CEMARE Research Paper 152

Economic analysis of marine ranching

D Whitmarsh

University of Portsmouth
Centre for the Economics and
Management of Aquatic Resources
Locksway Road, Portsmouth PO4 8JF
United Kingdom

First published University of Portsmouth 2001

For bibliographic purposes this publication may be cited as: Whitmarsh, D. 2001. **Economic analysis of marine ranching.**
CEMARE Res. pap. no.152.

Author affiliation:

David Whitmarsh
Centre for the Economics
and Management of Aquatic Resources
University of Portsmouth, Milton Campus
Locksway Road, PORTSMOUTH
PO4 8JF, Hampshire, England

E-mail: David.Whitmarsh@port.ac.uk

N.B.

This paper is a revised version of one given at the International Symposium on Marine Ranching, November 20-26, 2000, Seoul, Korea.

ISSN 0966-792X

Abstracted and Indexed in:
Aquatic Sciences and Fisheries Abstracts

Economic analysis of marine ranching

David Whitmarsh

CEMARE, Department of Economics, University of Portsmouth, UK.

ABSTRACT

Despite the obvious appeal of marine ranching as a way of reversing the effects of overfishing, doubts surround its biological and economic effectiveness. This paper focusses on the economic aspects of ranching, reviewing the pattern of success and failure and the factors which are likely to influence the economic performance of a given ranching programme. In general less is known about the economics than about the science of marine ranching, and to date relatively few empirical economic evaluations have been undertaken. Overall, the available evidence on established marine ranching programmes has produced a rather mixed picture. Recent assessments of the Alaskan salmon programme emphasise the difficulties of reaching an overall verdict, given that the economic effects of salmon enhancement vary widely between regions and stakeholder groups. The Japanese experience of flounder and red sea bream appears to have been successful in terms of economic efficiency, although the results are area-specific. Ranching of European lobster in Norway and the UK does not appear to be economically viable at the present time due to low recapture rates, but strategies for overcoming this constraint (e.g through the use of artificial reefs) may be possible. Ranching of Atlantic cod in Norwegian coastal waters has been judged to be unsuccessful in economic terms, while the feasibility of the cod enhancement programme in Maine (USA) is still under investigation. The case study research results, taken together with more general evidence of the experience of marine ranching as it operates in practice, suggest that the economic efficiency of ranching will vary according to: (i) the species selected (ii) the marine environment into which the species is introduced (iii) the technology of broodstock production (iv) the method of recapture (v) the market conditions applying to the purchase of broodstock and the sale of final product, (vi) the regime of property rights over the stock and the harvest and (vii) the extent to which harvesting pressure is controlled.

1. Introduction

Marine ranching, which in this paper will be taken to refer to the release of young fish into the marine environment for future harvest at a larger size, has an obvious appeal to coastal nations faced with declining fish catches. Indeed, the opinion of Ungson (1993, p.13) is that ranching is "one of the few alternatives left" for increasing productivity in ecosystems where catches are falling due to overexploitation and destruction of fishing grounds. Despite this potential, however, many observers remain agnostic about whether stocking of fish into the open marine environment can ever be effective, and the verdict of one commentator is that, notwithstanding scientific advances, "it is not yet possible to conclude that marine stock enhancement is or is not biologically and economically feasible." (Grimes, 1998, p. 23).

This paper is concerned with the economic aspects of marine ranching, and argues that policy decisions about ranching programmes need to be made in the light of information about their economic and social consequences. At the present time far less is known about the economics than about the science of marine ranching, and considerable doubt surrounds its cost effectiveness or economic viability. While it is likely that a significant number of economic feasibility studies exist in the 'grey literature' (Moksness, 1999), it would appear that relatively little hard evidence on the economic performance of marine ranching has found its way into the public domain. Arguably, however, such evidence as there is allows a number of tentative inferences to be drawn about the circumstances under which marine ranching might be economically successful, and the aim of the paper is to review this evidence. The paper focuses on the release and recapture elements of the production system, since it is these stages that have attracted the most controversy as regards economic viability and the justification for public funding. The paper starts by looking at marine ranching as an economic process, highlighting the bioeconomic implications which may follow from a programme of stock enhancement. It next discusses the role of economic evaluation in providing decision-makers with essential information, examining the ways in which such information can be obtained, and then moves on to review the current state of knowledge about marine ranching on the basis of published economic research. This is followed by a critical discussion of this evidence and the methodologies that have been employed in the various studies.

2. Marine ranching as an economic process

From an economic perspective, marine ranching represents a production system, capable of producing a number of outputs, using a variety of factor inputs and involving different processes. The outputs generate benefits to society, the most obvious benefit deriving from increased commercial landings of fish and its appropriation by harvesters in the form of higher net income (producer surplus) or by purchasers in the form of lower prices (consumer surplus). Economic benefits from ranching need not necessarily be associated with a marketed product, however, and in the case of recreational fisheries where access is free to the public the gains from stock enhancement are likely to be reflected in increased amenity and enjoyment to anglers. In principle this can valued in monetary terms by anglers' willingness to pay (WTP) for improved sport fishing opportunities. On the input side the important economic consideration is that the labour and capital involved in the ranching process (i.e. hatchery production, release, harvesting, research, monitoring, etc.) will have an opportunity cost, meaning that its use implies a sacrifice of output from another (possibly more valuable) economic activity. The relationship between the inputs and outputs of the production system defines its economic efficiency, and it is the identification of this relationship which is one of the principal purposes of economic evaluation (see below). It should be noted that part of this exercise involves the accounting for any spillover or external effects, which as we will see shortly are potentially important in the context of marine ranching.

The economic consequences that are likely to follow from a programme of marine stock enhancement depend in large measure on the underlying bioeconomics of the fishery that is being enhanced. This is explained in Figure 1, which provides a synoptic model of the marine ranching process. It is assumed that the fish stock is exploited by commercial fishermen, and that the amount of effort targeted at the stock is conditioned by the profitability of fishing. Profitability in turn depends on the market price of fish and the unit cost of harvesting, price being a function of the quantity of fish landed and unit cost being a function of stock abundance and the prices of factor inputs. It may be supposed that anything which increases profitability will make it more attractive to intensify the pressure of fishing, so that in an open-access fishery effort will increase. This can be expected to reduce the equilibrium level of fish stock biomass, however, causing catch per unit of effort to fall and unit harvesting costs to rise. These bioeconomic tendencies have important implications for the success of any marine ranching programme, since the stock-enhancing effects of additional broodstock (e.g. in the form of hatchery-reared juveniles) will be partially or wholly negated by the stock-depleting effects of increased fishing effort. The model thus serves to highlight one crucial point about marine ranching, which is that the economic performance of an enhanced fishery is likely to depend on the success with which the pressure of harvesting is controlled. This is an issue which is recognised in much of the literature on marine ranching, with a number of researchers rightly drawing attention to the need to regulate fishing effort in order to prevent the economic benefits of marine ranching from being eroded. Effort regulation is, of course, closely bound up with the issue of ownership and exploitation rights, which will define the ability to control access and to capture the rewards of any ranching operation (Bannister, 1991; Bartley, 1999a and 1999b; Hallenstvedt, 1999; Pickering, 1999).

3. The role of economic evaluation

3.1 Choices, trade-offs and objectives

The role of economic analysis is to provide decision-makers (e.g. politicians, fishery managers, funding agencies) with information that will enable appropriate choices and trade-offs to be evaluated concerning the allocation of resources to marine stock enhancement programmes. Examples of the type of choice that might need to be made concern:

(i) *management strategies*: e.g. If the aim is to assist the recovery of a severely depleted fishery, should the management authority impose tighter effort controls in order to reduce fishing pressure, or should it attempt to rebuild the stocks through the release of additional broodstock ?

(ii) *sources of broodstock input*: e.g. If the option of marine stock enhancement is chosen, should stocking be done with broodstock caught from the wild fishery, or with hatchery-reared juveniles ?

(iii) *production technology*: e.g. If a release and recapture operation is planned, should this be done using a purpose-build artificial habitat as a ranching substrate, or should the juveniles be released directly into the sea ?

(iv) *cost recovery*: e.g. If it is intended to recoup part of the cost of a ranching programme from the recipients, should this be done through a levy on landings or through the award of harvesting rights ?

These are all illustrations of discrete 'either-or' choices, but in other situations the decision-maker may be faced with the need to evaluate trade-offs between different performance criteria. A classic instance of this would be the problem of determining the optimal age at which hatchery-reared juveniles are released into the open ocean. The younger the age of release, the lower the average production cost but the higher the natural mortality and the greater the delay between release and recapture; conversely, an older release date for juveniles may enhance survival and shorten the time to recapture but will incur higher hatchery costs. It needs to be understood, however, that optimality is determined in part by the objectives which have been set for the ranching programme. To continue with the example of the appropriate age of hatchery release, if the primary goal of the programme were to increase fishery yields regardless of cost then the optimal release date would tend to be higher than if the manager were concerned with profitability or efficiency.

3.2 Approaches to economic evaluation

Two widely used assessment concepts are *economic impact analysis* and *economic efficiency analysis* (Milon et al., 2000), and their application to marine ranching is outlined in Table 1. These approaches may be applied either prospectively (i.e. ex ante) in order to see what the economic implications of a proposed project are expected to be, or retrospectively (i.e. ex post) in order to assess what impact or efficiency gains have actually resulted from an established ranching programme. *Ex ante* evaluations may be used as a management tool to help decide, for example, whether a proposed ranching project is worth undertaking or whether the scale of an existing project should be enlarged. *Ex post* evaluations may be used for comparing the projected and the achieved performance of a ranching programme that is currently in operation. As such it may serve to highlight the weaknesses or failures in the project planning process, and in so doing provide valuable feedback to managers or sponsoring agencies.

The first of the approaches, economic impact analysis, aims to establish what effect a ranching project has on specific economic variables. This might involve using *revenue analysis* to see whether an expanded enhancement programme would be likely to raise fishermen's gross earnings or revenue. The analysis would typically require the estimation of a demand function for the harvested product in order to determine the impact of changes in supply on market price (and hence on total sales revenue). More ambitiously, impact assessment might involve the application of *multiplier analysis* to measure the total economic activity generated by an enhancement programme (e.g. on output, income or employment) as a consequence of the interdependence between fishing and other sectors comprising the regional economy. The total economic impact will be made up of direct and secondary (i.e. indirect and induced) effects.

It needs to be stressed that impact analysis does not set out to determine whether a ranching programme is beneficial or detrimental in terms of its economic worth to society as a whole, since it does not consider the costs of implementing the programme. In this respect it differs fundamentally from economic efficiency analysis which has social welfare maximisation (defined in terms off the optimal allocation of resources) as its goal. This becomes clear when we consider two of the ways in which the approach is commonly applied, namely *cost-effectiveness analysis* and *cost-benefit analysis*. With cost-effectiveness analysis there is a presumption in favour of the least-cost option for achieving a given objective; with cost-benefit analysis, the presumption is in favour of the option which produces the highest ratio of monetary benefits to costs. In short, there is an implicit value judgement underlying economic efficiency analysis (i.e. that improvements in economic efficiency are desirable) which is absent from economic impact analysis. In a planning context this presumption in favour of efficiency is the basis of a number of decision criteria - notably, net present value (NPV) and internal rate of return (IRR) - that can be used to select and prioritise project options in terms of their economic value to society.

3.3 Problems of measuring costs and benefits

The costs and benefits associated with a marine ranching project may be difficult to quantify for a number of reasons. Where a project has a clearly defined objective, but one which cannot be easily measured in monetary terms (e.g. the rehabilitation of a severely depleted fishery) then it may only be feasible to use cost-effectiveness analysis rather than cost-benefit analysis. Where monetisation of benefits as well as costs is possible, cost-benefit analysis can (and arguably should) be undertaken. The costs and benefits of a ranching project will need to be discounted over a specified number of years using an appropriate rate to reflect the marginal opportunity cost of capital (Shang and Tisdell, 1997), but in practice the choice of discount rate in public sector ranching projects may be far from obvious.

A major problem in all economic appraisals is the need to account for *externalities*, which in the case of enhancement programmes are likely to stem from a number of sources. The clearest example of an externality in this context is where enhancement generates unintended third-party *benefits* to a particular group of people, as appears to have happened in the case of the red sea bream ranching programme in Kanagawa Prefecture, Japan (Masuda and Tsukamoto, 1998) where recreational catches of red sea bream have been rising faster than commercial catches. As a result anglers, who contribute only a small proportion of the costs of the ranching programme, now take a higher percentage of the stocked fish than do the commercial operators, who are the intended beneficiaries. Externalities may also take the form of *costs*, often arising from the environmental impact of stock enhancement. For example, major externalities may result from interactions between the wild fishery and the ranched stock, giving rise to two particular problems. Firstly, density-dependent factors in the marine environment may mean that the introduction of hatchery-reared fish may partially displace the natural stock, implying that the scope for increased total catches from the fishery will be less than expected. There is now quite strong evidence for this in the case of the hatchery program for pink salmon in Prince William Sound, Alaska (Hilborn and Eggers, 2000). Secondly, where cultured fish are a component of the commercial catch (i.e. creating a `mixed' fishery), there is a danger that the wild stocks may be over-harvested. This is a source of serious concern in the Pacific salmon fisheries, where increased hatchery production combined with high harvest rates has apparently led to a decline in the wild stock (Hilborn, 1992). In theory the over-harvesting problem can be mitigated by controlling fishing effort, but where fishermen take a fixed proportion of recruits from both the wild and the hatchery-reared stocks there is still a risk of natural stock extinction (Anderson and Wilen, 1985). Interactions between the wild fishery and ranched stock may be more complicated than this, however, and for species that are cannibalistic (e.g. cod) the success of ranching may actually be improved by high harvesting pressure on the adult (wild) fish. In such cases the paradoxical implication will be that `bad' management of the wild fishery will favour high recapture rates and hence good catches from the enhancement programme (Pedersen and Olsen, 1997).

3.4 Economic evaluation and the rationale for subsidies

Many marine ranching programmes throughout the World are supported by government (Ungson, 1993; Pillay, 1997; Welcomme and Bartley, 1998) and it is important that their economic performance be evaluated in order to establish whether public funds are used efficiently (Hilborn, 1998). A case may be made out for subsidising ranching if cost-benefit analysis reveals that the net discounted benefits are expected to be positive but that private capital for such a project would not be forthcoming because it was not expected to generate a commercial return. Such a situation would obtain where, for example, there were significant unpriced (i.e. extra-market) benefits that accrued to society as a whole but not to the investor. However, while cost-benefit analysis may justify public funding of ranching programmes in particular circumstances, there may often be a much wider set of reasons why in practice governments may be prepared to subsidise these activities. Stock enhancement programmes may be politically much easier to implement than the alternative of controlling fishing effort (Travis et al., 1998), having the added attraction that governments are seen to be ‘doing something positive’ to aid fishermen. Publicly-funded programmes may serve a more positive purpose, however, since in the complicated politics of fisheries a demonstrated commitment by management authorities to stock enhancement may be the only way to get fishermen to accept unpopular restrictions on their harvesting activity. In these circumstances ranching acts to re-inforce effort control rather than replace it.

Ranching may also be seen as a way of rectifying previous policy mistakes. This appears to be the reason why the Japanese government has been willing to subsidise sea ranching in coastal areas, where productivity has been reduced by environmental degradation caused by publicly-sponsored shore reclamation and marine pollution from industrial development (Ungson, 1993; Welcomme and Bartley, 1998). In this example the subsidy to ranching is a means of compensating Japanese inshore fishermen for lost fishing opportunities. Furthermore, as Hilborn (1998) has argued, enhancement programmes tend to have a self-reinforcing dynamic which is driven by “political need and technological curiosity” (p. 671) rather than public interest considerations. The point is, therefore, that while subsidies to ranching may in certain instances be justified on economic efficiency grounds as a means of overcoming cases of ‘market failure’ (i.e where projects which are socially beneficial would not be undertaken by commercial firms), this may not be the *de facto* reason why many such programmes are supported from public funds. In reality, the motive for subsidisation may have nothing to do with economic efficiency.

4. Empirical evidence on the economics of marine ranching

Table 2 identifies some of the main empirical studies that have been carried out to investigate the economic impact or efficiency of marine ranching. These studies vary considerably in their depth and scope, and in the remainder of this paper the discussion will centre on five species where there is now a reasonable body of knowledge concerning the economics of ranching. These are Pacific salmon, Japanese flounder, red sea bream, European lobster and Atlantic cod. While it might appear that surprisingly few economic analyses have been undertaken, given the very large number of ranching programmes now being conducted worldwide, it should be noted that other published material (dealing mainly with biological and technical aspects) frequently includes cost and price information on particular ranched species which can often shed light on their economic viability. Such studies have not been included in Table 2, however, which identifies only those research reports where a reasonably detailed economic analysis has been undertaken. In the assessments given below we present the findings of this research, supplemented as appropriate by material from other sources.

(i) Pacific Salmon

Salmon are uniquely suitable for marine ranching by virtue of their homing instinct, and it is therefore not surprising that these species were amongst the earliest to be developed as the basis of release and recapture fisheries. Ranching of the Pacific salmon species (genus Oncorhynchus) is in economic terms far more significant than that of Atlantic salmon (Salmo salar), with pink and chum varieties supporting large ranching programmes in Japan and Alaska (Isaksson, 1994).

In Japan the earliest attempt at stock enhancement for chum salmon began in 1876, and since that time it has been actively encouraged by the Japanese government (Kitada, 1999). Currently some 2 billion chum salmon are released each year (Ibid). Using data from the Hokkaido Prefectural Government, Kitada (1999) estimates the mean economic return rate (value of landings divided by the release costs) for this species to be 9.8. When the returns are discounted (at interest rates of 0.018 and 0.05) the economic returns become 9.1 and 8.0 respectively, which can be taken as evidence for the economic feasibility of salmon ranching. The progress of salmon ranching in the Pacific states of the US and Canada throughout the 1970s has been reviewed by Stokes (1982), who reports the ex ante empirical results of an economic impact analysis of Washington State's salmon fisheries and public hatcheries. Using an input-output model he demonstrates that ocean ranching produces a multiplier effect that could potentially raise employment and household income in the State as a whole, and in the light of this he concludes that if such an enterprise were profitable it could "make a significant contribution to sport and commercial capture fisheries and to Washington's economy generally." (p. 475). The study also draws attention to the effect which successful propagation could be expected to have on salmon prices, a prediction which was to become a real policy concern in the late 1980s and 1990s.

The problem of falling salmon prices and its significance for the Alaskan salmon enhancement programme has been addressed by Herrmann (1993), who examines the effect on fishermen's revenue of different salmon enhancement production levels. The results indicate that for pink salmon, given the market conditions prevailing at the time, a reduction in hatchery output would lead to higher revenues; for sockeye, expanded hatchery production would result in higher revenue but only to a modest extent. Boyce at al. (1993) use the results of this revenue analysis to conduct a more detailed cost-benefit analysis of the Alaskan salmon enhancement programme, which was used to generate projections over a 30-year planning horizon. Using producer surplus as the welfare measure, the results showed that the elimination of either pink or sockeye salmon enhancement production would reduce benefits to the State. When enhancement costs were taken into account, however, the situation is altered. In this case the elimination of pink salmon production was expected to increase net returns to the State by approximately 8% p.a. while the elimination of sockeye production was expected to increase net returns by 6% p.a. The statewide gains would not be uniformly felt, however, and some areas (e.g. Prince William Sound) would lose from such a strategy.

(ii) Japanese flounder

Flounder is an important marine resource in Japan, and stock enhancement programmes for this species (Paralicthys olivaceus), initiated in response to falling landings, date back to the early 1980s. The economic viability of the programme has been assessed in four studies, (Sproul and Tominaga, 1992; Kitada et al., 1992; Okouchi et al., 1999; Kitada, 1999), most of which focus on stock enhancement efforts in different parts of Japan.

The most detailed and rigorous of the studies is by Sproul and Tominaga (1992), who investigate the net economic returns to the enhancement project in Ishikari Bay, Hokkaido. The monetary benefits accruing to commercial fishermen were assessed using data on fish prices, stocking density, recapture rates and mean landing sizes. Costs attributable to the stock enhancement programme included culture and growout expenses as well as costs of research monitoring. Positive and negative externalities were assumed to cancel out, and only those benefits and costs attributable to the commercial fishery were considered. The authors estimate that the stock enhancement programme would generate a benefit-cost ratio of 3.15 (assuming a discount rate of 8% over a 26 year time horizon), and demonstrate using sensitivity analysis that the greatest improvement in economic returns would come from increases in fry survival after release. On the basis of this result they conclude that the flounder stock enhancement is economically viable for that particular fishery, but add a strong caveat regarding the need for effort control in order to prevent the success of such an enterprise being undermined by the effect of new entry into the fishery (p. 84). The study by Kitada et al. (1992) on the effectiveness of the flounder stock enhancement programme in Fukushima Prefecture comes to a similar conclusion regarding economic viability, but the methodology used differs somewhat from that used by Sproul and Tominaga. Though the approach used by Kitada et al. is similar insofar as it involved a comparison between the sale value of reared flounder and the cost of rearing, no attempt is made to discount the net economic returns over a specified time horizon in order to arrive at an estimate for the NPV or the benefit-cost ratio for the project. Moreover, a sensitivity analysis of the results is not undertaken. The distinctive contribution of this study, however, is that it provides two alternative estimates for the profitability of the enhancement programme (based on different assumptions regarding the cost of fingerling production), and in both cases the programme is shown to generate an economic surplus. Okouchi et al (1999) derive economic return rates for hatchery-reared flounder released into Miyiko Bay, Iwate Prefecture from 1987 to 1992. Economic return is calculated as the landed value of flounder divided by the release cost, where the latter includes juvenile production cost, facilities depreciation and labour. The ratio of landed value to release cost was less than 1.0 for releases in the years 1987 and 1988, but greater than 1.0 in each of the four years 1989 to 1992. Though the study does not undertake a formal economic appraisal of the hatchery release program, and specifically does not calculate NPV, it is nevertheless important in demonstrating a link between economic return, recapture rate and post-release survival. Using an analogous procedure, Kitada (1999) estimates the economic return rate for flounder in Japan as a whole to be 2.1. When the relevant NPVs are derived, the economic return rate is estimated to be 2.0 (discount rate = 0.018) and 1.8 (discount rate = 0.05).

(iii) Red sea bream

Red sea bream (Pagrus major) is a valuable and popular fish species in Japan, where for a number of years landings of bream from the capture fisheries have been on a downward spiral, in contrast to the rapid increase in supplies from aquaculture. Ranching of red sea bream in the Kagoshima Prefecture started in 1974, where it has been demonstrably successful in raising catches (Matsuda, 1992; Ungson, et al., 1995). In Kagoshima Bay there appears to be a high correlation between the number of fingerlings released and the weight of red sea bream landed (Matsuda, 1992). In order to examine the economic feasibility of the ranching programme, Ungson et al. (1995) carried out a cost-benefit analysis using a methodology similar to that employed by Sproul and Tominaga (1992) in the case of Japanese flounder. Monetary benefits to the commercial fishermen in Kagoshima Bay were calculated using data on the price of bream, stocking density, survival rate, recapture rate and mean landing size. Project costs included the expenses incurred in fingerling production, nursery culture and release, the construction of facilities and the costs of research. As in the Sproul and Tominaga (1992) study, it was assumed that any positive or negative externalities caused by the project would cancel out. Using an opportunity cost of capital (discount rate) of 8%, the benefit-cost ratio calculated over a 24 year time horizon was found to be 9.07. This result was supported by sensitivity analysis, which was used to identify minimum acceptable levels of the key variables. Given the very high benefit-cost ratio, none of these was at all close to acting as a limiting factor on the viability of the project. The authors conclude that the ranching of red sea bream in Kagoshima Bay is economically viable, but add the caveat that the findings of their study are area-specific and therefore "may not be true of other places in the prefecture or other parts of Japan." (p.199). They also stress the importance of one of the key assumptions underlying the cost-benefit analysis: that the number of fishermen operating in the fishery over the time horizon of the project remains constant. While this may be a valid assumption for the particular circumstances prevailing in Japan, the authors rightly warn against extrapolating from these findings to situations where effort is not so effectively regulated. In such cases there is a risk that the benefits of marine ranching will be dissipated as fishermen are attracted to the enhanced fishery by the lure of higher profits. The results of the analysis by Ungson et al. (1995) are corroborated by a more recent study by Kitada (1999), who similarly finds that the economic return to red sea bream ranching in Kagoshima Bay substantially outweighs the costs. Though the economic return rate measure is not identical with the benefit-cost ratio derived by Ungson et al., the figures are still noteworthy. Kitada estimates the undiscounted economic return to be 5.1, while the corresponding discounted figures are 4.5 (discount rate = 0.018) and 3.6 (discount rate = 0.05).

(iv) European lobster

(a) Norway

European lobster (Homarus gammarus) is one of four species making up the Norwegian Sea Ranching Programme (PUSH), and the economic viability of lobster ranching has been explored by Moksness et al. (1998) and Borthen et al. (1999). In the first study, Moksness et al. (1998) conduct a profitability analysis using data from the lobster release experiments at Kivitsøy and calculate NPV (at a discount rate of 10%) under different assumptions concerning recapture rate, juvenile production cost and market price. At the baseline recapture rate of 6%, current juvenile costs and market price for lobster produce a negative NPV. To break even, it would be necessary to reduce juvenile costs by 50% and simultaneously raise the recapture rate to 15%. In the second study, Borthen et al (1999) develop a simulation model based mainly on the Kivitsøy lobster release data. A 14% recapture rate is used in the simulations, with four scenarios explored. The first considers only the recapture of released juveniles, the second includes first-generation offspring, the third assumes a management regime in which only an autumn fishery is permitted while the fourth assumes a strategy of increasing the minimum landing size by 2 cm total length. The results of the first simulation produce a negative NPV, and it is shown that recaptures would have to rise from 14% to 23%

for the ranching program to break even. The results for the other three simulations are more favourable, with positive NPVs being shown in all cases.

(b) UK

Results of UK scientific research have shown that hatchery-reared European lobsters will survive and grow if released into the sea, and can be recruited to a fishery (Addison and Bannister, 1994). However, recapture rates have been very low - on average about 1-2% of the total number released and tested - implying that enhancement is unlikely to have a significant effect on commercial catches except possibly on a very localised basis within close proximity to release sites (Ibid). This calls into question the economic efficiency of the lobster stock enhancement programme, which in the UK has been investigated by three separate studies.

Lee (1994) develops a model to assess the benefits to producers and consumers from a prospective lobster stock enhancement programme involving the release of 500,000 juveniles p.a. Assuming a recapture rate of 10% and a delay between release and recapture of 5 years, the programme is expected to generate an increase in producer surplus and (as a result of lower market prices) an increase in consumer surplus, but both of these together are outweighed by the total cost of juvenile production. Using a discount rate of 5%, the benefit-cost ratio is estimated to be 0.312. Lee uses sensitivity analysis to demonstrate the strong influence exerted by the recapture rate and the cost per juvenile, and argues that if lobster stock enhancement in the UK is to be economically viable "significant improvements are needed in recapture rates and to hatchery rearing systems so that juvenile lobsters can be produced more cheaply." (p. 15). A rather different approach is taken by Whitmarsh (1997), who explores the possibility of using artificial reefs as a ranching substrate. Evidence suggests that lobsters from the wild population will tend to colonise artificial reefs (Jensen et al., 1994; Jensen and Collins, 1995; Jensen et al., 2000), and this raises the possibility that hatchery-reared juveniles released onto a suitably designed structure might form the basis of an economically viable fishery. The study uses a capital budgeting model of a ranching project involving the deployment of an artificial reef, onto which juvenile lobsters would be released and subsequently targeted for recapture. Benefits were assumed to be derived from sales revenue, while project costs included reef construction, hatchery production of juveniles and harvesting by fishermen. When the reef was assumed to be constructed of the cheapest material (quarry rock) the NPV of the project using a discount rate of 6% was positive. Sensitivity analysis indicated that, apart from lobster prices, the two most important variables affecting the viability of the project were the cost per juvenile and catch levels, the latter again pointing up the critical role played by recapture rates. Risk analysis showed that, even though the ranching project could be expected to be economically viable `on average', there was a chance (33%) that an unfavourable combination of circumstances would cause the project to fall below the threshold of acceptability. In a follow-up study, Whitmarsh et al. (1998) examined the effects of variations in harvesting cost on the economic viability of a reef-based lobster ranching project, and found that any departure from the zero harvesting cost baseline assumption caused the break-even recapture rate for the project to be significantly increased.

(v) Atlantic cod

The culture and release of Atlantic cod has a long history, and for this reason it is all the more surprising that that only comparatively recently has the economic viability of this endeavour been called into question. In Norway, where cod enhancement experiments date back to the 19^{th} Century, there is little evidence that released cod have enhanced local stocks and the consensus of opinion is that ranching has been economically unsuccessful (Grimes, 1998; Hilborn, 1998). Results of the enhancement programme in Western Norway, where more than 175,000 juvenile cod were released in Masfjorden between 1988 and 1990, indicate that there was no measurable increase in the cod stock (Tilseth, 1994). The economic failure of cod ranching in Norwegian coastal waters has been confirmed by Moksness and Stole (1997), who conclude that ranching would only be feasible if juvenile costs and post-release mortality could be significantly lowered. The importance of investigating the economic feasibility of sea ranching programmes before committing public funds has wisely been recognised in North America, where interest in cod enhancement has been rekindled during the 1990s by the severe decline in Atlantic groundfish stocks. The feasibility of enhancing cod stocks off the coast of Maine (USA) has been examined by Wilson et al. (1998), who develop a dynamic net present value model to determine the conditions under which a hatchery intended to augment natural production through a ‘put and take’ fishery would be viable. Rather than seeking to determine an absolute answer to the question of whether or not cod enhancement would be economically feasible, Wilson et al. argue that the appropriate use of the model is in sensitivity analysis that can generate a range of results that vary according to circumstances. The purpose of this, they maintain, is to “identify economic or biological bottlenecks that might be addressed through research and/or policy development”. (p. 680).

5. Discussion and conclusions

The available evidence on the economic performance of marine ranching programmes has produced a rather mixed picture. Of all the cases considered, the ranching of salmon is perhaps the most interesting because the studies that have been carried out have assessed both the impact and efficiency aspects of ranching, whereas for the other species it is primarily only the latter which is examined. For this reason it is appropriate to comment on the evidence related to salmon in rather more depth.

Formal cost-benefit analysis of the Alaskan salmon enhancement programme has indicated that the state would gain from the reduction or elimination of either pink or sockeye hatchery production, but this result needs to be seen in relation to the distributional consequences of such a strategy. A recent assessment of the Alaskan programme by Knapp (1999) has emphasised the difficulties of reaching an overall verdict, given that the economic effects of salmon enhancement vary widely between different regions and stakeholder groups. For example, while salmon fishermen in enhancement regions have probably benefitted from the programme, it seems likely that hatchery production has disadvantaged fishermen in other regions through lower prices. It is also claimed that some private non-profit (PNP) hatcheries would not be viable financially without continuing subsidies from the State (p. 552). Partly because of the different accounting perspectives that can be adopted, as well doubts about the reliability of formal cost-benefit studies, Knapp concludes that "the Alaskan salmon hatchery program is neither obviously an economic success nor obviously an economic failure." (p. 554). The situation regarding the economics of other ranched species can be summarised more briefly. The Japanese experience of flounder and red sea bream appears to have been successful in terms of economic efficiency, which could be taken to support the case for expanding such programmes. It needs to be emphasised, however, that the findings of the studies carried out on these species are area-specific and there is no guarantee that the factors favouring economic viability will be found elsewhere. Sea ranching of European lobster in Norway and the UK does not appear to be economically viable at present recapture rates and market conditions. However, the Norwegian simulation modelling suggests that economic performance could significantly improve if the possibility of first generation offspring are allowed for or management controls are used as a supplement to stock enhancement. The UK studies suggest that the economic performance of lobster stock enhancement might be improved by using artificial reefs as a ranching substrate, since this may enable recapture rates to be raised from their current low levels. Ranching of Atlantic cod in Norwegian coastal areas has been judged to be unsuccessful in economic terms, while the feasibility of the cod enhancement programme in Maine (USA) is still at the stage of preliminary investigation.

A comment on the methodology used in these economic evaluations is appropriate. The point has been made that in order to demonstrate that hatchery releases will increase stock abundance it is necessary to test two hypotheses: that released juveniles will survive and grow in the marine environment, and that they do not displace wild stocks of fish (Leber and Blankenship, 1994; Leber, 1999). In the present context the second of these conditions is at least as important as the first, because unless stock displacement effects are accounted for the economic benefits of a ranching programme will be overstated. This possibility does not seem to have been adequately acknowledged in some of the economic appraisals which we have reviewed, and often the methodology employed (based on estimated returns of hatchery fish alone) implicitly assumes that there are no externalities caused by stock displacement. Another methodological issue concerns the treatment of recapture costs, which in many of the studies has been assumed to be zero. This may be justified where an established fishery exists and where harvesting can be expected to take place with or without the additional stock, but it is clearly untenable where ranching creates a new fishery that demands additional fishing effort. Even where a fishery already exists, there may well be situations where the harvesting technique is such that increased catches cannot be taken at zero marginal cost. Crustaceans caught with baited traps are an example. A final problem relates to the cost of managing the fisheries and controlling effort, which most studies have correctly highlighted as being essential in order to protect the economic viability of marine ranching. Indeed, the success of marine ranching in certain cases may be attributable in part to the effectiveness in controlling the pressure of harvesting - Japanese flounder being an illustration of this (Howell, 1994). However, while the need for fisheries management is generally recognised, few of the studies appears to have acknowledged that management costs need to be factored into the economic appraisal calculations. The importance of doing this will be all the greater in situations where, as Laurec (1997) has suggested, ranching increases the number of stakeholders and hence the difficulties (and presumably the cost) of monitoring and control. If that is indeed the case then it cannot sensibly be assumed that the incremental management costs of a ranching programme will be zero.

Despite certain shortcomings with the studies which have been undertaken to date on the economics of marine ranching, they nevertheless help to identify the factors that are important to the economic performance of marine ranching programmes. It is important to remember, however, that 'performance' needs to be judged against the goals which have been set for a particular ranching programme, (Bannister, 1991; Hilborn, 1998; Travis et al., 1998), and a programme which might be judged to be an economic success against a criterion of increasing fishermen's incomes might be judged a failure when measured against the yardstick of generating a positive NPV. If we confine ourselves to the issue of economic efficiency, it would appear that the critical factors are: (i) the species selected (ii) the marine environment into which the species is introduced (iii) the technology of broodstock production (iv) the method of recapture (v) the market conditions applying to the purchase of broodstock and the sale of final product (vi) the regime of property rights over the stock and the harvest, and (vii) the extent to which harvesting pressure is controlled. Parameters to which the economic viability of ranching projects is especially sensitive include: (i) the recapture rate, (ii) the cost of juveniles (iii) harvesting costs, and (iv) the sale price of recaptured fish. The fact that some ranching programmes have ostensibly been successful whilst others have not testifies to the extent to which these factors vary in practice, and accordingly highlights the challenge faced by project planners and managers. This challenge stems not simply from an inability to *control* the production process but, more fundamentally, from a *lack of knowledge* of the economic relationships underlying the process. It is the role of economic evaluation to redress this deficiency and clearly future research initiatives could be usefully directed towards increasing the knowledge base with respect to the factors which affect economic performance and viability identified above.

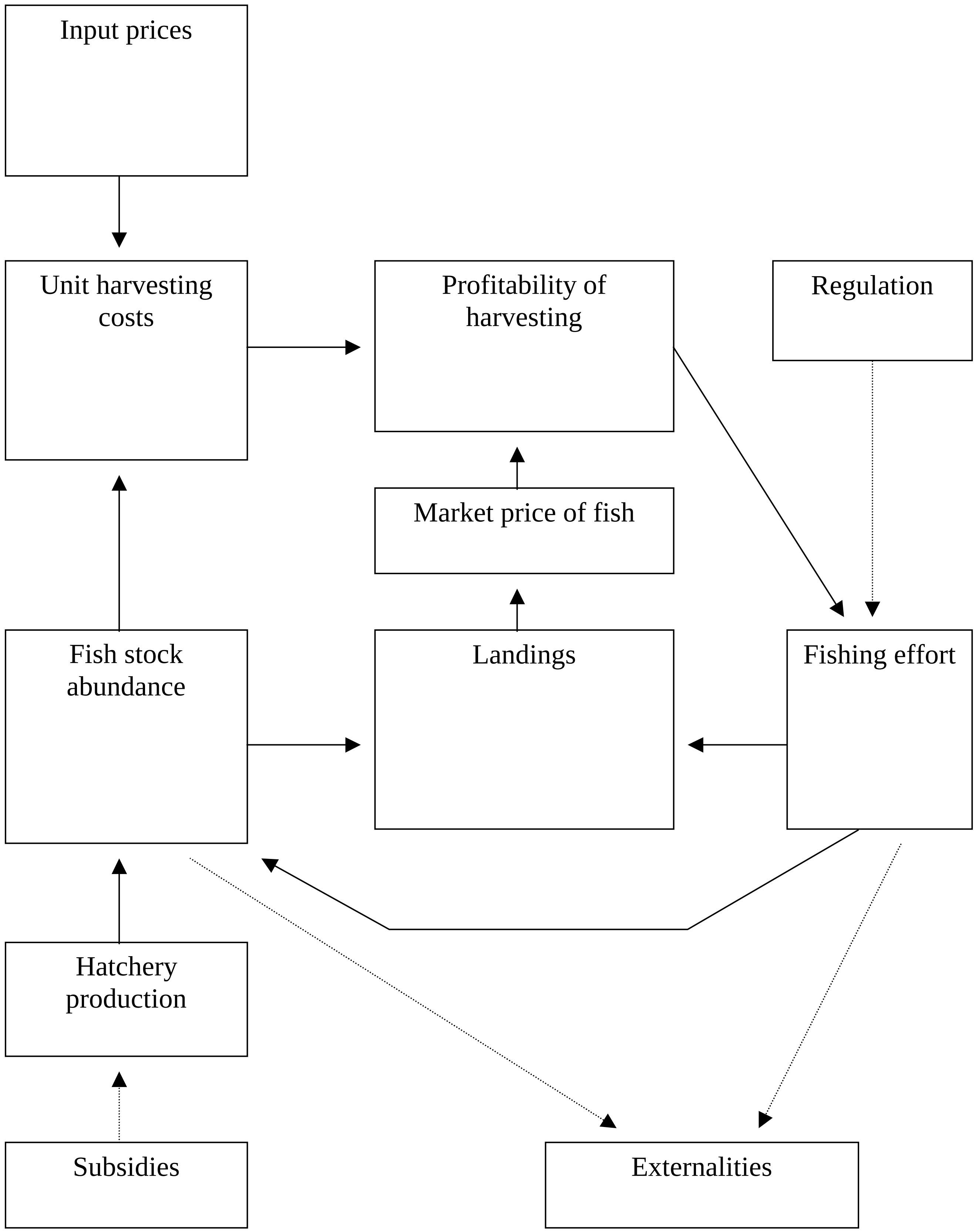
Table 1: Analytical frameworks for use in the economic evaluation of marine ranching

Type of evaluation	Specific application	Purpose	Appropriate use
Economic impact analysis	Revenue analysis	To estimate the impact of a ranching project on sales revenue from a fishery	Appropriate for assessing the localised socio-economic effect of a ranching project (e.g. on a coastal community dependent on fishing).
	Multiplier analysis	To estimate the total economic activity generated by a ranching project as a consequence of direct and secondary effects	
Economic efficiency analysis	Cost-effectiveness analysis	To determine whether a ranching project is the least-cost option for achieving a given objective	Appropriate for assessing the economic worth of a ranching project, judged from the standpoint of society as a whole
	Cost-benefit analysis	To determine whether the monetary benefits of a ranching project exceed its costs, taking into account both internal and external effects	

Table 2: Empirical economic evaluations of marine ranching

Fishery or species	**Region or country**	**Study**
Pacific salmon	Washington State, USA	Stokes (1982)
Pacific salmon	Alaska, USA	Herrmann (1993)
Pacific salmon	Alaska, USA	Boyce et al. (1993)
Pacific salmon	Hokkaido, Japan	Kitada, (1999)
Atlantic salmon	Norway	Moksness et al. (1998)
Japanese flounder	Fukushima, Japan	Kitada et al. (1992, 1999)
Japanese flounder	Hokkaido, Japan	Sproul and Tominaga (1992)
Japanese flounder	Miyako Bay, Japan	Okouchi et al. (1999)
Japanese flounder	Japan (all areas)	Kitada (1999)
Red sea bream	Kagoshima, Japan	Ungson et al (1993)
Red sea bream	Kagoshima, Japan	Ungson et al (1994)
Red sea bream	Kagoshima, Japan	Ungson et al (1995)
Red sea bream	Kagoshima, Japan	Kitada (1999)
European lobster	Norway	Moksness et al. (1998)
European lobster	Norway	Borthen et al. (1999)
European lobster	UK	Lee (1994)
European lobster	UK	Whitmarsh (1997)
European lobster	UK	Whitmarsh et al. (1998)
Atlantic cod	Norway	Moksness and Stole (1997)
Atlantic cod	Norway	Moksness et al. (1998)
Atlantic cod	Maine, USA	Wilson et al. (1998)
Arctic charr	Norway	Moksness et al. (1998)
Penaeid prawn	Australia	Rothlisberg et al. (1999)
Barramundi	Australia	Rimmer and Russell (1998)
Abalone	South Africa	Cook and Sweijd (1999)
Red Drum	Texas, USA	Matlock (1986)
Scallop	Japan (all areas)	Kitada (1999)

Figure 1: A synoptic model of marine ranching



REFERENCES

Addison, J.T. and R.C.A. Bannister, 1994. Lobster stock enhancement experiments. 1. Historical perspective 1850-1980. In: International Council for the Exploration of the Sea (ICES), Mariculture Committee, *Report of the Workshop to Evaluate the Potential of Stock Enhancement as an Approach to Fisheries Management. Council Meeting of the International Council for the Exploration of the Sea, 22-30 September 1994, St John's, Canada.* (ICES CEM 1994/F:9). Copenhagen, Denmark: ICES. 33-36.

Anderson, J.L. and J.E. Wilen, 1985. Commercial Fisheries vs Aquaculture: conflicts in the Northwest Salmon Fishery. *Proceedings of the Second Conference of the International Institute of Fisheries Economics and Trade. Vol. 2: a compendium of papers on seafood trade and markets, 20-23 August, 1984, Christchurch, New Zealand.* USA: Oregon State University. 127-140.

Bannister, R.C.A., 1991. Stock enhancement (workshop report). In: S.J. Lockwood, (Ed). *The Ecology and Management Aspects of Extensive Mariculture. ICES Symposium on Ecology and Management Aspects of Extensive Mariculture, 20-23 June 1989, Nantes, France.* (ICES Marine Science Symposia 192). Copenhagen, Denmark: ICES. 191-192.

Bartley, D.M. 1999a. Marine ranching: current issues, constraints and opportunities. In: *Marine Ranching: Global Perspectives with Emphasis on the Japanese Experience*. FAO Fisheries Circular No. 943, FIRI/C 943, Rome, 28-43

Bartley, D.M., 1999b. Marine ranching: a global perspective. In: B.R. Howell, E. Moksness and T. Svasand (eds) *Stock Enhancement and Sea Ranching.* Oxford: Fishing News Books, 79-90

Borthen, J., A-L Agnalt, and G. van der Meeren, 1999. A bio-economic evaluation of a stock enhancement project of European lobster; the simulation model LOBST.ECO with some preliminary results. In: B.R. Howell, E. Moksness and T. Svasand (eds) *Stock Enhancement and Sea Ranching.* Oxford: Fishing News Books, 583-596

Boyce, J., M. Herrmann, D. Bischak and J. Greenberg, 1993. The Alaska salmon enhancement program: a cost/benefit analysis. *Marine Resource Economics*, 8(4): 293-312

Cook, P. and N. Sweijd, 1999. The potential for abalone ranching and enhancement in South Africa. In: B.R. Howell, E. Moksness and T. Svasand (eds) *Stock Enhancement and Sea Ranching.* Oxford: Fishing News Books, 453-467

Grimes, C.B. 1998. Marine stock enhancement: sound management or techno-arrogance? *Fisheries*. 23(9), 18-23.

Hallensvedt, A. 1999. Management of enhanced stocks: social, economic and access issues. In: B.R. Howell, E. Moksness and T. Svasand (eds) *Stock Enhancement and Sea Ranching.* Oxford: Fishing News Books, 493-508

Herrmann, M. 1993. Using an international econometric model to forecast Alaska salmon revenues. *Marine Resource Economics*. 8(3):249-271.

Hilborn, R. 1992. Hatcheries and the future of salmon in the Northwest. *Fisheries*. 17(1): 5-8.

Hilborn, R. 1998. The economic performance of marine stock enhancement projects. *Bulletin of Marine Science*. 62(2), 661-674

Hilborn, R. and D. Eggers, 2000. A review of the hatchery programs for Pink Salmon in Prince William Sound and Kodiak Island, Alaska. *Trans. Amer. Fish. Soc*. 129: 333-350

Howell, B.R. 1994. Fitness of hatchery reared fish for survival at sea. *Aquaculture and Fisheries Management*. 25(Suppl.1), 3-17.

Ísaksson, Á., 1994. Ocean ranching; its role and contribution to Pacific and Atlantic salmon fisheries. C.W. Voigtlander, Ed. *The state of the world's fisheries resources. Proceedings of the World Fisheries Congress, Plenary Sessions*. New Delhi: Oxford and IBH Publishing, 1994, 133-149.

Jensen, A.C. and K.J. Collins. 1995. The Poole Bay Artificial Reef Project 1989 to 1994. *Biol. Mar. Medit.* 2(1), 111-122.

Jensen, A.C.; K.J. Collins; E.K. Free, and R.C.A. Bannister. 1994. Lobster (*Homarus gammarus*) movement on an artificial reef: the potential use of artificial reefs for stock enhancement. *Crustaceana*. 67(2), 198-211.

Jensen, A.C., Wickins, J. and Bannister, R.C.A.. 2000. The potential use of artificial reefs to enhance lobster habitat. In: A.C. Jensen, K.J. Collins and A.P.M. Lockwood (eds) *Artificial Reefs in European Seas*. The Netherlands: Kluwer, 379-401

Kitada, S., 1999. Effectiveness of Japan's stock enhancement programmes: current perspectives. In B.R. Howell, E. Moksness and T. Svasand (eds) *Stock Enhancement and Sea Ranching.* Oxford: Fishing News Books, 103-131

Kitada, S.; Y. Taga, and H. Kishino. 1992. Effectiveness of a stock enhancement program evaluated by a two-stage sampling survey of commercial landings. *Canadian Journal of Fisheries and Aquatic Sciences*. 49(8), 1573-1582.

Knapp, G., 1999. Alaska salmon ranching: an economic review of the Alaska salmon hatchery program. In B.R. Howell, E. Moksness and T. Svasand (eds) *Stock Enhancement and Sea Ranching.* Oxford: Fishing News Books, 537-556

Laurec, A., 1997. Can a convincing case be made for stock enhancement and sea ranching. Paper presented at the: *First International Symposium on Stock Enhancement and Sea Ranching, 8-11 September 1997, Bergen, Norway.*

Leber, K.M. 1999. Rationale for an experimental approach to stock enhancement. In B.R. Howell, E. Moksness and T. Svasand (eds) *Stock Enhancement and Sea Ranching.* Oxford: Fishing News Books, 63-75

Leber, K.M. and H.L. Blankenship, 1994. The need for a responsible approach to marine stock enhancement. In: Nosho, T. and K. Freeman, Eds. *Marine Fish Culture and Enhancement: Conference Proceedings, 4-6 October 1993, Seattle, Washington.* (WSG-WO 94-1 Seattle, Washington: University of Washington, Washington Sea Grant Program. 17-21.

Lee, D.O. 1994. *The potential economic impact of lobster stock enhancement,* York, UK: University of York, Department of Economics and Related Studies. (Based on dissertation submitted as part of MSc in Project Analysis, Finance and Development)

Masuda, R. And K. Tsukamoto, 1998. Stock enhancement in Japan: review and perspective. *Bulletin of Marine Science*, 62(3): 337-358

Matlock, G.C. 1986. Estimating the direct market economic impact of sport angling for Red Drum in Texas. *North Amer. J. Fish. Management*, 6: 490-493

Matsuda, Y., 1992. Marine ranching in Japan - from salmon to Red Sea bream. In: Yamamoto, T. and K. Short, Eds . *International Perspectives on Fisheries Managment with Special Emphasis on Community-Based Management Systems Developed in Japan. Proceedings of the JIFRS/IIFET/ZENGYOREN Symposium on Fisheries Management* , 26 August-3 September 1991, Tokyo, Japan . National Federation of Fisheries Cooperative Associations (ZENGYOREN) and Japan International Fisheries Research Society (JIFRS).

Milon, J.W., Holland, S.M. and Whitmarsh, D.J. 2000. Social and economic evaluation methods. In: W. Seaman (ed.) *Artificial Reef Evaluation with Application to Natural Marine Habitats*. Boca Raton: CRC Press, 165-194

Moksness, E. 1999. Economic evaluation of marine ranching. In: *Marine Ranching: Global Perspectives with Emphasis on the Japanese Experience*. FAO Fisheries Circular No. 943, FIRI/C 943, Rome, 44-52

Moksness, E. and R. Stole, 1997. Larviculture of marine fish for sea ranching purposes; is it profitable ? *Aquaculture.* 155, 341-353

Moksness, E., R. Stole and G. van der Meeren, 1998. Profitability analysis of sea ranching with Atlantic Salmon *(Salmo salar),* Arctic charr *(Salvelinus alpinus),* and European lobster *(Homarus gammarus)* in Norway. *Bulletin of Marine Science,* 62(2): 689-699

Okouchi, H., S. Kitada, T. Tsuzaki, T. Fukunaga and A. Iwamoto. 1999. Number of returns and economic return rates from hatchery released flounder *Paralichthys olivaceus* in Miyako Bay - evaluation by a fish market census. In B.R. Howell, E. Moksness and T. Svasand (eds) *Stock Enhancement and Sea Ranching.* Oxford: Fishing News Books, 573-582

Pedersen, T. and K.K. Olsen, 1997. Is there conflict between rational management of wild cod stocks and cod (*Gadus morhua* L.) enhancement success? Paper presented at the: *First International Symposium on Stock Enhancement and Sea Ranching, 8-11 September 1997, Bergen, Norway.*

Pickering, H., 1999. Marine ranching: a legal perspective. *Ocean Development and International Law* 30: 161-190

Pillay, T.V.R. 1997. Economic and social dimensions of aquaculture management. *Aquaculture Economics and Management*. 1(1), 3-11.

Rimmer, M.A. and D.J. Russell. 1998. Survival of stocked barramundi, *Lates calcarifer* (Bloch), in a coastal river system in far Northern Queensland, Australia. *Bulletin of Marine Science*, 62(2): 325-335

Rothlisberg, P.C., N.P. Preston, N.R. Loneragan, D.J. Die and I.R. Poiner, 1999. Approaches to reseeding penaeid prawns. In B.R. Howell, E. Moksness and T. Svasand (eds) *Stock Enhancement and Sea Ranching.* Oxford: Fishing News Books, 365-378

Shang, Y.C. and C.A. Tisdell, 1997. Economic decision-making in sustainable aquaculture development. In: Bardach, J.E., Ed. *Sustainable aquaculture,* Chichester, UK: John Wiley. 127-149.

Sproul, J.T. and O. Tominaga. 1992. An economic review of the Japanese flounder stock enhancement project in Ishikire Bay, Hokkaido. *Bulletin of Marine Science*. 50(1): 75-88.

Stokes, R.L. 1982. The economics of salmon ranching. *Land Economics*. 58(4): 464-477.

Tilseth, S., 1994. Overview of sea ranching of Atlantic cod and review of the Norwegian sea ranching program. In: Nosho, T. and K. Freeman, Eds. *Marine Fish Culture and Enhancement: Conference Proceedings, 4-6 October 1993, Seattle, Washington.* (WSG-WO 94-1). Seattle, Washington: University of Washington, Washington Sea Grant Program. 37-38.

Travis, J.; F.C. Coleman; C.C. Grimes; D. Conover; T.M. Burt and M. Tringali. 1998. Critically assessing stock enhancement: an introduction to the Mote Symposium. *Bulletin of Marine Science*. 62(2): 305-311

Ungson, J.R. 1993. Implications of sea ranching in developing countries. *NAGA, The ICLARM Quarterly*. 16(1): 11-13.

Ungson, J.R., H. Hirata and Y. Matsuda, 1994. Economic evaluation of the Red Sea bream ranching in Kagoshima, Japan. In: *Proceedings of the Sixth Conference of the International Institute of Fisheries Economics and Trade. IIFET Paris 92. Tome I, 6-9 July 1992, Paris.* Paris: IFREMER. 87-95.

Ungson, J.R.; Y. Matsuda; H. Hirata, and H. Shiihara. 1993. An economic assessment of the production and release of marine fish fingerlings for sea ranching. *Aquaculture*. 118: 169-181

Ungson, J.R., Y. Matsuda, H. Hirata and H. Shiihara, 1995. An economic benefit-cost estimation of the Red Sea Bream ranching in Kagoshima Bay, Japan. Liao, D.S., Ed. *International Cooperation for Fisheries and Aquaculture Development. Proceedings of the Seventh Biennial Conference of the International Institute of Fisheries Economics and Trade, 18-21 July 1994, Taipei, Taiwan. R.O.C.* Keelung, Taiwan. R.O.C.: National Taiwan Ocean University. 189-201.

Welcomme, R.L. and D.M. Bartley, 1998. An evaluation of present techniques for the enhancement of fisheries. In: Petr, T., Ed. *Inland Fishery Enhancements, Papers presented at the FAO/DFID Expert Consultations on Inland Fishery Enhancements*, 7 -11 April 1997, Dhaka, Bangladesh. (FAO Fisheries Technical Paper T374). Rome: FAO. 1-35.

Whitmarsh, D. 1997. Cost-benefit analysis of artificial reefs. In: A.C. Jensen (ed.) *European Artificial reef Research.* Proceedings of the 1st EARRN conference, Ancona, Italy, March 1996. Pub. Southampton Oceanography Centre, 175-193

Whitmarsh, D.J., S. Pascoe, A.C. Jensen and R.C.A. Bannister 1998. Economic appraisal of lobster stock enhancement using artificial reef technology. In: S.Pascoe, C. Robinson and D.

Whitmarsh (eds.) *Proceedings, European Association of Fisheries Economists Bioeconomic Modelling Workshop, December 17-18, 1997, Portsmouth, UK*. CEMARE Misc. Pub. No. 39, University of Portsmouth, 69

Wilson, J.A.; R.W. Langton; and C. Van Orsdel. 1998. A model for the preliminary analysis of the economic feasibility of Atlantic cod enhancement in the Gulf of Maine (USA). *Bulletin of Marine Science*. 62(2): 675-687