Financial risk analysis in aquaculture

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ABSTRACT

Financial risk analysis methods were compared with the standard components of a risk analysis (hazard identification, risk assessment, risk management and risk communication). Financial and related performance measures are critical in assessing financial risk. A variety of quantitative methods of financial risk assessment (release assessment, exposure assessment, consequence assessment and risk characterization) are presented. In financial risk assessment, financial analysis methods (capital budgeting, enterprise budgets, cash flow analysis, financial performance ratios, partial budget analysis etc.) are necessary. Numerous examples from aquaculture research illustrate methods for probabilistic risk estimation (probability trees, Bayesian networks and stochastic simulation) and non-probabilistic risk estimation (what-if/scenario-based analysis, sensitivity analysis and break-even analysis). Evaluation methods based on decision analysis principles are well-established in financial risk analysis. The paper illustrates the use of decision trees and Bayesian decision networks, risk programming (e.g. E-V efficiency and MOTAD), stochastic efficiency and multiple criteria/trade-off analysis (e.g. MCDM and AHP/ANP) for assessing financial risk in aquaculture. Since decision analysis methods are mature, a number of software packages that implement many of the methods are also represented. Financial risk analysis methods should be integrated in the early phases of hazard identification and risk assessment in order to truly manage financial risk in aquaculture. While many studies and techniques are available to analyze financial risk in aquaculture, the methods are not necessarily linked to the traditional components of a risk assessment. This paper links financial analysis with traditional risk analysis methods and demonstrates the utility of decision analysis principles in analysing risk in aquaculture.

INTRODUCTION

In aquaculture, financial risk refers to the potential loss associated with an aquaculture investment. Aquaculture investments may be public or private and made on behalf of stakeholders, including individual farmers, shareholders, farm enterprises, financial institutions and/or government institutions.

HAZARD IDENTIFICATION

Risk is defined as uncertain consequences, usually unfavourable outcomes, due to imperfect knowledge (Kaplan and Garrick, 1981; Hardaker *et al.*, 2004). Risk can be lowered by reducing or removing hazards, i.e. sources of risk. Hazards are tangible threats that can contribute to risk but do not necessarily produce risk. Agriculture and aquaculture are inherently risky financial endeavours (Goodwin and Mishra, 2000). In aquaculture, the hazards can be broadly classified as production threats or market (or economic) threats.[1] According to the United States Department of Agriculture (USDA) (Harwood *et al.*, 1999), United States producers of major field crops are concerned most with production yield and market price variability.

Financial risk represents the likelihood of a hazardous event occurring and the potential financial loss that could result. Figure 1 illustrates how financial risk links hazards to financial loss. The presence of hazards affecting production and market conditions (e.g. price, demand) can bring about financial loss.

Production threats

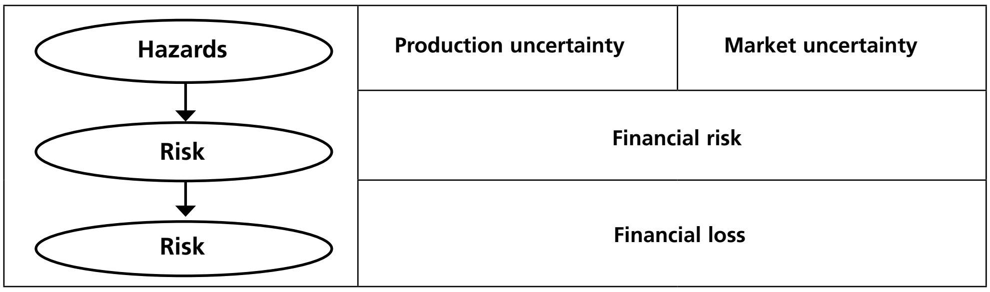
Production threats have a negative impact on saleable yield, resulting in a financial loss. Threats to production include disfavourable environmental conditions, equipment or other asset failure, poor-quality seedstock and broodstock, disease and pest infestation. The success of an aquaculture enterprise often depends on the tacit knowledge of a few experienced farmers and managers. Consequently, as with the performance of other assets, employee loss or disability creates financial risk because production may be disrupted (Barry, 1984; Harwood *et al.*, 1999).

Market threats

Market threats exist in the form of product prices and regulations. Industry competition or reduced demand can lead to decreasing sale prices of aquaculture products. In either case, decreasing market prices will reduce revenue associated with sale of aquaculture products. Escalating prices of production inputs also pose a market threat because they decrease producer profit. Likewise, producers are exposed to risk due to limited supply of inputs. A recent off-shore aquaculture economic study for Pacific threadfin in Hawaii illustrates this case. The large-scale production level that was needed for the off-shore enterprise to be profitable could not be supported by the existing supply of fingerlings (Kam, Leung and Ostrowski, 2003). Recent plans for a Hawaiian off-shore cage enterprise to vertically integrate by developing an in-house hatchery suggest the realization of the financial risks from market threats posed by the study.

Government policies and other institutional threats affect the aquaculture business climate by influencing interest rates and imposing tax incentives, trade restrictions

FIGURE 1
Market and production uncertainty are commonly viewed as sources of risks that lead to financial losses



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[1] See Barry (1984) and Harwood *et al.* (1999) for other classifications of risk in agriculture.

and environmental policies. For example, environmental impact assessment (EIA) and regular water sampling and analysis are costs of doing business for off-shore aquaculture production in the United States (Kam, Leung and Ostrowski, 2003). Government regulations contribute to risk because they can become increasingly demanding, costly to satisfy over time and may be subject to change.

Methods for identifying hazards with financial consequences

Preliminary information gathering helps to scope and structure a risk problem and lays the foundation for communicating risk. At the stage of hazard identification, the magnitude of the consequences and estimating the likelihood of occurrence are not critically important.

A variety of resources should be consulted to identify the hazards that contribute to financial risk. Stakeholders whose investments are at risk may provide significant insight when identifying hazards. These stakeholders can include the lenders who provide the financial support to farmers, farm owners, government agencies, consumers and members of related/affected industries.

When the hazards contributing to financial risk are not well defined, anecdotal reports are helpful in identifying hazards. Industry experts and the farmers themselves are typical secondary sources used to identify the pertinent production and market threats. Information can also be gathered from trade reports, news articles and published research (e.g. agriculture extension publications, journal articles, case studies). In gathering primary data, it's common to survey farmers and consumers, review state-of-the-art practices and gather information from members of related industries such as restaurant managers (Neira, Engle and Quagrainie, 2003, Engle *et al.*, 2005). Farmers can also be surveyed to identify hazards. In a direct marketing study for ornamental fish, for example, a producer survey identified sale prices and shipping costs as major issues prohibiting them from direct-marketing their products (Kam, Leung and Tamaru, 2005). Subsequent interviews with the ornamental wholesalers and aquaculture development programme members helped to complete the picture regarding issues affecting the ornamental industry.

In an import risk analysis (IRA) conducted by Biosecurity Australia (2006), potential hazards affecting prawn products were based on the list of diseases notifiable to the World Organisation for Animal Health (OIE, formerly the Office International des Épizooties), then refined to include diseases important to the importation of prawn and prawn products. A scientific team of specialists assisted in an IRA that identified nine diseases as hazards associated with the importation of uncooked prawns and prawn products intended for food consumption. For Hawaii, an IRA identified white spot syndrome virus (WSSV) from imported frozen commodity shrimp products as a hazard affecting local shrimp production (see Annex I). WSSV was the focus of the sample IRA based on anecdotal reports from farmers, industry experts and news sources.

Table 1 provides common examples of hazards in aquaculture as well as their sources of information.

FINANCIAL RISK ASSESSMENT

Risk assessments can be qualitative or quantitative in nature. A qualitative risk assessment is a reasoned and logical discussion of relevant factors expressed in non-numerical terms, such as high, medium, low or negligible. An excellent example of a qualitative IRA can be found in Murray (2002). Quantitative methods are useful for investigating financial risk in aquaculture because financial risk generally implies monetary loss. While qualitative methods are a viable and popular approach to analysing risk, this paper on financial risk highlights quantitative methods as a departure from qualitative methods commonly used in risk analysis. Some aspects of non-probabilistic risk estimation can be used in conjunction with qualitative risk assessments.

TABLE 1
Examples of hazards in aquaculture

Hazards		Sources of Information
Market threats • Decreasing sale prices (prices of outputs) • Increasing production costs (prices of inputs) • Availability (scarcity) of inputs • Escalating interest rates • Decreasing market demand • Limited market access • Creditor instability	**Production threats** • Seedstock low quality or limited availability • Broodstock low quality or limited availability • Equipment/asset failure • Decreasing growth rates • Disease spread • Lack/loss of skilled labour • Detrimental environment/weather conditions • Limited availability of food (especially in extensive systems)	**Primary data** • Farmer experience/hunches • On-site/field visits • Interviews with industry experts • Individual farm data • Surveys **Secondary Data** • News sources • Agricultural extension reports • Industry reports • Case studies • Anecdotal reports

TABLE 2
Elements of a financial risk assessment

Elements of a risk assessment	Defined with respect to financial risk
Release assessment	Identifying the extent to which a production or market threat could affect the aquaculture industry.
Exposure assessment	Identifying the likelihood that the hazard(s), if present, will affect the aquaculture enterprise (or stakeholder).
Consequence assessment	Identifying the financial consequences associated with the exposure to the hazard(s).
Risk characterization	Estimating the potential financial consequences associated with the hazard(s) identified.

A risk assessment refers to the process of identifying, estimating and evaluating the consequences of exposure to a hazard or a source of risk.[2] Risk assessment terminology is commonly associated with biological and environmental hazard applications (e.g. Calow, 1998; OIE, 2006). The traditional risk assessment definitions can be adapted for financial risk assessment in aquaculture (Table 2).

Release assessment

After production and market threats have been identified, a release assessment is needed to determine the extent to which potential hazards exist. The practice of risk assessment presumes that it is possible to estimate the uncertainty of the hazard existing. Quantitatively, uncertainty can be estimated in the form of probabilities (or probability distributions). When probabilities are difficult to estimate, a range of values can reflect uncertainty in the form of scenarios (e.g. best case, most likely and worst case).

For biological production threats, a release assessment will generally rely on a pathway analysis to trace the method by which a pathogen reaches the production site. As illustrated in Figure 2, pathways of exposure can be used to trace production loss attributed to contamination and the quality of broodstock and seedstock from a pond or hatchery or from the wild. For example, Hawaiian aquaculture industry members argue that white spot syndrome virus (WSSV) import risk in Hawaii may be traced to the country of origin and subsequent retail distribution channels of frozen commodity shrimp products (FCS) as illustrated in Figure 3. Trade data and incidence reports are useful for estimating the probability of a hazardous pathogen release in an importing country. Based on WSSV-outbreak incident reports, FCS import rates by region and consumption estimates, the probability of WSSV-infected retail FCS products was estimated at 32 percent for Hawaii (Kam, 2006).

In contrast to biological threats that pose financial risk, many other production threats are not due to pathogen transmission. Consequently, a pathway analysis is not necessary for a risk assessment. Production threats that originate on the farm-site are a distinct departure from biological threats traditionally traced by risk assessment

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[2] Some risk frameworks consider hazard identification to be the first step of a risk assessment.

FIGURE 2
Release pathway for exotic shrimp introductions indicating points of inspection (adapted from Johnson 1990, based on Kam 2006)

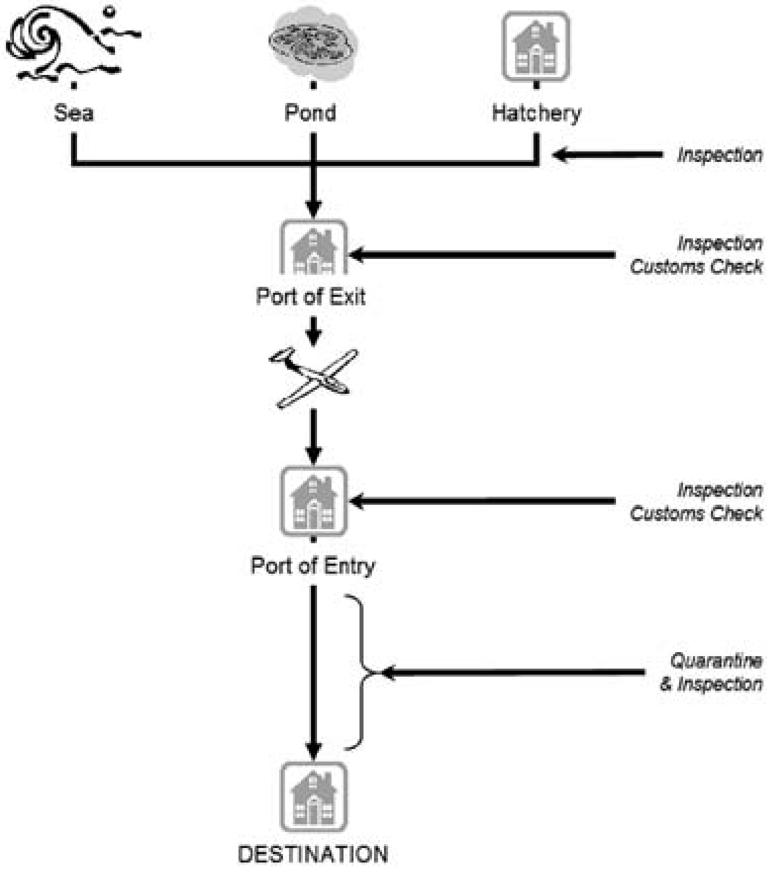
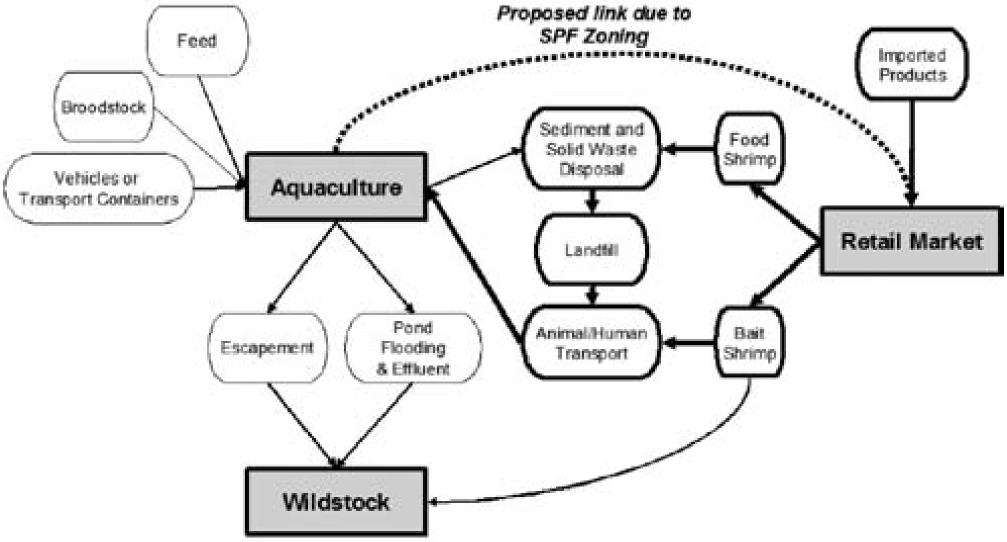


FIGURE 3
Pathways of white spot syndrome virus (WSSV) exposure between Hawaiian shrimp aquaculture, retail markets and wildstock



methods. Potential hazards that are farm-specific such as growth variation can be estimated using expert input or based on farm historical data. Other on-site risks include equipment failure, which can be quantified using expert estimates or farm data on downtime for repairs and services.

For market threats, a hazard can include the potential decrease in sale prices or demand. Hazards also come in the form of increases in the price of production inputs (e.g. cost of seedstock, broodstock, feed, water) or demand of products. Industry data are a good resource for identifying fluctuations in the volumes and prices of products sold, as well as input prices.

Exposure assessment

In contrast to release assessments that describe the extent to which the hazard exists in the environment, exposure assessments are specific to the investor(s) (or stakeholders). In biological and chemical risk analysis, exposure assessment often involves an estimate of the likelihood of intake by human or environment. Likewise, in financial risk analysis, exposure assessment involves an estimate of the probability that a hazard will affect a farm, entire industry or other unit of analysis. In studying an aquaculture industry, a hazard may affect each farm differently. Just as some populations are more resilient to biological hazards, some farms are more resilient to hazards. Their resilience or susceptibility to the threat will depend on production technologies, business strategies, site characteristics and other risk-mitigating practices. Differences between farm characteristics and practices and their association with financial risk allude to potential financial risk management strategies.

Determining the financial risk factors for a farm is often based on tacit knowledge. An exposure assessment helps to illuminate the factors contributing to financial risk and fosters risk communication. General perceptions of a farm's level of exposure in comparison to other farms can underscore the characteristics and strategies that lower a farm's financial risk. In a WSSV import risk study (described in Annex I), 13 shrimp farms were considered in the risk analysis. Different levels of exposure, based primarily on location, characterized each farm. As illustrated in the WSSV example in Figure 3, farm location influenced the extent of the WSSV threat from bait shrimp used at nearby fishing sites, shrimp truck food sales, food waste, FCS retail shrimp and disease transmission from neighbouring farms. Each farm's level of biosecurity practices (e.g. sanitary practices or physical security) was subjectively evaluated, implying further reductions in a farm's exposure to WSSV and thus financial risk. Table 3 summarizes the major farm characteristics and practices that affect financial risk.

Financial risk factors that expose farms to hazards can also be determined from farm performance measures. For example, Hambrey and Southall (2002) have identified "risk exposure" indicators such as total investment required before achieving return, time delay ("lead time") before return occurs, crop (harvesting) cycle and working capital required for a cycle. Most farms, however, do not document sufficiently detailed information needed to calculate these types of risk exposure measures. Furthermore, such risk exposure measures are often difficult to obtain for small farms. For example, while return on labour is important for smaller-scale enterprises, the data required to produce the estimates are not always available.

TABLE 3
Farm characteristics and practices that influence financial risk

Farm characteristics & practices	Examples
Crop/product selection	Diversification, specialization
Technology & practices	Operation protocols, equipment
Location	Coastal, inland, isolated
Financial leverage	Interest rates, amount borrowed
Infrastructure	Fencing, circulation system

Consequence assessment

Consequences refer to outcomes, usually a loss such as monetary loss, production loss or socioeconomic loss. The consequences can represent a single aquaculture enterprise, entire industry representing multiple enterprises or a regional economy.

Financial consequences

Since many of the principles underlying a financial risk assessment are based on financial analysis, a basic understanding of financial analysis methods is highly recommended. A training manual by Engle and Neira (2005) developed for tilapia farm business management and economics provides explanations of farm-level financial analysis methods with detailed examples for a Kenyan tilapia farm. Other useful measures and indicators of financial performance relevant to aquaculture and fishery activities can also be found in the technical paper by Hambrey (2002). Some examples of financial efficiency measures for risk assessment are presented in Table 4.

Financial risk analyses focus primarily on profitability indicators. Financial profitability can be measured in a variety of ways, including profit (net revenue or net income), return on production inputs (e.g. capital, water, land and labour), profit margin, return on investment (ROI) and internal rate of return (IRR). In order to measure profitability, a careful accounting of the costs is needed. When estimating the financial cost of a hazard, it is necessary to identify the fixed costs and variable costs. Costs that vary with production are called “variable costs” (also called operating costs). In contrast, fixed costs are costs that are incurred regardless of production activity (sometimes referred to as overhead or ownership costs). Some examples of fixed and variable costs are available in Table 5.

The distinction between fixed and variable costs is useful when conducting partial budget analyses, which investigate the impact of small changes on profit. An example of a partial budget analysis is presented in Box 1. For hazards and managerial decisions with long-term impacts, fixed costs and variable costs are needed to generate financial statements for the budget period. In addition to profitability, measures of solvency, liquidity and cash flow can be derived from financial statements including enterprise budgets, income statements, cash flow statements and balance sheets over a budget period.

Variable costs include production costs, costs of goods sold and even expenses not directly tied to the production of products

TABLE 4

Measures of financial efficiency (from Engle and Neira (2005) [1]

Solvency	Liquidity	Profitability (or viability)	Cash flow
• Debt/asset ratio • Equity/asset ratio • Debt/equity ratio • Net worth	• Current ratio • Working capital	• Profit/ha/crop (or profit/ha/yr) • Return on investment • Net farm income • Return to labour and management • Return to management • Rate of return on farm assets • Rate of return on farm equity • Operating profit margin ratio • Gross margin • Net change in profit (from partial budget analysis) • Break-even price • Benefit to cost ratio	• Cash flow coverage ratio • Debt-servicing ratio • Cash flow risk and sensitivity ratio

[1] Definitions available in Hambrey (2002) and Engle and Neira (2005).

TABLE 5

Examples of fixed and variable costs

Fixed costs	Variable costs
• Rent[1]	• Feed
• Management salaries	• Labour
• Office expenses	• Water
• Equipment depreciation	• Maintenance
• Other asset depreciation	• Sales tax

[1] In some cases, rent is treated as a variable cost; see discussion on “classifying costs” below.

BOX 1

Developing a partial budget analysis: a partial budget analysis for feed-type decision for a tilapia farm

Engle and Neira (2005) created a training manual on *Tilapia Farm Business Management and Economics* that includes a guide to creating a partial budget. The following excerpt is taken from the manual:

Partial budgets are used when considering a relatively small change on the farm. Changes may involve building additional ponds, changing type of feed, changing stocking rates with polyculture etc. Table 6 presents an analysis of a proposed change on a tilapia farm: whether or not to switch the type of feed from a pelleted diet to rice bran. The advantage of the rice bran is that it costs less than pellets. However, the disadvantage is that FRCs are higher and growth rates lower with rice bran. Bran was assumed to exhibit lower cost (3.5 Keynan shillings (KSh)/kg), but a higher FCR than pelted diet feed.

A switch to rice bran would result in reduced tilapia revenue of KSh 624 000. This reduced revenue results from lower yields of fish when fed rice bran as compared to pellets. No additional cost would apply to a switch from pellets to rice bran, nor would there be any additional revenue Table 6 also provides details of the reduced costs that would be incurred by switching to rice bran. The net change in profit would be negative (KSh -180 561), suggesting that switching feed is not profitable.

TABLE 6
Partial budget analysis used to evaluate the economic effect of changing from a pelleted diet feed to rice bran (all figures in Kenyan shillings, KSh)

	Feed		
Value of parameters that change	**Pelleted diet**	**Rice bran**	**Change in cost**
Tilapia sales	1 046 400	422 400	624 000
Feed total cost	419 904	72 074	347 832
Fingerlings total cost	108 000	59 904	48 096
Interest on operating capital	80 341	32 830	47 511
Additional costs			
None			
Reduced revenue			
Tilapia sales	624 000		
A. Total additional costs and reduced revenue	624 000		
Additional revenue			
None			
Reduced costs			
Tilapia fingerlings	48 096		
Feed	347 832		
Interest on operating capital	47 551		
B. Total additional revenue and reduced cost	443 439		
Net change in profit (B-A)	(180 561)		

or services but that vary with production volume. The variable costs associated with a hazard can include a decrease in sales resulting from unsaleable products. For market hazards, variable costs could include increases in the cost of seedstock, broodstock, feed or water. Production threats could include low food conversion ratios (FCR) that result in increased feed requirements or lower production output. Additional labour could also be required in response to production threats.

Fixed costs associated with a hazard can include the one-time expenses associated with the realized financial threat. These costs can include additional clean-up costs, preventive control measures (disease control), fines, equipment repair or enhancements. Many fixed costs require additional supporting information to identify depreciation costs and interest levels that may change on an annual basis (Engle and Neira, 2005).

BOX 2

Classifying costs to calculate profitability: a financial analysis of a Pacific threadfin hatchery

A spreadsheet model was developed to determine the viable scale for a commercial Pacific threadfin (*Polydactylus sexfilis*) hatchery in Hawaii (Kam *et al.*, 2002). The production scheme was modeled after state-of-the-art practices performed at the oceanic Institute in Waimanalo, Hawaii. For a hatchery enterprise producing 1.2 million fry per year, the cost associated with raising one 40-day old 1.00 g fry is estimated at US$0.2201 (Table 7). The largest variable costs are in labour and supplies, which comprise 49 and 9 percent of the total production cost, respectively. The combined annualized fixed cost for development and equipment is approximately 12 percent of total production cost. Based on a 20-year statement of cash flows for fry sold at US$0.25, the 20-year internal rate of return (IRR) was 30.63 percent. In comparison to the US$0.2201 unit cost for 1.2 million fry production, analyses of smaller enterprises producing 900 000 and 600 000 fry per year reflected significant size diseconomies, with unit costs of US$0.2741 and $0.3882, respectively (Figure 4).

Demand to support a large-scale Pacific threadfin commercial hatchery was uncertain. Since smaller-scale commercial hatcheries may not be economically feasible, facilities may seek to outsource live feed production modules or pursue multiproduct and multiphase approaches to production. An analysis of the production period length, for example, indicated that the cost for producing a day-25 0.05 g fry is US¢ 17.25 before tax and suggested the financial implications of transferring the responsibility of the nursery stage to grow-out farmers (Figure 5). Evaluation of the benefits gained from changes in nursery length, however, must also consider changes in facility requirements, mortality and shipping costs associated with transit, and the growout performance of and market demand for different size fry.

Additional analyses can be found in the original study, which estimated the potential cost savings associated with the elimination of rotifer, microalgae and enriched artemia production. Managerial decisions, however, would also consider the quality and associated production efficiencies of substitutes.

Classifying costs as either fixed or variable will depend on the nature of a farm's business. For example, in a Pacific threadfin hatchery economics study (Kam *et al.*, 2002), rent was treated as a variable cost because the amount of rent charged was based on a percentage of gross revenue. While salaried personnel are considered fixed costs, hourly labour and commission-based compensation are variable costs. Consequently, cost items like personnel expenditure may require further detail to specify the portion that is fixed vs variable (e.g. salary vs wages). However, for practical purposes, labour expenses are generally fixed and not typically adjusted in response to actual yields (Samples and Leung 1986). An example of a financial analysis based on an enterprise budget for a Pacific threadfin hatchery is given in Box 2.

FIGURE 4

Size economies for scaled Pacific threadfin hatchery production levels in US¢

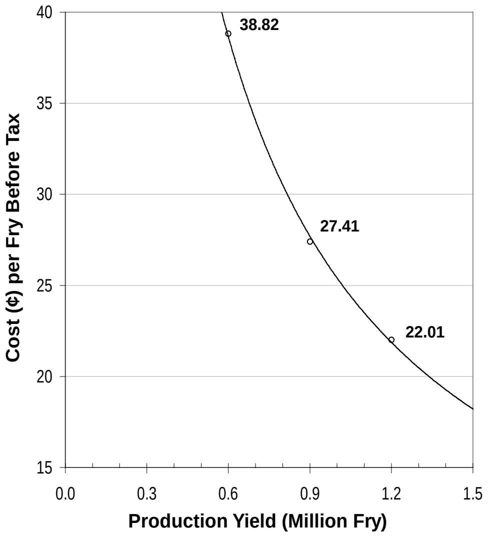


FIGURE 5

Farm production cost (US¢/fry) from spawning to early nursery

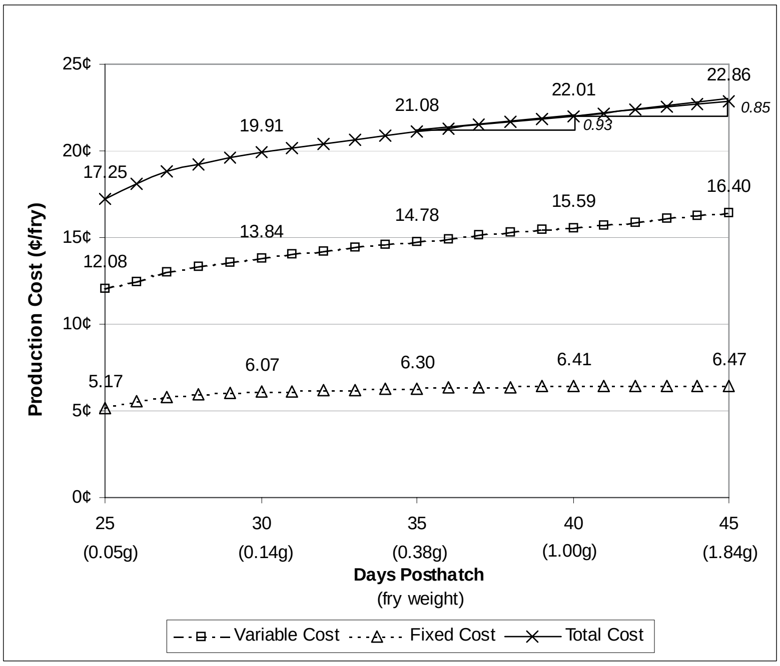


TABLE 7

Annual income in US$ for a hypothetical Pacific threadfin hatchery producing 1.2 million fry

Annual Income	Year 1	2	3	4	5[1]
Gross Receipts from Production	210 000	300 000	300 000	300 000	300 000
Variable Operational Costs					
- Feed	5 442	5 442	5 442	5 442	5 442
- Supplies	24 985	24 985	24 985	24 985	24 985
- Energy	10 228	10 228	10 228	10 228	10 228
- Facilities Rent	4 200	6 000	6 000	6 000	6 000
- Labour	129 993	129 993	129 993	129 993	129 993
- Maintenance	1 557	1 557	1 557	1 557	1 557
- General Excise Tax	1 050	1 500	1 500	1 500	1 500
Total Variable Costs	177 454	179 704	179 704	179 704	179 704
Fixed Costs					
- Equipment Depreciation	10 331	10 331	10 331	10 331	10 331
- Development Depreciation	20 817	20 817	20 817	20 817	20 817
Total Fixed Costs	31 148	31 148	31 148	31 148	31 148
Contingency	8 873	8 985	8 985	8 985	8 985
Total Operational Expenses	217 475	219 837	219 837	219 837	219 837
Interest Expense	46 099	45 819	45 511	45 172	44 799
Total Expenses	263 574	265 656	265 348	265 009	264 636
Net Income Before Tax	(53 574)	34 344	34 652	34 991	35 364
Income Tax	0	6 756	6 819	6 888	6 964
Net Income After Tax	(53 574)	27 588	27 833	28 103	28 400
Cost per Fry Before Tax	0.3125	0.2201	0.2198	0.2195	0.2192
Cost per Fry After Tax	0.3138	0.2270	0.2268	0.2266	0.2263

[1] The first five years of the Income Statement are exhibited in Table 6. Fixed costs remain constant after the second year based on straight-line depreciation and production cycles that are less than a year. Variations in net income after year two are due to declining loan interest expenses and increasing income tax accrued.

Economic consequences

Financial risk can be viewed as a contributing factor to economic risk. The economic impact on an industry reflects the cumulative financial consequences experienced by industry members. When examining economic consequences, or "economic risk," we are also concerned with the impact on other industries within a region or between regions of interest, generally with less concern for the individual farm financial details. An input-output model, for example, considers relationships between different industry sectors. An input-output model defines how output from one industry becomes input of another industry among different sectors for a cross-section of the economy. Based on the structure of the economy as it relates to product consumption, the impact of policies could be projected for a regional economy or national economy. A more detailed analysis could also include welfare assessments (i.e. consumer and producer surpluses) using econometric and welfare analyses.

Other consequences

Socio-economic consequences may also be considered when evaluating financial risk. Environmental damages, social impacts (e.g. employment and income distribution issues), and the effects on international and domestic trade are also valid measures to consider. Industry performance measures (e.g. proportion of farmers experiencing a loss or farmers receiving return on labour that is lower than the wage rate) may be useful measures when considering regional socio-economic agendas (Hambrey and Southall, 2002). Principles of utility and methods for defining evaluation criteria can help to consolidate social, economic and financial considerations. These methods will be discussed later in terms of risk management objectives.

The results of a release assessment, exposure assessment and consequence assessment are combined to form a risk characterization for a hazard (or multiple hazards). Financial consequences signify the difference between financial risk characterization from other forms of risk characterization. A financial risk analysis can be conducted for any hazard that contributes to a financial loss. Methods for estimating the financial loss, or risk estimation are discussed next.

Risk characterization

The process of risk characterization produces a risk estimate that reflects the consequences and likelihood of a hazard affecting a farm. Consequently, a risk estimate integrates the results of the release assessment, exposure assessment and consequence assessment. Financial risk characterizations quantify the relative impact of hazards in comparison to a baseline – ideal situation – where no hazard exists. When no baseline is available, the consequences associated with different hazards are often compared when making risk management decisions.

Financial risk cannot be measured by budgets or performance ratios because they are based on average values and do not account for uncertainty. Consequently, principles of financial analysis are a necessary first step in financial risk assessment. Since risk is a relative measure, a financial analysis is usually conducted first as the reference point for subsequent risk analysis. For risk analysis, methods for integrating aspects of uncertainty are needed. When characterizing financial risk, decision analysis methods allow us to consider uncertainty that affects the financial measures of interest.

Decision analysis refers to the body of methods used to rationalize and assist choices under uncertainty (Hardaker *et al.,* 2004). In addition to providing managerial decision support, decision analysis techniques encourage transparency of the problem, which is essential for risk communication. This section on financial risk characterization presents modelling uncertainty using decision analytic methods. The identification and evaluation of choices will be discussed further in the section on Financial Risk Management.

From a decision analysis perspective, there are two approaches to estimating uncertainty: probabilistic and non-probabilistic estimation. In probabilistic estimation, likelihood estimates and probability distributions are used to quantify uncertainty. In non-probabilistic estimation, uncertain events – for which the likelihood of occurring

TABLE 8
Common decision analysis methods for characterizing risk

Probabilistic estimation	Non-probabilistic estimation
• Probability trees • Bayesian networks • Stochastic simulation	• What-if (scenario-based) analysis • Sensitivity analysis • Break-even analysis

is not specified – are portrayed as scenarios. Common methods for probabilistic and non-probabilistic estimation are listed in Table 8 and described next.

Probabilistic risk estimation

The probability of release, exposure and the magnitude of the consequences must be determined in order to characterize risk. When using probabilistic methods to estimate financial risk, we assume that it is possible to assess the relative likelihood of uncertain events that have a financial impact (Hardaker *et al.*, 2004; Chavas, 2005).

Uncertainty is usually expressed in terms of probabilities that are based on either frequencies or degree of belief. These approaches are respectively referred to as frequentist and subjectivist views of probability. Savage (2003) provides an excellent tutorial on using probability to represent uncertainty. In the frequentist school of thought, probability is defined as a relative frequency ratio. From the subjectivist school, probability estimates define the degree of belief that the event will occur. The discussion on random variables given in Savage (2003) introduces statistical principles that are at the heart of risk analysis.

It is rare for a risk analysis to rely purely on historical data. Data alone may not reflect uncertainty about specific current and future situations. Consequently, risk analysts will utilize probabilities based on existing frequency data as well as subjective estimates to suit their analysis. As illustrated by Hardaker *et al.* (2004), market hazards such as the variation in grain price can be based on historical data. However, probability based solely on historical data could fail to take into account anticipated changes in grain price due to current international trade talks or similar pertinent issues.

BOX 3

Characterizing financial risk using probability trees: measuring the impact of infected imported shrimp products on farm profit

A hypothetical farm will receive an annual profit of US$ 512 940. When a WSSV outbreak occurs, the farm experiences a negative profit of -$1 574 710. The negative profit resulting from an outbreak reflects the production cost, broodstock loss and lost revenue from down-time and expenditures such as clean-up costs and start-up costs. These outcome values are represented in the terminal nodes located at the far-right of the tree.

The secondary nodes in Figure 6 suggest that the probability of an outbreak depends on whether WSSV-infected frozen commodity shrimp products are present (i.e. pathogens release in the environment). If infected products are present, the likelihood of a farm outbreak is 90 percent, and only 1 percent when infected products are not present. Based on this information, the expected value when infected products are present is 90 percent x -$1 574 710 + 10 percent x $512 710 = $1 365 945. At the left-most parent node, the expected value is based on WSSV hazard from infected frozen shrimp estimated at 16 percent. Using the same method for calculating expected values as before, the expected overall farm profit due to the WSSV hazard was not very optimistic at $196 640.

The potential loss due to the WSSV hazard is also useful in measuring risk. Using the $512 940 as the baseline profit for the farm, the cost of the WSSV hazard is $1 061 770 (= $1 574 710 - $512 940). This expected farm profit of $196 640 and potential loss of $1 061 770 reflects the farm financial risk due to probability of contamination by WSSV-infected products.

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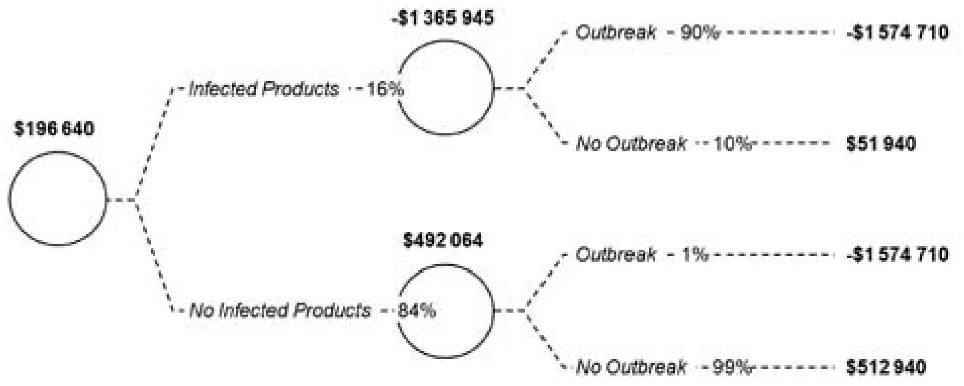
[1] McInerney, Howe and Schepers (1992) and McInerney (1996) define disease cost, or more generally, the cost associated with a hazard as the output loss + disease expenditure.

FIGURE 6

Probability tree for a simplified white spot syndrome virus (WSSV) import risk problem. Created with XLsim (AnalyCorp, 2002)



Created with XLsim (AnalyCorp 2002)

Financial risk can be characterized using expected values and uncertainty described by variability in the outcome. Probability trees, Bayesian networks and stochastic simulation are three approaches to calculating expected values and outcome variability for financial measures.

(a) Probability trees

A probability tree (or scenario tree) is a useful way of illustrating how expected values and their variability can characterize risk. Probability trees begin with an initial event and outline the various pathways and outcomes. Each fork signals that a mutually exclusive event will occur. In traditional probability trees, circles represent the chance nodes and the consequences (outcome values) are located in the far right. The outcome value at the end of each pathway represents the terminal wealth, in this case, the financial measure of interest (revenue, gross sales, net income etc.). The expected value at each fork is the sum of the probability of each event occurring multiplied by the corresponding consequences. In evaluating financial risk, a probability tree can be used to calculate the expected value, the average financial outcome and the range of financial outcomes. A demonstration of how a probability tree can be used for WSSV import risk characterization is given in Box 3 (based on Kam, 2006).

Even with the aid of software such as XLsim (AnalyCorp, 2002), it may be difficult for a risk analyst to identify every possible pathway and the associated financial consequences. Bayesian networks provide some relief from the burden of determining and manually accounting for the consequences of all pathways considered in a probability tree.

(b) Bayesian networks

A Bayesian network is a compact representation of a probability tree. Like probability trees, Bayesian networks consist of chance nodes represented as circles and consequence (or utility) nodes represented as polygons.[3] The relationships between nodes are specified by joint probability tables. A Bayesian network equivalent of the probability tree for the simplified WSSV import risk problem is exhibited in Figure 7.

Bayesian networks can be used to calculate the same expected value estimates as probability trees. The probabilities of complex pathways that are difficult to calculate in probability trees can be computed easily with Bayesian networks. Consequently, as problems become more complex, Bayesian networks may be a more eloquent way

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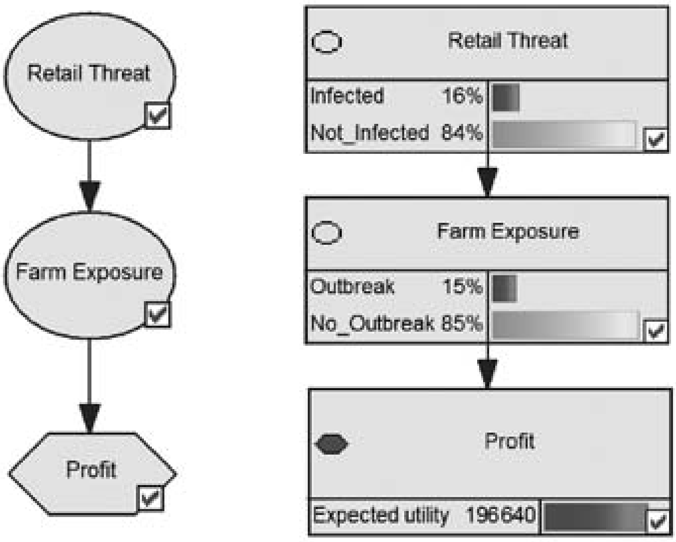
[3] In Bayesian networks, utility nodes are commonly represented as diamonds. The GeNIe software (2006) used for the exhibits adopted the convention of trapezoids to represent utility nodes.

FIGURE 7

Bayesian network example for a simplified white spot syndrome (WSSV) import risk problem. Created with GeNIe (DSL, 2006)



Release Assessment	Probability
Infected retail products	16%
Non-infected retail products	84%

Exposure Assessment	Infected	Not Infected
Outbreak	90%	1%
No outbreak	10%	99%

Consequence Assessment	Farm Profit (US$)
Outbreak	-$1 574 710
No outbreak	$ 512 940

of characterizing risk. Bayesian networks are also extremely efficient at calculating the joint and marginal probabilities that are useful for evaluating risky decisions.[4] For example, based on the Bayesian network results for the WSSV import risk problem in Figure 7, the 15 percent overall probability (marginal probability) of a farm exposure is evident. Bayesian networks also provide a visually succinct way of communicating the financial risk problem. Consequently, Bayesian networks have computational as well as conceptual benefits for complex models.

(c) Stochastic simulation

Stochastic simulation methods are useful when the financial risk is associated with complex relationships. When stochastic methods are used, the probabilities associated with each event are based on repetitive sampling (usually Monte Carlo sampling or Latin hypercube sampling) for a specific number of iterations based on specified input distributions. A detailed explanation of stochastic simulation methods can be found in Hardaker *et al.* (2004).

The input probabilities may be described by a variety of continuous distributions (e.g. triangular, normal, beta, log-normal, uniform) or discrete distributions (e.g. Poisson, exponential, user-specified). Since the input variables are defined as distributions, outcome variables are also characterized by distributions. Therefore, stochastic simulation permits us to characterize risk in terms of the expected value and the probability distribution of the financial outcome values of interest. A short example of a financial risk characterization for a tilapia farm is given in Box 4.

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[4] Discussed later in the section on Financial Risk Management.

BOX 4

Financial risk due to market and production variation – a bioeconomic stochastic simulation model for tilapia farm profitability

Engle and Neira (2005) demonstrated a stochastic simulation approach to modelling financial risk associated with market price and production variation for tilapia farms using Crystal Ball. Normal probability distributions were used for tilapia sale price and feed price (market variation). Production variation was modeled based on a triangle distribution for FCR. Triangular distributions are commonly used when there is insufficient information to define a normal distribution but the boundaries of the distribution (maximum and minimum) can be estimated.

The model demonstrates how stochastic simulation can be used to characterize risk based on the average net return/ha, potential range of net returns/ha range and the likelihood of profitability for a tilapia farms (i.e. positive net returns/ha). A 97 percent likelihood of positive profit is indicated by the portion of the distribution to the right of the dashed line in Figure 8.

BOX 5

Comparing financial risk due to production variation: using stochastic simulation to compare earthen pond and recirculating aquaculture systems (RAS) for shrimp production

Stochastic simulation was applied to a bioeconomic model for earthen pond and RAS shrimp production (Moss and Leung, 2006). Parameters for survival, mean harvest weight, mean growth weight and FCR were the sources of production uncertainty considered. Probability distributions were specified for each of these parameters based Based on the simulation results, the risk associated with each farming method was compared. As exhibited in Table 9, the average cost was higher for the earthen pond system than the RAS (US$ 7.04/kg vs $4.48/kg), and with a greater range of uncertainty (US$ 4.66–13.36 vs $3.51–5.97; Figures 9 and 10). Other statistical measures such as the coefficient of variation (CV = standard deviation/mean) can help to compare the risk associated with each system. For example, the earthen pond CV was higher than that of the RAS (0.189 vs 0.088), suggesting that the RAS is less risky financially. A comparison of the cumulative probability distributions suggests that the RAS systems are more efficient than the earthen pond systems (discussed later in Box 21).

Stochastic simulation methods are commonly used in conjunction with bioeconomic production models. A comparative cost analysis for shrimp, for example, was conducted by Moss and Leung (2006) for earthen pond systems and recirculating aquaculture systems (RAS). Production, variable and fixed cost assumptions were used to compute the cost of shrimp production to formulate a financial risk analysis for each system (see Box 5). Dalton, Waning and Kling (2004) studied market variations in electricity consumption, electricity price, wage rates and inflation parameters, as well as biological variations in survival rate and FCR. The cost per fish was compared for different combinations of production levels and feeding technologies. Valderrama and Engle (2001) studied the impact of variation in production, yield, shrimp price, seed cost, feed volume, feed price and fertilizer on shrimp farm profitability in Honduras. Their study used a variety of financial performance measures to assess financial risk, including gross receipts, total costs, net returns, net returns/ha, breakeven price and breakeven yield.

Eliciting probabilities is a challenge when complex interactions exist in a stochastic simulation model. Even when the interactions may be known intuitively, the joint

FIGURE 8

Probability distribution of net returns/ha (in Kenyan shillings, KSh) for a tilapia farm using pellet feed in Kenya

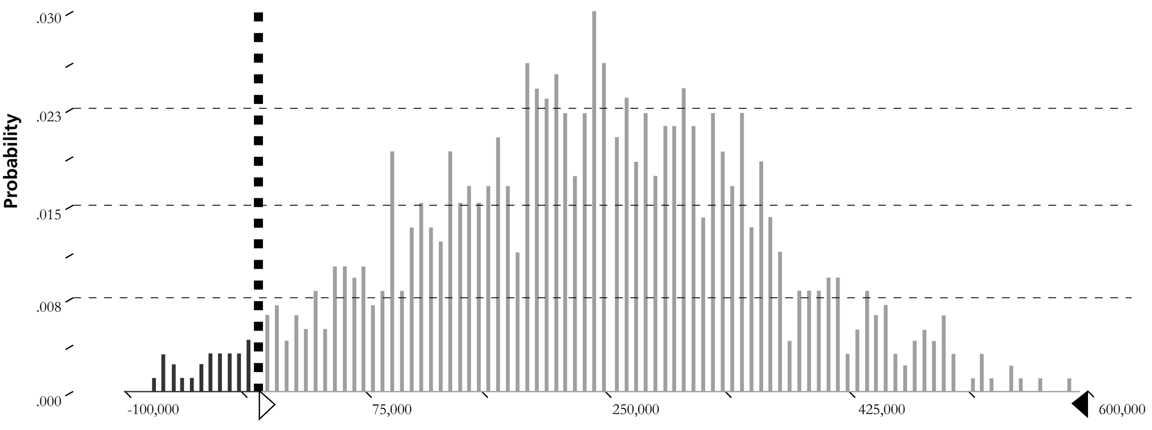


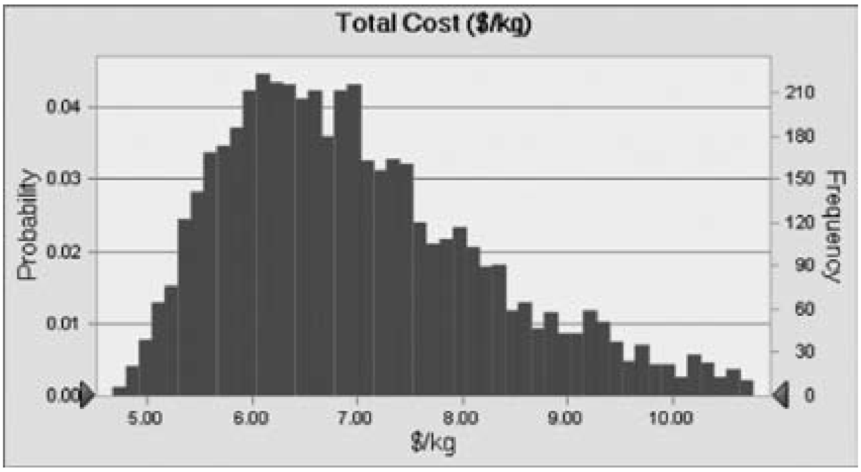
TABLE 9

Summary statistics for the sensitivity analysis of total, fixed, and variable costs (US$/kg)

Summary Statistic	Earthen ponds			Recirculating aquaculture system		
	Total	Fixed	Variable	Total	Fixed	Variable
Mean	7.04	2.56	4.48	4.48	1.29	3.19
Median (50 percentile)	6.80	2.45	4.34	4.45	1.27	3.18
Standard deviation	1.33	0.58	0.79	0.39	0.17	0.26
Coefficient of variation	0.19	0.23	0.18	0.09	0.13	0.08
Minimum	4.66	1.56	3.04	3.51	0.92	2.54
Maximum	13.36	5.00	8.51	5.97	1.90	4.09

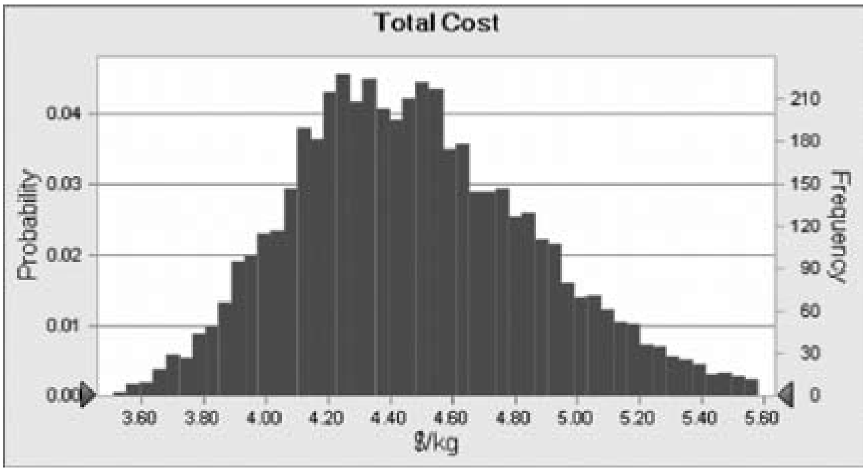
FIGURE 9

Distribution of total shrimp production cost for earthen ponds (US$/kg)



probability distributions can be difficult to define. If data are available, most stochastic simulation software packages will offer features to help fit a probability distribution to the existing data. Examples of financial risk assessments using stochastic simulation methods that rely on probability distributions fitted to industry data are shown in Boxes 6 and 7.

FIGURE 10
Distribution of total shrimp production cost for the recirculating aquaculture system (RAS) (US$/kg)



BOX 6

Using existing data to fit a probability distribution: a probabilistic risk analysis for the effect of prawn production yield on farm profitability

Probability analysis was used to study the impact of production yield variation on financial risk (Samples and Leung, 1986). Since a variety of factors (production costs, feed, water etc.) affect prawn production in a complex way, historical on-farm freshwater prawn data were used to fit probability distributions for three classes of pond size. Based on the data, a lognormal probability distribution was found to best model production variation for each class of farms. Financial risk was measured in terms of the average farm profit per surface hectare. Based on the results, the smaller ponds were more profitable (i.e. more efficient with their land) on average, but experienced greater risk reflected in the variation of profit (Table 10). Our perception of farm risk may be worsened by the fact that the right-skewness of the profit per hectare data (outcome variable) indicates that more farms experienced lower profits than the average of their class.

BOX 7

Using existing data to fit a probability distribution: a stochastic simulation for the effect of uncertainty on catfish farm profitability

Stochastic variables were used in a budget model to estimate financial risk for catfish farms in the Mississippi Delta (Kazmierczak and Soto, 2001). The stochastic variables used in the model were farmgate price, catfish yields and feed cost. BestFit (Palisade Corporation 1997) was used to approximate the distributions of prices and yields from historical data. Net returns were estimated for different size farms and culture methods (single-batch or multiple-batch). For both culture methods, the distribution for net returns (financial outcome variable) was negatively skewed beta distributions for each farm size. The results suggested that higher than average returns are likely for the farms modelled in the study. Further analysis suggested that economies of scale exist whereby larger farms have a lower cost of production.

TABLE 10

Selected statistical tests concerning the normality of freshwater prawn yields

Pond size	Profit $US/ha (Number of farms)	Standard deviation($US)	Coefficient of variation	Skewness
< 0.4 ha	2 308 (66)	878	0.38	1.105*
0.4–0.8 ha	2 038 (78)	585	0.29	1.432*
> 0.8 ha	1 813 (47)	523	0.28	1.967*

*p < .001

Non-probabilistic risk estimation

Risk can be characterized using probability estimates (probability trees and Bayesian networks) and probability distributions (stochastic methods) to model production and market uncertainty. Probability estimates are useful when expert knowledge or historical data are available. In contrast, non-probability estimates, described next, are useful when unprecedented situations and exploration is needed to characterize financial risk.

(a) What-if analysis

"What-if" analyses are useful for exploring different scenarios – sometimes called scenario-based analysis. A what-if analysis can be likened to exploring different paths of the probability tree, but without the probabilities or information about the likelihood of the scenario occurring. Scenarios can be used to describe multiple parameters that may change simultaneously. What-if analyses are particularly useful when the probability of each scenario occurring is unknown, i.e. not suited for probabilistic risk estimation.

An analysis of the effect of a farm's size is an example of a scenario-based analysis. When studying different size farms or production levels, the enterprise operations can change in terms of equipment, overhead (fixed costs) and operating costs (variable costs). Usually larger-scale production systems benefit from size economies as a result of production efficiencies (Kam *et al.,* 2002; Kam, Leung and Tamaru, 2006). However, this is not always the case, as found for prawn farms by Samples and Leung (1986) and for catfish farms by Kazmierczak and Soto (2001) (see Boxes 6 and 7).

What-if analyses are also useful for studying the feasibility of different production systems (e.g. pond, tank fishpond, earthen pond, recirculation system) (Kam *et al.,* 2003, Moss and Leung, 2006), feeding strategies (Kazmierczak and Soto, 2001) and scope of operations (Kam *et al.,* 2002). The what-if approach can be used to characterize the risk associated with different hazards as well as different degrees of hazard release (worst case, best case and most probable) as described in Box 8.

(b) Sensitivity analysis

Sensitivity analyses are useful for well-established production systems with clearly defined inputs and outputs (Hambrey and Southall 2002). Instead of using average (or typical values) to calculate profitability, a range of values is used for a parameter of interest. A sensitivity analysis usually consists of a table of values reflecting the range of possible values. Sensitivity is often communicated in the form of percentage changes, e.g. percent increase in profit with respect to the percentage change in cost. A sensitivity analysis helps to examine how changes in the variables representing the hazards of concern affect financial outcomes (e.g. profitability) and identify the most influential variables in a financial model. In some cases, results of a sensitivity analysis may be more useful than the financial measure determined by the model.

Sensitivity analyses are frequently used to study the impact that changes in market prices or biological parameters have on profitability. Posadas and Hanson (2006), for example, analyzed IRR sensitivity to nursery survival rates and weekly growth for shrimp. An example of a cost sensitivity analysis due to length of the nursery period

BOX 8

Using existing data to fit a probability distribution: a stochastic simulation for the effect of uncertainty on catfish farm profitability

Three scenarios were considered in evaluating the effect of disease risk on seabass and Atlantic salmon producer profitability (Thorarinsson and Powell, 2006). The impact of vaccination on operating income and net savings was examined for the worst case, best case and most probable level of unmitigated mortality due to disease. Based on the results of the analysis, vaccination was concluded to have a positive effect on operating income and net savings for the salmon producer. Seabass producers generally benefited from vaccination, except in the best case scenario (i.e. low disease mortality rate of 5 percent), where the cost of the vaccination could exceed the marginal benefit of decreasing the low level of mortality.

A sensitivity analysis was also conducted that compared market price with the changes in income. The results were used to determine the market price required by the seabass farmer to compensate for the additional cost of vaccination under each mortality scenario. A break-even analysis was used to estimate the minimum efficacy of the vaccination in order for the vaccination investment to be worthwhile. As expected from the what-if analysis results reported above, a seabass producer would require a higher potency (relative percent survival (RPS) of 25 percent) than the Atlantic salmon producer (RPS of 8 percent).

BOX 9

Using sensitivity analysis to identify significant threats to profitability: studying the effect of market and production uncertainty on offshore Pacific threadfin cage culture

A feasibility study for an offshore Pacific threadfin (*Polydactylus sexfilis*) cage production system was conducted for Hawaii (Kam, Leung and Ostrowski, 2003). The hypothetical six-cage system was based on the biotechnological requirements of and productivity demonstrated by the Hawaii Offshore Aquaculture Research Project (HOARP).

The total cost of production was estimated at US$ 3.97/lb for the production system projected to yield 914 271 lb of Pacific threadfin annually. The largest costs contributing to annual operating expenses of $3 626 556 were feed (30 percent), labour (17 percent), stocking (12 percent) and shipping (11 percent). Sensitivity analyses were conducted for several production hazards (average growth rate, stocking density, FCR and survival) and market hazards (feed price, sale price, seedstock price, leverage and loan interest rate) listed in Table 11. When comparing the sensitivity of multiple parameters, the changes in the parameter and outcome values are converted to percentages with respect to a baseline value. When percentages are used for the sensitivity analyses, the most sensitive parameters can be determined based on the largest of the unitless measures. Based on the results in Table 12, production costs are most sensitive to increased stocking densities, survival rates and average growth rates. Using the sensitivity information, management can determine which parameter values can be feasibly changed in order to reduce production costs by a desired amount.

In Figure 11, the changes in the average daily growth rate (horizontal axis) are compared to production cost and IRR. The graph is useful for determining the growth rate needed to achieve a desired rate of return. For example, in order to achieve a 20 percent rate of return, fish growth must reach an average of 3.5 g/day, resulting in estimated production cost of $3.31/lb.

BOX 10

Comparing the sensitivity of multiple parameters: a sensitivity analysis comparing milkfish production systems on profitability

Kam *et al.* (2003) conducted economic evaluations of three different commercial milkfish (*Chanos chanos*) growout systems in Hawaii. Cost structures and spreadsheet models were developed for a tank, pond and Hawaiian fishpond system (Table 13). Based on the observed practices of milkfish culture as a secondary or tertiary crop, capital costs and several operating costs were prorated to accurately depict current farm practices. The results of this study were consistent with the Hawaiian farmers' perspective toward milkfish as a species that is secondary to core production based upon current market conditions and input requirements.

A profit sensitivity analysis of the pond and tank systems with respect to sale price, production yield, labour, feed and stocking indicated that sale price, as expected, had the largest impact on profitability, followed by feed (Figures 12 and 13). The pond system was also more appealing based on the incremental returns to variable costs for percent change in the sale price in comparison to the tank system (Table 14). Cost and profit sensitivity to the level of milkfish production were also evaluated, but are not presented here.

was illustrated in Box 2 as part of the Pacific threadfin hatchery case study. In Box 9, profit sensitivity to changes in market and production uncertainty is illustrated for Pacific threadfin cage culture.

A sensitivity graph can visually demonstrate the relationship between two variables. A spiderplot displays multiple sensitivity plots for different input parameters (e.g. average growth rate, stocking density, FCR, price) as percentages against an output performance variable such as net income. Consequently, spiderplots are used to identify which of the parameters have the largest influence on performances. Examples of spiderplots for tank and pond milkfish production systems can be found in Box 10.

(c) Break-even Analysis

Sensitivity analyses are also useful for determining breakpoints and threshold values, as seen in the earlier fish vaccination example in Boxes 8 and 9. This form of analysis is called a break-even analysis, where only the value of a single parameter is determined. Annual revenue and expenses, rate of return, market (or salvage value) equipment life and capacity utilization are common factors studied in break-even analyses (Sullivan, Wicks and Luxhog, 2007). Break-even analyses are sometimes considered a special case of sensitivity analysis. These critical values, or switching values, indicate where values of certain parameters may trigger unacceptable outcomes (Hambrey and Southall, 2002). Boxes 11 and 12 include break-even analysis examples that reflect the critical values needed to be profitable.

Commentary on quantitative perspectives

Deterministic methods presume that the consequences associated with a hazard are precisely known. Deterministic estimates do not account for uncertainty. Consequently, the deterministic case is usually considered as the baseline situation for comparative purposes. The label "non-probabilistic" risk estimation was used in our discussion to indicate that uncertainty is present, but is difficult to approximate using probability estimates.

Other quantitative methods exist aside from the probabilistic, non-probabilistic and deterministic approaches previously described. In fuzzy set theory, events are not

TABLE 11
Parameter ranges for sensitivity analyses

Parameter	Minimum	Baseline	Maximum
Average growth rate	1.50 g/day	2.29 g/day	3.50 g/day
Stocking density	80.77 g/m^3	109.04 g/m^3	484.62 g/m^3
FCR	1.00	2.39	2.50
Feed price	US$ 0.25/lb	US$ 0.50/lb	US$ 0.75/lb
Sale price	US$ 2.00/lb	US$ 4.00/lb	US$ 5.00/lb
Seedstock price	US$ 0.20 ea	US$ 0.29 ea	US$ 0.35 ea
Survival	50%	61.8%	100%
Leverage (% borrowed)	0%	0%	100%
Loan rate (30 years)	6%	–	12%

TABLE 12
Production cost sensitivity to parameter changes

Parameter	Average % Change in production cost for a % increase in parameter	Baseline (= 100%)	Minimum (change from baseline, %)	Maximum (change from baseline, %)
Average growth rate	- 0.36	2.29 g/day	- 34.6	+ 52.6
Stocking density	- 0.10	109.04 g/m^3	- 25.9	+ 344.4
Food conversion ratio (FCR)	+ 0.32	2.39	- 58.2	+ 4.6
Feed price	+ 0.32	US$ 0.50/lb	- 50.0	+ 50.0
Sale price	+ 0.03	US$ 4.00/lb	- 50.0	+ 250.0
Seedstock price	+ 0.14	US$ 0.29 ea	- 31.0	+ 20.7
Survival	- 2.74	61.81%	- 19.1	+ 61.7

treated as mutually exclusive, but as having membership (association) with a other events (Bezdek 1996). Consequently, fuzzy sets convey information about similarities as opposed to relative frequencies. These quantitative perspectives are contrasted in Table 17.

Like a bioeconomic model, financial risk characterization links production and financial (economic) parameters. When the relationships between a hazard and its financial consequences are formalized in a risk characterization, it is possible to systematically compare alternative strategies. These linkages are generally specified during the financial risk assessment (release assessment, exposure assessment and consequence assessment).

BOX 11

Using sensitivity analyses and break-even analysis to assess critical values: tilapia farm net return sensitivity to feed price, survival rate and farm size

Engle and Neira (2005) provide examples of sensitivity and break-even analyses conducted for tilapia budgets by varying feed prices, survival rate and farm size. Useful information can be drawn from the analyses exhibited in Table 15(a-c). For example, it is possible to conclude from Table 15a that as feed prices increased from Kenyan shilling (KSh) 8/kg to KSh 16/g, net returns/ha decreased from KSh 397 812 to KSh 84 284. Breakeven sale prices increased from KSh 62/kg to KSh 92/kg. In Table 15b, as the survival rate increased from 75 percent to 95 percent, net returns/ha increased from KSh 149 533 to KSh 274 920 and break-even prices above total costs decreased from KSh 83/kg to KSh 75/kg. In Table 15c, as farm size increased from 0.5 to 8 ha, net returns/ha increased from KSh 228 445 to KSh 251 803, and break-even prices above total costs decreased from KSh 156/kg to KSh 9/kg.

FIGURE 11

Production cost (US$) and internal rate of return (IRR) sensitivity to changes in stocking density

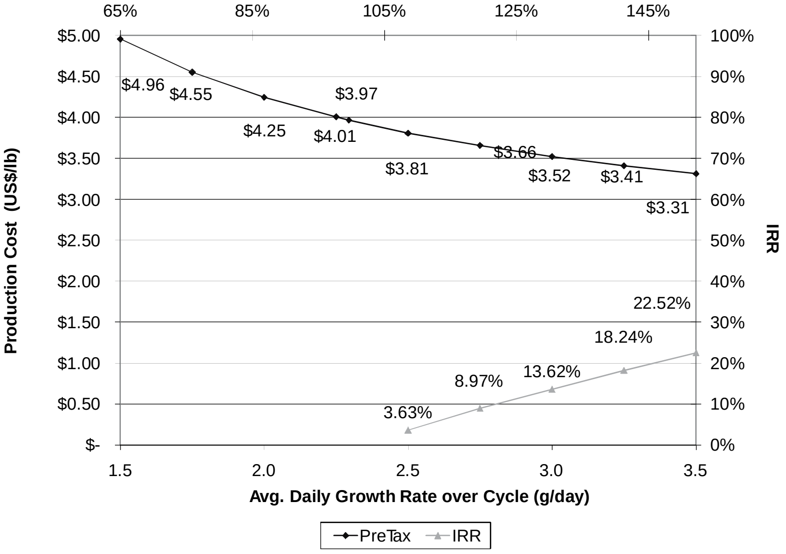


FIGURE 12

Profit sensitivity for a pond production system.

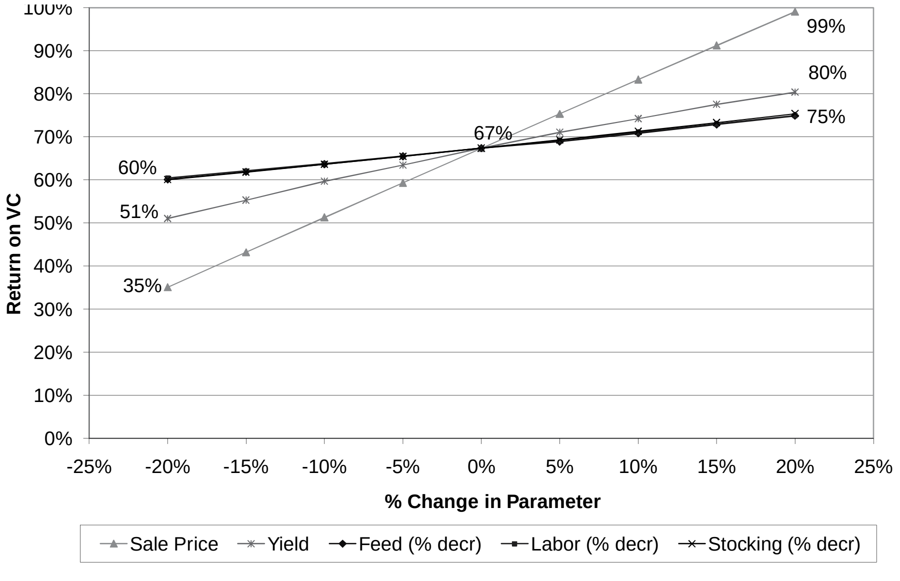


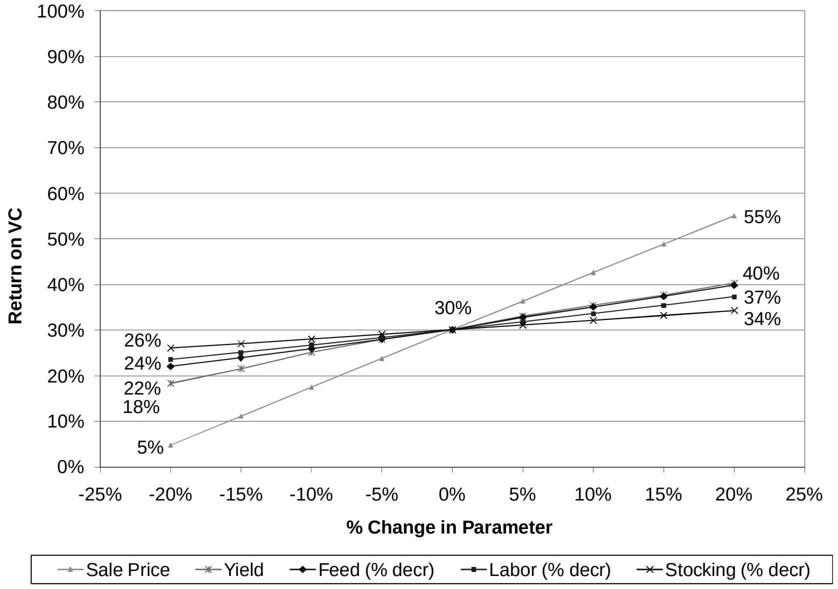
TABLE 13

Profitability of the three systems evaluated

Profitability Measures	Pond	Tank	Fishpond
IRR	[1]	[1]	192.35 %
NPV (US$)	$ -362 456	$ -124 189	$ 407 132
Marginal return (Rev-VC, US$/lb)	$ 1.20	$ -0.04	$ 1.46
Return on VC	67%	30%	59%
Return on TC	-9%	-21%	49%

[1] IRR value not available because NPV < 0

FIGURE 13
Profit sensitivity for a tank production system



% decr = percent decrease

BOX 12

Using break-even analysis to assess critical values: determining off-shore aquaculture production requirements needed in order to be profitable

A break-even analysis was conducted using an enterprise budget model developed for the Pacific threadfin off-shore aquaculture enterprise described in Box 9. The minimum value required to achieve a desired 20 percent 20-year IRR was determined using the Goal Seek feature in Microsoft Excel.

Based on the results of the break-even analysis in Table 16, the parameter that would require the smallest percentage change was the sale price, followed by improving survival rates. Since sale price may be out of the control of the manager, he may consider improving production methods, striving to achieve a 90.25 percent survival rate or a growth rate of 3.35 g/day. Other production measures require greater change in terms of percentages. Managerial insight would be needed to determine which parameters can be realistically improved in order to earn a 20 percent IRR.

TABLE 14
Profit sensitivity (return to variable costs) for pond and tank production systems

	Pond production		Tank production	
Parameter	**Baseline**	**Return on VC/ % Change in parameter**	**Baseline**	**Return on VC/ % Change in parameter**
Sale price	US$ 3.00/lb	+ 1.60%	US$ 3.00/lb	+ 1.25%
Yield (density)	10.00 fish/m^3	+ 0.74%	100.00 fish/m^3	+ 0.61%
Labour	797.17 hr/yr	- 0.36%	594.43 hr/yr	- 0.34%
Stocking (fry price)	US$ 0.25 ea	- 0.38%	US$ 0.25 ea	- 0.20%
Feed (FCR)	0.75	- 0.37%	1.50	- 0.42%

TABLE 15

Sensitivity analyses and break-even analysis

(a) Effect on net returns and break-even price above total cost of varying feed prices

Feed price (KSh/kg)	Net returns (KSh/kg)	Break-even price (KSh/kg)
8	397 812	62
10	319 430	69
12	241 048	77
14	162 666	92

(b) Effect on net returns/ha and break-even price above total cost of varying survival rates

Survival rate (%)	Net returns (KSh/kg)	Break-even price (KSh/kg)
75	149 533	83
80	181 005	81
85	241 048	77
95	274 920	75

(c) Effect on net returns/ha and break-even price above total cost of varying farm size

Farm size (ha)	Net returns/ha (KSh/kg)	Break-even price (KSh/kg)
0.5	228 445	156
1.0	241 048	77
3.0	249 256	25
5.0	250 898	15
8.0	251 803	9

TABLE 16

Parameter values required for profitability

Parameter	Minimum	Baseline (= 100%)	Maximum	Value required for profitability (> 20% IRR)	Change from baseline (%)
Average growth rate	1.50 g/day	2.29 g/day	3.50 g/day	3.35 g/m^3	+ 46.3%
Stocking density	80.77 g/m^3	109.04 g/m^3	484.62 g/m^3	177.36 g/m^3	+ 62.7%
FCR	1.00	2.39	2.50	0.89[1]	- 62.8%[1]
Feed price	US$ 0.25/lb	US$ 0.50/lb	$ 0.75/lb	US$ 0.18/lb	+ 64.0%[1]
Sale price	$ 2.00/lb	$ 4.00/lb	$ 5.00/lb	$ 4.88/lb	+ 21.8%
Seedstock price	$ 0.20/lb	$ 0.29 ea	$ 0.35 ea	–[1,2]	–[2]
Survival	50.00%	61.81%	100.00%	90.25%	+ 46.00%

[1] Parameter value required for 20% 20-year IRR outside of sensitivity range.

[2] Seedstock price required <US$ 0.00 ea, % change not feasible. (A fry sale price of US$ 0.00 ea yields a 14.44% IRR).

TABLE 17

Contrasting the perspectives of different quantitative approaches

Quantitative methods	Perspective
Deterministic	Certainty exists (no uncertainty, no risk)
Probabilistic	Uncertainty exists and is approximated
Non-probabilistic	Uncertainty exists and is explored
Fuzzy sets	Uncertainty viewed as membership with one or more states

FINANCIAL RISK MANAGEMENT

Risk assessments inform risk management, the process of evaluating and reducing risks. Risk reduction will depend on the risk management evaluation criteria or financial objectives. Financial risk management implies that something can be done to reduce risk with respect to the financial risk objective. The basic process of financial risk management includes:

- defining the risk management objective(s),
- specifying the decisions that may reduce or remove the hazards, and
- selecting an evaluation and monitoring method.

Risk management objectives

Risk management evaluation criteria are usually based on the outcome measures identified in the consequence assessment. As suggested earlier, financial risk assessment objectives are usually based on measures of profitability. In the shrimp production example in Box 5, the earthen pond system was compared with the recirculation system based on production cost. In this example, cost minimization could be a risk management objective, and the decision would entail choosing between the earthen pond system or recirculation system. A short list of possible risk objectives is presented in Table 18.

Expected utility maximization

The emphasis of the consequences or the evaluation criteria considered thus far has been monetary in nature. In decision analysis, the criteria can be a single attribute such as profit or represent multiple attributes. One common method for combining or converting values into a general measure of utility is through the use of an additive weighting scheme. According to the principle of rational choice, we prefer alternatives that maximize our expected utility. The expected utility maximization principle is conventionally used in decision analysis.

Risk aversion

When a decision-maker is assumed to have a risk-neutral attitude, a simple additive weighting scheme is used. Risk-aversion and risk-seeking attitudes require that risk be embedded into the weighting scheme. Utility is a flexible measure that can incorporate monetary and subjective criteria. Risk attitudes, for example, can be used to adjust traditional profit-maximizing analyses to reflect risk-averse behaviour (Jin, Kite-Powell and Hoagland, 2005). For example, when faced with greater risk, risk aversion may increase and our investment level will decrease. The evaluation methods previously discussed include methods for balancing the trade-off between profit-maximizing objectives with uncertainty. A demonstration of subjective expected utilities methods can be found in Hardaker *et al.* (2004).

Precautionary principle

The precautionary principle reflects a preventive approach to risk management. The precautionary principle can be contrasted with "monitor-response" regulatory

TABLE 18
Examples of risk management objectives and decisions

Risk management objective	Examples of decisions to mitigate risk	
	Action decisions	Test decisions
• Maximize profit • Minimize production cost • Minimize revenue (production) loss • Minimize environmental impact • Maximize employment • Poverty reduction	**Production Threats** • Crop diversification • Harvesting schedule • Production contracts • Crop insurance • Vaccination • Biosecurity practice • Yield (revenue) insurance **Market Threats** • Direct marketing • Leasing inputs • Enterprise diversification • Marketing contracts • Hedging in futures • Futures options contracts • Government subsidy • Rural development programmes • Vertical integration	• Biosurveillance • Agricultural inspections • Monitoring • Equipment maintenance • Water quality monitoring

frameworks, which can be viewed as a weak approach since the damage will have already been done. According to Hambrey and Southall (2002), the reactive approach is a "permissive principle" that is dangerous when considering hazards whose impacts are persistent and irreversible. The precautionary principle can be found as Principle 15 of the Rio Declaration of the United Nations Conference on Environment and Development (UNCED). The principle explicitly states that "*where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*"

At the surface, the precautionary principle could appear to reduce our confidence in methods highly regarded as having scientific rigor. Yet, by taking into account the precautionary principle, it is still necessary to identify cost-effective measures to prevent irreversible damage. Therefore, from the precautionary principle perspective, risk management methods will not seek to determine if any preventive measures should be taken, but rather which preventive measures should be carried out.

The Safety-First Rule

The "safety-first approach" is a form of lexicographic utility that is commonly used in risk analysis. As an alternative to expected utility maximization rules, the approach specifies that decisions must preserve the safety of a firm's activities, followed by a profit-oriented objective. Robison *et al.* (1984) outline the three safety-first criteria for use in risk management (see Box 13).

Management Decisions

Risk management explores alternative strategies that potentially reduce consequences, examines the feasibility of implementing measures and involves periodic review of the effectiveness of policies implemented. The alternative strategies can be classified as action decisions and information decisions. Action decisions remove or reduce hazards to reduce risk – the potential for negative consequences. Test decisions gather evidence to inform action decisions (Jensen 2001). This perspective of risk management, referred to as the "test-action" risk framework is illustrated in Figure 14.

Most risk assessment frameworks do not permit a systematic comparison between different kinds of intervention and existing farmer/fisher activities (Hambrey and Southall, 2002). However, the test-action risk framework has been demonstrated to be general enough to compare the effectiveness of different risk management strategies and compare the relative risk between hazards (Kam, 2006).

BOX 13

Safety-first rules

1. Choose an alternative that maximizes expected returns ($\bar{E}$),
   where the probability of a return less than a specified value (E_{min}) does not exceed a stipulated probability (P).
   $\mathbf{Max\ \bar{E},\ s.t\ P(E \leq E_{min}) \leq P}$
2. Choose an alternative that maximizes income at the lower confidence limit (L),
   where probability of the a lower income does not exceed a stipulated probability (P).
   Max L, **s.t.** $P(E < L) \leq P$
3. Choose the plan with the smallest probability of yielding a return below specified level (E_{min}).
   $\mathbf{Min\ P(E < E_{min})}$

Actions to remove or reduce hazards

The financial risk characterization examples given in the preceding section on Risk Characterization illustrated a number of comparative analyses. Such comparisons are useful for financial risk management and can be viewed as action decisions to remove or reduce hazards. In the shrimp production cost analysis in Box 5, for example, an enterprise may use the risk analysis to decide between earthen pond or recirculation system methods. Feed types (Box 1), production length (Box 2), species (Box 8) and production level (Box 11) are also examples of risk management decisions that could improve profitability.

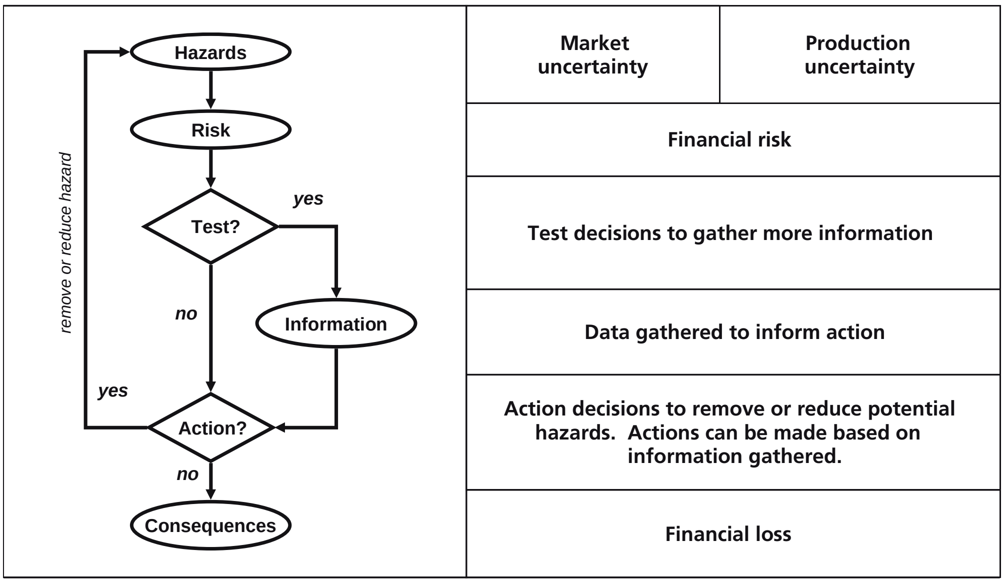
Farm enterprises can reduce financial risk in a number of ways. Farmers can reduce production threats by diversifying their product mix, changing their scale of production and re-allocating resources. The financial structure of the farm can be adjusted to combat market threats (e.g. a change in financial leverage will cause a change in the debt to equity ratio). Yield insurance is a preventive means of mitigating financial risk. In exchange for a fixed insurance premium, producers will receive protection from uncertain but potentially large losses. Like market interest rates, insurance premium rates may be based on the insured's return to productive capital, adjustment reflecting a positive rate of time preference, premium for expected inflation and a risk premium (Goodwin and Mishra 2000).

Examples of managerial decisions concerning direct marketing and biosecurity policies can be found in Annex I. Harwood *et al.* (1999) detail a number of management actions to reduce risk; other examples of action decisions to reduce risk are given in Table 18.

Tests to gather information

Tests are performed to gather information that is used to inform decisions. In risk assessment, an informative test results can reduce uncertainty and be used to revise release and exposure estimates and the expected utilities of subsequent decisions. Based on the revised expected utilities, a decision-maker might proceed with a management plan that reduces potential financial loss.

FIGURE 14
Risk management viewed as a test and action decisions to reduce consequences



Test information is not usually free. Monitoring, biosurveillance, forecasts and laboratory analyses are examples of test decisions. Test decisions might incur expenses associated with labour, materials or revenue foregone. Ideally, the cost of a test will not exceed the potential financial benefit. An example of a biosecurity risk problem considering biosurveillance as a strategy can be found in Annex I. Another example of a test decision will be presented in the section on Decision Trees and Baysian Decision Networks.

Evaluation methods

In the previous section on Risk Characterization, a number of decision analysis methods were employed for risk characterization. The following sections briefly introduce some methods for evaluating financial risk management decisions using decision analytic methods.

Decision trees and Bayesian decision networks

A common method to represent decision scenarios (a series of test and action decisions) is to use decision trees. Decision trees are an extension of probability trees (previously introduced in the section on Probabilistic Risk Estimation). Decision forks are indicated by squares and can occur at any point along the sequence of events. At each decision fork, managers can make a decision that maximizes the expected value (or utility).

Many decisions are difficult to model with traditional decision trees because decisions and outcomes are rarely linear or independent of one another. Test and action decisions can occur at different stages and in a variety of combinations. For complex models using decision trees (DTs), analysts must compare the probabilities of all branches of the tree. In contrast, Bayesian decision networks (BDNs) provide a succinct representation that clearly indicates the independencies of the model and efficiently estimates complex probabilities that are difficult for decision trees.

Both DTs and BDNs are used to analyze the impact of a sequence of test and action decisions to manage risk. In managing financial risk, we seek to determine parameter values that maximize profitability or to identify parameters that could have a strong influence on profitability. An example of the simple WSSV import risk model is presented as a decision tree and a Bayesian decision network in Box 14.

The value of test information can be calculated using DTs and BDNs. As demonstrated in Box 14, it is possible to observe the "break-even" point that would cause a decision-maker to not to ban imported products. A calculation of the value of information (VOI) for test-decisions such as biosurveillance or monitoring can provide valuable information about the amount that an individual would be willing to pay for the expected change in outcome. The expected value of information can serve as a measure of the importance of the uncertain parameter.

In VOI analysis, the results of test-decisions are fed back into a model (DT or BDN) to inform subsequent decisions using Bayesian inference. The feedback is accomplished by inverting a DT (or message passing in BDNs) and exploiting Bayes theorem to calculate the *a posteriori* probabilities. Research by Forsberg and Guttormsen (2006), presented in Box 15, studied how the value of price information could be used to influence production planning. An example of the measurement of the value of biosurveillance is discussed in Annex I.

Risk programming

Risk programming is frequently used in agriculture for whole-farm planning and also has a long history of use in aquacultural farm management. Risk management studies concerning stocking densities, scheduling decisions, level of intensity, scale of production, level of investment and disease management have employed risk programming methods (Hatch *et al.,* 1987; Hatch and Atwood, 1988; Kusumastanto,

BOX 14

Risk management using decision trees (DTs) and Bayesian decision networks (BDNs): movement restriction decisions affecting farm profit

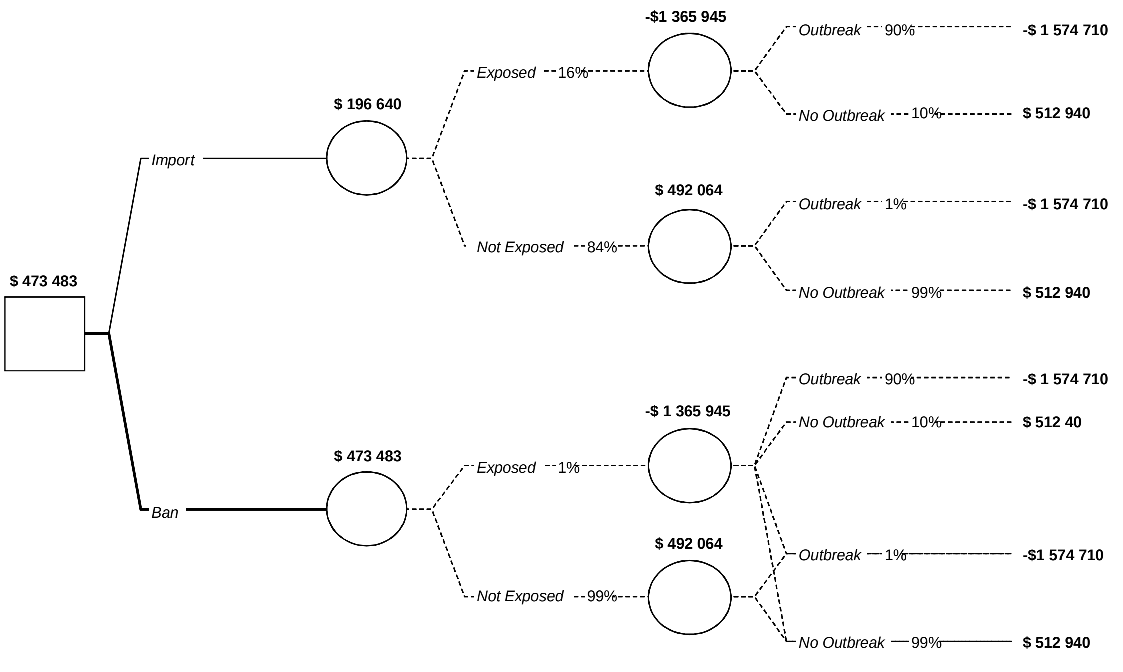
In the simple DT for the policy of a movement restriction (Figure 15), the expected utility associated with a ban is US$473 483 for the farm. Therefore, from the farmer's perspective, an import ban is preferred rather than no movement restriction at all (farm income of $196 640). These findings can also be represented in the form of a BDN in Figure 16.

In this simple movement restriction example, the cost of the ban was not explicitly stated. However, based on the decision tree, the value of the import ban is $473 483 - $196 640 = $276 843. This reflects the maximum value that a decision-maker would be willing to pay before the alternatives have an equivalent expected value.

This can be easily seen if we associate a cost with the movement restriction equal to $273 843. This equality can be seen in the expected values estimated for the movement restriction decision in Figure 17. (The expected values of the movement restriction are not exactly the same due to rounding error.) Adding a cost for the movement restriction requires a few more steps in a decision tree than in a Bayesian decision network. For the decision tree, the cost would have to be incorporated into the right-most terminal nodes along the movement restriction "ban" path.

FIGURE 15

Decision tree for a movement restriction for frozen commodity shrimp



Jolly and Bailey, 1998; Valderrama and Engle, 2004). The objectives usually seek to maximize profit subject to farm resource constraints and other restrictions.

Risk programming utilizes a sophisticated set of algorithms to find an optimal solution to a set of constraints expressed as equalities and inequalities. Risk programming is an extension of traditional mathematical programming methods (see Annex II and Box 16 for examples). In comparison to linear programming, which seeks to optimize

FIGURE 16
Bayesian decision network for a movement restriction for frozen commodity shrimp

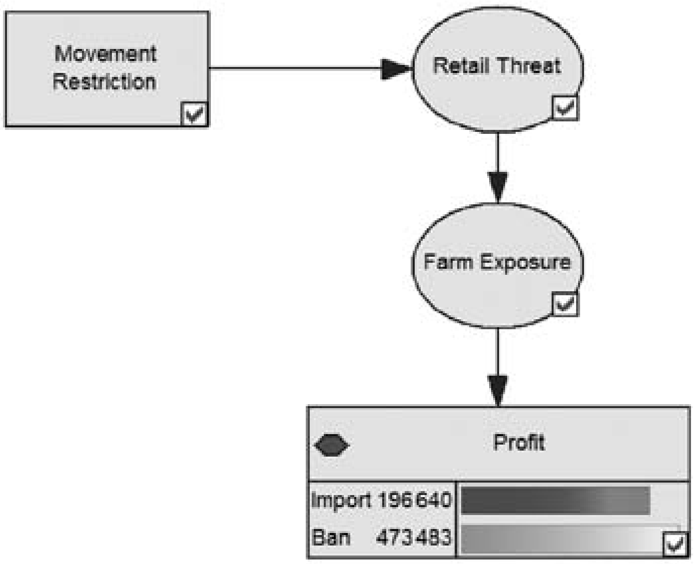
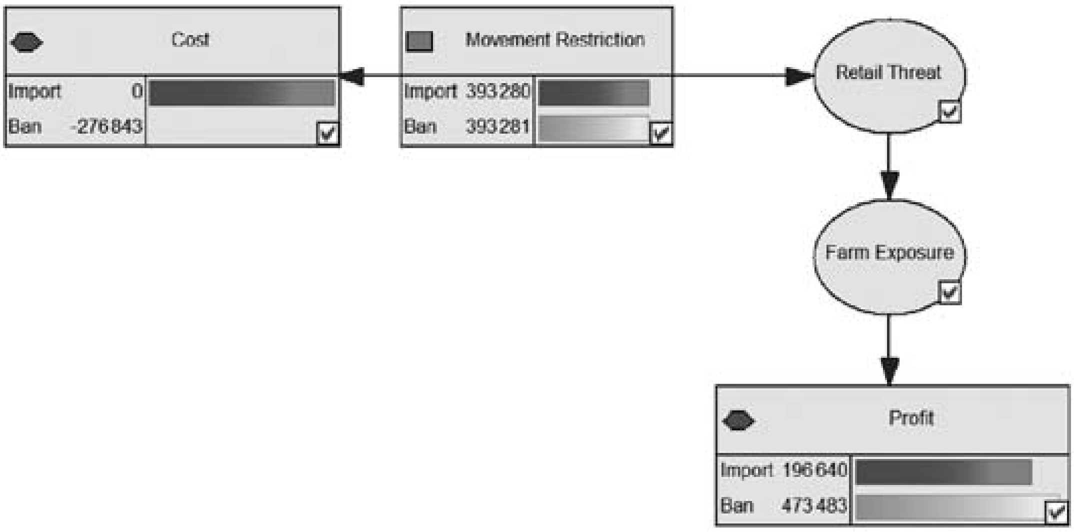


FIGURE 17
Using a Bayesian decision network to determine the decision cost (US$) in which the alternatives are equivalent



(e.g. profit-maximize), risk programming oftentimes seeks to minimize uncertainty in the outcome performance metric. Additional information about risk programming and mathematical programming models can be found in Hardaker *et al.* (2004).

(a) E-V efficiency

Expected value-variation efficiency (E-V or mean-variation efficiency) frontiers are often used to inspect an efficient set of solutions. Efficiency analyses are useful when the preferences are unknown. In E-V efficiency, an alternative *A* is preferred to *B* if the

BOX 15

Value of information analysis. Estimating the value of price information on salmon farm profit

A salmon farm harvesting model was developed by Forsberg and Guttormsen (2006). The impact of price uncertainty on harvesting decisions and farm profit was examined. The premise of their study was based on the notion that price information could be used to determine if it is more profitable to harvest (and sell) now or postpone harvesting. If a salmon farmer knew that the salmon price would go down or remain constant, a farmer would opt to harvest and sell his products. Alternatively, if he found that the price would increase in the future, he would postpone harvesting until that time. Consequently, DTs can be used to estimate the value of the market price forecast – even in cases where the forecast may not be perfect.

The management objective was to maximize NPV. The decision variables was a batch harvesting decision. The optimal harvest plan was determined for four scenarios:

Scenario 1: Constant price per kg regardless off fish size
(baseline scenario = no information)
Scenario 2: Seasonal adjusted prices, same price regardless of fish size
(imperfect information A)
Scenario 3: Seasonal adjusted prices, dynamic weight dependent
(imperfect information B)
Scenario 4: Actual prices (perfect information).

For each scenario, the value of information (forecast model) is equal to the difference between the optimal harvest of the scenario, e.g. $\bar{E}2$, and the optimal harvest of the baseline scenario, $\bar{E}_1$. VOI = $\bar{E}_2 - \bar{E}_1$. The VOI estimates for each of the information scenarios are presented in Table 19, where perfect price information is the most expensive. Based on the results of the analysis in Table 20, a farmer would be willing to pay at most 165 Norwegian kroner (NKr) for the forecasted price information in scenario 2, and 313 NKr for the forecasted price information in scenario 3.

BOX 16

Linear programming for a network scheduling model: using linear programming measuring managerial decisions on profit and effluent discharge

A linear programming model was used by Engle and Valderrama (2004) to compare Best Management Practices (BMPs) on farm profitability (net returns/ha) and net nutrient discharge for semi-intensive shrimp farms in Honduras. The decision variables included stocking density, duration of grow-out cycle and water exchange strategy. In comparison to most studies that examine profit under production constraints, the BMP study also considered compliance with effluent discharge limits as a constraint. The study revealed the burden of additional fixed costs associated with implementing the BMPs, particularly for smaller farms.

expected utility (E) of A is greater or equal than B, and the variance (V) of A is equal or less than B, i.e. $E_A \geq E_B$ and $V_A \leq V_B$. The E-V efficient set includes only non-dominated alternatives. The E-V approach is commonly used in optimal investment portfolio problems, and likewise for analogous resource allocation problems. In conducting an E-V analysis, each alternative is plotted in two-dimensional E-V space, where the expected utility is on the vertical axis and the variance is measured along the horizontal axis. An alternative is said to be E-V efficient if there is no other alternative that lies in its "north-western" quadrant. An illustration from Hardaker *et al.* (2004) is given in Box 17.

TABLE 19

Harvesting plan, profit and value of information (VOI) for different price scenarios and fish groups

	May	September	October	Profit (in NOK) [2]	VOI [3]
Scenario 1					
Group 1			103 (5.3 kg)		
Group 2			122 (6.3 kg)	279 000	baseline
Group 3		68 (6.5 kg)	64 (7.2 kg)		
Scenario 2					
Group 1	54 (2.6 kg)[1]				
Group 2	66 (3.2 kg)			444 000	165
Group 3	78 (3.8 kg)				
Scenario 3					
Group 1		62 (4.7 kg)	34 (5.3 kg)		
Group 2			122 (6.3 kg)	592 000	313
Group 3			139 (7.2 kg)		
Scenario 4					
Group 1		92 (4.7 kg)			
Group 2		109 (5.6 kg)		1 279 000	1 000
Group 3		125 (6.4 kg)			

[1] Average weight of the harvested fish in parentheses.

[2] Profits from operation in the planning period, i.e. (Sales income – Variable cost) – Value of the fish by January 1.

[3] VOI is extra profit compared to scenario 1.

BOX 17

E-V efficiency analysis: comparing alternative crop rotation methods

In an example from Hardaker *et al.* (2004), the impact of crop rotations (alternatives K, J, I, F, G, H) on profit was demonstrated. Based on the E-V plot in Figure 18, the alternatives I, J and K are non-dominated and comprise the E-V efficient set that a manager may choose from. The manager's choice will depend on his attitude toward risk. The lines corresponding to utility levels (where, $U_1 < U_2 < U_3$) are iso-utility (indifference) curves. The angle of the curves represents typical risk aversion attitudes.

E-V efficient frontiers are also suitable for non-linear programming models. Non-linear programming, including quadratic programming methods, is used when the utility functions are non-linear, outcome performance values are not normally distributed or risk aversion exists for larger consequences. A similar method considers standard deviation as a measure of uncertainty, called E-S efficiency. (Standard deviations are equal to the square root of the variance and measure the actual units of the performance measure.) In E-S efficiency, any alternative is dominated if another alternative is above and to the left in E-S space. The linear equivalent of E-V efficiency considers the mean absolute deviation, described next.

(b) MOTAD

In contrast to the use of variance or standard deviation in E-V and E-S efficiency, MOTAD (Minimization of Total Absolute Deviations) represents uncertainty as the mean absolute deviation, M. The use of the mean absolute deviation is often desired because a simpler linear program is required for the solution. In MOTAD the total deviations are averaged using the probabilities of the states. The mean absolute deviation is used as a constraint for the problem, and the linear program is solved for various values of M. The initial value for the constraint is set arbitrarily high and solved for progressively smaller values of M. An E-M efficient frontier, however, only provides approximation of the E-V frontier. A variation called Target MOTAD programming follows the same process, however, a target income is set, and the mean deviation from the target *d* is the uncertainty constraint. An example of target MOTAD risk programming is exhibited in Box 18. A variation on MOTAD programming for measuring financial risk in aquaculture that been conducted for multiperiod planning (Kusumastanto, Jolly and Bailey 1998) is given in Box 19.

(c) Scheduling

Risk programming is frequently used to mitigate price risk and yield risk. Stochastic dynamic programming, for example, has been used to optimize production scheduling for catfish (Hatch, Atwood and Segar 1989) and shrimp (Hochman *et al.*, 1990; see Box 20) .

Stochastic efficiency

For stochastic simulation methods, the comparison between alternatives requires more than a comparison of expected values. Since outcome values may be non-normally distributed, expected utility maximization will not take into account uncertainty inherent in the decision. When average values do not adequately reflect the inherent risk, cumulative distributions functions (CDFs), for example, may represent risk more effectively.

BOX 18

Target MOTAD risk programming example: a risk-efficiency approach to making shrimp production plan decisions

A risk programming method by Valderrama and Engle (2002) for shrimp farming in Honduras evaluated the impact of alternative production plans on expected income. A linear program (LP) was developed that modelled physical constraints (land, harvest and transfer) and financial constraints (cash flow requirements, debt balancing and annual borrowing limits) for three farm-size scenarios. The LP and Target MOTAD were solved using GAMS (GAMS Development Corporation 2007). An efficient set of production plans that maximized farm income were determined for each of the farm scenarios. Each plan described four possible management decisions that met a safety (i.e. target) level of income: stocking month, stocking density, length of the grow-out cycle and water exchange regime. An example of the Target MOTAD solution for E-M efficiency is shown in Table 20.

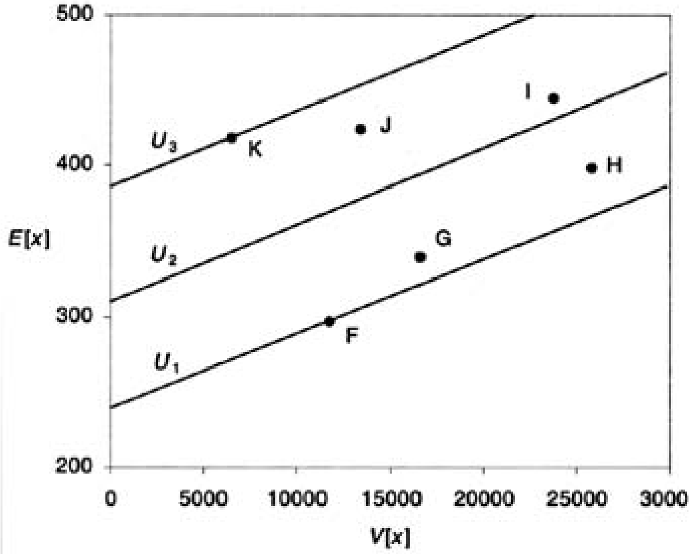
BOX 19

MOTAD multiperiod programming example: a risk-efficiency approach to making shrimp production plan decisions

A MOTAD multiperiod programming aquaculture production model was created by Kusumastanto, Jolly and Bailey (1998). Three types of aquaculture systems (extensive, semi-intensive and intensive) and three scales of production (2-ha small-scale, 5-ha medium-scale and 10-ha large-scale farms) were considered. The financial performance objective was to maximize net present value (NPV). Other financial measures were observed, including total investment, annual operating cost, net benefit-cost ratio (NBCR) and internal rates of return (IRR). International price variability with respect to yield variability was the main consideration of the study. The risk-efficient strategies were determined for farms in different provinces based on the MOTAD multiperiod programming.

FIGURE 18

Six crop rotations in E-V space and three indifference curves representing risk aversion [1]



[1] Expected value, E[x], and Variation, V[x]. Refer to text for explanation of E-V (Expected Value-Variation) efficiency.

TABLE 20

Summary of production activities selected in the resolution of the LP models as outlined by the GAMS output. Annual farm yields and objective function values (US$) are indicated for three different farm-size scenarios

	Farm-size scenario		
Farm size (average size)	**< 150 ha (73 ha)**	**150–400 ha (293 ha)**	**> 400 ha (966 ha)**
Annual farm yield (kg/ha)	1 256	1 384	1 401
Objective function value (US$)	$790 878	$3 439 390	$12 057 904
Production activities (ha)			
10 05 11 LW[1]	8		
10 12 19 LW	25	200	700
11 12 19 LW	40	93	266
01 12 19 LW	8		
03 20 11 LW	25	200	700
04 15 21 LW	6		
05 15 21 LW	33	93	266
06 15 21 LW	33	200	700

[1] Activity codes: Stocking month (10 = October); stocking density (5 PL/m^2); length of grow-out cycle (11 weeks); water exchange (LW = low water exchange rates).

Stochastic efficiency analysis refers to comparing risky prospects based on the full distribution of outcomes. In stochastic dominance methods, pairwise comparisons of the outcome distributions are made between alternatives. We assume that the decision-maker prefers more to less, or a positive marginal utility for the performance measures, in first-degree stochastic dominance. Graphically, this means that the CDF of one alternative must always lie below and to the right for profitability performance measures (or to the left for cost performance measures). Stochastic dominance methods are frequently used in assessing aquaculture decisions for performance measures including net returns/ha and production cost (Kazmierczak and Soto, 2001; Dalton, Waning and Kling, 2004; Moss and Leung, 2006). If the paths of the CDFs cross, neither alternative dominates based on first-degree assumptions. Other criteria for stochastic dominance

BOX 20

Risk programming for a scheduling problem: a stochastic dynamic programming model for maricultured shrimp

The difficult task of scheduling shrimp production was investigated using a stochastic dynamic decision model (Leung *et al.,* 1989, Hochman *et al.*, 1990). The model determined the optimal stocking and harvesting schedules for a 24-pond shrimp farm modelled after Oceanic Institute practices in Hawaii. The model took into account seasonality and market price variation based on historical data and growth variation based on experimental trials.

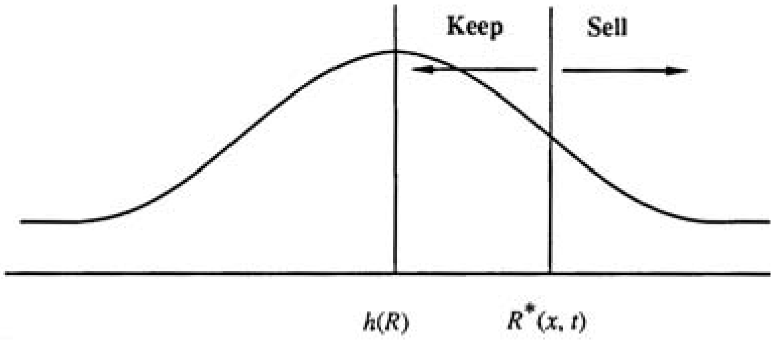
Decision rules were expressed as either cutoff revenues based on random market price and shrimp weight, or as cutoff prices and cutoff weights when only prices or weights were random. When the current realized value is less than the cutoff value R^* (P^* or W^*), the decision is to keep the crop and delay the decision to sell for another period. The cutoff revenue decision is illustrated in Figure 19.

The results of the analysis produced the probability distribution for a crop to be sold for in any given week. Based on the distributions, the corresponding cutoff values for revenue, price and weight were determined for each week. An example of the results for week 13 (November/December) is presented in Table 21.

The scheduling problem was turned into a financial investment problem, where a farmer would decide if investing in a technology to control the environment (i.e. reduce undesirable seasonality effects) would be worthwhile. This simulation experiment was conducted by applying the ideal summer conditions for the entire year. By comparing the net returns of the controlled environment (Table 22a) with the natural environmental conditions (Table 22b), the upper limit of the annualized investment cost was determined. Based on the actual market price data assumed and optimal scheduling policies, a farmer would be willing to spend about US$ 100 000 for the controlled environment system.

FIGURE 19

Schematic of the keep sell decision and cutoff revenue



BOX 21

Stochastic efficiency methods to choose between risky prospects: comparing alternative production systems on total cost of production

The stochastic simulation study by Moss and Leung (2006) in Box 5 compared production cost for earthen ponds with recirculation aquaculture systems (RAS). Based on the comparison of the cumulative probability distributions illustrated in Figure 20, the recirculation system stochastically dominates the earthen pond system.

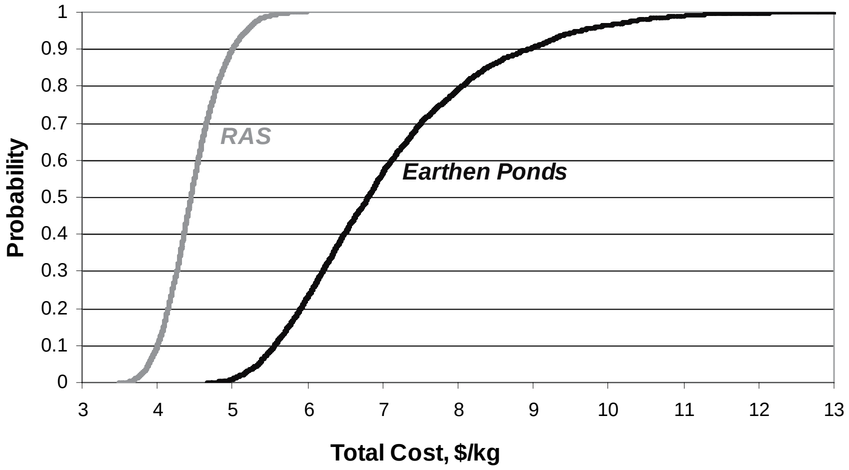
BOX 22

Stochastic efficiency methods to choose between risky prospects comparing cost uncertainty between feed technology

Dalton, Waning and Kling (2004) investigated the risk efficiency of juvenile haddock production systems according to feeding technologies (a combination and scheduling of rotifers, artemia and inert diet). Based on an examination of the CDFs for different feeding technologies (Figure 21, Table 24), the late introduction of the inert diet (microparticulates at 42–180 days; "42 MP") dominated the alternative feeding technologies, followed by 35MP and 30MP.

FIGURE 20

Cumulative distribution with respect to total cost (US$/kg) for earthen ponds compared with recirculating aquaculture systems (RAS)



have increasingly higher restrictions and are increasingly conceptually complex. A list of stochastic efficiency methods is given in Table 23. The details regarding stochastic efficiency methods can be found in Hardaker *et al.* (2004). Two examples of stochastic dominance based on cost are given in Boxes 21 and 22.

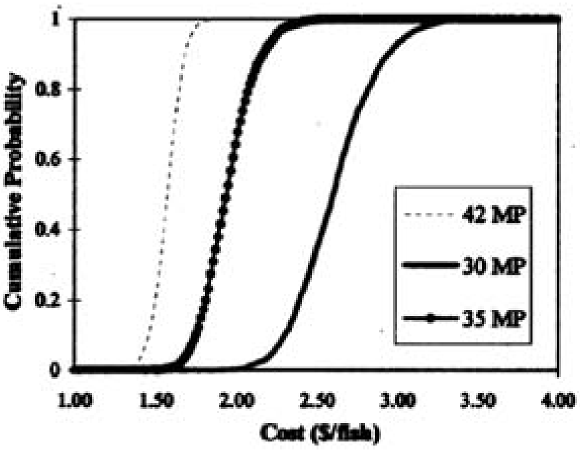
Multiple criteria (trade-offs) analysis

As previously discussed, risk management objectives can be based on financial, economic, socio-economic or other measures of utility. Risk management may be further complicated by the need to satisfy the interests of multiple stakeholders, each with their own agenda. For example, individual farms will have a profit-maximizing objective, while consumer welfare may be valued from an economy-wide perspective. Sustainability is also a multifaceted objective comprised of criterion measures. Even with a farm enterprise, a manager will have several goals that may be in conflict or require trade-offs. Two methods for handling multiple criteria, or trade-offs, are Multicriteria Decision Making (MCDM) and the Analytic Network Process (ANP).

(a) MCDM

MCDM problems involve alternatives that must be evaluated based on conflicting criteria. Conflicting criteria can exist when there are competing interests (by stakeholders) or when tradeoffs must be made. Depending on the nature of the problem, multiple objective programming (MOP) or compromise programming (CP) may be applied. MOP methods are useful when at most two objectives must

FIGURE 21
Cumulative distribution of total annual per-fish costs for three feeding technologies. (MP = microparticulates)



be simultaneously optimized. As more objectives are considered, MOP methods are difficult for risk management because the number of efficient solutions grows exponentially. CP methods, in contrast, are best suited for a large number of objectives because the method searches for a best compromise solution without putting the burden of evaluating a large number of solutions manually.

Goal programming is another popular MCDM method that is frequently used for aquaculture planning. Goal programming has been used in aquaculture development and planning for Thailand (Parton and Nissapa 1997) and Egypt (El-Gayar and Leung, 2000). An MCDM example for sustainable shrimp farming in Mexico is given in Box 23.

BOX 23

MCDM model for considering tradeoffs: analysing tradeoffs in shrimp sustainability with competing objectives

An MCDM model was developed by Martinez-Cordero and Leung (2004) to evaluate sustainable shrimp farming in the northern states of Mexico (Sonora, Sinaloa and Nayarit). The planning objectives considered were employment (E), foreign exchange earnings (XG), economic rent (ER) maximization and total pollution (TOTALPOLL) minimization. Land availability and local market demand constraints were considered. Management decisions would have to determine the shrimp farming production system for the five-year period. Three levels of intensity were considered (extensive, semi-intensive and intensive shrimp farming).

The Feasible Goals software (Dorodnicyn Computing Centre of the Russian Academy of Sciences 2006) was used to determine the efficient tradeoffs among the four objectives. As expected with most multi-objective optimization models, the analyses of the values determined for a single-objective optimizations were higher than the values of the optimal multi-objective case. This finding is expected since tradeoffs were built into the optimization problem.

In Feasible Goals, the results and tradeoffs of the MCDM model are presented as Pareto optimal tradeoff curves (Figure 22). The graphical results of the tradeoff curves characterized how the three economic objectives (ER, XG and E) were affected by the environmental objective (TOTPOLL). The results of the model could inform policy-makers about the location, production intensity and species that would promote sustainability by taking into account the competing objectives.

TABLE 21

Cutoff revenue, price, and weight for week 13

Age (x)	Case A: Random revenue			Case B: Random price			Case C: Random weight		
	Ordinal scale	Probability to Sell	Cutoff revenue ($1 per 1 000 animals)	Ordinal scale	Probability to Sell	Cutoff price ($/kg)	Ordinal scale	Probability to sell	Cutoff weight (g/animal)
1-6	20	0.00	keep	20	0.00	keep	20	0.00	keep
7	19	0.05	101	20	0.00	keep	20	0.00	keep
8	19	0.05	124	19	0.05	6.70	20	0.00	keep
9	17	0.15	137	17	0.15	6.90	20	0.00	keep
10	15	0.25	156	14	0.30	7.09	19	0.05	22.73
11	13	0.35	176	12	0.40	7.45	14	0.30	23.55
12	10	0.50	195	9	0.55	7.71	5	0.75	24.04
13	7	0.65	214	6	0.70	7.95	1	0.95	24.51
14	3	0.85	223	3	0.85	8.08	0	1.00	sell
15	0	1.00	sell	0	1.00	sell	0	1.00	sell

TABLE 22

Results for scheduling policies based on actual market price data (in US$)

(a) Natural environmental conditions

Start Stocking In	Average harvest age from stocking (wks)	Average harvest weight (g)	Cycle per year	Market price ($/kg)	Net returns (US$)
Random Price					
Spring	14.00	27.89	3.31	8.84	357 453
Summer	12.50	25.42	3.79	8.43	279 429
Fall	13.25	27.02	3.57	8.78	322 719
Winter	13.50	26.91	3.46	8.60	303 806
Fixed Scheduling					
Spring	13.00	25.89	3.54	7.81	100 008
Any Season	11.00	21.79	4.00	6.84	-82 464

(b) Controlled environmental conditions

Start stocking in	Average harvest age from stocking (wks)	Average harvest weight (g)	Cycle per year	Market price ($/kg)	Net returns (US$)
spring	14.00	29.18	3.36	9.17	450 879
Summer	13.50	28.15	3.50	9.28	491 672
Fall	13.50	28.15	3.50	8.93	390 147
Winter	13.75	28.67	3.43	9.26	425 630

TABLE 23

Stochastic efficiency assumptions

Stochastic efficiency method	Risk assumptions
First-order stochastic dominance (FSD)	Positive marginal utility
Second-order stochastic dominance (SSD)	Risk aversion
Third-order stochastic dominance (TSD)	Coefficient of absolute risk aversion decreases with income or wealth
Convex stochastic dominance (CSD)	Alternatives are superior than a combination of the other alternative

TABLE 24

Per-fish total cost for three feeding technologies (US$/fish)

Feed Technology	Mean	Median	Standard deviation	Skewness	Minimum	Maximum
30 MP[1]	2.61	2.60	0.25	0.37	1.89	3.78
35 MP	1.94	1.94	0.16	0.46	1.36	2.69
42 MP	1.57	1.57	0.09	-0.06	1.24	1.91

[1] MP = microparticulates

(b) AHP/ANP

The Analytic Hierarchy Process (AHP) is a theory of relative measurement used to prioritize alternatives based on composite ratio scales that represent relative measures of preference and feelings (Saaty 1999, 2001). In AHP, judgments are broken down into complex structures that include benefits, opportunities, costs and risks. Each alternative is scored on each criterion measure. The criterion scores are combined by a ratio weighting scheme that reflects the decision-maker's relative importance for each criterion. AHP is widely used in multicriteria decision making for resource planning and allocation and in conflict resolution.

The Analytic Network Process (ANP) extends AHP to problems with dependence and feedback. ANP is useful for a thorough and systematic analysis of factors influencing risk and where feedback and dependence are inherent. The AHP/ANP weighting scheme relies on systematic comparisons, which can be a demanding process when numerous criteria are considered. AHP/ANP methods are implemented in the Super Decisions software by Creative Decisions (2005). More information on AHP/ANP can be found in Saaty (2001).

Decision analysis software to assess financial risk in aquaculture

Decision analysis software packages are frequently used in financial risk analysis in aquaculture. The software packages mentioned throughout this paper and others are listed in Table 25.

FINANCIAL RISK COMMUNICATION

Risk communication occurs throughout risk analysis, such that information and the opinions of stakeholders are incorporated throughout the risk analysis. Results of the risk assessment and proposed risk management measures are communicated to decision-makers and stakeholders, and relevant feedback is used to revise the risk assessment.

Estimating the probabilities can be a challenge. Production threats are particularly difficult to estimate because they are farm-specific and the data are not usually available. Common methods employ the use of probability wheels and reference lotteries. Barry (1984) and Hardaker *et al.* (2004) offer insights and methods for eliciting subjective probabilities.

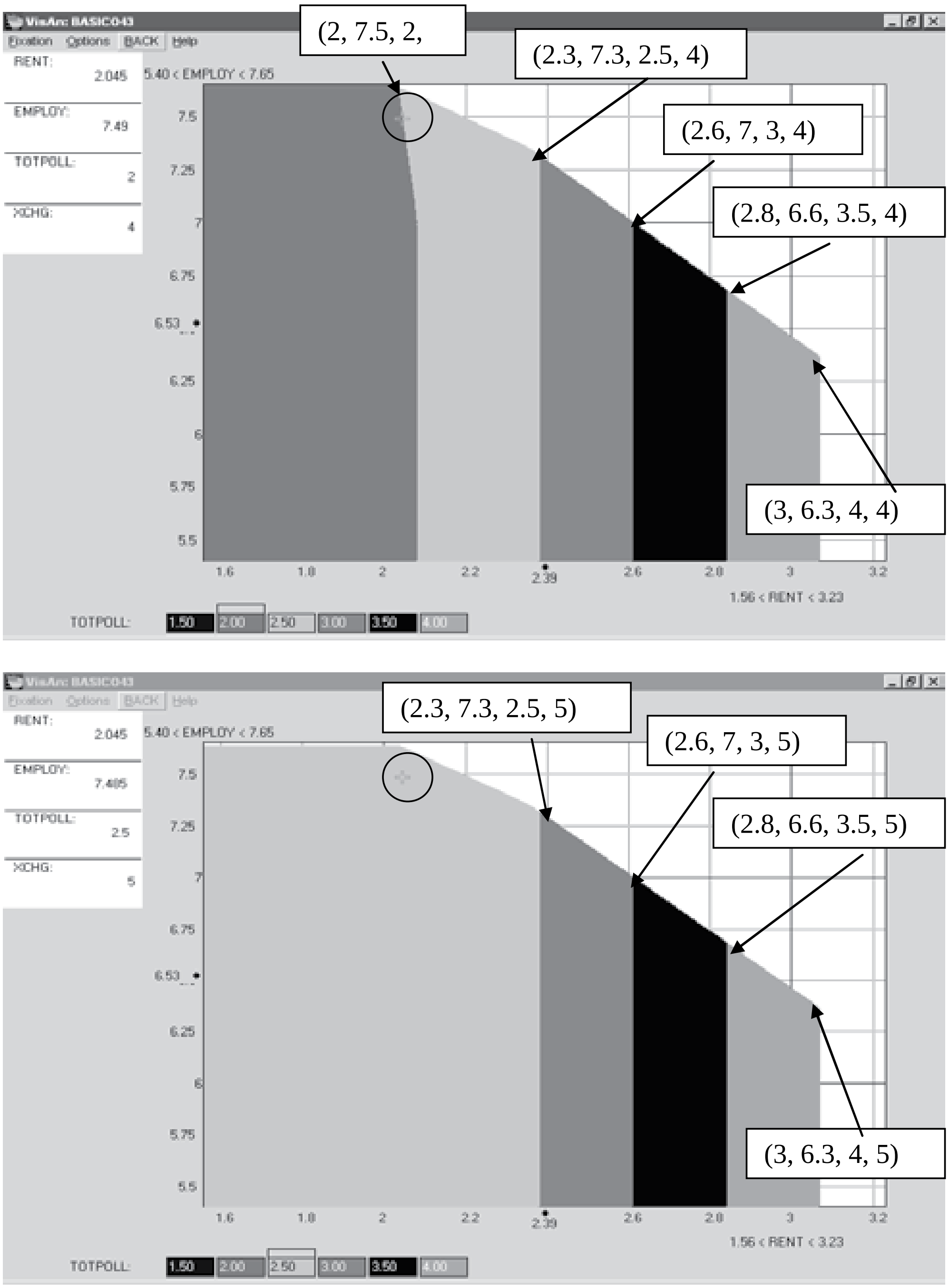
Financial ratios can be a useful communication tool. However, some financial ratios are complex and difficult for wide audiences to interpret. Since the results of a risk

TABLE 25
Selected decision analysis software

Software Package	Vendor	Features
@Risk	Palisade	Stochastic simulation
Crystal Ball	Decisioneering	Stochastic simulation
Feasible Goals	Dorodnicyn Computing Centre of the Russian Academy of Sciences	Efficiency frontiers, decision maps, MCDM
GAMS	GAMS Development Corporation	Linear optimization, risk programming
GeNIe	Decision Systems Laboratory	Prediction, diagnosis, Bayesian networks, Bayesian decision networks
Goal Seek (feature in MS Excel)	Microsoft Excel	Single-parameter optimization
Simetar (MS Excel add-in)	Simetar, Inc.	Regression, stochastic simulation, statistical analysis, econometric modelling, forecasting
Solver	Frontline Systems	Linear optimization, risk programming
Super Decisions	Creative Decisions Foundation	ANP, AHP, (multi-criteria)
What's Best (MS Excel add-in)	Lindo Systems	Linear optimization, risk programming
XLSim (MS Excel add-in)	AnalyCorp	Decision tree, probability tree

FIGURE 22

Multicriteria Decision Making (MCDM) optimization: trade-offs between economic rent and employment. Upper plot: fixed foreign exchange earnings (XG) at $400 million; lower plot: fixed XG at $500 million


RENT: 2.045
EMPLOY: 7.49
TOTPOLL: 2
XCHG: 4

RENT: 2.045
EMPLOY: 7.405
TOTPOLL: 2.5
XCHG: 5

analysis are meant to inform decision-makers, interpretable results and a transparent process are necessary. Risk analysts should strive to use the simplest financial measures that can communicate the major issues.

As witnessed in the examples given throughout this paper, spreadsheet models are useful in risk analysis. Spreadsheets continue to grow in popularity and can be used by non-programmers. A number of sophisticated add-ins have been developed for Excel that can be used to analyze risk. The spreadsheet interface and add-in features assist in visualizing model uncertainty. Many of the risk analysis results in this paper were presented as probability distributions, cumulative probability distribution graphs and decision trees, which are helpful in communicating risk and comparing scenarios to wide audiences.

The decision analysis methods require that a problem be decomposed. The process of decomposition creates transparency and fosters communication. Many decision analysis software packages used in risk analysis are equipped with visual aids. Probability trees, decision trees, Bayesian networks and Bayesian decision networks, for example, illustrate causal relationships that can help to communicate the risk problem and results of the analysis. Consequently, in addition to the analytical benefits of software packages, the software packages also enable communication and promote risk understanding.

FUTURE CHALLENGES

Aquaculture ventures are inherently risky. The need to conduct financial risk analyses to reduce the potential for financial loss is clear. In spite of the variety of rigorous methods described in this document, it is not clear whether these financial risk analysis methods are widely put in practice at the present.

Financial risk analysis requires a background in financial analysis methods and generally requires the assistance of risk analysis tools. Although commercial software packages are becoming easier to use, farmers and policy-makers may require the assistance of risk analysts/modellers to decompose their financial risk concerns. Without the available resources or assistance, practitioners may not view these evaluation methods as practical or may find existing models unusable. Education, software accessibility, training and assistance will be needed in order for financial risk analysis to be widely adopted in aquaculture.

Even if the financial risk problem is decomposed, sufficient data may not be available to estimate uncertainty and characterize the financial risk. Farm-level cost and production data and industry statistics are often difficult to obtain. In particular, aquaculture production data are not regularly collected in surveys conducted by agricultural ministries or are limited to highly aggregated values. Consequently, risk analysts are obliged to seek secondary or anecdotal information to approximate the release, exposure and consequences associated with a hazard.

Methodologically, the linkage between financial risk and traditional risk analysis is weak. While many studies and techniques are available to analyze financial risk in aquaculture, the methods are not necessarily linked to the traditional components of a risk assessment (i.e. release assessment, exposure assessment, consequence assessment and risk characterization). Financial aspects in traditional risk analyses are frequently appended to risk assessments formulated for biological, ecological or environmental risk. Consequently, the financial losses only reflect aggregate values and may disregard production and price uncertainty. Since financial losses are often an afterthought, the financial analyst of the risk analysis team may be too far removed from the details and overlook factors that contribute to financial risk. Thus, it is vital that financial risk analysis methods be integrated in the early phases of hazard identification and risk assessment in order to truly manage financial risk in aquaculture.

CONCLUSIONS

In our discussion of financial risk analysis, we claim that the methods can be applied to most sources of risk, including biological, ecological and environmental hazards. The financial aspects usually measure enterprise profitability, but can also be used to measure the performance of an entire industry or economy and consider socio-economic factors. Financial and related performance measures are critical at the time of consequence assessment. The methods for release and exposure assessment in financial risk assessment are less mature than in other areas of risk assessment.

Financial risk assessment relies on static financial analysis tools, such as enterprise budgets, partial budgeting, cash flow analysis and feasibility studies. Financial risk assessment methods supplement these traditional tools by considering uncertainty from market threats and production threats. Uncertainty is characterized using probability estimates, probability distributions and scenarios.

The decision analysis approach was proposed as the method for financial risk management. In applying decision analysis methods for risk, we define risk management objectives (financial or other criteria), consider alternative strategies and select an evaluation method. A number of evaluation methods were presented that are implemented in commercial software packages. The graphical software tools and decomposition of the financial risk problem support risk communication.

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ANNEX I

FINANCIAL RISK ANALYSIS EXAMPLE

SPF WSSV-import risk for Hawaii shrimp aquaculture

Specific-pathogen free (SPF) shrimp provide added value to Hawaii's shrimp export industry. The Hawaiian SPF shrimp farming industry has been growing steadily over the last ten years due to a strong international market for SPF broodstock sold for farm production. From 2002 to 2003, Hawaiian exports of certified disease-free shrimp broodstock rose from US$ 1.7 million to $2.4 million in sales, growing from 20 percent to nearly 25 percent of the value of Hawaiian shrimp and prawn production. The SPF label enables Hawaii to market to Asian countries that desire SPF products or those that are limited to importing SPF products that are free of specific diseases (Sing 2003). The viability of Hawaii's SPF industry depends on a number of market factors, including sale price and demand. Increased competition can exert downward pressure on SPF sale prices, resulting in lower profit margins for shrimp farmers. The demand for Hawaii's SPF products depends on the preservation of the SPF-label and disease-free image.

Hazard identification

The State of Hawaii is a protective haven for a variety of agricultural products; however, its biosecurity is compromised by the introduction of invasive species and foreign animal diseases. Viral pathogens threaten the productivity and survival of Hawaii's local shrimp industry. Isolated occurrences of infectious hypodermal and hematopoietic necrosis virus (IHHNV) and white spot syndrome virus (WSSV) outbreaks have been reported on Oahu and Kauai, signaling that Hawaii's shrimp and prawn aquaculture industry may be in imminent danger. Aquatic diseases such as IHHNV and WSSV are hazards that threaten shrimp production and bring about financial consequences.

Risk assessment for WSSV

Based on existing literature and the beliefs of local aquaculturists, frozen commodity shrimp (FCS) were identified as the hazard of interest for investigating WSSV import risks.

Methodology

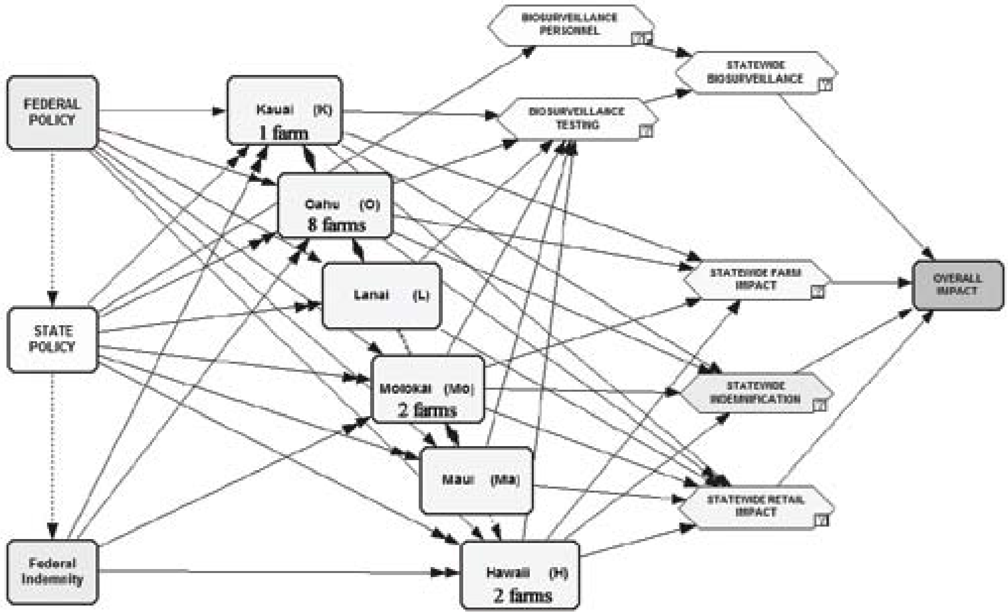
A "test-action" biosecurity risk framework was developed that translates biosecurity decisions into tests and actions for the purpose of analysing biosecurity risk. From a decision-theoretic point of view, decisions are viewed as having action aspects that reduce consequences and/or test aspects that gather information (Jensen 2001, Korb and Nicholson 2004). This perspective on decision-making offers an accounting method for biosurveillance measures, particularly the value of information resulting from test decisions. The framework was used to fulfil the research objectives for investigating WSSV import risk associated with frozen commodity shrimp (FCS):

1) developing a Bayesian decision network (BDN) to model WSSV import risk,
2) determining the "best" policy networks (i.e. combinations of policy decisions) and
3) estimating the value of biosurveillance for mitigating WSSV import risk.

A BDN is a specific type of influence diagram that can be used for modelling causality, defining preferences based on expected utilities and incorporating uncertainty for decision-making using Bayesian calculus. A BDN was created based on the test-action biosecurity risk framework to model the impact of WSSV biosecurity policies,

FIGURE 1

Full white spot syndrome virus (WSSV) biosecurity import risk Baysian decision network (BDN). (Numbers located on each island submodel reflect the number of active shrimp farms assumed)



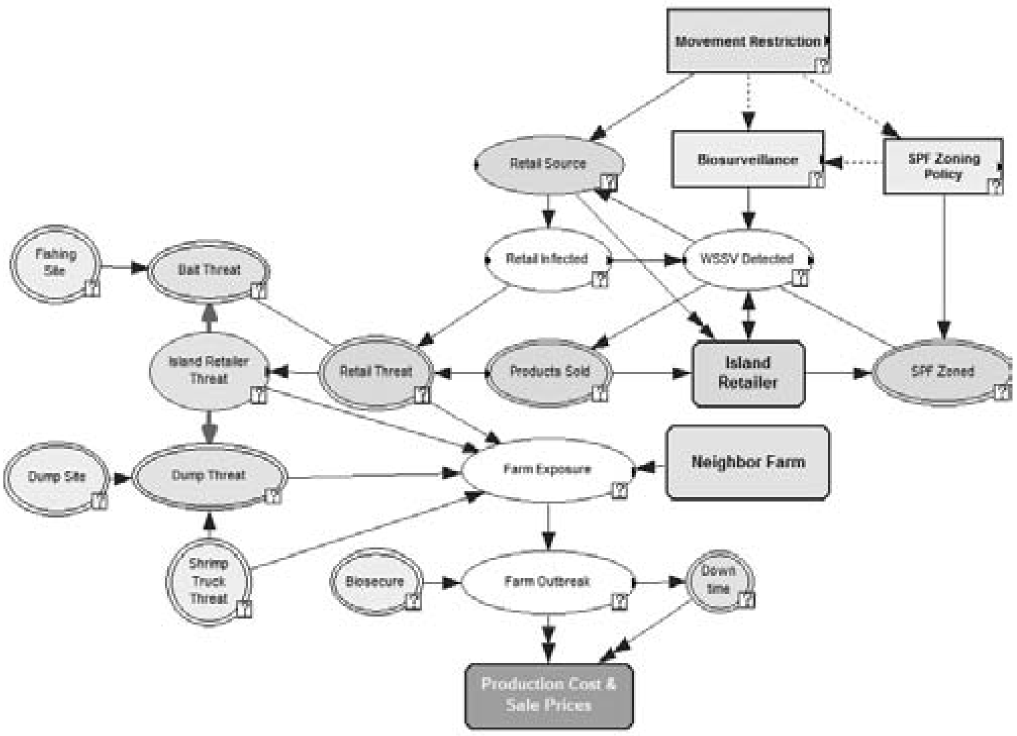
including a national movement restriction, biosurveillance and SPF zoning for FCS retailers (Figure 1).

Release assessment
According to trade data and country disease status, an estimated 32 percent of Hawaii's FCS products are infected with WSSV. The primary pathway of exposure was identified as contamination from imported FCS that are either sold for consumption or as fishing bait. According to the WSSV epidemiological pathways assumed (Kam 2006), both humans and animals were considered to be vectors for transporting infected FCS products from dump sites, fishing sites and shrimp trucks. Unavoidable environmental risk (e.g. WSSV-carriers live in the ocean) was also included in the model to account for uncertainty. When no intervention is taken, the retail threat is equal to the Hawaiian FCS disease prevalence of 32 percent.

Exposure assessment
Farm WSSV exposure depends on a farm's location. Infected products sold by retailers can reach a dump site, becoming a dump threat to a nearby farm (Figure 2). Similarly, infected bait shrimp sold by retailers can be left at fishing sites, posing a bait threat to a nearby farm. The infected products can reach a shrimp farm by human or animal vectors. The average farm in the 13-farm statewide model had a 15.9 percent probability of WSSV exposure based on the complex interaction of environmental threats surrounding each farm. The probability of farm exposure would be higher for farms with a higher-than-average combined environmental threat.

Consequence assessment
The probability of a farm outbreak depends on a farm's exposure to WSSV and the farm's level of biosecurity. For the average farm included in the model, the probability of a farm outbreak was estimated at 14.0 percent. Farms with above-average levels of biosecurity would have a lower probability of an outbreak.

FIGURE 2
Baysian decision network (BDN) example for single farm exposure



Farm outbreaks depend on farm characteristics, including environmental threats and farm biosecurity. Environmental threats (fishing bait threat, dump threat, truck threat and retail threat) increase a farm's potential exposure to WSSV. For a given level of WSSV-exposure, farms with higher levels of biosecurity have a lower probability of an outbreak.

Risk management

Thirty-two central policy combinations of SPF zoning, biosurveillance levels and national movement restrictions were examined using the WSSV biosecurity import risk BDN. The 32 management strategies (or "policy networks") were compared based on farm profit, retail profit, state expenses for biosurveillance and the factors combined. According to the expected value for each strategy, the policy that maximized the overall impact (retailer profit and farm profit, less biosurveillance expenses) was a United States movement restriction that prohibits the import of FCS from WSSV-positive regions. Without factoring in any direct costs due to a movement restriction or economy-wide aspects, a movement restriction resulted in an overall increase of \$12.21 million (20.4 percent of the baseline overall impact of \$60.04 million). Since no costs directly associated with the movement restriction were considered, the \$12.21 million also represents the value or maximum amount we would be willing to pay for the benefits of the movement restriction policy.

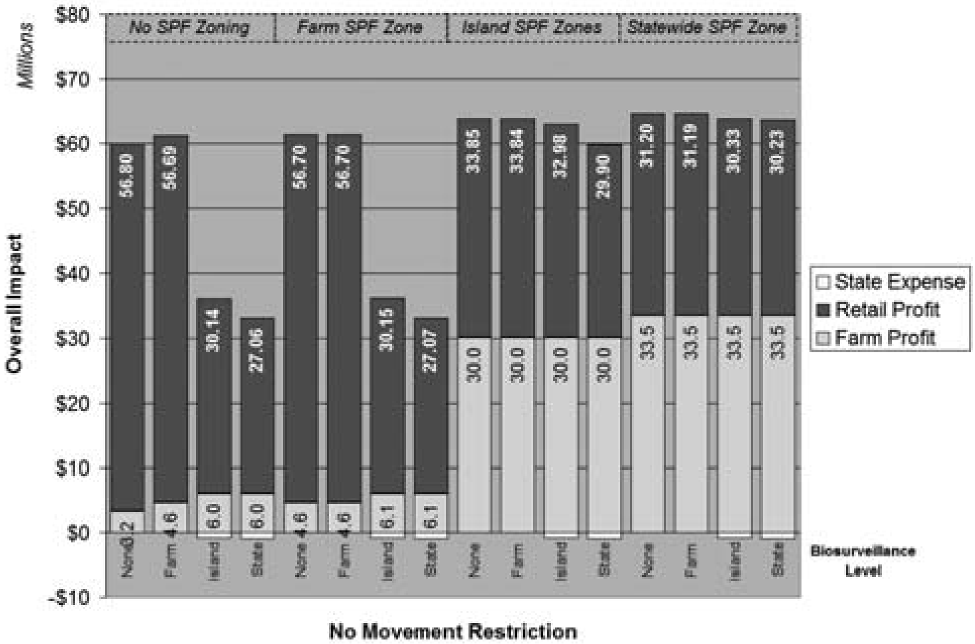
When a movement restriction was simulated, retail profit increased to \$66.22 million and farm profit increased to \$6.04 million from the baseline values of \$56.8 million and \$3.24 million, respectively. While additional SPF zoning and biosurveillance generally benefit the farm, retail profit decreases because retailers must purchase higher-cost SPF shrimp locally (Figure 3).

In the WSSV import risk model, the cost of a United States movement restriction was not specified. However, the results of the simulation experiments suggest that the

FIGURE 3
Comparing retail profit, farm profit, and state expenses under a national movement restriction policy

movement restriction was worth $12.21 million based on the cost assumptions. If a United States movement restriction is considered too prohibitive, the next best policy was statewide SPF zoning. A statewide SPF zoning policy resulted in an increase of $4.62 million in the overall impact. Under statewide SPF zoning, farmers increased profit by $30.23 million due to the additional sale of SPF shrimp that served as a

FIGURE 4
Comparing retail profit, farm profit, and state expenses under state policies (no movement restriction)



substitution for local FCS consumed. The result suggests a policy trade-off because retailers would incur a loss of $25.61 million due to lower profit margins due to higher-cost SPF shrimp (Figure 4).

Additional biosurveillance was an inferior policy. When no movement restriction was considered, biosurveillance had a negative effect and under any level of SPF zoning. The negative consequences resulting from biosurveillance were due to two types of costs. The first consequence was the direct cost of statewide biosurveillance, estimated at $69 000, $972 000 and $1.07 million for farm-level, island-level and statewide biosurveillance, respectively. The second consequence was due to the small possibility of WSSV-positive test findings, resulting in non-saleable products and a loss for retailers.

TABLE 1

Effect of a specific pathogen free (SPF) farm zone policy

Assessment endpoint	Baseline	Farm SPF zone policy
Epidemiologic		
Retail infected	31.86%	31.74%
WSSV detected	0.00%	0.00%
Retail threat	31.86%	31.72%
Farm exposure[1]	15.88%	8.78%
Farm outbreak[1]	13.97%	8.26%
Financial		
Farm profit	$ 3 235 770	+1 412 100[2]
	5.4%	+2.35%[2]
Retail profit	$ 56 804 400	-102 800[2]
	94.6%	-0.17%[2]
Overall impact	$ 60 040 170	+1 309 300[2]
	100.0%	+2.18%[2]

[1] Average value.

[2] Increase (+) or decrease (-) from baseline value.

SPF zoning requires that the local shrimp aquaculture industry supply retailers with SPF shrimp products. Farm production would have to increase by 13x the current level of production for island-level SPF zoning and 15x for statewide SPF zoning in order to satisfy FCS consumption. The increase would mean either an increase in production by existing farms, the establishment of new farms or both. However, it is unlikely that the Hawaiian industry could grow to the size necessary to satisfy the estimated FCS consumption levels.

Consequently, in order to efficiently manage WSSV import risk, policy-makers may consider farm-level SPF zoning. The baseline level of farm production can satisfy the estimated level of FCS retail sales within the one farm-zone located on Oahu. Farm-level SPF zoning mainly benefits the three farms located in the zone where WSSV exposure is potentially high. Even with the protection of the SPF zone, the model considers the risk of infected retail products coming from outside of the SPF farm-zone. Therefore, after considering the retail threat from outside of the zone, the SPF farm-zone resulted in a $1.31 million increase in the overall impact, 2.18 percent of the baseline overall impact (Table 1). Since the volume of retail products sold in the SPF zone was quite small, the retailers only lost 1.71 percent of the baseline overall impact, equal to a loss of $102 800. In contrast, farm profit increased by $1.41 million due to the decrease in WSSV exposure in the SPF zone. A farm-level SPF zone was estimated to reduce the average farm exposure and farm outbreak to about half of the baseline values, to 8.8 percent and 8.3 percent, respectively.

Only the direct costs of biosurveillance were considered in this risk analysis. Costs for a national movement restriction, SPF zoning and other economy-wide impacts could give a complete picture of the overall benefit of central policies aspects were not considered. While additional costs of SPF zoning are not considered, the analysis of the effects of the SPF farm-zone tells us that such a policy would be worth $1.31 million based on the WSSV import risk BDN assumptions. Since retailers experience a loss of $102 800, policy-makers or farmers could consider compensation for the retail loss by offering subsidies or a discount on SPF products sold by farms to retailers within the farm-zone.

In the biosecurity import risk model, the retailer was designed to experience a negative impact due to a biosurveillance policy that prohibited the sale of the proportion of products that test positive for WSSV. Clearly, retailers would be wary of such an unfavourable biosecurity policy. The risk of expected losses resulting from biosurveillance, however, could serve as incentive for retailers to comply with SPF zoning or to purchase products from WSSV-negative regions. As observed in Figures 3 and 4, biosurveillance was only marginally beneficial at the farm-zone level. Therefore, SPF zoning and more generally, retailers' compliance with purchasing pathogen-free products may be preferred over other forms of biosecurity strategies.

ANNEX II

PARTIAL BUDGET ANALYSIS EXAMPLE

Using a partial budget to compare marketing strategies for different size farms

Hawaii's ornamental aquaculture products are held in high regard among producers and aquarists worldwide. Aquaculture ornamentals branded "Made in Hawaii" often evoke a mystique of rare, exotic and natural products. Their desirability is partly due to Hawaii's pristine tropical environment, which supports year-round production and is conducive to producing disease-free, healthier and higher quality fish.

Despite the positive reputation of Hawaii's ornamentals, the local aquaculturists find it difficult to compete in the global niche market. Asian competitors leverage low prices and product variety to penetrate the United States market. In 1992, the Los Angeles port, which is used by most Asian wholesale ornamental fish distributors, was the destination port for 39 percent of all United States ornamental aquaculture imports (Chapman *et al.* 1994). Hawaii's ornamental aquafarmers could tap the United States mainland West Coast market, which is predominantly served by Southeast Asia and Florida wholesalers. Wholesalers provide a value-added service, creating additional layers in the ornamental fish distribution network. Wholesalers often operate in tandem, where secondary wholesalers sell their products to primary wholesalers, who distribute products directly to retailers. Each of these layers in the distribution network cuts into an ornamental aquafarmer's potential profits.

Optimal product mix

A spreadsheet model was used to determine the ornamental product mix that maximized net sales based on farmgate price, water consumption, pack density and overpack allowance. The species in the product mix were selected based on their ability to contribute to the farm's profit. Each product line's contribution to farm profitability is affected by the profit on the sale of each fish, stocking density and pack density for each product. The optimization model maximizes profit by varying the farm's product mix, while constrained by the maximum and minimum number of species, harvestable capacity, supply (minimum) and demand (maximum). A description of each of the constraints appears below in Table 1.

In general, a farm will want to produce highly valued fish that are in demand. High-value fish, however, are usually stocked and harvested at densities lower than fish of less value, utilizing more of a farm's production capacity. In addition, pack density is typically lower for highly valued fish than for less valuable fish, resulting in increased shipping costs per fish and the landed price of each product. Restricting demand for each product prevents an enterprise from overproducing highly valued fish that earn

TABLE 1
Constraints used in the ornamental product optimization worksheet

Parameter	Constraint
Product lines	*minimum ≤ no. of products ≤ maximum*
Harvestable capacity	gallons harvested ≤ harvestable capacity The harvestable capacity (in gallons) was assumed to be 25% of the total water capacity of the farm based on the 3 to 4-month production cycle.
Supply	*specie production quantity ≥ minimum production quantity* The minimum production quantity for a selected product line (default of one case per month).
Demand	*specie production quantity ≤ maximum production quantity* The maximum product quantity for a selected product line (default of one case per buyer-week).

TABLE 2
Summary of key farm characteristics

Farm characteristics	Small farm	Large farm	Co-op farm
Total water capacity (gal)	27 000	180 000	540 000
Maximum harvest capacity (gal)	6 750	45 000	135 000
Average number of fish per week	2 677	16 186	48 980
Average number boxes per weekly order	2	5	5
Fish product variety	8	26	40
Estimated number of customers	5	10	30
Average shipping weight per weekly order (lbs)	59	144	148

high profits after taking into consideration its landed price. All of these factors are incorporated in the optimization of a product mix.

The optimal product mixes for three farm scenarios were based on a secondary wholesaler analysis in which air cargo shipping fees and box charges were passed onto a primary wholesaler distributing to Washington State retailers (see Kam, Leung and Tamaru 2006 for details). The freshwater ornamental product mixes, yielding annual farmgate sales of US$ 57 649, $227 066, and $703 732 for small, large and co-operative farms, respectively, were used in the partial budget analyses. Selected factors differentiating the three farm scenarios are exhibited in Table 2.

Partial budget analysis

A partial budget reflects the additional costs and revenues that result from a shift in business strategy, in this case, direct marketing to retailers (or primary wholesaling). The net change in income (difference between positive and negative impacts) is an estimate of the net effect of making the proposed change from farmgate sales to direct marketing to retailers. A positive difference indicates the potential increase in income if the change in strategy is made. Conversely, a negative difference is an estimate of the reduction in income if the change to direct marketing is adopted. Costs considered in this partial budget analysis included changes to shipping, marketing and risk associated with United States mainland West Coast distribution.

The results of the partial budget analysis was used to determine the feasibility for farmers to direct-market their products to the United States and to distribute products through United States mainland wholesalers are given in Tables 3 and 4, respectively. Direct-marketing was found to be profitable for the large and co-op farm sizes. Wholesaling to mainland distributors was not a profitable strategy for any of the produce scenarios. Break-even analyses exhibited in Tables 3 and 4 were used to determine the minimum-mark-up on farmgate prices in order for the change in strategy to be beneficial (i.e. to achieve a positive net change in income).

TABLE 3

Summary of direct marketing (primary wholesaling) partial budget and break-even analyses (all figures in US$)

Partial budget analysis	**Small farm**	**Large farm**	**Co-op farm**
Wholesale revenue	$151 264	$602 810	$1 863 247
Farmgate revenue	57 649	227 066	703 732
Total positive impacts (change in revenue)	93 615	375 743	1 159 515
Shipping and handling	36 091	145 998	456 489
Marketing costs	37 933	94 148	172 114
Reduced returns (Non-payment and excess mortality)	22 690	90 421	139 744
Total negative impacts	96 714	330 567	768 346
Net change in income (NCI), assuming a 200% farmgate markup[1] (67% gross margin)[2]	(3 100)	$45 176	$391 169
NCI as a % of change in net sales	-3.31%	12.02%	33.74%
Break-even Analysis			
Wholesale markup on the farmgate price[1]	207%	174%	135%
Gross margin on sale price[2]	67%	64%	58%

[1] In this analysis, markup refers to the percentage calculated using the difference between sale price and farmgate price, divided by farmgate price: markup = (sale price – farmgate price)/farmgate price.

[2] The gross margin refers to the percentage calculation based on the difference between the sale price and farmgate price, divided by the sale price: gross margin = (sale price – farmgate price)/sale price.

TABLE 4

Summary of secondary wholesaling partial budget and breakeven analyses (all figures in US$)

Partial budget analysis	**Small Farm**	**Large Farm**	**Co-op Farm**
Wholesale revenue	$76 866	$302 755	$938 309
Farmgate revenue	57 649	227 066	703 732
Change in revenue	19 216	75 689	234 577
Shipping and handling paid by retailer	21 405	68 760	213 534
Total positive impacts	40 622	144 449	448 111
Shipping and handling	24 291	82 818	256 820
Marketing costs	33 257	74 566	114 197
Reduced returns (Non-payment and excess mortality)	13 670	52 290	81 050
Total negative impacts	71 219	209 673	452 068
Net change in income (NCI) assuming a 33% farmgate markup[1] (25% gross margin)[2]	($30 597)	($65 224)	($3 956)
NCI as a % of change in net sales	-159%	-86%	-1.7%
Break-even Analysis			
Wholesale markup on the farmgate price[1]	101%	70%	34%
Gross margin on sale price[2]	50%	41%	25%

[1] In this analysis, markup refers to the percentage calculated using the difference between sale price and farmgate price, divided by farmgate price: markup = (sale price – farmgate price)/farmgate price.

[2] The gross margin refers to the percentage calculation based on the difference between the sale price and farmgate price, divided by the sale price: gross margin = (sale price – farmgate price)/sale price.