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Enhancing or restoring the productivity of natural populations of shellfish and other marine invertebrate resources

Cover:
Illustration representing women engaged in artisanal fishing of the clam *Venus antiqua* in southern Chile. Emanuela D'Antoni.

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A broad review is provided of factors relevant to enhancing populations of invertebrate resources and methods promoting their recovery by natural recruitment, restocking or habitat restoration. The review focuses on the biological, technical, environmental, economic and biological factors affecting the feasibility of restoring or enhancing productivity of commercially valuable local invertebrate populations. Three categories of enhancement activity are recognized: restoring or enhancing stocks by conventional management methods, transplanting or seeding, and the use of juveniles produced from collectors in the wild or from hatcheries. Some guidelines are provided on issues related to enhancing recruitment, site selection, experimental closures and ecosystem considerations including predator control, as part of a stock management and enhancement programme. Ownership and co-management issues, and the necessary decisional rules for successful management, are discussed, as well as how to reconcile the enhancement programme with other uses of the coastline. Spatial and geographical considerations are addressed, including allocation of areas for enhancement, rotational harvest schemes, use of refugia for protecting juveniles and the spawning stock, and the impact of the use of coastal zones for other human activities.

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PREPARATION OF THIS DOCUMENT

This document has been prepared as part of the regular programme activities of the FAO Marine Resources Service, Fishery Resources Division, aimed at promoting improved practices for the assessment and management of fisheries through the production of background documents, technical guidelines and handbooks. In several parts of the world, the productivity of natural populations of marine invertebrates have come under excessive pressure, as rising demand and prices for these generally high-value species lead to their overexploitation. Environmental changes to nearshore environments due to other human activities have on occasions contributed to damaging nearshore stock productivity further. A partial solution has been to enhance or restore populations of nearshore areas, using techniques that range from those resembling extensive aquaculture, to the scientific management of stocks as used for finfish populations. This document reviews the scientific knowledge derived from enhancement activities in shellfish and other invertebrate populations, and attempts to extend the concept of "enhancement" to include any activity which increases the productivity of a marine resource, whether this is by controlled harvesting, stock additions or habitat/environmental manipulation. Multidisciplinary guidelines and operational criteria for conducting and assessing invertebrate stock management programmes are also provided.

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ABSTRACT

A broad review is provided of factors relevant to enhancing populations of invertebrate resources and methods promoting their recovery by natural recruitment, restocking or habitat restoration. The review focuses on the biological, technical, environmental, economic and biological factors affecting the feasibility of restoring or enhancing productivity of commercially valuable local invertebrate populations. Three categories of enhancement activity are recognized: restoring or enhancing stocks by conventional management methods, transplanting or seeding, and the use of juveniles produced from collectors in the wild or from hatcheries. Some guidelines are provided on issues related to enhancing recruitment, site selection, experimental closures, ecosystem considerations including predator control, as part of a stock management and enhancement programme. Ownership and co-management issues, and the necessary decisional rules for successful management are discussed, as well as how to reconcile the enhancement programme with other uses of the coastline. Spatial and geographical considerations are addressed, including allocation of areas for enhancement, rotational harvest schemes, use of refugia for protecting juveniles and the spawning stock, and the impact of the use of coastal zones for other human activities.

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INTRODUCTION

This study focuses on issues related to the scientific management and the feasibility of enhancement or recovery of stocks of commercial marine invertebrates. The review touches on a taxonomically wide range of resources, with inevitably special emphasis placed on those edible species colloquially referred to in English as shellfish. These include both molluscs and crustaceans, as it is here where much of the practical experience in invertebrate management and enhancement is to be found, but we have extended the review to include other invertebrate resources such as echinoderms which are now of importance for inshore fisheries.

Productive natural populations of invertebrate resources are coming under pressure as rising demand and prices for these generally high-value species leads to their overexploitation (Castilla and Defeo, 2001). A decreasing trend in global catch rates and landings from overfishing in the absence of proper management has on occasions led to stock collapse. Nonetheless, in comparison with marine finfish populations where stock enhancement methods are still controversial and limited in success, more positive results have been achieved in enhancing or restoring shellfish populations of nearshore areas. In fact, shellfish culture has been suggested for other purposes in addition to food production, namely, ameliorating nutrient-rich effluents and suspended materials coming from fish farming, and reducing algal densities (e.g. Folke and Kautsky, 1989). In other areas and for other species, shellfish populations suffer negative population impacts from human activities other than fishing and thus may serve as indicators of nearshore ecosystem health. Although we do not enter into this subject area in detail, issues related to consumer health may result from the effects of coastal pollution on shellfish beds, and shellfish monitoring may be used to monitor chemical and bacterial pollutants resulting from other human usages of coastal waters.

Although questioning whether enhancement activities represent a reality or what he calls “techno-arrogance”, Grimes (1998) notes that in the decade from 1986 to 1996, there have been major conferences on roughly a biennial basis on the theme of the practice and evaluation of marine stock enhancement, reflecting an increasing enthusiasm by managers with this theme. But he asks whether our state of knowledge is adequate to make this more than just an interesting concept? The answer for finfish stocks is certainly ambiguous in many cases and for macrocrustacea also, despite some interesting developments that will be mentioned in this text. For molluscs and some echinoderms however, the accumulation of experience suggests that in many cases, stock enhancement activities have been successful when viewed from a commercial perspective, if the necessary habitat carrying capacity was available (Castilla, 1988; Andrew *et al.*, 2002). In fact, most failures stem from a lack of prior evaluation of the availability of suitable habitat. In this respect, Grimes (1998) notes that aspects of the ecology of juveniles in their actual or potential nursery habitats, have become research priorities for enhancement activities. Experience in Japan, the country which has made most efforts to apply these technologies, were summarized by Nakata (1995), and seem generally to reflect some important successes, especially where technology and ecological intuition are applied hand in hand with a knowledge of species biology. In the final instance, success must be evaluated economically, but even here a case can be made for leniency, if it involves the reintroduction of a species to its original habitat (especially if after this has been accomplished successfully, enhancement can be terminated). In the case of some sports fisheries where incidental expenditures by enthusiasts generate considerable revenues outside the fishery sector, Grimes (1998) documents cases where cost-benefit analyses (in the case of sports fish) have shown a positive return even if less than one percent of the stocked animals are recaptured.

As for fish resources, conventional management measures such as minimum size limits and reductions in catch or in fishing effort have their role in stock enhancement of shellfish, by reducing fishing mortality and increasing survival of spawning stocks. Classical methods of stock assessment (e.g. Beverton and Holt, 1957), often will need to be reviewed and adapted however, to take into account the very varied shellfish life histories of invertebrates, and this effort began in the 1970s (see e.g. Caddy, 1975; Conan, 1984; Fogarty and Murawski, 1986; Orensanz and Jamieson, 1998; Smith and Botsford, 1998). Stock assessment methods applied to crustacean populations were discussed by Cobb and Caddy (1989), and more recently widely applied, e.g. in workshops of FAO Regional Bodies, such as WECAFC (2000) for shrimp and groundfish fisheries, and WECAFC (2001) for spiny lobsters. Specific studies on diverse topics of stock assessment methodologies have been published on crustaceans (Arena Barea and Defeo, 1994; Rugolo *et al.,* 1998), molluscs (Rueda and Urban, 1998; Palacios, Orensanz and Armstrong, 1994, 2000; Orensanz *et al.,* 2003) and echinoderms (Andrew *et al.,* 2002; Chen and Hunter, 2003). As for finfish stocks, uncertainties in stock estimates, and major but often hidden changes in fishing power, coupled with risk-prone management, have led to collapses of some stocks. Although this text does not enter into detail on stock assessment methods, which are dealt with elsewhere in FAO publications (e.g. Sparre and Venema, 1992), inevitably we touch upon some of the issues involved in the routine management of these resources. Even with a previously successful management scenario, pressures from new entrants may lead to stock declines if there is an effectively open access regime, so that stock assessment alone without a linkage to management decision-making will of course prove ineffective.

Cowx and Welcomme (1998) provide an extensive review of some methodologies used for finfish enhancement in freshwaters, and some of their conclusions undoubtedly apply to marine invertebrates also (see also Welcomme, 1996). They concluded that limits to production had already been reached in most freshwater systems, and that environmental conditions continue to deteriorate as a result of human activities in watersheds. That production from many shellfish populations has declined under inadequate management regimes was documented by various authors in the review of invertebrate fisheries assessments by Caddy (1989a, b); not only by overfishing, but because nearshore resources are also susceptible to environmental degradation, as are the fishery resources of enclosed marine systems (e.g. Caddy, 1993a; de Leiva Moreno *et al.*, 2000). Hence, it would be difficult to discuss shellfish management issues separately from the environmental management of coastal waters, lagoons and estuaries. In fact, in many situations, the health and productivity of invertebrate populations is the best indicator of environmental integrity: see, for example, “mussel watch” programmes for monitoring coastal pollution (O'Connor, 2002). The use of habitat restoration to improve yields of marine coastal species does occur locally, and important actions of this kind can be subsumed under the establishment of marine parks or marine protected areas (MPA’s). Shellfish restoration cannot be considered independent of other activities to restore the coastal environment, but projects principally aimed at restoring ecosystems such as seagrasses and other vegetation (e.g. Dennison *et al.,* 1993), may incidentally consolidate bottom sediments and provide settlement substrates for shellfish such as bay scallops and juvenile penaeid shrimps (Coles *et al.,* 1987).

Other actions which have affected productivity of invertebrate populations have generally occurred at a much larger scale and have rarely been considered under the heading of fisheries management methodologies. For example, the reduction of nutrient runoff, primarily with the intention of improving water quality first in estuaries and river runoff (e.g. the Rhine - Boddeke and Hagel, 1995) and only later in receiving basins (e.g. in Dutch coastal waters – Boddeke, 1989), has nonetheless had impacts on shellfish production in estuarine and adjacent coastal areas. As noted by Cowx and Welcomme (1998), the main objective of ecosystem interventions in developed countries, rather than increasing the fishery productivity, is the more ecologically motivated one of restoring degraded marine environments. In some cases this may also affect shellfish production. Improving inshore water quality should not be discounted as an important mechanism, or precondition, for shellfish stock enhancement, in ensuring that the product meets health requirements for human consumption. In North America, polluted inshore shellfish grounds may be closed due to sewage runoff and health impacts, but such areas may still play an important role as spawning refugia seeding adjacent open grounds (Estevez, 2002). In some case however (e.g. Boddeke and Hagel, 1995), the reduction of nutrient runoff by pollution abatement in order to reduce eutrophic effects in coastal waters, may actually reduce productivity of shellfish stocks, although what the net effect of eutrophication is on all human activities in the coastal zone remains a controversial question. Nonetheless, control of runoff of nutrients, sediments and especially disease vectors affecting shellfish grounds (Klinck *et al.,* 2001), the smothering of shell and gravel habitats, and the need for their restoration, are all important considerations in a successful stock enhancement programme. This might include for example the replanting of sea grass beds and restoration of coastal wetlands for reasons other than stock enhancement *per se*, such as for the conservation of biodiversity. The linkage between environmental manipulation and shellfish production is a very sensitive one, as illustrated by Figure 1, which shows the synergistic effect of three common anthropogenic effects on estuaries: increased outflow of nutrients, of sediments, and reduced water outflow due to irrigation and flow manipulation.

In tropical environments, the intensive stocking of coastal ponds and lagoons for penaeid shrimps and other shellfish resources has become economically important, but raises controversial issues relating to the incidental effects of shrimp culture on local communities and coastal fisheries for the wild stocks (Primavera, 1991). For example, the social conflicts between intensive pond culture and the rights of local fishers has become a heated issue in coastal waters around the tropics in recent years (James, 1999). In fact, the excessive proliferation of shrimp ponds at the expense of the natural barrier of mangrove forests, may affect an important nursery area for coastal fishers, as well as reducing protection to coastal lands from storm surges. Thus, some questions related to aquaculture and restoring inshore shellfish resources fall directly under the provisions of integrated coastal area planning (Chua, 1997). Deforestation of mangrove areas for pond culture not only impacts the use of coastal mangrove forests as a nursery area for natural fishery stocks (Robertson and Duke, 1987), for firewood production, and as noted, protection against storm surges (Jagtap *et al.,* 1993). Another issue that falls within the context of interactions of invertebrate enhancement activities with other uses of coastal waters, relates to the practice of using the voluminous bycatch of shrimp trawling, consisting of juveniles of commercial species and trash fish and invertebrates, to feed pond/raised fish and shrimp (Naylor *et al.,* 2001). Although this practice avoids waste, it is also likely to negatively affect supplies of low-priced fish for food security. The end products of intensive aquaculture may often be exported, without a large share of the benefits necessarily returning to the coastal community, and intensive development of pond-culture may impinge on traditional access rights to harvest shellfish and other resources. All of these issues are ancillary, but form part of the larger picture that has to be taken into account when planning a fishery enhancement activity.

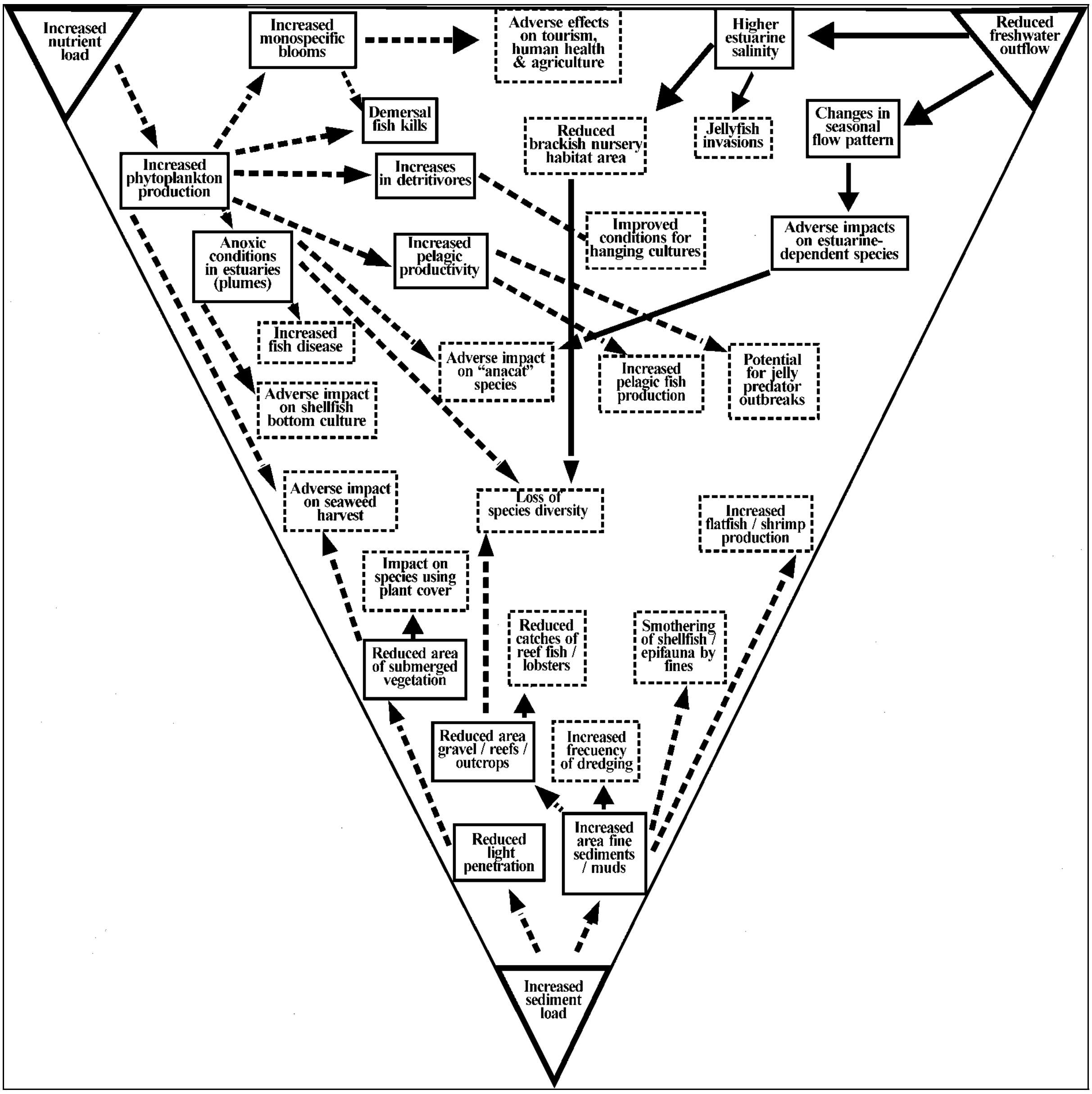

Figure 1 Diagrammatic representation of some linkages between three human impacts on estuarine fisheries and shellfish culture: increased nutrient loading, increased outflow of sediments and reduced freshwater inflow, typical of rivers subject to irrigation or blockage by barrages or dams (from Caddy and Bakun, 1995).

Many developed and some developing countries have implemented restocking programmes in order to restore threatened or endangered resources, such as for example, pearl oysters. As noted by Sims (1993), if animals are transplanted into, and grown successfully in their transplanted environment, and are allowed to mature and spawn, it may not be necessary to repeat an enhancement exercise annually. In such cases, the benefit/cost ratio for this approach over time is almost certain to be positive in light of the train of benefits a healthy invertebrate population should yield into the indefinite future. The potential for enhancement activities appears to have increased with the ratification of the 200-mile Exclusive Economic Zone, especially for those countries (see Kitada, Taga and Kishino, 1992) which have ceded some managerial responsibility for coastal resources to local government or fishers' cooperatives. Although earlier enhancement activities using large-scale release of very young organisms were of doubtful success, some new small-scale developments provide a more promising picture, but one where careful consideration of the ecological, social and economic context is needed. In many countries, legislation does not permit the exclusive access rights to a marine area that these methodologies require if enhancement is to be implemented by the private sector, or local municipal agencies, and this emerges as a major constraint on the creation of productive employment in coastal economies. Hence, over-centralized governmental decision-making is probably one of the major handicaps to coastal shellfish management, while devolvement of decision-making over local resources provides a favourable climate and support to local initiatives. Under favourable circumstances, stock enhancement using seeded organisms may be a viable alternative management strategy for shellfish stocks, but one where a number of problems are not always evident prior to commencing such a programme, as will be discussed in the following sections.

In the specific case of shellfisheries, some intrinsic characteristics of stocks impose additional problems and constraints to the implementation of enhancement programmes. Benthic invertebrate populations are usually spatially structured resources with patchy distributions (e.g. Caddy, 1975; Orensanz and Jamieson, 1998). Their population dynamics are extremely labile, and sensitive to variations in environmental conditions, even on a reduced scale of meters. This may generate spatial gradients in growth rate, recruitment and mortality (Caddy, 1989b, c; Schoeman and Richardson, 2003). Marked preferences for habitats and other environmental factors often show up this way, and highlight the need to consider spatial distribution patterns carefully when planning stock enhancement programmes. Another factor of utmost importance for sessile and sedentary stocks is the occurrence of density-dependent (DD) mechanisms controlling growth, mortality and recruitment at small operational scales. The effect these processes have on recruitment, however, may show up at varying spatial scales depending on whether DD occurs before or after dispersal of eggs and larvae. Pre-dispersal DD processes include reduction of growth and fecundity at high density due to competition for space or food, and the DD of fertilization rate in broadcast spawners. Typical post-dispersal DD processes involve settlement or recruitment inhibition, or post settlement mortality due to high densities of local adult residents, where gregarious settlement of larvae in the neighbourhood of adult conspecifics occurs (Orensanz *et al.*, 2003). The markedly different spatial scales at which these processes operate vary according to the life cycle of each species, their mobility, the speed of larval development, and larval life stage duration (e.g. Perry, Walters and Boutillier, 1999). Castilla and Defeo (2001) call for a detailed species-specific analysis when planning stock enhancement programmes.

In this document we analyse several different techniques for promoting the active enhancement of productivity in shellfishes. Some guidelines and criteria for conducting and assessing enhancement programmes are also provided. The book is presented in eight main Chapters. Chapter 1 describes the functional categories of invertebrates and how this leads to differing management and enhancement modalities. The basic mechanisms for shellfish enhancement are defined, namely natural stock regeneration, experimental cultivation and seeding, and habitat restoration issues. Chapter 2 provides some broad generalizations on stock assessment methodologies, as well as suggesting information requirements for monitoring stock condition and recovery. Management guidelines are discussed, including the development of some specific indicators useful for evaluating stock status, the relative merits of different management tools, the organizational requirements for management, and the implications of harvest control laws for restoring shellfisheries. This Chapter also deals with some biological