Artificial reef investment : an assessment of information needs in the analysis of project risk

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Abstract

The use of artificial reefs in the creation of commercial and recreational fisheries has received growing attention in recent years, and artificial reef development programs are now being undertaken by a number of countries worldwide. Despite a substantial volume of scientific information on the technical and biological aspects of artificial reefs, however, comparatively little is known about their economic characteristics. Specifically, considerable doubt still surrounds the circumstances under which artificial reefs could be considered a worthwhile investment, judged from the standpoint of either the commercial enterprise or society as a whole. Economic appraisal of proposed reef investments is complicated by the uncertainty which attaches to the expected costs and benefits, and for this reason risk analysis become an essential component of any project evaluation.

This paper is based on a case study of artificial reefs built for the purpose of lobster production in the UK. The project being investigated involves the controlled release of hatchery-reared juvenile lobsters on to a suitable substrate, and subsequent harvesting of the adult lobsters once they have attained the minimum landing size. A comparison is made between two possible construction materials (quarry rock and manufactured blocks) in terms of the standard criteria for project selection. Both project options are subject to risk and the paper demonstrates that this can be quantified so long as information is available on the probability distribution of parameter values.

1. Introduction

Artificial reef (AR) research has made significant advances in recent years, and the growth in the number of reef research projects is reflected in the plethora of published articles and abstracts devoted to this field (Seaman. 1996). It is clear, however, that most of the progress has been confined to aspects of AR biology, while comparatively little is still known about the economic characteristics of reefs or the social implications of their deployment. Reviews of AR research conducted by Bohnsack and Sutherland (1985) and Seaman (1996) have confirmed the predominance of biological studies, with only limited attention given to socio-economic aspects.

The need to redress this imbalance is now widely accepted (Rev, 1990; Willmann, 1990; Seaman, 1996; Whitmarsh, 1996), with arguably the most urgent imperative being for a clearer understanding of the factors affecting the economic viability of AR projects. This paper attempts to throw some light on this issue by reporting the results of an economic appraisal of an AR project for lobster production in the U.K.. Project selection criteria are used to evaluate two alternative construction options, and the paper goes on to show that the risk and uncertainty, which are inherent to the project, can be quantified so long as information is available on the probability distribution of parameter values.

2 Ranching of Lobsters on ARs

In the UK there is much interest at the prospect of using ARs to enhance lobster stocks and thereby provide the basis for a long-term directed fishery. European lobsters *(Homarus ammurus)* are a high unit value species with an established market, and ARs could provide in principle the hard substrate on which these creatures depend.

A small experimental AR was constructed in 1989 off the S. Coast of England in Pool Bay, and has been monitored regularly by scientists from the University of Southampton (Collins, et al., 1992; Jensen, et al., 1994; Jensen and Collins, 1995; Jensen and Collins, 1996). The reef consists of 8 separate piles of blocks made from cement-stabilized Pulverized Fly Ash (PFA), the aim of the study being to test the environmental suitability of PFA and to assess the potential of reefs for fisheries enhancement. Within 3 weeks of deposition, lobsters were found to be present on the reef, and subsequent monitoring has demonstrated that lobsters have used the reef as a long-term habitat. The reef is believed to hold 1 lobster per $2m^2$. However, though the reef has been shown to be attractive to lobsters, it is doubtful whether natural colonization alone would ever be sufficient to support a commercial fishery or to justify the construction of an AR on purely economic grounds.

In this respect the progress made in the UK on lobster stock enhancement holds out considerable promise for the economics of lobster ranching based on ARs (Addison and Banister, 1994; Burton, 1992; Wickins, 1994). Stock enhancement work has demonstrated that hatchery reared juvenile lobsters will survive and mature into fishery sized animals within approximately 5 years, with recaptured lobsters displaying site fidelity. The problem hitherto has been that the recapture rate has been too low to justify stock enhancement on economic grounds (Lee, 1994). One possible way to overcome this, therefore, might be to release juvenile lobsters onto a suitable man-made structure where they can be more easily targeted for recapture once fully grown.

To explore this possibility further, a capital budgeting model of an AR project for the production of European lobsters is developed. The model is based on a study originally undertaken by the University of Portsmouth on behalf of the UK Government department responsible for fisheries (the Ministry of Agriculture, Fisheries and Food) and a major commercial company with an interest in alternative uses of fly ash. The Portsmouth study reviewed the status and potential of ARs and examined the circumstances under which a reef project for lobster production might be an appropriate use of public funds (Whitmarsh, Pickering and Sarch, 1995). Here we shall be using the model to examine in more detail the economic characteristics of such a project, giving particular attention to risk and uncertainty.

3. A Capital Budgeting Mode! of a Proposed Ar Project

3-1 Assumptions and data

3.1.1 Production

The production system, which forms the basis of the model, is shown in stylized form in Figure 1. The reef is assumed to consist of 5,000 tonnes of solid material (boulders or manufactured blocks) deposited over an area of 30,000m^2 in a location suitable for the attraction and retention of lobsters. The optimal scale of reef is difficult to determine, but the evidence suggests that 5,000 tonnes is probably the minimum realistic size. The design and configuration of the reef is assumed to be similar to that currently in existence in Pool Bay, i.e. consisting of a number of separate piles of material arranged at regular intervals on the sea bed, each approximately 1 meter high by 4 meters across. Though a wide range of construction materials could potentially be used to build such a reef, the analysis considers just two: boulders of quarry rock and manufactured blocks of cement-stabilized fly ash.

Given its structure and siting, natural colonization of the reef can be expected to take place by adult lobsters from the wild population. It is known that natural colonization will need to be supplemented by artificial stocking of the reef with hatchery-reared juveniles, and the strategy is therefore to release juveniles (aged approximately 3 months) onto the reef from year 1 and annually thereafter. The reef is assumed to have sufficient crevice space to accommodate 5,000 market-sized lobsters, and this was also the figure taken as the number of juveniles to be released on to the reef each year. Since it takes 5 years for juveniles to be recruited to the fishery, it is anticipated that harvest levels would be low in the early stages of the project, with catches consisting entirely of lobsters drawn from the wild population. Once they are established on the reef, however, it is expected that hatchery-reared lobsters will eventually account for the bulk of catches. It was assumed that some 45% of the standing stock of adult lobsters could be harvested each year, implying an expected annual catch of 2,250 animals once all the crevice space was fully occupied. This production level would be reached in year 6 and maintained thereafter, subject to year-to-year variations around the mean due to fluctuations in the natural environment and the pressure of fishing.

3.1.2 Valuation of costs and benefits

The three main components of cost were: (i) the construction of the artificial reef, (ii) stocking of the reef with hatchery-reared juvenile lobsters, and (iii) harvesting the standing stock.

Of the two construction options considered, the least costly involved the use of quarry rock. Allowing for sea transportation and placing, the total cost of constructing a 5,000 tonnes reef was put at £53,625. The corresponding figures for a reef constructed of ash blocks was almost double that (£102,090). The difference is accounted for by the fact that, even though the combined cost of the raw materials (PFA, gypsum, cement) was only slightly greater than that of quarry rock, the supply of ash blocks involved a secondary processing stage which would obviously be absent in the case of the primary aggregate. The production of 3-month old juvenile lobsters and their placing onto the reef was estimated to be £1.00 per juvenile, giving a total cost of £5,000 p.a.. Harvesting the reef using the standard method of baited pots incurs operating expenses and labor costs, the latter being rather more difficult to estimate than the former. The reason for this was because the (currently) very limited occupational mobility of labour employed in the UK fishing industry made it necessary to shadow price labour at an appropriately low rate. That adjustment having been made, the harvesting costs were estimated to be £1.08 per lobster, implying that at maximum production (2,250 lobsters per year) the total harvesting costs would be £2,430 p.a..

The main source of economic benefit from the reef project was taken to be the marketed output of lobsters. Estimated harvests were monetised using an average of real ex-vessel prices landed in the UK over the period 1992-4, giving a figure of £4.14 per 1b. Since there was no evidence of a rising or falling trend of prices, it was assumed that this figure would remain constant in real terms over the life of the project, and could therefore be projected forward in order to forecast the future stream of revenue. The scale of the reef project was sufficiently small that it could be safely assumed that the price of output would be unaffected by the additional supplies coming onto the market. Quite clearly, this assumption becomes untenable if the construction of a very large reef project were ever to be countenanced.

The possibility that the reef project might generate externalities was also considered. On the benefit side, there are the opportunities, which an AR could offer to recreational fishing, given that the structure is likely to attract species, which could be targeted by sport fishermen. In a number of countries (notably the US), it appears to be the case that recreational fishing is often the primary benefit to be derived from ARs, and in such situations reefs may be constructed principally for that purpose (McGurrin, 1989; Murray, 1994; Murray and Betz, 1994). In Europe ARs have generally not served a recreational function, but the potential clearly exists. On the cost side, there are two possible adverse impacts. Firstly, there is the negative effect, which the presence of an AR might have on trawling due to damage caused to nets. Secondly, there is the potentially harmful environmental impact brought about by the leaching of heavy metals from the PFA blocks. Lack of data precluded any reliable assessment of these externalities, but in our judgement the external costs would in most situations be trivial in comparison to the potential external benefits. Indeed, it is reasonable to suppose that in practice the adverse effects described above could be largely avoided. In the first instance it is relatively straightforward matter to plan the siting of a reef away from trawling areas, and in the second place the scientific evidence suggests that leaching from the PFA structure need not occur, provided the blocks are adequately stabilised. Admittedly, there is still uncertainty over the very long-term stability of such material in a marine environment.

3.1.3 Variation in parameter values

A summary of the data used in the analysis is presented in Table 1. Because of the importance of measuring project risk, an attempt was made to estimate the likely year-to-year variation in parameter values. In the case of price, this was fairly straightforward since published data are available covering a period of some 20 years from which it is possible to estimate the standard deviation and coefficient of variation of the series. For all the other parameters, however, the very limited information meant that the only practical solution was to estimate a most likely value and then to make an assessment of the percentage variation either side of it. The data needed for this exercise was based on discussions with a very large number of organisations and individuals whose help and assistance is gratefully acknowledged.

3.2 Results

3.2.1 Economic worth of the project

Measures of project worth are presented in Table 2, which shows the net present value (NPV) and benefit-cost ratio (BCR) for the two project options as a function of the discount rate. The value of the discount rate at which NPV equals zero and BCR equals 1.0 defines the internal rate of return (IRR), which in the case of the AR constructed of blocks is 5.1% and for the AR constructed of rock is 8.0%. This difference is to be expected, given that rock is the cheaper of the two materials. Since the purpose of the appraisal is to establish the circumstances under which ARs for lobster production are likely to be a worthwhile public sector investment, it is appropriate to judge these projects against the UK government's recommended test discount rate (TDR) of 6 % (H.M. Treasury, 1991). Using this as the yardstick, then on the IRR criterion an AR constructed of ash blocks would narrowly fail the rest of acceptance while one constructed of rock would pass. This is confirmed if we use the NPV and BCR criteria: at a 6% TDR, a reef constructed of ash blocks produces an NPV of £20,313 and a BCR of 0.80 (fail), while in the other case the NPV is £28,152 and the BCR 1.52 (pass).

3.2.2 Risk and uncertainty

Sensitivity analysis can be used to examine the effect of changes in the underlying assumptions on the economic viability of the AR project. Here we will focus on the project option which is above the line of economic acceptability (i.e. having a BCR **>** 1.0) and see how sensitive this result is to variations in each of the parameters from their base level. Figure 2 illustrates the effect of production and price changes on BCR**.** Recall that in the base case an AR constructed of rock was expected to generate a BCR *of* 1.52 (at a 6% TDR). The sensitivity graph shows that it only requires a fall in price of about 14% to switch the project from being acceptable TO unacceptable. On the production side, lobsters in the size range 85mm-90mm harvested from year 5 represent the largest single category of output. These would consist mainly of hatchery-reared lobsters that by year 5 would be above the minimum landing size and would be recruited to the fishery. Figure 2 shows that a fall in catches of about 33% from their expected level reduces the project to the margin of acceptability. It should not be inferred from this that the project is 'less sensitive' to production changes than to price changes: obviously, increases or decreases in the total quantity produced in each year across all size categories would have the same effect on sales revenue as an equivalent change in price. Here we are considering production from a single age and size band in isolation changes in which will necessarily have less impact than changes in the total level of harvest.

Figure 3 illustrates the effect of changes in the three main cost elements on BCR. There is a fairly clear ranking in terms of sensitivity with changes in the cost of juvenile lobsters having the most impact on project viability. As the graph shows, the BCR would be reduced to its threshold of 1.0 by a rise in juvenile costs of approximately 34%. The comparable changes for construction costs and harvesting costs are 52% and 85% respectively.

While sensitivity analysis is useful for identifying the parameters, which exert an especially strong influence on a project, in itself it says nothing about the likelihood of each of the parameters deviating from their expected value. As such, it is more appropriate for dealing with situations of pure uncertainty than risk. Fortunately, however, it is possible to use the information obtained on the variations in the parameter values (Table 1) in order to undertake formal risk analysis. This was carried out using a computer-based simulation model (@RISK) in which the BCR was repeatedly recalculated across 1,000 iterations with different combinations of parameter values (Figures 4 and 5). Instead of the more traditional method of Monte Carlo simulation, a stratified sampling technique (Latin hyper cube) was employed on the grounds that it is more effective at bringing about convergence with a given number of samples. For each of the two project options, the expected value of the BCR produced by the simulations is slightly higher than the result derived previously (0.828 as against 0.8, 1.623 as against 1.52), but the implication is the same: an AR constructed of ash blocks fails the test of acceptability, while one constructed of quarry rock passes. The important point revealed by the analysis, however, is that in both cases there is reasonably wide distribution of outcomes around the expected value. This is made explicit in Table 3, which shows in each case the *chances of BCR falling above or below the critical value of 1.0.* When the reef is made of blocks, it will be seen that even though the project on average would be expected to fail the test of acceptability, there is still a 33% chance that it will pass. With the quarry rock option, on the other hand, even though the expectation is that on average this would be an acceptable investment project, nonetheless there is still almost a one-third chance that it will fall 'below the line'. This is a risk that policy-makers may not be prepared to take.

4. Conclusion

The use of artificial reefs for lobster production shows considerable promise, and it is important that progress in both the science and economics of reef research be maintained. It has been suggested that a way forward might be to construct an AR in an appropriate location and to follow this with the controlled release of juvenile lobsters, which would subsequently be targeted for recapture. The economic feasibility of such a venture has been examined using a capital budgeting model of a proposed AR project, from which it can be concluded that the circumstances under which the construction of a reef for lobster production might be deemed to be worthwhile are both realistic and attainable. The analysis also demonstrates that it is possible to quantify project risk so long as information can be obtained on the probability distribution of parameter values.

The analysis has nonetheless made a number of simplifying assumptions, and may well have raised as many questions as it has tried to answer. What, for instance, would be the effects of scaling up the reef investment? If an AR very much larger than the one envisaged in this paper were to be constructed, could we simply extrapolate from our results in order to assess the net economic benefits? At what point might technical, legal, financial, or market constraints become binding? If there is any realistic prospect of an AR investment project being undertaken by either a commercial, or a public sector organisation lines are questions that will require answers. Another important line of inquiry concerns the externalities to AR construction. The suggestion made here, that the external benefits of ARs could be quite large on account of their potential use for recreational purposes, is an obvious area for further investigation. Finally, we need to bear in mind that the deployment of ARs on any significant scale may have quite far-reaching effects on a fishery by virtue of the fact that they will enhance the scope for resource rent capture and thereby, alter the level and distribution of total fishing effort. One implication of this may therefore be that future research on ARs by economists will need to be within a bio-economic modeling framework.

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Table 1: Artificial reef project: variation in parameter values

Parameter	Units	Variation		
		Lower	Most likely	Lip per
1 Lobster price	£/lb	2.48	4.14	6.62
Catch: 85mm-90mm (years 1-2)	Number	60	120	180
Catch: 90mm-l00mm (years 1-2)	Number	40	80	120
Catch: 85mm-90mm (years 3-4)	Number	150	300	450
Catch: 90mm-100mm (years 3-5)	Number	100	200	300
Catch: 85mm-90mm (from year 5)	Number	450	1,350	2,025
Catch: 90mm-100mm (from year 6)	Number	450	900	1,350
Juvenile costs	£/lobster	0.90	1.00	1.50
Juveniles released	Number	4,750	5,000	5,250
Harvesting costs	£/tone	0.864	1.08	1.296
Quarry rock	£/tone	4.25	5.625	7.00
Pulverised fly ash (PFA)	£/tone	2.50	4.50	6.50
Gypsum	£/tone	3.00	4.50	6.00
Cement	£/tone	36	40	44
Manufacturing costs	£/tone	5.00	8.50	12.00
Sea transport	£/tone	2.20	5.10	8.00

Note: In the case of price a normal distribution is assumed with a mean value of 4.14 and a standard deviation of 0.83. The lower and upper figures given above refer to 2 x S.Ds either side of the mean. For all other parameters it is assumed that the variation is assumed by a modified triangular distribution with three times the value corresponding to the 10th percentile of the distribution, the most likely value, and the value corresponding to the percentile of the distribution.

Table 2: Economic worth of artificial reef projects

Discount Rate	Ash blocks NPV	BCR	Quarry rock NPV	BCR
0%	601528	6.89	649993	13.12
1%	320462	4.14	368927	7.88
2%	171523	2.68	219988	5.10
3%	86965	1.85	135430	3.53
4%	35596	1.35	84061	2.57
5%	2378	1,02	50843	1.95
6%	-20313	0.80	28152	1.52
1%	-36545	0,64	11920	1.22
8%	-48606	0.52	-141	1.00
9%	-57848	0.43	-9383	0.83
10%	-65110	0.36	-16645	0.69

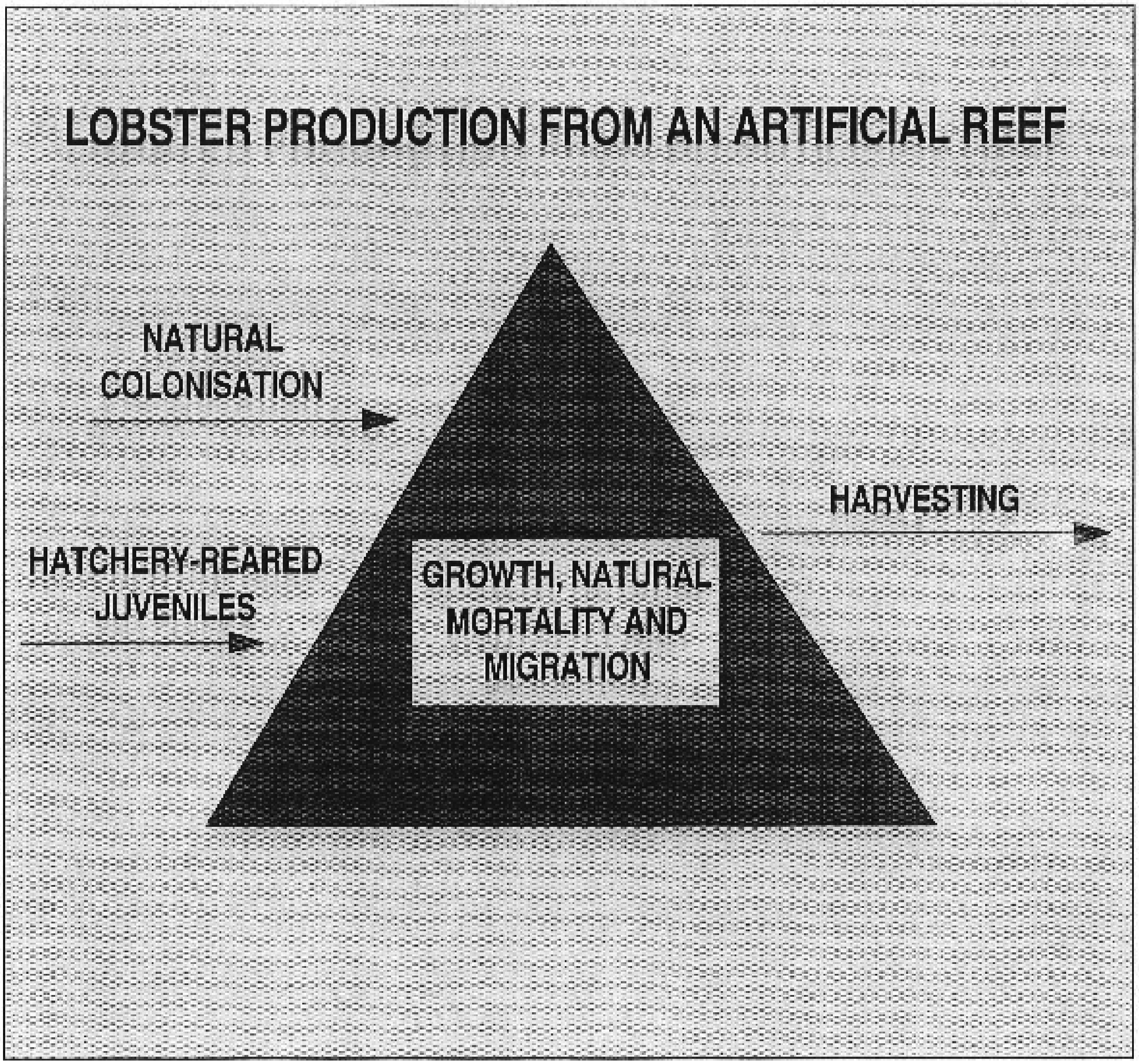
Table 3: @RISK Simulation Statistics: computer printout

Worksheet: REEF RISK.WK3	BCR(BLOCKS) (in Cell A:B87)	BCR(ROCK) (in Cell A:B90)
Expected/Mean Result =	0.8287245	1.62359
Maximum Result =	4,151929	6.961424
Minimum Result =	- 1.035965	-1.035965
Range of Possible Results =	4-636596	7.997389
Chance of Positive Result =	95.2	95.2
Chance of Negative Result =	4,8	4.8
Standard Deviation =	0,586516	1.207733
Skewness =	0.8855087	1.038399
Kurtosis =	4,754442	4.788476
Variance =	0.344001	1;458619
ERRs Calculated =	0	0
Values Filtered =	0	0
Simulations Executed =	1	1
Iterations =	1000	1000

Percentile Probabilities (Chance <= Shown Value)	BCR(BLOCKS) (in Cell A:B87)	BCR(ROCK) (in Cell A:B90)
0%	-0.484669	-1.035 965
5%	0.005925307	0.01283131
10%	0.1507122	0.2862464
15%	0.2566371	0.4800788
20%	0.3363102	0.6477462
25%	0.4202S09	0.7676182
30%	0.4974425	0.9312042
35%	0.5641959	1.073291
40%	0.62697 S	1.196432
45%	0.695603	1.333278
50%	0.755S838	1.432383
55%	0.8276677	1.564566
60%	0.8993044	1.690869
65%	0.9720053	l.839113
70%	1,055577	2.030612
75%	!.[65478	2.2495S6
80%	1.25S744	2.465665
85%	1,382212	2.763656
90%	1.57524	3-193575
95%	1.888824	3.916739
100%	4.151929	6.961424

Probabilities for User Selected Values:	Prob of >= Value	Prob of >= Value
Value # 1=	1	1
Probability #1=	33.1	68.12679

Figure 1


LOBSTER PRODUCTION FROM AN ARTIFICIAL REEF
NATURAL COLONISATION
HATCHERY-REARED JUVENILES
GROWTH, NATURAL MORTALITY AND MIGRATION
HARVESTING

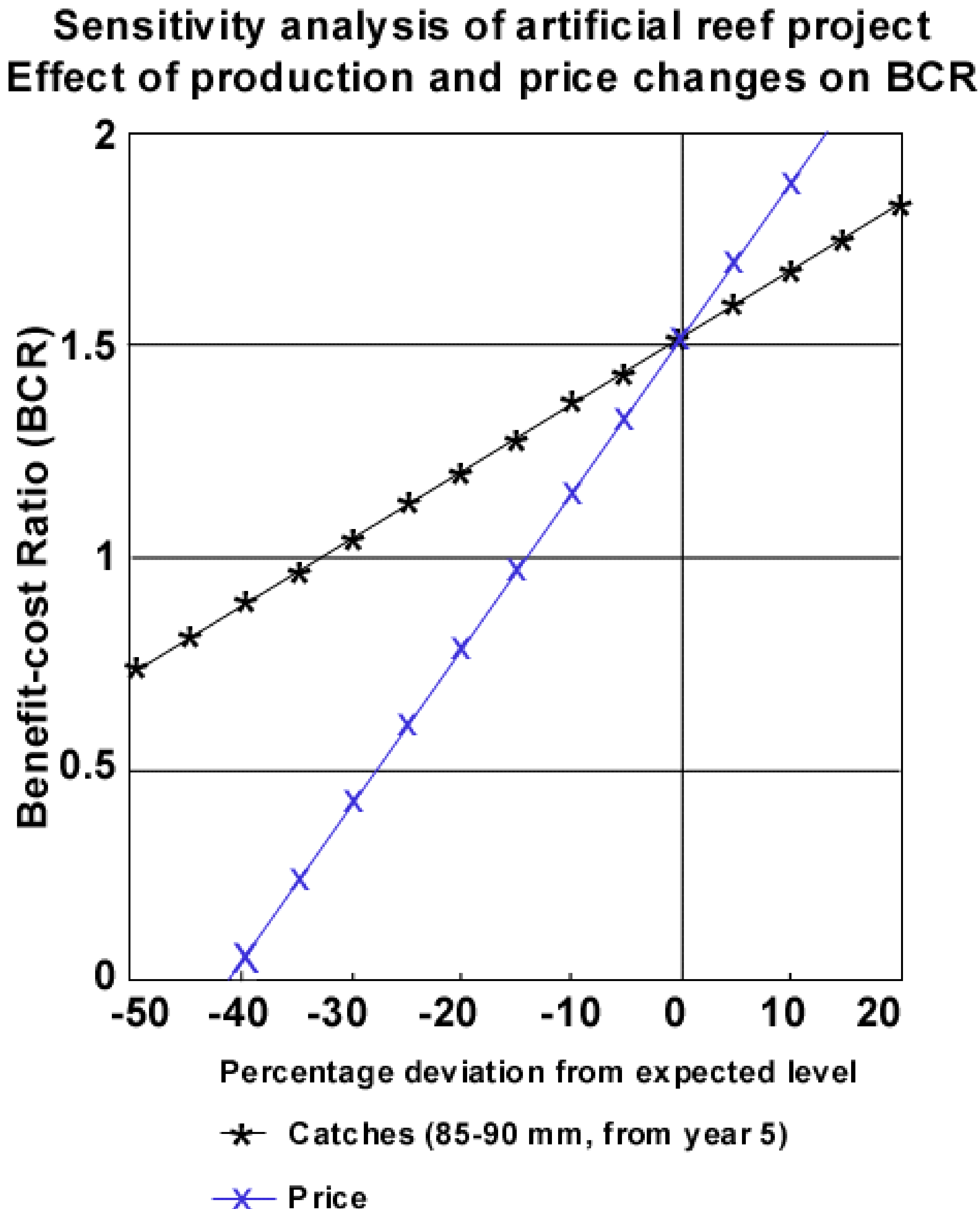

Sensitivity analysis of artificial reef project
Effect of production and price changes on BCR
Benefit-cost Ratio (BCR)
2
1.5
1
0.5
0
-50
-40
-30
-20
-10
0
10
20
Percentage deviation from expected level
Catches (85-90 mm, from year 5)
Price

Figure 2

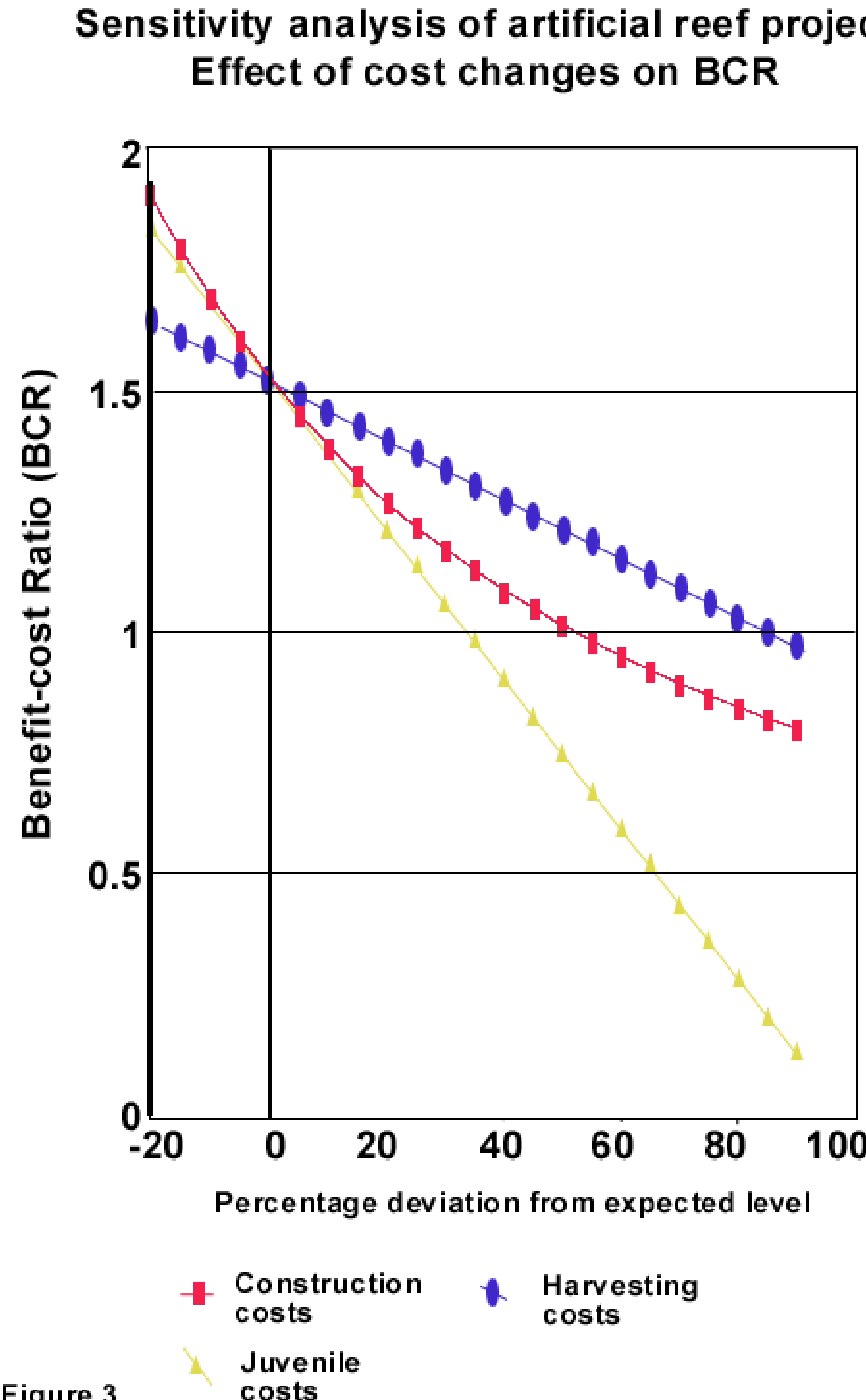
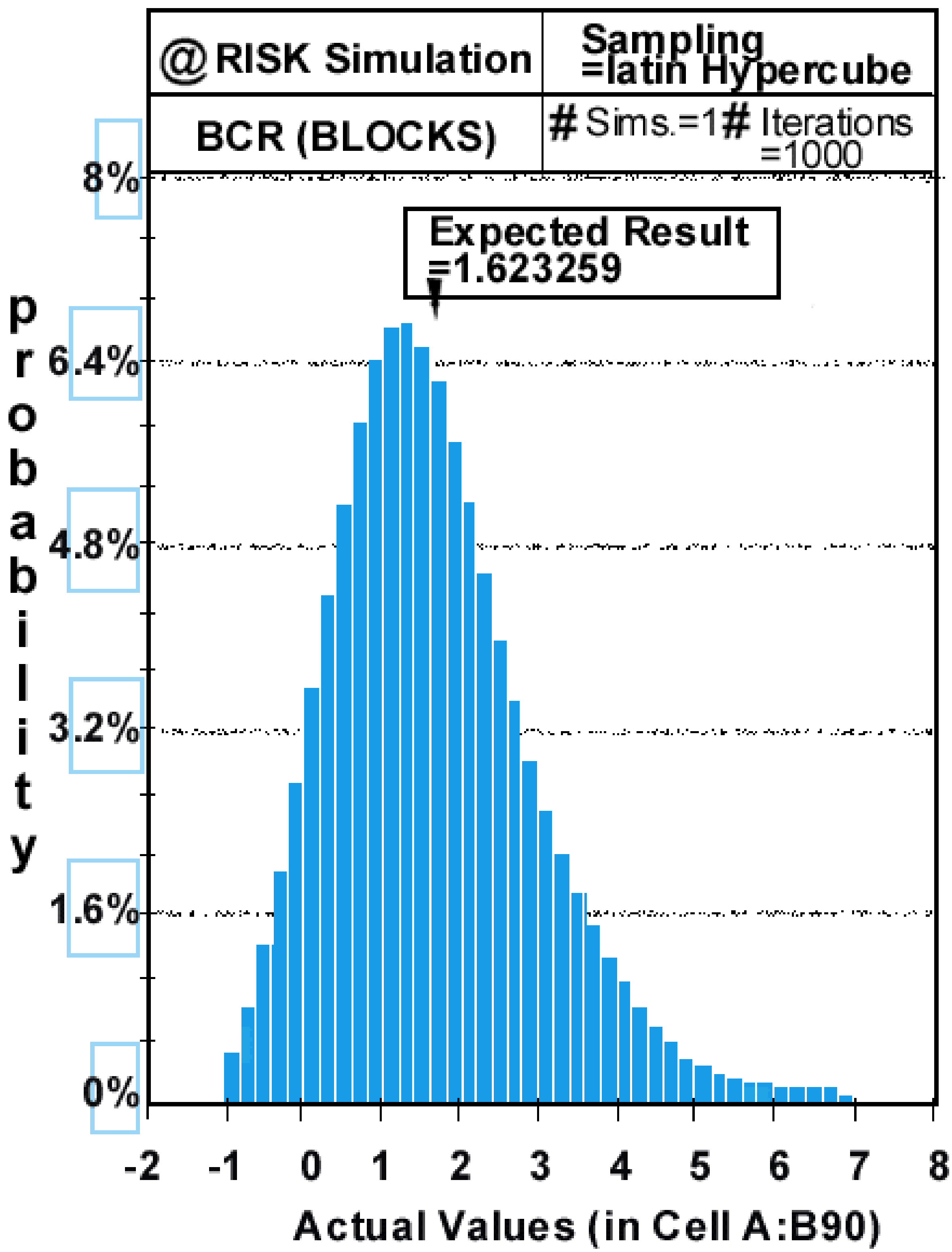
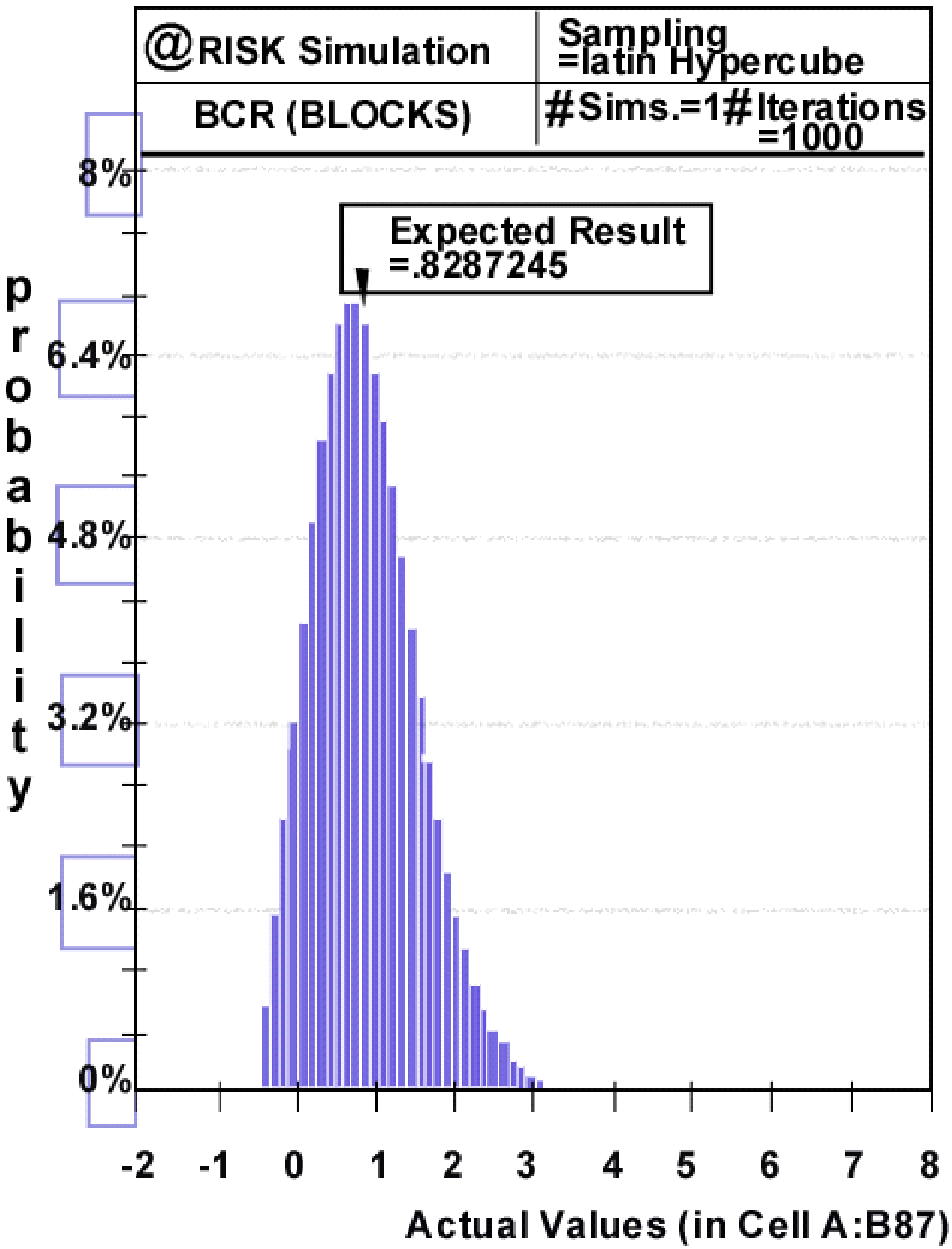

Sensitivity analysis of artificial reef project
Effect of cost changes on BCR
Benefit-cost Ratio (BCR)
2
1.5
1
0.5
0
-20
0
20
40
60
80
100
Percentage deviation from expected level
Construction costs
Harvesting costs
Juvenile costs

Figure 3



@RISK Simulation
Sampling =latin Hypercube
BCR (BLOCKS)
Sims.=1# Iterations =1000
Expected Result =1.623259
probability
8%
6.4%
4.8%
3.2%
1.6%
0%
-2
-1
0
1
2
3
4
5
6
7
8
Actual Values (in Cell A:B90)


@RISK Simulation
Sampling =latin Hypercube
BCR (BLOCKS)
#Sims.=1#Iterations =1000
Expected Result =.8287245
probability
8%
6.4%
4.8%
3.2%
1.6%
0%
-2
-1
0
1
2
3
4
5
6
7
8
Actual Values (in Cell A:B87)