

Setting priorities for the research and development of new products exemplified by aquaculture

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Abstract

Applied research is often motivated by the economic benefits it will give rise to. These benefits are due to either improved production techniques or new products. The realisation of these objectives depends much on the assessment of different research alternatives and allocation of resources between them. Also within aquaculture research one of the main goal is to start production of new species. Successful research will effect the profitability of the production by changing such factors as the feed coefficient, the mortality, the roe proportion, the fish price uncertainly, etc. The aim of this study is to develop a general and theoretical approach that could be used in priority setting of different research project for example in aquaculture.

A model of the decision of a potential fish farmer considering to start culturing a new species is build in order to determine the sensitivity of the profit to variations in both variables and the uncertainty concerned. Influence diagrams are used as a modeling method because uncertainty and its formulation are crucial, especially before a species is in production. The structure of the model is general and it can easily be used for almost any species, the payoffs of different types of research are the result of the costs and the probability of success of the research projects are evaluated independently. The information on the payoffs, costs and feasibility are then used to compare different research elements and to draw conclusions of the appropriate research policy for different species.

The use of the model is illustrated with a case study of whitefish *coregonus spp.* On the basis of the whitefish data used, the result is that improvement in the feed coefficient would benefit the fish farmer twice as much as the equal percentage improvement in mortality or growth.

Keyword: Research and development (R & D), Priority Decision analysis, Influence diagrams, Aquaculture

1 Introduction

One of the primary tasks of research and development (R&D) is to start production of new products. Products already invented but not commercially under production could be profitably produced if the production process is altered as a consequence

of successful research. Often the production process is highly complicated and each individual R&D project will only affect part of it. The allocation of the R&D efforts so that the prospect of getting the commercial production of the new product started is therefore a highly complicated but relevant task.

One of the main tasks within aquaculture research all over the world is to make aquaculture of new species profitable (for example Canada 1995 or European Commission 1995). More species would benefit both consumers' processor and the fish farmers. As a result of R&D combined by innovative entrepreneurship not only the total aquaculture production has grown at a rate of about 10% per year during the past ten years, reaching a total of 19.9 million metric tons in 1992 (Muir 1995), but also the number of farmed species has increased considerably. Although many species are produced today that were not produced before the further development will to a large extent depend on how efficiently the research topics can be prioritised and the research resources allocated.

The starting point for the decision on what research to undertake is usually the individual research proposals. In the process of making the choice of which research projects to start the cost of the projects and the probabilities of their success are often carefully examined. The benefit side, that is will they result in a new product or not are often not systematically assessed. Usually only the importance of the factors influenced by the research for the profitability is stressed, without any assessment of how much a change in one or some of these parameters will improve the profit. The decision on what research to undertake is therefore commonly based on a combination of an assessment of the costs and the intuition of the benefits.

Logical R&D management should contain two different phases. First an economic evaluation of potential results has to be undertaken and then the costs and probabilities of a selection of potentially valuable research projects have to be determined (e.g. Nelson and Winter 1982). Decision analysis can be utilized in both tasks (Matheson 1983).

In this study a new approach, for allocating R&D efforts with the objective of getting the production of a new product profitable will be introduced.^{1[1]} The method will be developed for the special case of aquaculture of a new species. Decision analysis is applied in order to determine which sort of new information would be crucial for the decision to start to farm a new species. A model of the assessment that a potential farmer has to make before starting to farm a new species is built. Influence diagrams are used as the modeling tool, since many of the factors that are affecting the profit of a product not yet on the market are by nature quite uncertain (e.g. Nelson and Winter 1982). Also the results of research projects are very uncertain and often they depend on coincidences and other unforeseen happenings (Metcalf 1994).

The objective of the modeling is to compare the effect of improvements in the parameter values that can be altered as a result of successful research. Examples of such parameters are the feed coefficient, the growth rate, the mortality and the price uncertainty. For some of these parameters research can only reduce the uncertainty, while for others new knowledge can change both the expected value and its variance. When the goal of the research is to get a new species at the market the benefit of different projects is determined by how likely it is that the

research result will shift the expected value of the profit function from being negative to positive.²[2] (Figure 1)

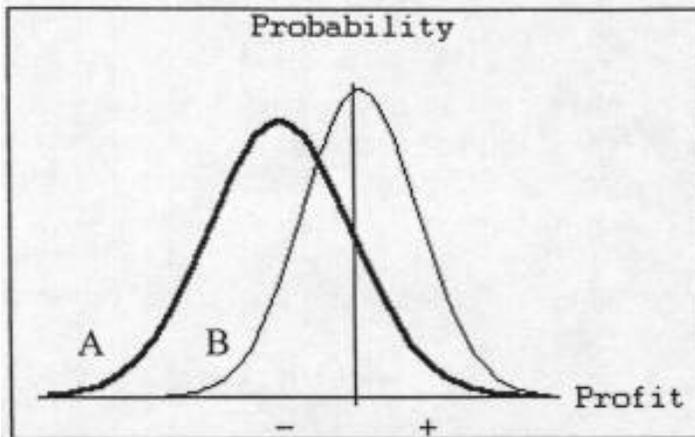


Figure 1. At present, the probabilistic density function of the profit from aquaculture of a new species has a negative expected value, otherwise someone would already farm that species (A). The goal of this modeling is to find the parameter(s), where a change as a consequence of research most likely will change the distribution so that the expected value is positive (B).

The modeling will result in an assessment of the payoffs of different types of R&D. This assessment has then to be considered together with the costs and feasibility of the R&D projects.³[3] For this purpose a second influence diagram model is constructed, in which the result of the first model are used as the assessment of the payoffs of the different R&D projects. The information on the costs and the feasibility of the projects is the other components of this model.

The focus of this study is on the allocation R&D resources, not on the optimal amount of these efforts. These issues are however linked and the modeling approach developed could well be used also as an input when determining the total volume of the R&D activities. The question of the right amount of R&D and especially how much should be made by the public sector and how much by the industry itself is a complex one. It involves such issues as the structure and competitiveness of the specific market, the market failures (especially linked to the public good aspects of knowledge) in the specific market as well as in the economy as a whole. The optimal amount of research consequently lies outside the scope of this study⁴[4].

The objective of the study is to develop a general approach for allocation of R&D efforts in order to start production of a new product. The method is developed for aquaculture of new species. This particular issue was chosen since a rational and systematic tool is especially important when the profitability is determined through an integration of biological, technical and economical processes. Since this task is of general interest, a theoretical approach that could be used for almost any

species is developed in this study. Because the goal is to develop a useful tool for real decision making the approach is tested with Finnish data for whitefish *Coregonus spp.* [5], however at this stage only for illustrative purposes.

The article is structured in the following way. In section 2 we will present decision analysis and influence diagrams, that are the modeling technique we will use. In section 3 the problem will be set out in detail. Section 4 consists of the model developed in order to determine the benefits of different improvements for the profitability of a new aquaculture species and the model integrating this information with the costs and feasibility of different R&D projects. In section 5 the models are applied to whitefish *Coregonus spp.* Finally the whole approach as well as the concrete application is discussed in section 6.

2 Decision analysis and influence diagrams

Decision analysis is a group of methods used to reveal how to be logical in a complex, dynamic and uncertain situations (Howard 1983). Decision analysis has developed from statistical decision theory and utility theory. Decision making in this context is understood as a quantitative evaluation process including comparison of alternative courses of action. With decision analysis, complicated problems are clarified in order to provide a rational basis for the choices to be made and supply the justification based on the relevant available information. Decision analytical methods can be applied when the decision making body is a single individual as well as when it is a group of people.

In decision analysis, large problems are first decomposed into smaller and more easily manageable parts. Decision alternatives (what can be done), objectives and values (what is preferred, factors affecting the result (what is known) as well as risks and uncertainties are systematically. The most important parts of the problem can then be found out and they can be considered in detail. Decision analytical methods simulate rational decision-makers not the psychological decision making process. The most important element is usually not the result of the modeling as such, but that the process helps the decision-maker to develop better understanding of the problem (Goodwin and Wright 1991).

Influence diagrams are networks describing interactions between variables and flow of information in the system. In the approach, the parts of the system the decision-maker can affect are separated from those which are uncontrollable from his point of view. Thus, an influence diagram model contains different kinds of variables: decisions to make, uncertain variable and deterministic variables. Parameters known for certain have single values which are either exogenous or determined by deterministic functions. This means that the output value of deterministic variable is known immediately after the states of the variables influencing it are known. (e.g. Oliver and Smith 1990)

Uncertainty and its formulation play an essential role in Bayesian approaches, such as influence diagrams. In influence diagrams uncertain variables are expressed using either continuous or discrete probability distributions. Since continuous distributions can be hard to handle and may also be difficult to comprehend they are often discredited in the way that the variable is given probable outcomes with certain point probabilities. Probabilities can be empirical, which means that they are calculated on the basis of some observed frequencies. On the other hand, they

can also be some persons subjective perception of the likelihood of the occurrence of an event.

Deterministic variables are linked to uncertain variables by calculation of the conditional joint probability distribution with Bayes' rule^[6].

The result of the model will be the probability distribution of the objective function, that is a function describing the decision criteria. The relationships between all variables must be unidirectional and the diagram can not contain cyclic dependencies.

With an influence diagram the parameter uncertainties are combined into the objective function and the risk profile that is the probability distribution of the objective function is obtained. The decision has not to be made based only on a single deterministic output value calculated under the assumptions of fixed input values. The sensitivity of the objective function to variations of variables can also be studied. This property is essential in our application of setting priorities for research, including the risks as probability distributions in a model differs from comparative statistics of a deterministic model in the sense that the joint analysis might ad the risks differently for different decision alternatives.

Influence diagrams are usually represented as graphic networks. This helps formulating and structuring problems as well as improves communication (Oliver and Smith 1990). The influence diagram approach is not dependent on a certain software, the calculations can be done also for example with a spreadsheet program. Often a special application software is used partly because they take advantage of graphic properties of influence diagrams. The notation of nodes depends on the software, but usually there are three types of nodes, which are represented with different shapes: decisions with rectangles, probabilistic nodes with ovals and deterministic nodes with rounded rectangles. All details (outcomes, choices and payoffs) are contained in the nodes. We used the presentation and solution procedure of ADA (1995).

3. The Problem - allocation of resources for different research alternatives, when aiming at production of a new product

A new product can simply be defined as a product that is presently not at the market. This can be due to several reasons, the product might not be invented or production might not be profitable with present input prices and technology. Here we will focus on the case where a product is not produced because it is not profitable at present. The situation could however be altered through research resulting in a cheaper production.

Before the production of any new product is started, some sort of assessment of the costs and revenues has to be conducted. This might be carried out on a very general level, in the mind of the entrepreneur, or it could include large amounts of calculations, market studies and formal modeling. No firm would however start

$$P[A \setminus B] = P[A]P[B/A] / \sum P[A_i]P[B/A_i]$$

(see for example Milton and Arnold, 1990)

^[6]This does not automatically imply that the mean value of the function of expected profits just has to be positive. Some firms might not be willing to start production unless they are almost certain that they will not lose money, they are avoiding risk and are said to be risk averse. Other firms might start production, although the mean value of the expected profit is negative, as long as there is a certain possibility that they will get a possible profit, these firms are not afraid of risks and are called risk seeking. (Varian 1992, Kreps 1990)

^[8] Since the amount of potential farmers of a new specie is large one can assume that at least one of them is risk neutral, therefore the expected values can be used without considering risk attitudes.

^[9]Marketing, including advertising might change the demand for the products. Also research of for example the health effects of frequent consumption of fish and roe might also change the demand, it can, however, either result in an increase or decrease depending on the findings.

production of new products unless they think that they will get some profit out of it.⁷[7]

The assessment of the expected profit will have to include some evaluation of the demand for the product along with an evaluation of the production process and the costs involved. When the production process is technical or otherwise complex, this part has to be carefully considered, since even a small part of the process might make the whole production either impossible or non-profitable. Much of the R&D work within firms as well as in research institutes is focused on just a part or several parts of the production process. In order to determine how to set priorities among the possible research issues a view of the whole process determining the profit of the production is needed. (e.g. Nelson and Winter 1982)

The decision to start commercial production of a new aquaculture specie is no different from the decision to start production of any other product. The goal of the firm is to make profit, in order to assess if this will be achieved or not. The demand for the specie has to be evaluated and considered together with the production process and its costs. At present, the expected profit must be negative, since otherwise someone would already farm the specie and therefore it could not be called new.⁸[8] Aquaculture does, however, differ from many other forms of production in the respect that the production process includes many biological sub processes.

The possibilities to farm a specie and the costs involved depend on biological characteristics of the fish and the swarm. Therefore, much of the research has been focused on research affecting biological parameters such as for example mortality and growth. When the goal at the research is to get production of a new species started, then the benefits of different research projects have to be determined based on a total assessment of how they affect profits.

Since the goal of this approach is not to evaluate the profitability of aquaculture of a new specie, but to determine the relative benefits of different research possibilities, the next task is therefore to determine which variables can be affected through research and how. The expected output prices, in the case of aquaculture the price of fish and in some cases roe, can not be affected by research⁹[9], but an improved understanding of the markets through economic studies can reduce the uncertainty, i.e. reduce the variance of the distribution. This is also the case of the input prices, in the case of aquaculture the price of feed and fingerlings, which in addition can be reduced by R&D of feed and fingerling production. Biological research of the factors affecting the production, the feed coefficient, the growth rate, the mortality and the proportion of roe, can result in a changed expected value as well as in a changed variance.

The range of research possibilities is often quite large, including breeding, development of vaccines and feed, technical research of how the fish are fed, lighting and temperatures. At the concrete project level, the amount of possible projects is even larger. There might be dozens of different research schemes of for example new vaccines or feed. The results of research are always very uncertain

and they are gained after a quite long time-period, which makes it a difficult task to determine which projects to start. Often the decision to start or finance a project is done on the basis of expert evaluations frequently collected by peer review. This is usually the case irrespective of whether the decision is taken by a firm, a research institute or a foundation. (Grossman and Shapiro 1986)

To summarise, the aim of this study is to develop a tool for allocating of a given research budget when the goal is to get the production of a new product started. In determining the benefits of the different R&D projects the essential elements of the whole production process should be included and considered from the perspective of the potential producer. Finally, these benefits should be combined with the cost and likelihood of success of the research options in a systematic way.

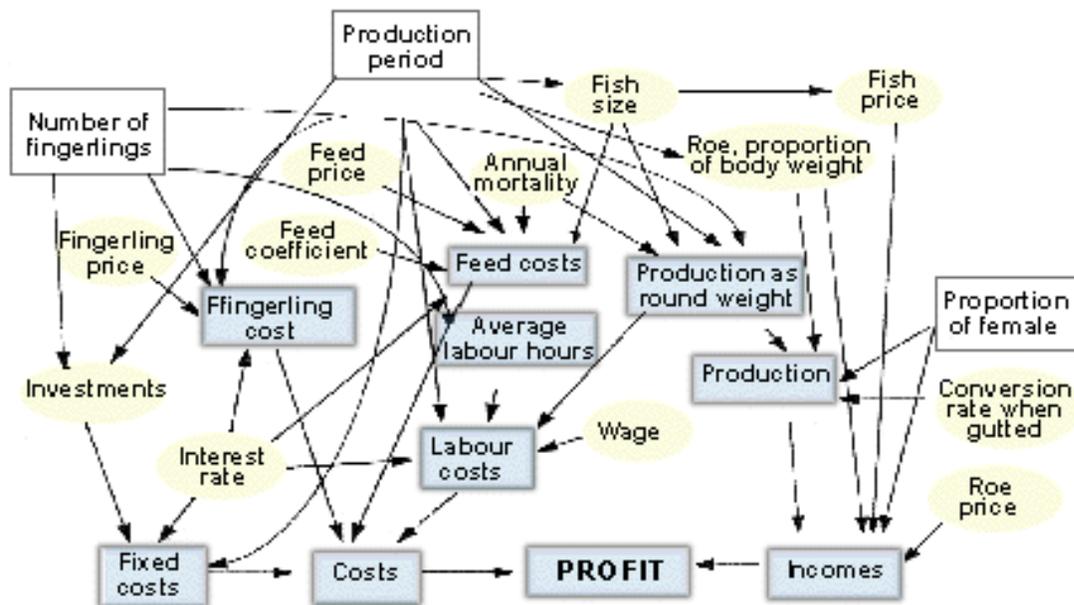
4. Modeling the benefits of different research alternatives and the decision which projects to start when aiming at a new species for aquaculture

4.1 A n-model of the decision to farm new species

In order to determine how different types of research could affect the profit a cost benefit model is built. Since many of the factors in the model are uncertain the model is built by influence diagrams instead of as a traditional deterministic cost-benefit model. This also makes it easy to use discontinuous functions, which sometimes are more realistic representations of for example roe production or prices of different size classes.

The structure of the model is illustrated in Figure 3 and the functions linking the parameters and distributions are given in tables 1 and 2. The model created is general and should, therefore, with only small modifications be useful anywhere. Values of the exogenous parameters and the shape of the distributions along with their parameters will depend on the species, area, market, etc. For some species, parts of the model would have to be extended in order to include especially important characteristics. When for example using the model for arctic char (*salvelinus alpinus*) temperature adjustments have to be included. When part of the model is expanded, one has, however, to remember that the model has to be quite general, since the uncertainties involved are very large. No part of the model should also be made much more detailed than the others, since then risk that the uncertainties add incorrectly increases.

figure 2- The influence diagram model of the costs and benefits of aquaculture of a new species



Although the model contains the same type of elements as traditional influence diagrams, they have to be considered in a slightly different light. Since this model is a description of the calculations made before production is started all values are a priori and no decisions can be assumed to take place after some additional information has been revealed. The goal of the modeling is also quite different from the normal use of influence diagrams. Influence diagrams are normally used to compare different decision alternatives, study their sensitivity and make risk assessments. However, the interest of this model is focused on a comparison of changes in the distribution of the profit function as a result of changes in different parameter distributions as a consequence of research.

The length of the growing period can vary from a few months to continuous growth depending mainly on the thermal conditions of the area. In the model the length of the growing period is set between zero and one. The length of the production period determines how many, at most on year, growing periods the fish are cultured. In the model a year end and the growing period is fixed to the time when the fish is sold and thus a year in the model does not mean a calendar year.

Table 1. Variables of the model

variable	Symbol
Production period (years)	t
Length of growing period (years)	α
Number of fingerlings	N
Proportion of females	γ
Roe price	P_R
Roe as a proportion of body weight	τ
Fish price	P_F
Feed price (i.e. cost of feed/kg)	C_F
Feed coefficient *	ω
Initial weight	W_{init}
Average weight gain (in i:th year)	q_i
Fingerling price (i.e. cost of a fingerling)	C_g
Annual mortality (in i:th year)	M_i
Average labor hours	L
interest rate	δ
Gutted weight	ϕ
Wage (opportunity cost of labor)	W
Additional labor cost	S
Other costs	Z
investments	I

· Feed amount kg/wet weight gains of fish g . The feed consumption of dead fish is calculated separately 50 the influence of mortality is float included in the feed coefficient.

Table 2. Equation

Number	Variable	Equation
1	Profit	$\pi = R - C$
2	Costs	$C = C_f + C_r + C_g + C_L$
3	Fixed costs	$C_f = \sum_{i=1}^t (1 + \delta)^i \cdot I \cdot \delta$
4	Feed costs	$C_r = \sum_{i=1}^t \left[(1 + \delta)^i \left(\left(\frac{1 + \alpha}{2} \right)^i - 1 \right) \left(c_f \cdot \bar{m} \cdot \left(M_i \cdot N \cdot \frac{q_i}{2} + N \cdot q_i \prod_{j=1}^i (1 - M_j) \right) \right) \right]$
5	Fingerling costs	$C_g = (1 + \delta)^{(t+1)} \cdot N \cdot c_g$
6	Labour costs	$C_L = (1 + \delta)^{(t+1)} \cdot \frac{(s \cdot w \cdot L + z \cdot D_r) \cdot \alpha}{(t - 1 + \alpha)} + \sum_{i=2}^t (1 + \delta)^{(t+1-i)} \cdot \frac{(s \cdot w \cdot L + z \cdot D_r)}{(t - 1 + \alpha)}$
7	Incomes	$R = ((D \cdot P_f) + (D_r \cdot \tau \cdot \gamma \cdot P_R))$
8	Production	$D = (\phi - \tau \cdot \gamma) \cdot D_r$
9	Production as round weight	$D_r = \prod_{i=1}^t (1 - M_i) \cdot N \cdot S$
10	Fish size	$S = w_{\text{min}} + \sum_{i=1}^t q_i$

Since the costs and the incomes occur at different points of time discounting has to be made in order to make them comparable. The discounting will depend on when the costs and incomes occur and will therefore be different for different species, areas, etc. Costs and incomes in the model have been made comparable by calculating the future value of all costs to the time when the products are. In the functions in table 2 the following assumptions and approximation have been made:

- Fingerlings are always bought at the beginning of the first growing period which not necessarily is at the beginning of the production period.
- Fixed costs are assumed to take place at the beginning of each year so that capital costs occur before the fingerlings are bought.
- Because the growth and the feed consumption predominantly occur during the growing period are the feed costs discounted if as they occur at the middle of the growing period.
- Most of the mortality is assumed to occur during the growing period (75-80% of the annual mortality), caused mainly by high temperatures and low oxygen saturation of the water. The cost of feed caused by dead fish is therefore assumed to take place at the middle of each growing period.
- Labor costs are assumed to spread evenly throughout the year and they are discounted from the middle of each year.
- Roe is collected at the same time when the fish is gutted.

4.2 Priority setting of research alternatives

In order to systematize the decision making of which of the alternative research projects to start a second influence diagram model is developed. This model connects the benefits from different improvements, determined by the previous model (section 3.1), the costs of the possible research projects and their likely results. The input to the model on the likely results, e.g. the probability distribution of the outcomes, is by nature subjective. It will depend on the views, intuitions, etc.

of either the decision-maker or the experts consulted. With the use of formal decision-making analyses, as for example influence diagrams, the decision can be broken down systematically into parts where historical facts are available or were the subjective assessment totally dominates. In addition, the use of decision analysis will make it possible for the decision-maker to explicitly consider the appropriate risk preferences.

The influence diagram model developed in order to help the decision on which projects actually to start and which not, is by nature not very general. Many of the essential elements will depend on the available resources and the species concerned. In this section only general aspects of the model are described, a concrete example is given in section 5.3.

The possible research projects that could be started are the decision variables. Projects that could be undertaken at the same time are different decision variables whose different states are projects that are distinct alternatives. One state of each variable is not to start the project. Other possible state might for example be different sized projects. Each project will result in some costs which are dependent of the state of the project variable. The value of the improvements will be determined by how-much the expected profit will be improved, which is calculated with model 1. As Roberts and Weitzman (1981) we assume that the costs are additive during the whole project, while benefits are received when the project is completed.

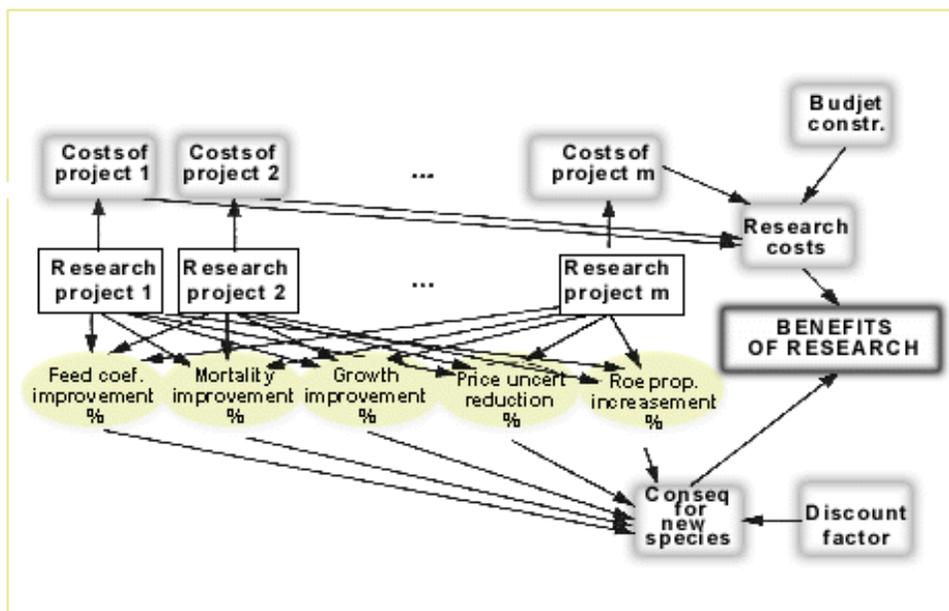


Figure 3. An influence diagram connecting the benefits with costs and feasibility assessments of the research alternatives

Table 3. The variables and equations connecting the benefits with the costs and feasibility assessments

Variable	Symbol	Function
Research projects (1...m)	RES _j ^v	
The states of RES _j (0...v), where mean no research	RES _j	
Reduced roe price uncertainty (%)	% P _R	Will be characterized by a different probability distribution for all different combinations of projects (j = 1 ...m) and all the different states (v =0...v)
Increased roe proportion of body weight (%)	%τ	-''-
Reduced fish price uncertainty (%)	% P _F	-''-
Reduced feed coefficient* (%)	%ω	-''-
Increased average weight gain (in i:th year) (%)	% q _i	-''-
Reduced annual mortality (in i:th year) (%)	% M _i	-''-
The costs of project j	CR _j	CR _j = f(RES _j ^v)
Budget constraint	Bud	
Total research costs	RC	
Consequence for new species	Con	Con = f (%P _R , %τ, % P _F , %ω, % q _i M _i)

The data, of the costs and the likely improvements, needed for the model could be obtained in two separate ways, depending on for what purpose and by whom the model is used. The model could be used by a research team in order to focus their own R&D efforts. In this case the estimates of the likely improvements and the cost data would describe their own assessment of the likely results of the alternatives and their costs. In this case the model would be a tool for structuring the internal discussion. The model could also be used by an independent foundation or the management to evaluate the best combination of research alternative by independent teanis. Then the cost data would come from the proposals and the correctness of the likely improvements through the research, could be evaluated by independent experts, for example by peer review.

5. An example whitefish

5.1 The data used in the whitefish model

In order to test the usefulness of the theoretical model developed in section 4.1 the data was collected and the model adjusted to suit analysis of whitefish. The data used is described in tables 3 and 4. Apart from the feed coefficient and the mortality the parameters describe properties of an individual fish. The two exceptions are characteristics of a swarm. The goal was to find as realistic data as possible. If there was no confident data available estimates by experts were used. For instance, there are rather good time-series of the price of whitefish in different size groups, but on the other liand the knowledge of average labor hours is quite inexact and the estimate quite uncertain.

The biological data in general is based on studies that have been carried out in the Finnish Game and Fisheries Research Institutes aquaculture laboratory in Laukaa. There was no commercial data of whitefish cultivation available until this study has been made. However, at the same time some commercial experiments of white fish cultivation have been started.

Table 3. Summary of the probabilistic data of the economic model for whitefish *Coregonus spp.*

variable	Distribution	Mean value	s.d.
Roe price	Pareto	48.30 FIM per kg ¹	18.04
Roe as proportion of body weight			
in 2nd year	Normal	0.048 ²	0.011 ⁴
in 3rd year	Normal	0.12 ²	0.028 ²
Fish price			
Size class I (over 0.8 kg)	Normal	22.88 FIM per kg ¹	2.7 ⁴
Size class II (between 0.4 and 0.8kg)	Normal	18.49 FIM per kg ¹	2.7 ⁴
Size class III between 0.25 and 0.4 kg)	Normal	12.41 FIM per kg ¹	2.7 ⁴
Size class IV (under 0.25 kg)	Normal	9.59 FIM per kg ¹	2.7 ⁴
Cost of feed	Normal	5.2 FIM per kg ¹	0.5 ⁴
Feed coefficient	Normal	1.4 ³	0.6 ³
Average weight			
After 1st production year	Normal	0.26 ⁷	0.045 ³
After 2nd production year	Normal	0.76 ⁷	0.14 ²
After 3rd production year	Normal	1.5 ³	0.30 ³
Fingerling price	Normal	1.0 FIM per fingerling ³	0.1 ³
Annual mortality			
In 1st production year	Normal	25 percent ³	0.02 ³
In 2nd and 3rd production year	Normal	12.5 per cent ³	0.01 ³
Interest rate			
(6 month hellebore (1994) + 2,8 percent)	Normal	5,21 ⁵ +2,8 ⁶	0.34 ⁵
Conversion factor for gutted weight		90 per cent of body weight ²	
Coefficient of additional labor costs		1.7 ⁴	
Wage (opportunity cost of labor)		36,96 FIM per hour ⁸	
Average labor hours		$330.2 * \ln((\text{amount of fingerlings} / 1000) + 1)$ ⁴	

- 1 SVT Official statistics of Finland 1995:5
- 2 Koskela Juha 1991
- 3 Koskela Juha; estimate
- 4 Ronkanen Asmo, Mickwitz Per and Veitola Kristiina ; estimate
- 5 Bank of Finland 1994
- 6 KERA 1995
- 7 Koskela Juha et. al 1989
- 8 Statistics Finland: Buetin of statistics 1995:11

Table 4 Investments to start production of whitefish *Coregonus spp*

	Production period 1 year	Production period 2 years	Production period 3 years
Investments Large amount of fingerlings	2522000 FIM	3388400 FIM	3388400 FIM
Medium amount of fingerlings	1197000 FIM	1522000 FIM	1522000 FIM
Small amount fingerlings	316700 FIM	319200 FIM	319200 FIM

Honkanen Asmo, Mickwitz Per and Veitola Kristina; estimated on the basis of necessary growing space and other constructions.

5-2 The whitefish model

The whitefish model is based on the general model presented in section 4.1. The equations in table 2 were used to link the variables. The alternative production periods for whitefish are 1, 2 or 3 years and the growth period (a) in southern Finland, where production seems most likely is at average half a year.

In addition to the data described in previous section the decision alternatives in table 5 were used. The alternative lengths of the production period are based on cultivation experiment but also the common knowledge of the suitable size of whitefish at the market. If the roe has a market value it makes sense to maximize the proportion of females. In the case of whitefish, the other properties than the roe production are not dependent of the sex of the fish. Whitefish roe is more expensive than whitefish meal. Until roe production starts the sex of the fish is irrelevant. Therefore, the only relevant alternatives in the model are no females and only females. The alternative numbers of fingerlings are based on the experiences of rainbow trout production in Finland, in such a way that the alternative "small" mainly is considered as cultivation where whitefish is cultured jointly with rainbow trout. The values were chosen in order to represent enterprises of different scale.

Table 5. Summary of the decision alternatives in the model for whitefish *Coregonus* spp.

Decision	Alternatives	Value
Production period	1 year 2 years 3 years	1 year 2 years 3 years
Proportion of females	none females all females	0 per cent 100 per cent

The price per kilogram for whitefish depends on the size of the fish. Smaller fish is worth less than bigger fish not only per fish but also per kilogram. The price does not, however, increase continuously, but in discontinuous "steps". When the discontinuous price function is combined with uncertain growth, represented by one normal distribution for each production period, the result will be an asymmetric profit function when at least one of the growth distributions overlaps more than one "price step" (figure 4).

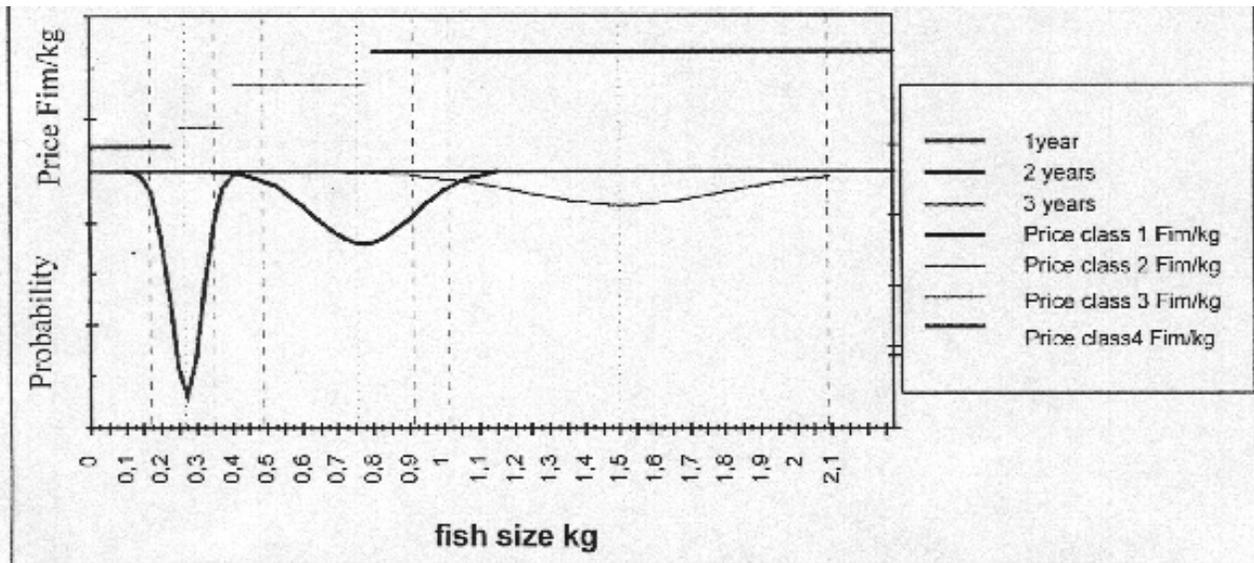


Figure 4. The price and expected growth for whitefish. The expected values and 95% confidence intervals for fish size are marked in figure with dashed lines.

As can be seen in figure 5, the farming is not profitable when the variables are at the present state. If this would not be the case there would already be production and whitefish could not be used as an example. Since the expected profit is negative, the optimum decision combination is small amount of fingerlings and a one-year growing period. The proportion of females does not make any difference since the fish is not producing any roe in the first growing year.

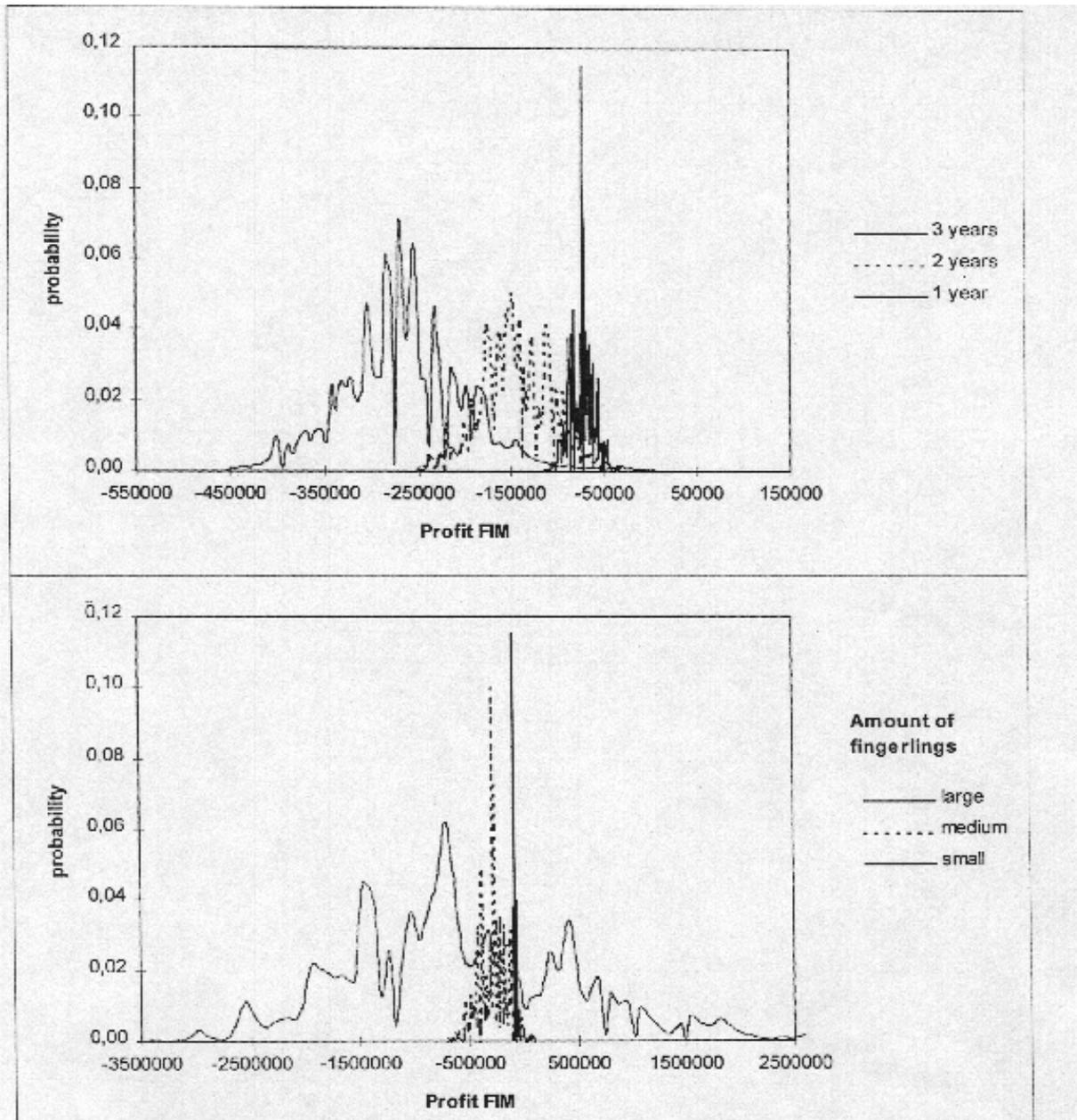


Figure 5, The distributions of profits of the farmer with the present data for one, two and three years growing periods (upper picture) and for small, medium and large firm (lower picture).

5.3 The cost and feasibility assessment for some possible whitefish research projects

In the case of whitefish, the essential parameters that can be affected by research are the growth rate, the feed coefficient, the survival rate, the proportion of roe and the price uncertainty. There are several potential projects affecting them all. The growth rate can be increased for example by developing better feed, taking into account the needs of whitefish in different environmental conditions, or by selecting

the best growing individuals for farming.

In order to exemplify how research alternatives could be chosen, a hypothetical situation with five different types of projects is considered. These projects are feed-research, research into disease prevention (vaccine, etc.), a selective breeding program, research of the demand for whitefish and research into the growth conditions. Successful feed research would increase the growth rate and reduce the feed coefficient. Disease prevention research could only improve the survival rate. A successful breeding program would mainly result in an improvement of growth, but also have some influence on the feed coefficient and the survival. The research of the demand would diminish the uncertainty concerned to the fish price. Research of the growth conditions would have consequences for the feed coefficient, the growth, the mortality and the proportion of roe.

For all five research-projects, three possibilities were considered: not to start the project, to start a small project or to start a large project. Projects not started will not cause any cost or improvements. For projects started, both the costs and the improvements in the parameters vary ¹⁰. The cheapest project would be a small demand study (about FIM 100 000), while the most expensive one would be a large breeding program (about FIM 11 million). The expected improvements in the parameters were usually around 10 per cent. There were, however, large variations between the improvements of the parameters caused by different projects. If the parts of a project are not very dependent of each other or the results could be achieved in several ways, the uncertainty is usually smaller for the larger projects.

The benefits of the research are not the improvements of a parameter as such, but the change in the profitability of whitefish farming they will cause. These benefits are calculated with the influence diagram model in section 4.2.

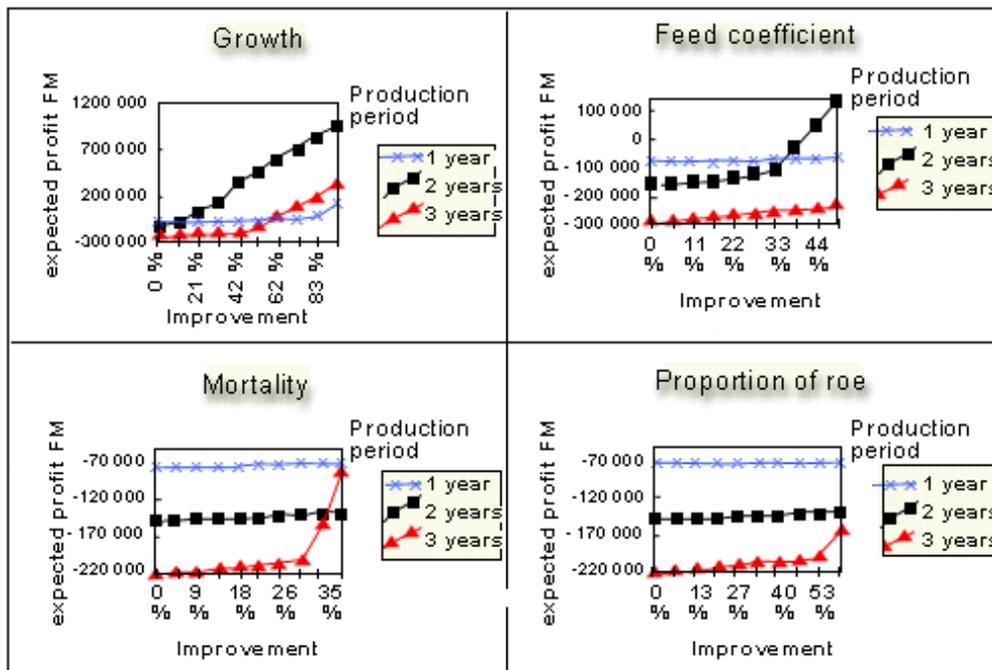


Figure 6 Expected profits as a function of growth, feed coefficient mortality and

proportion of roe, while other variables stay unchanged.

The parameters were individually changed from their nominal values and the influence on the expected profit of a fish farmer was analyzed. Figure 6 shows how improvements in the distribution of the growth, the feed coefficient, the survival (i.e. reduced mortality) and the proportion of roe affect expected profit. With the present data, production is still not profitable. The optimal decision strategy for nominal values is therefore a small amount of fingerlings and only one year production (figure 6).

For the projects in the example the estimates used were obtained through interviews with experts at the Finnish Game and Fisheries Research Institute. In a real situation the cost figure could be obtained from concrete research proposals and the expected improvements from either internal or external expert.

profitable. The optimal decision strategy for nominal values is therefore a small amount of fingerlings and only one year production (figure 6).

The assessment of the benefits of research is however not as simple as shown in figure 6. Since in reality several variables can be affected at the same time, the shape of each profit function depends on the state of all the other variables as well. For example if the growth or feed coefficient was improved enough to make the expected profit positive, it would be profitable to culture fish longer than one year. Thereafter even a small increase in the proportion of roe affects the profit drastically (whitefish are not producing any roe in first year).

In our example, we are however only considering projects with expected improvements around 10 per cent and our main focus is on what research to do in order to make cultivation profitable, not on the research that should be done after it has become profitable. The error of estimating the benefits with a hyper-plane, even though we know that in reality the surface has a different shape is therefore not large.

In our example, we consider the optimal allocation of a FIM 7 million research budget. The best allocation in this case would be to start a large feed research project, a large project of the growth conditions and a small disease prevention project. No breeding program and no demand analyses would be undertaken.

6 Discussion and conclusions

The problem addressed in this study was how to allocate the budget for R&D projects, when aiming at making production of a new product profitable. In order to allocate the research budget the benefits of successful research have to be combined with the costs of the projects and the likely improvement for each of the projects. This can be done in several ways. Here we have introduced an approach where the benefits are determined through an analysis of the profitability of a potential new producer. Thereafter the effects on the profit are combined with the likely improvements and costs of different R&D projects.

In the model, introduced for aquaculture, several assumptions were made while calculating the fixed costs. In order to keep the model simple the assumption that own capital should have the same rate of return as borrowed capital has been made. With this assumption, one can avoid any considerations of the share of own capital. It is, however, clear that as long as the capital markets are not perfect or there are transaction costs there is a difference between the interest rate for

borrowed capital and the alternative income of the firms own capital. Another assumption of the capital costs is that the new investments each year equal the depreciations, and therefore the nominal capital costs will be the same each year. The error because of these assumptions is however small compared to other sources or errors in the model.

Although the investment estimates, in the empirical application, are very uncertain, this is not as big a problem it first may appear. An error in the investment parameter, will have a large effect on the point where aquaculture of whitefish becomes profitable, but this is not our primary interest. The concern here is the effects of different R&D projects on the profitability, which would result in production of a new product. An error in the investment estimate would effect the profit function in all cases, the profit functions would therefore all be equally scaled and the relative merits of the different research possibilities would remain the same.

In many previous studies of the production possibilities of new products, only some of the factors determining the costs and benefits for a potential new producer have been considered. Often the factors focused on have been chosen primarily by technical and not economic criteria's. For example, in studies of production of new aquaculture species, the main focus has been on the biological and environmental aspects, without a systematic link to the profit (e.g. Krieg et al 1992, Treadwell et al 1992 and Ross and Beveridge 1995).

Although aquaculture has been used as an example and data for a specific species to be analyzed, the goal has been to develop an approach that could be of much wider use. The presented method is useful if the production process is complex and it is not a priori known which individual parameter is the most essential for the profitability. Only then it makes sense to start with a cost-benefit model. Modeling the profitability with influence diagrams is useful when the parameters or the relationships are uncertain. This is usually the case for production of new products. With the concrete example it has been demonstrated that the procedure introduced is not just a theoretical one, but also a practical tool for decision making in real situations.

In our approach the value of the results of the different R&D projects is only determined by the effect they have on the production of the new product under consideration. Often, however, research findings can be used for several purposes. In such cases the other benefits should be included at the last stage either as exogenous effects, with a probability distribution if they are uncertain or by combining the benefits from several cost-benefit models.

The tool developed for setting priorities of R&D projects in this study is most useful in a situation when the research budget is substantial and the amount of projects that can be undertaken at the same time is not very large. If the research budget is small the two stage modeling approach introduced here is too complicated and costly. If on the other hand the number of possible projects that could be simultaneously undertaken is very large, not only the computer capacity but also the uncertainty of joint effects will limit the usefulness of the presented approach. In both these cases other approaches, especially based on the analytic hierarchy process (Saaty 1990), are recommended.

References

ADA, 1995. Decision Programming Language DPL. ADA Decision Systems, Menlo

Park, CA. 443 p.

Bank of Finland 1995- Personal communication 25-8.1995

Canada 1995. Federal Aquaculture Development Strategy. Communications Directorate Department of Fisheries and Oceans. Ottawa, Ontario. 18 p.

Dasgupta, P. and Stiglitz, J. 1980. Industrial Structure and the Nature of Innovative Activity. *Economic Journal* Vol. 90, 266-293.

Goodwin, P. and Wright, G. 1991. *Decision Analysis for Management Judgement*. John Wiley & Sons, Bath. 308 p.

European Commission 1995. Report - VI Meeting of Directors of Fishery Research Organizations in the European Union. France, Arcachon 29-31 May 1995. 29 p.

Grossman, G. and Shapiro, C. 1986. Optimal Dynamic R&D Programs- *Rand. Journal of Economics*, Vol. 17, 581-593.

Howard, R.A.- 1983. The Evolution of Decision Analysis. In Howard, R.A. and Matheson, J.E. (edit.) 1983. *Readings on the Principles and Applications of Decision Analysis* Vol 1. 5-17.

Kera 1995. Personal communication, September 1995.

Koskela, J., Lindgren, S. and Vaisanen, J. 1989. Paljonko siiasta saadaan perattua kalaa ja filetta. *Suomen Kalankasvattaja* 5/89, 26-29.

Koskela, J. 1991. Siiän käytöstä lihan ja mädin tuotantoon ruokakalaviljelyssä. *Suomen*

Klankasvattaja 1/91, -K-i-45.

Kreps, D.M. 1990. *A Course in Microeconomic Theory*. Harvester Wheatsheaf-Cambridge, 850 p.

Krieg, F., Quillet, E. and Chevassus, B. 1992. Brown Trout, *Salmo trutta* L.: a New Species for Intensive Marine Aquaculture. *Aquaculture and Fisheries Management*, Vol. 2.3, 557-566,

Matheson, J. E. 1983. Overview of R&D Decision Analysis. In Howard, R-A. and Matheson, J.E. (edit.) 1983. *Readings on the Principles and Applications of Decision Analysis* Vol 1. 327-331.

Metcalf, J. S. 1994. Evolutionary Economics and Technology Policy. *The Economical journal*. Vol. 304, 931-944.

Milton, J. S. and Arnold, J. C. 1990. *Introduction to Probability and Statistics. Principles and Applications for Engineering and Computing Sciences*. McGraw-Hill, Singapore. 700 p.

Muir, J. F. 1995- Aquacultural Development Trends: Perspectives for Food Security. International Conference on Sustainable Contribution of Fisheries to Food Security. Kyoto, Japan 4-9 December 1995. 133 p.

Nelson, R. R. and Winter S. G. 1982. An Evolutionary Theory of Economic Change. The Belcpnap Press of Harvard University Press, Cambridge. 437 p.

Official Statistics of Finland 1995:5- Prices Paid to Fisherman. 20 p.

Oliver R.M and Smith J- Q 1990. Influence Diagrams, Belief Nets and Decision Analysis, John Wiley & Sons, Essex. 453 p.

Roberts, K. and Weitzman, M. 1981. Funding Criteria for Research, Development and Exploration Projects. *Econometrica*, Vol. 49, 1261-1288.

ROSS, L.G. and Beverige, M. C. M. 1995. Is Better Strategy Necessary for Development of Native Species for Aquaculture? A Mexican Case Study. *Aquaculture Research*, Vol. 26, 539-547.

Saaty, T. L. 1990. How to Make a Decision: The Analytic Hierarchy Process. *European Journal of Operations Research*, Vol. 48, 9-26.

Statistics Finland 1995:11. Bulletin of Statistics. 84-85.

Treadwell, R., McKelvie, L. and Maguire, G. B- 1992. Potential for Australian Aquaculture. Abare Research Report 92.2, Australian Bureau of Agricultural and Resource Economics, Canberra, 81 p.

Varian, H. R. 1992. *Microeconomic Analysis*. W,W. Norton & Company. New York- 506 p.

10[1] In this study we will not evaluate the benefits from the new product to the WHOLE society and therefore no attention have been paid to if and how much research should be undertaken in order to introduce it.

10[2] Although the distribution in figure 1 is normal, this is only for illustrative purposes, in reality there is no need to expect them to be normal, or even symmetric or unimodal. For example in the case studied in section 5, the shapes of the profit function are far from normal (Figure 5).

10[3] Of course it would be possible to do the process in the reverse order, that is to start with the cost and feasibility of different projects and then consider their payoffs. It has, however, been stated that not only has the order followed here been more common it has also been more likely in resulting in commercially successful projects (Nelson and Winter 1982).

10[4] On the optimal amount on research for example Dasgupta and Stiglitz (1980).

10[5] One of the biggest weaknesses of the Finnish fisheries' sector is the few species that can be supplied regularly in large quantities. The professional fishermen can only guarantee a steady and large supply of Baltic herring. The only species provided by the fish farmers is rainbow trout. This also makes the fish farming industry very vulnerable for market disturbances, especially since rainbow trout is competing at the domestic as well as at broader markets with the Norwegian Atlantic salmon. One of the most important priorities for the Finnish fisheries research is therefore studies that would result in profitable commercial aquaculture of at least one other species besides rainbow trout. The new species in Finland that are supposed to be closest to being profitable are whitefish and arctic char.

10[6] Bayes' theorem for calculating conditional probabilities of event A_j on condition of B is :