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Commercial scale invertebrate fisheries enhancement in Australia: Experiences, challenges and opportunities

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ABSTRACT

Stock enhancement or "assisted recruitment" for fisheries management in Australia is at an experimental R&D phase. Development of the science has focused largely on finfish targeted by the recreational sector; however it is considered that high value invertebrates will be the best candidates for commercial scale fisheries enhancement. Three main ingredients are required; technical capacity, governance capability, and the 'correct' species. The technical capacity needed is in the area of hatchery production and wild release methodologies, whilst the governance capability needed is informed policy that accounts for the complexities and interdisciplinary nature of stock enhancement. In particular, the appropriate articulation of policy to support economic development and integration into wild fisheries is currently lacking. If successful stock enhancement is implemented, the nature of fisheries management changes because the recruitment side of the fisheries equation is under substantial control, rather than just the production side. Management responses will require significant innovation, with a renewed emphasis on understanding the stock, rather than policing the fishers. By way of illustration, recent initiatives and key challenges encountered in Australian invertebrate fisheries are investigated through case studies. An example of a commercially-viable enhancement fishery that reflects solutions to the key challenges is also presented. The review ends with an argument to re-establish the context of stock enhancement in the discipline of ecological enhancement. This is a crucial and positive step forward for it recognises that, in principle, any renewable aquatic ecosystem has the potential to be enhanced instead of just depleted.

1. Introduction

The validity of releasing or moving animals to enhance marine fish stocks as part of a management toolbox is gaining wider acceptance as the science develops. Enhancement science in fisheries or more specifically, the study of "assisted recruitment" is an integrated and interdisciplinary practice that supports an ethically-based set of management principles known as the "Responsible Approach" [1–3]. The principles provide guidance and consilience to a diverse discipline including aquaculture, economic analysis, fisheries stock assessment, population and evolutionary genetics, fish behaviour studies, underwater technology development, disease management, and policy governance frameworks. The diversity arises from the recognition that management intervention in complex natural systems is unlikely to be successful and responsible unless there is a greater understanding of not just the ecological, but also the economic, social and institutional/governance issues [4,5]. Marine enhancement programmes do not have a large record of success stories however; the allure of a 'quick fix' is a legacy that still influences a popular perception of the practice [6], namely that stock enhancement is a 'slow and dirty' response to an environmental degradation or perturbation, poor fisheries management, or a failing aquaculture industry.

Successful implementation of stock enhancement is a complex endeavour requiring the knowledge and resources of socio-economic and evolutionary-ecological disciplines and there are few examples where all principles have been covered [7]. Thus a pragmatic approach has been advocated in Australia to date, with an emphasis on developing enhancement science through small-scale experiments, and a focus on recreationally important finfish rather than commercially fished species [7,8]. Consequently there has been limited incentive to extend the reach of enhancement programmes beyond the initial breeding and release phases, which do support commercially viable aquaculture hatcheries. Enhancement of commercial fisheries however, can only occur when successful culture and release methodologies are combined with well understood survival rates and Government policy which supports integration of enhancement into wild fisheries

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management.

The objectives of this paper are to review the development and challenges of commercial-scale invertebrate fisheries enhancement in Australia, the roadblocks to be overcome, and likely successful candidates in the future. In the interests of maintaining the pragmatic position, the concept of a “stock” in a fisheries enhancement framework is first reviewed, to identify key limitations regarding the efficacy of this practice, followed by a summary of relevant studies. The complexities of enhancement are then distilled into two key challenges related to economics and stock identity. To complete the review, an example of a commercially-viable enhancement fishery that reflects solutions to the key challenges is presented, along with an argument in support of re-establishing the context of stock enhancement in the discipline of ecological enhancement. This is a crucial and positive step forward for it recognises that, in principle, any renewable aquatic ecosystem has the potential to be enhanced instead of just depleted.

2. Self-regenerating stocks and the limitations of enhancement

At the heart of the stock-enhancement conundrum is a conflict between the expected and observed behaviour of fish stocks. Separate fish stocks are assumed, and best practice fisheries management is able to make assessments, conclusions, and statements about “stock status”. A stock is considered, implicitly or explicitly, a self-regenerating population [9] and the objective of controlling fishing mortality (i.e. management) is to support this pre-existing regenerative capacity. Of what relevance therefore, is the concept of “stock enhancement” or “assisted recruitment” when a stock has already evolved its self-sustaining strategy? This paradigm, which confers “Lazurus-like” powers on the compensatory dynamics that connect a stock to its progeny, whilst increasingly challenged in recent times by stock collapses [10], and a general lack of clear evidence for density dependent responses in recruitment [11], is still a major theoretical roadblock in discussions about the efficacy of enhancement.

To work in practice, the idea of a self-regenerating stock requires first, that there is an evolutionarily and ecologically stable group of organisms, a “stock”, which can be uniquely identified; second, that a measurement of both stock stability and the compensatory dynamic can be made, for example, through genetic and population analysis. Early synthesis of these ideas was presented in the self-regenerating models of stock and recruitment [9,12], which demonstrated mathematically, the plausible causal factors (e.g. density-dependent growth and survival in the larval phase) that could underlie the perturbation and recovery trajectories in observed fish stocks in the North Atlantic following cessation of fishing during the first two world wars. The large positive effect from the reduction in fishing effort on stock size confirmed the existence of density dependent compensation and the fundamental importance of controlling fishing. Environmental or density-independent effects however, were considered equally important, and both were viewed as key components to the self-regenerating model. Quantification of environmental factors has been problematic though, as their effect is often masked or exposed by fishing mortality depending on the extent of erosion of compensatory reserve in exploited stocks [10]. Only those species where pre-settlement processes dominate recruitment exhibit relatively consistent environmental influences [13].

Development of stock–recruitment–environment relationships for both invertebrate and finfish species has highlighted the variability and range of productivity within a single stock [14–16]. An illustrative example is provided in the self-regeneration model for North Sea cod (*Gadus morhua*) [16]. This study found from an analysis of a 50-year time series, that the shape and the position of the compensatory dynamic of the stock is not fixed, but varies in response to environmental conditions. Specifically, a high spawning stock (2,000,000 t) could produce an order of magnitude variation in recruitment (range: 50–650 million), depending on the availability of zooplankton and sea-temperature. At a low spawning stock (40,000 t) however, recruitment was far less variable (180–200 million) and largely independent of environment. Although their model only explained 45% of the variability in the time series, it was a large improvement in the 10% explanation by the more traditional stock–recruitment models [16]. Faced with the stochastic nature of natural recruitment, an explanatory R^2 of 0.45 may be approaching a maximum in many, if not most, species.

From an enhancement perspective, the challenge is to demonstrate how the ‘assisted recruitment’ process will co-exist with a given stock's self-correcting mechanisms. An important hypothesis is that the compensation (e.g. recruitment bottleneck) may occur at sizes below that at which animals are released from enhancement programmes. So it could be possible to enhance stocks to densities above that which can occur with natural recruitment. Another is that stock–recruitment–environment relationships are generalised for the stock. At a smaller scale however, there are likely to be situations where enhancement can increase production even with high levels of natural recruitment, on account of the abundance of suitable habitat which itself compensates for low larval supply. Two relevant conclusions from the North Sea cod model [16] are: firstly, enhancement will always result in increased biomass at low spawning stock; secondly, enhancement could result in an equally large increase in biomass at high spawning stock, or it may not have any effect at all. Success depends on the ability to understand and predict the environmental conditions and assess whether the stock is at carrying capacity, as well as acceptance of the intrinsic stochastic nature of natural recruitment. In simple terms, it is a solid bet that in any given year or location, the stock is experiencing less than the maximum recruitment (recruitment limitation) and enhancement will reap a positive effect on biomass.

Even with its uncertainty, the self-regeneration model for North Sea cod represents an exceptional case of knowledge of a “stock”. Management has adopted the pragmatic definition, namely that a ‘unit stock’ be an operational, rather than a biological matter of most stocks [17]. This pragmatism stems from a dearth of knowledge of the true population parameters of a stock (growth, natural and fishing mortality, reproduction, and recruitment), and a need to sustain it with limited resources. To be successful with an assisted recruitment programme however, requires a greater knowledge of critical stock parameters, in particular, the multiple pathways responsible for self-maintenance. For example, the theoretical concept of recruitment limitation [18] is a key idea in support for the efficacy of enhancement, but knowledge of the spatial and temporal scale of the ‘bottlenecks’ that cause the limitation is required in order to benefit from it. On the production side of the equation, density dependent growth in the recruited stock may act to reduce the expected biomass resulting from successful enhancement [19], unless it has been specifically accounted for.

The key to successful enhancement is to know when to “intervene” in any given stock's “regenerative cycle” to capitalise on the limitation present at a particular point in the cycle. Given the general lack of evidence for regularity in this cycle within exploited fish stocks however [11], successful enhancement of commercial scale fisheries will require a substantial amount of empirical testing rather than relying primarily on theoretical evaluations. A pertinent example for Australian invertebrate fisheries is the 10 years of research which preceded the commercial