fishes.

While man rarely has the time nor the incentive to search out individual morsels of food scattered in the expanse of the ocean, a fish can and does. With few exceptions, man has not developed a taste for the smaller pelagic organisms low in the food chain. Edible fish can concentrate this protein source in a form acceptable and available for human consumption, providing the fish can then be economically harvested. The ideal fish are salmon, who, by their nature, migrate from the land to forage at sea and return at maturity to the precise location from whence they originally migrated. The technique is called salmon ocean ranching.

SALMON OCEAN RANCHING

In a salmon ocean ranching venture, young salmon are reared in hatcheries, where they are protected from most natural hazards. Once they reach a size where predation and juvenile mortality is much reduced, the fish are released to forage and fatten at sea. Adults still return home by the homing instinct characteristic of anadromous fish, but they do not have to face the risks of rapids, floods, pollution and hungry bears. Instead, they swim back to a fish trap, placed close to a selected river mouth. Brood stock are isolated from the population and the rest, still in prime condition, are sold in the marketplace.

SALMON RANCHING LOCATION

Where should a salmon ocean ranch be established? A number of factors must be considered. Good quality freshwater of the right temperature is needed to hatch salmon eggs and rear juveniles. A location with tidal influence must be found where smolts (juveniles ready to migrate to saltwater) are released and adults recaptured. Political, economic, and social, as well as biological and oceanographic conditions have to be favorable. It is advantageous not to have an established salmon catch fishery nearby which may take a high percentage of the fish before they can return to your facility.

Of all the factors involved, proper oceanographic conditions and a good source of feed at sea are probably the most important. If salmon have a rich ocean pasture, they stay healthy, grow fast, survive in higher numbers, come back larger, and bring a better price. If they do not have good forage, they return at less desirable sizes or do not come back at all.

A salmon pasture with extraordinary promise lies in the southern Pacific Ocean south of about 40° south latitude. Strong upwelling creates ocean waters rich in nutrients all the way around the Antarctic continent.[2] Biological productivity in terms of potential salmon feed is enormous.[3]

Previous Salmon Projects in the Southern Hemisphere

Domsea was not the first to successfully introduce Pacific salmon to the southern hemisphere. The New Zealanders[4,5] transplanted chinook salmon, *Onchorhynchus tshawytscha,* from the Sacramento River, California, to South Island, N.Z., in the early years of the twentieth century. They thrived and spread to many rivers on South Island.

The Chilean government and the University of Washington, Seattle[6,7], unsuccessfully attempted to introduce chinook and coho salmon, *O. kisutch,* to rivers between Valdivia and Puerto Montt, Chile. The Japanese and Chilean governments have been attempting to establish chum salmon, *O. keta,* in Aisen province 1976,[8] but, to date, there have been no returns.[9]

DOMSEA PESQUERA CHILE'S PROGRAM

Chile juts into the southern Pacific Ocean as far as 56° S. The southern third of the country has abundant rainfall with rushing streams and clear water. Topograpy and climate on Chile's western facing coastline is similar to that of equivalent latitudes in the northeast Pacific, where some of the world's largest native salmon runs exist. There were no native salmon runs in Chile, hence, no salmon fishery. For these reasons, Domsea Pesquera Chile, Ltda. now operated by Fundacion Chile of Santiago, picked the island of Chiloe for our first effort to introduce Pacific salmon in the southern hemisphere.

Chiloe, at 42° S, is somewhat more northerly than we would have wished, and we were uncertain about the effects of ocean current patterns offshore. However, Chiloe is accessible by road, and close to commercial ship and air service located in Puerto Montt. Locations farther south involve significantly more transportation and logistical problems. The objective of the project was to establish an economically profitable salmon run and logistical considerations are key to good economics.

Problems and Solutions

Every aquaculture project faces a series of problems to overcome and this one was no exception. Problems varied from the very basic, such as money and time, through engineering and biological problems to esoteric ones such as the reversal of seasons. Many of them are closely interrelated.

Selection of the Right Salmon—There are six species of Pacific salmon and numerous different stocks of each. Stocks of salmon in each stream are at least a little different and sometimes significantly different from those in other streams. Even within a single species, stocks hatch at different times, are adapted to different water temperatures and chemistries, migrate at different times, feed in different places in the ocean, and return at different times. Furthermore, different stocks mature at different sizes and return at various states of flesh condition, hence, with different marketability. The problem was what species or stock to select so as to have the best chance of a successful return?

The closer the match of environmental conditions between the original habitat of a transplanted group of fish and the new habitat, the less stress must be overcome. Domsea first evaluated the biological parameters in the receiving site and potential donor sites. Final selections were made considering temperatures, water quality, latitude, and other factors. However, it is impossible to consider or even recognize all of the factors involved in a transplant of this nature.

Each release was restricted to the minimum number of fish believed to provide a reliable indication of successful returns. As many releases of different stocks as possible were made within the financial resources of the project. This approach, using a maximum number of releases with minimum viable release numbers, provides the best chance of success with at least one stock. Successes are expanded and failures dropped.

Releases were made with three stocks of coho, two stocks of chinook, and one stock of steelhead, *Salmo gairdneri*. Returns from the *Oncorhynchus* releases are summarized in Table 1. Steelhead returns have been minimal. The chinook program is being expanded using progeny from returning adults. Coho and steelhead releases in Chiloe have been suspended. While several

Table 1. Releases and returns - Curaco de Velez, Chile

Species	Release Date	No. Released (1000's)	Returned Through July 1981 (No.)
Coho (Skagit)	Late '77	90	30 - Early '79
Spring Chinook	Mid to Late '78	120	334 - Late '79 817* - Late '80 to early '81
Coho (Skagit)	Late '78	30	6 - Early '80
Spring Chinook	Mid to Late '79	190	817* - Late '80 to early '81
Coho (Skykomish)	Late '79	210	20 - Mid '81

* Spring chinook returns to date for late '78 and late '79 releases combined due to difficulty in separate identification.

releases have not been successful, one, the chinook, has. Our strategy of multiple small releases worked.

Dealing With a Low Budget.—Domsea Pesquera Chile was given a low budget to establish salmon runs compared to most other programs with similar objectives. Considerable thought was given to means of reducing costs. Traditional salmonid aquaculture projects involve the construction of buildings for hatcheries and extensive concrete or earthen enclosures for rearing. We attempted to postpone major capital costs by utilizing natural "enclosures" found in Chiloe.

The first shipment of salmon eggs was placed for final incubation in a deep pool near the mouth of a stream entering Lago Popetan, a lake approximately 1 km wide and 2 long. Conditions appeared suitable, provided the stream did not flood excessively. Available information promised several weeks more than necessary for incubation before fall storms began. We were not lucky; early torrential rains created a flood which destroyed the eggs. With a second shipment, we were more successful and most of the eggs hatched without incident.

Fry taken from incubating trays were placed in floating net pens in Lago Popetan. Pens with dimensions of approximately $8 \times 8 \times 5$ m with a mesh size of 1 cm^2 were anchored in the lake. Net pens are relatively inexpensive and have a number of significant advantages in protected lake waters. They are not subject to floods, rapid temperature changes, pump failures, or screen blockages. The enclosed fish will survive occasional inattention by inexperienced local aquaculturists.

Salmon reared in pens in Lago Popetan grew at expected rates and mortalities were low. They were in excellent health and ready for release on schedule. It was necessary, however, to transport them 25 km to a release point near the ocean. Such transport imposes stress on fish and if they are released immediately involves a risk of significantly reducing returns.

Attempting to reduce costs by rearing pre-migratory salmon in natural freshwater enclosures proved technically feasible. The approach involved risks and problems which, however, made it unacceptable in practice. We found it necessary to construct a traditional, if unsophisticated, salmonid rearing system to continue the program.

The Need for Early Results.—Domsea Pesquera Chile was first established as a commercial enterprise. Salmon ocean ranching, as a business, has an unusually long development period before the first profits can be expected. Those who provide financing for such a venture are anxious to see results as soon as possible.

One approach to a transplant of salmon to a new area is to carry out site specific studies. Such studies provide valuable information, but are expensive, take much time, and still do not definitely answer the key question: Will any of the fish return?

Domsea took the position that the best test would be to release fish. We knew that some mistakes would be made which could have been avoided by careful study. But fish releases would cost little more than site studies, and they *would* answer the over-riding question as to whether or not the salmon will come home. Our chinook adults returned, the test strategy succeeded.

Reversed Seasons.—The original salmon eggs for the project had to come from the northern hemisphere, where seasons are exactly opposite from the southern hemisphere. Eggs sent to Chile when they would normally be ready to ship would arrive in the increasing heat of summer rather than in the cool declining temperatures of early winter. We were quite concerned that the altered temperatures would stress the eggs with resultant high mortalities.

Salmon eggs develop at a rate directly proportional to temperatures of the incubating water. In their native regions, salmon have evolved their reproductive schedule to provide hatching at a time where emergent fry enter stream environments close to the optimum time for survival. How could it be possible to match optimum southern hemisphere emergence times with northern hemisphere eggs?

We allowed eggs to develop at northern hemisphere temperatures for approximately one week and then artificially cooled the incubation water to just above 0° C. Water was partially recycled in the hatchery to reduce energy costs. Development was greatly reduced, and the eggs were ready to hatch in April rather than in January. April in the southern hemisphere is equivalent to October in the northern hemisphere. Temperatures in the fall in Chiloe were, with one exception, down to acceptable levels and egg survivals were good.

A Region of Low Technical Development.—Chiloe is, as yet, a region of relatively low technical development. Electrical power is available, but outages are frequent. Some mechanical equipment can be acquired in Santiago, 1200 km to the north, but frequently it is necessary to go to the northern hemisphere for specialized items. Supply lines for advanced fish culture equipment can be measured in thousands of kilometers and weeks of time. If a facility in an area like Chiloe is to be dependent on continuous functioning of powered equipment, it must be loaded with expensive power back-up and redundant systems. Otherwise, it always operates on the brink of disaster.

Domsea Pesquera Chile attacked this problem by designing the facility at Curaco de Velez around gravity flow water and low density culture. There are no electrical pumps in the system, so it is immune to power failure. Low density culture gives more time to solve problems. Oxygen deficiencies and metabolic wastes build up more slowly. Disease outbreaks are less likely to occur and those that do occur tend to spread more slowly. Low density culture may have other advantageous effects on fish which are only beginning to be understood.

Operating with a low intensity fish culture system, we were able to utilize the strengths of locally recruited staff who have done much of the day to day work. These people had no formal fish culture training and little mechanical experience. They have, however, been brought up on farms and with farm animals and have a farm-bred sense of what it takes to make things grow. They learned quickly and have done an excellent job.

Domsea has had good fish survival with no disease outbreaks and no major fish kills. Low density culture and gravity water flow have worked well for a new industry in a remote area.

To Dig a Pond.—A contractor was hired to build two ponds at Curaco de Velez. He brought in a bulldozer and began to dig. The underlying ground was softer than anticipated and the bulldozer quickly sank into the muck until it was mired above its tracks. Efforts to drag it out were to no avail. The contractor was forced to take the machine apart piece by piece and reassemble it on solid ground, a process that took some 3 weeks.

In order to fulfill his contract, the contractor hired laborers with hand shovels. Two pools 40 × 10 × 1.5 m were completed in less than 3 months. Costs were not unreasonable as wages in Chiloe were relatively low. Local people were anxious to work on the job in order to make a little extra money. Furthermore, the hand dug ponds were better finished than would have been possible with power equipment. All subsequent pools have been dug in this manner by hand. The method turned out to be good for Domsea in terms of cost and good for the local economy in terms of employment.

The Maturation of Spring Chinook.—Adult salmon must usually be held in freshwater for a period of time. Spring chinook, our most successful run, return earlier in the season than other species and require a maturation time of up to 6 months. Mortalities with spring chinook adults have been notoriously high in North America and we were quite concerned about survival.

Domsea built a large dirt bottom maturation pond. It was deep enough and the water opaque enough so that it was not possible to see to the bottom. The objective was to provide an enclosure for the adult salmon where they would feel safe and comfortable and not have a strong urge to struggle further upstream. Struggling salmon abrade themselves, become exhausted, and are subject to saprolegnia as well as other disorders.

Chinook adults were placed into the maturation pond, where they immediately settled to the bottom. They rarely came back to the surface and almost never attempted to jump at the intake flow. Density was kept low, less than 4 kg/m^3 of water. Survival was over 95%!

CONCLUSIONS

Domsea Pesquera Chile established a salmon ocean ranching program in an isolated region of Chile in 1976. The program was carried out with a relatively low budget and staffed exclusively by Chilean nationals with the exception of the first 18 months. A number of problems were encountered, some of which are discussed previously in this paper. Not all of the solutions attempted worked out well, but the key ones did. Domsea Pesquera Chile was able to achieve the first confirmed returns of Pacific salmon in South America.

ACKNOWLEDGMENT

The author wishes to acknowledge the valuable contributions of R. Noble, K. Blackburn, I. Villa, E. Salo, C. Mahnken, R. Rodriguez, G. Evans, III,

J. Torres, K. Stuart, M. Correa, and other Chileans and North Americans who helped make this project a success.

REFERENCES

1. Lindbergh, J., R. Noble and K. Blackburn.
   1981. First Returns of Pacific Salmon in Chile. C.M. 1981/F:27 International Council for the Exploration of the Sea.
2. Everson, I.
   1975. The Living Resources of the Southern Ocean. Southern Ocean Fisheries Survey Programme, Food and Agriculture Organization of the United Nations.
3. Joyner, T., C.V.W. Mahnken and R.C. Clark.
   1974. Salmon—Future Harvest from the Antarctic Ocean? MFR Paper 1063, Marine Fisheries Review, Vol. 36, No. 5.
4. Personal communications, J.S. Campbell.
5. Waugh, G.D.
   1980. Salmon in New Zealand in Salmon Ranching, John E. Thorpe ed., Academic Press Ltd., London 24/28 Oval Road, London N.W. 1, pp. 277-303.
6. Personal communication I. Villa and E. Salo.
7. Joyner, T.
   1980. Salmon in South America in Salmon Ranching, John E. Thorpe ed., Academic Press Ltd., London, 24/28 Oval Road, London, N.W. 1, pp. 261-276.
8. Japan International Cooperation Agency.
   1979. Introduction into Aisen, Chile on Pacific Salmon No. 3, Transportation and Rearing Trials with Chum Salmon, *O. keta*, 1976-1978. Aliaky Nagasawa E. and Gustavo Arya G., 52 pp.
9. Personal communication R. Mendez.