Economic Feasibility of Sea Farming: Operational Perspective

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Sea Farming is expected, as with many other industries, to require the development of new technology for cages, nets, vessels and equipment. Also, new techniques for operations such as fish control, feeding, waste management, grading, and harvesting will evolve, driven by economics, feasibility and profit.

Personal experience in the expansion of the mussel farming industry on the North Pacific demonstrated that innovative, new economic incentives can drive the development and deployment of new industry. Fishing vessels evolved from small, 30 meter LTV former whalers, to large, 100 meter, $10m vessels catching and processing $100m, per year. If there are similar incentives or opportunities in the oyster industry, the sea farming, fishing, farming and shellfish industry will evolve in a similar way.

Advancements in cage technology have made it possible to control and feed the exposed, high current areas. Ocean Ear Sea Cages are an example of this technology developed by Ocean Ear Technologies. To reiterate what Atlantic Seaweed of the Great South Bay, Cape Cod, Mass., demonstrated, many of the operational challenges of farming in these conditions.

Here, we learned that reducing the number of "new events" in the facility is very important when growing oysters because stressors can lead to increased mortality. There are many stressors resulting from wind, storms, waves, predators, water quality, disease, nutrients, etc. The number of these events can be reduced over the grow out life of the fish, the result will be a more efficiently grown animal that will be competitive in fish farm markets.

Second, we learned that the economics of scale and labor reduction will be important as future plans investigate operational ways to reduce the expenses on growing large numbers of fish in the open ocean. The following are the key operational aspects of sea farming that will be discussed in this paper:

1. Fish must be transferred to cages which are in...
remote areas offshore. Strategies exist for utilizing offshore sites for grow-out and for open-ocean sites for heart leafing.

1. Fish breeding and site maintenance are expensive with remote controlled and automated methods.
2. Mortality rates can be reduced using existing technology such as an artificial environment system.
3. Geographical location of fish will be difficult in large areas and may not be necessary with farming operations offshore.
4. Nutrient or feeding efficiency can be improved by placing the cages against the wind or moving the cages to different parts, chosen in increasing order.

In conclusion, there are major opportunities for increased yields with the use of fish farming technology currently available. Research and design of new technology to increase the efficiency of fish farming will bring us closer to the future of fish farming. This paper has provided some of the basic information on offshore farming, and the following sections will discuss the potential and alternative techniques used in offshore farming.

From our experience with Ocean Spar cages, we found that the number of stress events during growth-out is very important because growth and conversion rates are optimized. Stress events, such as the number of times the system is disturbed, can reduce the overall efficiency of the fish farming system. This paper examines the potential and alternative techniques used in offshore farming. The following are the key operational aspects of offshore farming, which will be discussed in this paper. They are the same as found in open-ocean farming:

1. Fish must be transferred to cages which are in more remote areas. This can be done by towing a cage on a large water tank.
2. Fish feeding in remote areas may use automated feed platforms requiring fewer vessels, with larger quantities of feed on each trip.
3. Nutrient or feeding efficiency can be improved by placing the cages against the wind or moving the cages to different parts, chosen in increasing order.
dose bottling could eliminate the need for net
cleaning during grow-out. (Figure 2)

3. Mortality removal could be done using an ex-
pelling technique such as an anti- or other auto-
nated system instead of divers. (Figure 3)

4. Environmental harvesting could use integrated fish
hulling systems in the sea cage (Figure 4) and
fish transport could be simplified by towing the
sea cages to decluttered ports, closer to processing
and the market.

As a company, we want to understand the econom-
ics of these different operations. In this paper I have
used cost figures for salmon Atlantic salmon from
John Penrose’s (Penrose, 1995) paper written for the
state of Alaska which summarises salmon farming
costs from the low end in Chile to the high end in
North America and Norway (Table 3). If we can grow
salmon at efficiently offshore an intense then this tech-
ology will apply to other species and before the farming
methods and equipment will be developed.

But, before I get into the cost comparisons of op-
erations, I want to make some comments about off-
shore sites of the future and list some assumptions
about the size of a hypothetical farm used for this
discussion. For example, as farmers consider moving to
more exposed areas, the first sites should be as close as
possible in existing offshore farms and accompanying
support. This accomplishes two things: 1. the offshore
location can be used for grow-out while utilizing the in-
shore site for rearing eggs, and 2. the closer the loca-
tions the lower the transportation costs will be to
and from the cages. Also important will be to choose
moderate energy sites available. By choosing areas
within close proximity and moderate energy, new
methods can be developed for future, more remote sea
farming. I am not suggesting that sites are chosen that
can not extend seed cages or fishing circles. Instead
these “transitional” sites must have the equipment and
create new techniques while continuing to give returns
to the investors. Our company’s policy will be to en-
courage the careful screening of new sites to help pro-
tect the farmers investment while expanding the fran-
tier of farming.

For this discussion and spreadsheet, the following
assumptions were used for the hypothetical off-
shore farm: cultivation rates and stocking densities
are based on standard results from Penrose’s report
(Figure 5)

1. It is assumed that the cages in an offshore
location will be used for grow-out only and the
labor site is for rearing only partially grown
salmon. These small fish would be released at
one kg, size from the inshore “parent” farm to
the offshore location where they are raised to
four kg. These bigger fish will be stronger and
more likely to survive the current and any pos-
sible stress events.

2. The farm size is 2,500 metric tons (m.t.) gut-
ted weight (6,000,000 lbs.) of annual produc-
tion. This size was selected to achieve economy
of scale and amortize the equipment over a rea-
nsonable number of pounds of production.

3. Six hundred and fifty thousand small salmon
are transferred during the year to the sea cages
and 625,000 are harvested after adding 3 kgs.
(75% of their body weight) in about six months.

4. Growing densities were based on lnrarre re-
sults. For this I picked a conservative range of
11 to 18 cages, each 5000 cubic meters to raise
225,000 salmon per year. The densities range
from 21 kg per m^3 to 31.6 kg per m^3 at a max-
imum grow-out.

5. Feed conversion is assumed to be 1:4:1 for
gutted yield although these are studies that indi-
cate better conversion with exercised fish in
higher current (Selming, 1993).

6. This paper will assume conservatively that the
offshore sea cages are located eight km from
inshore support. In some places such as St.
George, New Brunswick, sites could be as close

as more kilometers to landbase farm support. Near Seattle to the Strait of Juan de Fuca we have a site 25 km from an indoor farm.

7. It is assumed that the current range from one to 2.5 knots and storm waves (maximum seven meters) occur on only rare occasions. These facts are what clearly distinguish an offshore designation. Existing floating structures such as cranes will not withstand these conditions for extended periods.

8. Finally, it is assumed for this discussion that hired vessels are available and that the rates are economical at $2500 per 8000 fish per day for a vessel capacity of a conservative estimate based on tender operators in Seattle.

Using these eight assumptions, now I'd like to discuss two possible low and high cost range of the two operations and try to show that offshore can compete with nursery operation. After that I'll review the capital expense requirements and finish with some summary remarks.

**OPERATION 1: FISH TRANSFER TO SEA CAGE**

Because offshore suggests greater distances, stronger equipment, and bigger vessels, the challenge is to develop an efficient way to transport fish safely. A hired 200-ton capacity vessel, 85 meters long, with a pump and full crew can carry 6000, one kg, partially grown salmon (density 53 kg/m³) and cost $5000/day. An eight-knot speed sailing eight hours to the offshore site, the round trip takes only one hour. If another three hours is allowed for the loading and unloading, the total would be four hours to handle 6000 small fish with two trips, 12,000 fish are handled for $4000 per day. For 54 days of transfer, that is 655,000 total salmon transferred for $170,000 vessel cost. Adding the cost for 54 days (25% of one year) of a $50,000 per year, off shore, and farmer responsible for fish transport is $12,500. Therefore I used 4.2 cents per lb. (offered) for the high cost in fish transfer to fish offshore. (Table 1)

The low-end cost of the range of one cent per lb. is based on looking sea cages with a greater number of one kg, salmon included. A 850-hp tugboat can tow a 3000 m² cage with 25,000 fish (density of 50 kg/m³ compared to the density of 53 kg/m³ in the well boat) at one knot for a cost of $250.00 per hour for an eight-hour trip one-way and allowing for loading and unloading that is $1960 for one day. There would be 36 of these trips per year or $67,000 total for tugboat rental to transfer 501,000 partially grown salmon. Adding a small whaler's labor for 70 days at $5000 results in a total of approximately $48,000 or one cent per lb. (offered) (Table 1).

It is possible that offshore operations above could have a three cent per lb. (offered) advantage over the cost of the well boat. If favorable tidal currents can be utilized for higher speed, and special bags or smaller sea cages designed, the cost to move fish could become even more economical for remote operations.

**OPERATION 2: FISH FEEDING**

Total annual feed requirements for grow-out of 2500 m³ of partial fish (2730 m³ when fish is 3500 m³ using a conversion factor of 1.4 to 1. Seventy-five per cent of their weight, or 2625 m³ is needed to add three-quarters of the weight, or 3500 m³, for growth outdoors. That computes to about seven days per day, transported and distributed to the 11 to 15 cages. To calculate the high cost of the range 1.3 times the total feed cost that the feed is contained on a 15-ton vessel with a seven-ton feed capacity. This vessel would be owned by the farm and is included in the capital equipment expenses. For this operation I assumed that the feed cost per lb. would be raised, for determined hard feeding of the fish in the offshore cages. (Table 1)

The low end of the range assumes a normal feed station and only one operator. This option is probably
extreme because in close proximity and with moderate energy the bays will be easily secured by the small fleet used at the high end season. The process of transferring 72 ml of feed for 10 days of feeding would require a hired vessel at \$300/day. Thirty

seven days out of the year would transfer 24.6 ml. If the vessel is large enough for 24.6 ml, the total cost for the workers and the hired vessel would be \$17,000 for 2.1 cents per lb of fish produced (Table 1).

To obtain the range of the cost for feeding, it should be pointed out that when the automated equipment was added to the labor cost the high and low end ranges are 23 cents per lb (2.00 lb/hr, \$102 labor) and the high 1.9 cents per lb (0.02 lb/hr, \$0.01 equipment). The reason for this reversal is that in a moderate energy type of system it is more economic to have the high end cost per lb would be $100,000 per 10 years. This makes the so-called low three cents per lb (0.02 lb/hr, \$0.01 equipment) and the high 2.3 cents per lb (0.02 lb/hr, \$0.01 equipment). The reason for this reversal is that in a moderate energy type of system it is more economic to have the high end cost per lb be less than the high end cost per lb.

**Operation 3. Net Cleaning and Mort Removal.**

Net cages will be cleaned by marine growth but the sampling approach could be to do not cleaning until after harvest. At that time the net pen is removed and cleaned on the shore or submerged in lower light conditions. An experiment that was carried out by Page and Stewart was to submerge a fouled cage for seven weeks to induce fouling. Algae growth had settled on the netting actually died and fell off at mid current.

Several months later when it was reinstalled, the netting was clean.

Gill flaps were more difficult to remove and will probably require periodic cleaning with something like the IDEMA test that many farmers now use. Besides hydraulics for washing, "safe" anti-fouling sprays are now being used effectively and continue to be developed. These hold promise for reduced fouling and could be very effective at limiting the need for cleaning after growth and limiting shelf life loss.

For purposes of this paper net cleaning of the sea cages was considered a minor expense during growth and is included in the 25% of the total labor expense (see later in table showing 25% inshore component). This figure ranges from two cents per lb, dressed fish to eight cents per lb (Table 1).

The cost range would cover net cleaning of the small cages, the labor expense for cleaning the offshore pens after grow-out, and any other expense associated with the cleaning phase of the operation.

Mortality (mortality removal). Daily for as frequently as in practical, net removal will still be an important function for the offshore farmer because of the fish farmer's need to observe the fish stock's health. For this growth period from one kilogram to four over six to seven months, it is assumed there will be about five percent loss or 25,000 fish. Divers can be used, which I have considered for the high end of the range. For the discussion I am assuming that there will be two full-time days spent per cent with their insurance and equipment) \$160,000 per year or three cents per lb. of dressed fish (Table 1).

The vessels they use would be the two trawls owned by the farm's 13.7-meter feeding vessel or the 8.5-meter boat included in the equipment.

To calculate the low end of this cost range, it has been assumed that an inexpensive 5mm system is involved and that one harvester can remove more than every cage each day. As \$500/yr (for a skilled offshore fa-
been that it is only one cent per lb. of dressed fish produced for labor (Table 1). This is the kind of information that can reduce the need for fish farm workers in the more inaccessible locations of the future.

**OPERATION 4: HARVESTING**

The last operation that I would like to discuss is harvesting and transfer of the salmon to the processor. This process is the reverse of juvenile fish transfer from shore to the offshore site, but the fish now weigh four lbs. and can be crowded to increase the density for transport to port. From remote, higher energy locations, we can provide smaller windows of opportunity to transfer fish as soon as technology has been developed to make it easier. For this discussion I will assume that the salmon are processed, ashore and transported by the coastal boat for the high-end cost example and stored in a sea cage for the low-end cost operation.

I will also assume the same vessel used to carry harvest fish back after it delivers partially grown salmon (39 return trips). In those 108 return trips (54 days) the 170 ton capacity vessel can transport 4,500, or 4 lbs. of fish per trip. This is a density of 150 lbs/m³ and 150 lbs/m³ is allowable with a good circulating system. Since I am assuming that 39 of those 108 return trips can transport salmon back to port, another 39 trips are required to harvest 625,000 salmon. This would cost $15,500,000 for the third vessel.

A total of 78 days per year of farm workers' time was assumed as necessary for transfer of harvest fish for this total two-voi farm (78 days or $375,000/13% of $375,000 per year if $100,000 each). Therefore, 39 days at $600/day for the bond vessel plus $375,000 (78 days) for farm labor in 3.4 cents per lb. dressed to harvest 2,000 tons (Table 1). This represents what I have called the high end of the range. If all of the trips for harvest were independent of the small transfer, the cost for 78 days with two trips per day would be 6.3 cents per lb. and 3.4 cents. If I used the higher 6.3 cents per lb., the total cost of the fish transfer to and from the offshore site would be

overstated and misleading because return trips after small fish transfer can carry fish back to market. Figures for transporting harvested fish to the processor should be between 3.4 cents and 6.3 cents per lb. according to the reliable Seattle salmon farm.

For the other side of the cost range, harvesting fish in a sea-cage to process processing could be done with a tug just as partially grown fish were transferred offshore. A 500 ton cage with 24,000 lbs. of salmon has a density of 192 lbs/m³, way below the 130 lbs/m³ density used in the small boat. The bid for cost of towing the cage at one time to an inshore processor eight km. away, was $200 a four ton, or $800. Allowing again for loading and unloading, $500 per trip was used. For 36 days that is $41,000. Add labor of $10,000 for two workers for 20 days and the total is $51,000 or one cent per lb. for taking harvest fish to the processor via a towed cage (Table 1).

To revise, because return trips to an eastern harvested salmon, it is misleading that harvest cost appears lower than partially grown salmon transfer. If the two expenses (small fish transfer, 3.4 cents and harvest transfer, 5.0 cents) were averaged the high cost would be 3.8 cents per lb. and the low end would be the same at one cent per lb. This range of $0.97 to $1.08 per lb. could be used as the cost of moving fish between inshore and offshore and may be more useful.

Use capital equipment expense for harvesting, nothing was needed since built vessels were assumed for both fish transfer options.

**Capital equipment review:**

Now I will review the amortized capital equipment items for offshore. In Table 1, the Fixed Cost and capital equipment expenses of the equipment that I assumed was needed for offshore operations. The total amortized cost of equipment for offshore ranged from $0.86 to $1.33 per lb. of fish processed according to Ford's paper. Because 25 percent of the fish weight is added moisture, I used 25 percent of the average between the two values to arrive at the expense needed.
for cages, and other equipment to partially grow the fish. The figure is two cents per lb. of fish produced ($0.19) if the fish are fed 75% of the average of $0.87. The same figure of $0.19 is used for both the high and low ends because I weighted the average on the low side, believing that small cages are less expensive today than if you can use the floating gravel.

The vessel cost is the largest expense associated with any sea farm because this includes the entire installation. Based on our experience of eight exposed south installations, the $5 per ft. figure should be adequate to cover the cost of the installation. The vessel size is determined as described earlier.

The amortized vessel expense of $100,000 per vessel is $10 per ft. for 10 years, and we have used the $10 per ft. figure to cover the cost of the vessel cost. This includes the cost of the vessel, installation, and associated costs.

The fourth item on the capital equipment list is feeding equipment. One cent per lb. of feed is required for each 250-lb. of fish produced. The cost of feed depends on the size and type of fish being produced.

Finally, the fifth item in the equipment section covers miscellaneous equipment and includes a 1/5 cent per lb. of fish produced. It includes higher on the low end and is a function of the size and type of fish being produced.

**SUMMARY**

New sites for fish farming will open up if two requirements are met: 1) If the technology exists to securely hold the fish in higher-energy conditions, and 2) if people are economical enough to grow the fish so that the product can be competitive in the marketplace. Our company feels that the Ocean Space sea cages are examples of equipment that easily in large measure the first requirement. At this conference we are hearing about other technologies that could prove to be the ones. For the second requirement, this paper has suggested that labor costs for the four operations of offshore farms are less than or equal to the smaller farms. Although these results have not been fully tested, my experience in the fishing industry tells me
that these are conservative savings and there will be
great opportunity for future sea farming investors just
as there was for indoor farmers over the last 20 years.

Of course assumptions were made in the
discussion that took advantage of economy of scale that
increased production while reducing labor. But if all
assumptions are based on conservative premise results,
then it should be possible to have even greater reduc-
tions off shore. Labor represents only 7 percent to 10
percent of the total cost of off shore fish production so
this analysis, as significant cost savings are hard to
squeeze out of these direct costs. The number of man
per sea farmer (which is used as a standard measure in
farm productivity) ranged from high productivity low
labor cost of 325 M. tons per man year to a low of
108 M. tons per man year for the offshore scenario
in this discussion. These figures assume a high cost for
a sea farmer of $50,000 per year because of their more
specialized, requiring skills. If you need an average
annual labor cost of $30,000 the range goes to 95
M. to 64 M. per man year. In Norway, productivity
levels are as high as 182 M. tons per man year and
this may not include a share of the owns labor costs or
harvest costs. Yet it may still be between the low and
high ends in my analysis. One hundred and sixty-five
metric tons per man year or better is probably achieve-
able in remote locations using automation and towed
sea cages. Only experience will show us if these fig-
ures are possible, but this should challenge us to search
for more productive methods and equipment.

Our company believes that improvements in tech-
nology and efficiency will make it possible to move
into these high energy locations and open up vast
new areas of potential. As I've emphasized above, ev-
every attempt should be made to make this a "safe"
transition by using moderate energy areas first for grow-
ting, and then moving to the more difficult, remote sites
with these new found skills and equipment. I believe a
good case will be made for these offshore costs being
driven even lower by the efficient use of labor and
equipment in areas closest to farming support and
infra-structure, i.e. processing, good labor force, mar-
kets in big cities, etc.

Regarding vessel vessels, the sea farming industry
will find economical sea going craft for hire (or sale)
from industries such as fishing and oil. These vessels
and the sea farming crew that go with them will be well
suited for some of the operational tasks. Also because
the fishing industry is on the decline, these used and
"old" vessels will be more affordable than new
vessels, especially during the transition to more distant
offshore sites. Other equipment needed such as feeding
machines or fish feeders are being developed by the
industrial farmers, and that same technology will apply
to offshore farms. As with any manufacturing firm, if
the quantities produced increase, the cost of producing
them goes down as manufacturers try to increase mar-
tet scale and profit.

Finally, I'd like to finish on a "what if" note. The
cost of the cages for offshore operations represent
the largest portion of capital so there will be pressure to
find ways to reduce the $48-60 per lb. assumed
cage cost. The present savings will come if densities
can be increased in high-current areas with sizable cage
volumes. Most fish farmers are skeptical of increasing
densities because their experience is limited to
indoor, generally low-energy sites and the cages nor-
ally floating cages. high losses in volume in
even moderate currents, badly stressing the fish. With
a stable, growing volume, a properly designed cage
is like a bucket or well boat with clean water being
exchanged often. At OCE'S site in the Straits of Juan
de Fuca, the 5000 m3 of water in our cages was com-
pletely changed every 42 seconds, all day long. Also if
weight gain (feed conversion) is en-
hainged in higher currents by exercise (209g),
faster growth will be another benefit. Therefore, if
cage densities can be doubled the capital expense for
the cages goes from a range of $2,500,000 to
$2,250,000 to $2,501,000. This is only to that an amortization that is based
to a cage life of ten years and more, and the invest-

184
mean per lb. of fish raised is quite reasonable—at least more attractive to investors.

Combined cost savings from operational methods and automation should make it possible for future sea farmers to easily compete with fish grown in pens. If it is then determined that better water exchange, stable passing volumes, better temperature control, good dissolved oxygen, exercising fish, and higher water quality, results in a more efficiently grown animal, then open-ocean sea farming will attract investors to grow fish that can compete with other fish and meat products. I think that all of us here believe it warrants further investigation and investment.

References


Figure 1. Central Feeding, 20,000 m² Sea Farm Layout
### Table 1: Fixed and Variable Costs

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Inshore</th>
<th>Offshore, N. America</th>
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<tbody>
<tr>
<td>Labor</td>
<td>$4.50 - $5.50</td>
<td>$6.42 - $7.42</td>
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<tr>
<td>Fuel new boats</td>
<td>$0.75 - $0.85</td>
<td>$0.75 - $0.85</td>
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<tr>
<td>Other (fringe benefits, insurance, etc.)</td>
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<td>$0.00 - $0.25</td>
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<tr>
<td>Total Misc. Costs</td>
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<td>$6.75 - $7.85</td>
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<tr>
<td>Management</td>
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<td>$0.25 - $0.35</td>
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<tr>
<td>Total Direct Production Costs</td>
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<td>$6.90 - $8.00</td>
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(continued on facing page)

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<table>
<thead>
<tr>
<th>Fixed Costs</th>
<th>Amount</th>
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<tr>
<td>Amortized</td>
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<tr>
<td>Annuity</td>
<td>$0.11 - $0.30</td>
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<tr>
<td>Amortized harvest of 5.5 M lbs (1350 wts)</td>
<td>$0.11 - $0.30</td>
</tr>
<tr>
<td>Induce small cages, 25% of fish are blightings</td>
<td>$0.11 - $0.30</td>
</tr>
<tr>
<td>31-36 lbs, 3000 lbs weight</td>
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<tr>
<td>Amortized to 5.5 M lbs</td>
<td>$0.11 - $0.30</td>
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<tr>
<td>Two tanks, 375K &amp; 375K</td>
<td>$0.11 - $0.30</td>
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<tr>
<td>Amortized to 5.5 M lbs</td>
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<td>Amortized to 5.5 M lbs</td>
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<td>Total equipment</td>
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<td>5% - 10% Total amortized capital expenditures</td>
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<td>Total direct production costs***</td>
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<td>1% - 5% cost of money</td>
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<tr>
<td>100% - 100%</td>
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</table>
Figure 1. Monte Carlo with abeliod
Figure 5. Key Assumptions for Hypothetical Sea Farm

- Cages are used for grow-out only
- Annual production is 2,500 metric tons, gilled weight
- 625,000 fish are harvested from 650,000 post-smolts
- Approximately eighteen to eighteen 5,000 m³
cages are needed to raise 625,000 salmon
- Feed conversion rate (FCR) is 1.4:1 for gilled yield
- Cages are located approximately eight kilometers
offshore
- Currents range from one to two knots and
storm waves are a maximum of seven meters
- Herring roe is readily available and
economical

Figure 4. Harvest mode, Sea Station MR2