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Lessons learned from Japanese marine finfish stock enhancement programmes

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Abstract

We examined the efficacy of marine stock enhancement for coastal finfish in Japan. To do this, we used four case studies of the red sea bream *Pagrus major* and the Japanese flounder *Paralichthys olivaceus* to establish whether hatchery releases augmented total production without replacement of wild fish. The catches by age of released and wild fish showed that hatchery-reared fish contributed 36.4 ± 17.8% to total production of red sea bream and 22.6 ± 11.3% to flounder, respectively. About 50% of the variation in total catches was explained by capture of hatchery-reared fish for red sea bream, and 29–38% for flounder. However, the scope for increased production was limited by carrying capacity, particularly at release sites. Replacement of wild fish by hatchery-reared juveniles was suggested in one case. The comparative analysis of macro-scale catch history revealed that the average contribution of hatchery-reared fish was 9.5% for red sea bream and 11.7% for flounder, and the global dynamics of wild populations does not appear to be linked to stock enhancement activities. Our results suggest the need for a cautious approach to stock enhancement programmes. We also address the biological potential, the limitations, and the future prospects of marine stock enhancement.

Keywords: Marine stock enhancement; Potential and limitation; Replacement of wild fish; Red sea bream; Japanese flounder

1. Introduction

Since the late 1980s, global fisheries landings have declined due to over-fishing and habitat degradation (Pauly et al., 2002). Moreover, recreational fisheries have had a great impact on many valuable over-fished marine fish species (Coleman et al., 2004). In 2001, marine aquaculture contributed 15.1 million tonnes (15.5%) to world marine fisheries production (FAO, 2002). However impacts of aquaculture on ecosystems have become a matter of concern (Dalton, 2002), and aquaculture cannot be expected to compensate for the supply shortage. Marine reserves and areas with limited levels of fishing effort are expected to allow sustainable fisheries (Pauly et al., 2003). Marine stock enhancement (MSE) is another option for fisheries management. The term *stock enhancement* is generally used for artificial propagation to augment natural production by releasing cultured juveniles. The idea refers to the terms *supplementation* used for salmon hatchery-release programmes (Waples and Drake, 2004) and *supportive breeding* in conservation biology (Ryman and Laikre, 1991). *Stock enhancement* encompasses the terms *sea ranching* and *restocking*, which emphasize the intra and inter-generation effects for augmentation of fishery production or biomass, respectively. This paper focuses on finfish MSE and does not deal with crustaceans, shellfishes, other invertebrates, or salmon. However, many lessons drawn here will be relevant to stock enhancement activities in general.

Attempts to augment marine finfish production by releasing hatched larvae started in the 1870s, mainly using cod and plaice, but no evidence of a benefit was documented (Blaxter, 2000; Svåsand et al., 2000). Norway's comprehensive MSE research, involving the release of one million young cod during the 1980s and 1990s provided much ecological information. No significant increase in cod production was achieved, however, and recapture rates varied widely from

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0 to 31.3% (Svåsand et al., 2000). Nonetheless, releases of juveniles may continue to be used as a management tool due to increased pressure on local fisheries resources from recreational fishing and tourism (Svåsand et al., 2000; Moksness, 2004). MSE for European lobster was found to be promising (Agnalt et al., 2004).

Japan initiated an MSE programme in 1963, focusing mainly on demersal fish and shellfish, which do not migrate over large areas, because good recapture efficiencies cannot be expected for highly migratory pelagic fish. To date, the Japanese programme has involved the release of juveniles of more than 50 marine species (Imamura, 1999; Kitada, 1999). In the USA, there is renewed interest in MSE due to the availability of new aquaculture and marking technologies. Research oriented MSE projects are under way in 12 states (Leber, 2004) for several stocks, including red drum and red snapper which have been impacted significantly by recreational fishing (Coleman et al., 2004). Thirty-three developing countries have reported marine stocking activities involving 59 species (Bartley et al., 2004).

On the other hand, concerns about the impact of hatchery programmes on wild stocks have been raised in the USA and Scandinavia since the late 1980s, (Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, 1996; Hindar et al., 1991). The main concerns regarding hatchery supplementation are genetic impacts on wild populations (Waples, 1991; Utter, 1998) and replacement of wild fish by hatchery fish (Walters, 1988; Hilborn, 1992; Hilborn and Winton, 1993; Hilborn and Eggers, 2000; Sweeting et al., 2003). In recent years, the controversy has widened to include effects of continuous releases on evolution and conservation of endangered salmon species (Gustafson et al., 2001; Health et al., 2003; Myers et al., 2004). In response to such concerns, a responsible approach for MSE has been proposed (Blankenship and Leber, 1995). A review of genetic effects of hatchery fish on Pacific salmon and steelhead found only limited empirical data demonstrating such effects on wild populations (Campton, 1995).

A recent review of salmon hatchery programmes concluded that hatchery fish have an important role in recovery and supplementation of wild stocks (Brannon et al., 2004). A hatchery reform programme was established in 1999 to evaluate Washington State salmon hatcheries (Blankenship and Kern, 2004). Research on the pink salmon stocking programme in Prince William Sound (Smoker, 2004) has claimed that the stocking programme has provided large benefits to the region (Smoker and Linley, 1997; Wertheimer et al., 2001), while identifying a range of replacement possibilities from 0 to 50% loss in yield from wild stocks (Wertheimer et al., 2004). A comprehensive review has summarized potential biological risks and benefits of supplementation with empirical studies in Pacific salmon and suggested a reasonable approach to stock enhancement (Waples and Drake, 2004).

In supplementation of wild stocks, the primary concern is the possible replacement of wild fish. Hilborn (2004) pointed out that the competitive impacts of stocking will only be detectable at the production scale, and cannot be tested with a pilot project. Two years releases with a total of 220,000 genetically marked cod juveniles in Norway significantly increased the frequency of the marker allele in the released population in the years after release (Jørstad, 2004). The investigation demonstrated that released cod recruited into the wild population, but whether the change in allele frequency signified replacement or augmentation is unknown. Releases of 334,100 alizalin-marked turbot over 3 years were used to examine the ratio of marked to wild fish 3 years after release but found no indication of replacement (Støttrup et al., 2002). Also, releases of 128,000 European lobster over 5 years found no sign of replacement (Agnalt et al., 2004). However, the average number of releases per year (25,000–110,000) may have been well below carrying capacity. Compared to salmon hatchery programmes, most MSE thus remains at an experimental or pilot scale. As a result, replacement of wild fish in MSE programmes has not been documented and their potential has not yet been fully evaluated. The most urgent and important issue is to evaluate the potential of MSE based on real evidence.

In this paper, we examine several large-scale MSE programmes in Japan to establish whether hatchery releases have augmented total production without replacement of wild fish, and discuss the potential of MSE through comparative analysis of macro-scale catch histories. We do not deal with the genetic effects of Japanese MSE on wild populations (Kitada and Kishino, 2004), which are beyond the scope of this paper and need further research.

2. Japanese marine stock enhancement programmes

The Japanese government started the MSE programme in 1963 aiming to improve coastal fisheries depleted due to rapid industrialization after the Second World War. A total of 16 National and 57 prefectural marine hatcheries are now under operation. According to the latest statistics (Fisheries Agency and Japan Sea-Farming Association [FA and JASFA], 1980–2004), a total of 76 million juveniles from 37 finfish species, 221 million juveniles from 12 crustacean, 3213 million spat from 26 shellfish, and 78 million juveniles from 8 invertebrates were produced in hatcheries and released into coastal waters in 2002. Japanese flounder *Paralichthys olivaceus* and red sea bream *Pagrus major* have been the two most important finfish species for Japanese MSE programmes, and have been released throughout Japan. During mid 1970s and 1980s, recapture rates of released juveniles with external tags were estimated based on tag recoveries reported by fishers (Kitada et al., 1994), the same method used in Norway for cod (Svåsand et al., 2000). However, such tag reporting surveys resulted in biased estimates despite efforts