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Review

Is hatchery stocking a help or harm? Evidence, limitations and future directions in ecological and genetic surveys

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ABSTRACT

Hatchery fish stocking for stock enhancement has been operated at a massive and global scale. However, the use of hatchery fish as a means of stock enhancement is highly controversial, and little is known about its effects on wild stock and consequences for stock enhancement. Here we review the scientific literature on this subject in order to address a fundamental question — is hatchery stocking a help or harm for wild stock and stock enhancement? We summarized 266 peer-reviewed papers that were published in the last 50 years, which describe empirical case studies on ecology and genetics of hatchery stocks and their effects on stock enhancement. Specifically, we asked whether hatchery stock and wild stock differed in fitness and the level of genetic variation, and whether stocking affected population abundance. Seventy studies contained comparisons between hatchery and wild stocks, out of which 23 studies showed significantly negative effects of hatchery rearing on the fitness of stocked fish, and 28 studies showed reduced genetic variation in hatchery populations. None of these studies suggested a positive genetic effect on the fitness of hatchery-reared individuals after release. These results suggest that negative effects of hatchery rearing are not just a concern but undeniably present in many aquaculture species. In a few cases, however, no obvious effect of hatchery rearing was observed, and a positive contribution of hatchery stock to the abundance of fish populations was indicated. These examples suggest that there is a chance to improve hatchery practices and mitigate the negative effects on wild stocks, although scientific data supporting the positive effect on stock enhancement are largely missing at this moment. Technically, microsatellite-based parentage assignments have been proven as a useful tool for the evaluation of reproductive fitness in natural settings, which is a key for stock enhancement by hatchery-based stocking. We discuss implications of these results, as well as their limitations and future directions.

Contents

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1. Introduction

The world human population increased from 3 billion to 6 billion between 1959 and 1999. According to the U.S. Census Bureau, it is more than 6.8 billion now (as of December 2009). The continuous growth in human population has created strong demands for food production worldwide. Fish production is no exception. World fisheries supplied 144 million tons of food in 2006, providing >15% of the average animal protein intake to 2.9 billion people (FAO, 2009). Existing wild fish stocks have been largely exploited, and aquaculture business is developing rapidly (Nomura, 2008; Subasinghe et al., 2009). Currently more than 40% of the seafood (30% of fish species) is supplied by aquaculture (Fig. 1).

Nevertheless, Fig. 1 shows that more than 50% of fishery production still depends on captured fish and natural resources. To meet the increased demands for food supply, capture fisheries explored fishing grounds both intensively and extensively. As a result, overexploitation, together with habitat destruction, became one of the biggest problems in global fisheries and ecosystems (Jackson et al., 2001). Restoration efforts have been made, but the consequences of such efforts are yet to be seen at the global scale (Hutchings, 2000; Hilborn, 2007; Worm et al., 2009).

One of the most popular tools for restoration is a release of hatchery-reared fish in the wild (hatchery stocking, hereafter). The majority of the hatcheries are 'production hatcheries', whose purpose is to enhance fish production for commercial and recreational uses. Thus, a primary focus of this type of hatchery is to release fry or juveniles into natural environments and enhance the stock of interest. However, the contribution of stocked fish to the population size is difficult to measure. Many environmental and ecological factors can influence the conditions of natural populations, and the population size might change with or without hatchery stocking. Thus, the success and effectiveness of fish stock enhancement have long been questioned and discussed (Needham and Slater, 1944; Greene, 1951; Leber, 2004; Bell et al., 2008).

Another goal of hatchery stocking is conservation of natural resources. In this case, hatchery productions are used not only to increase the population size through a direct contribution of hatchery fish in the wild, but also to maintain self-sustainable local wild stock. Therefore it takes broader aspects of considerations to achieve the goal of this type of hatchery, such as the conditions of wild stock and environmental carrying capacity (e.g., Ryman, 1991). This is even more so if the hatchery has the dual goal of production and conservation. With the rapid development of molecular techniques, many genetic methods have become available for fishery science in the last few decades (Ryman and Utter, 1987; Lowe et al., 2004). While the power of such methods has been demonstrated in a variety of applications, general results from their applications to the evaluation of hatchery stocking remain unclear.

In this article, we review the scientific literature which evaluates the effects of hatchery rearing and stocking. The primary goals of this paper are (1) to summarize empirical case studies over the last 50 years and draw general conclusions about the effects of hatchery stocking on wild stock and stock enhancement, and (2) to discuss missing information and future directions. We include evaluation surveys on both production and conservation hatcheries, and the target organisms include teleost fish species and aquatic invertebrates. We specifically focus on ecological and genetic aspects of hatchery stocking. Other aspects, such as socio-economical and political ones, are equally important but discussed elsewhere (Hilborn, 1998; Waples and Drake, 2004).

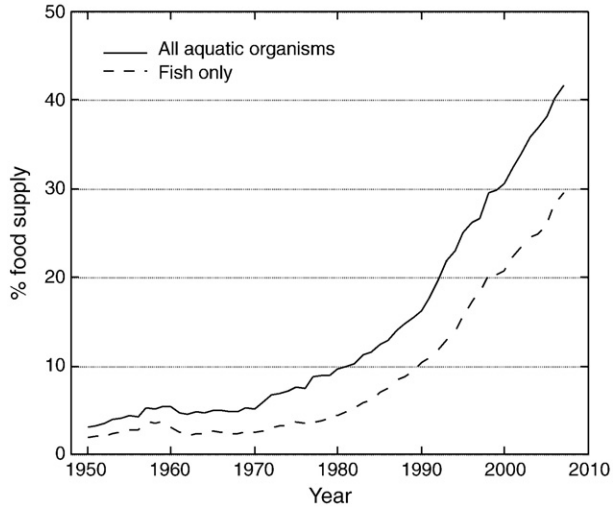

Fig. 1. Percentage of food production from aquaculture and hatcheries among world fishery productions. 'All aquatic organisms' includes fish and aquatic invertebrate species, but it does not include aquatic mammals and plants.
Source: FAO, 2009.

2. Results

2.1. Overview

We used ISI Web of Knowledge (apps.isiknowledge.com), SCOPUS (www.scopus.com) and PUBMED (www.ncbi.nlm.nih.gov) online database search systems to collect peer-reviewed publications. Keyword searches for 'evaluation', 'stock enhancement' and/or 'hatchery' yielded 520 hits (as of August 2009). These papers contained studies on teleost fish, shellfish and other aquatic invertebrates ('fish' hereafter for simplicity), but not aquatic mammals or plants.

To concentrate on empirical case studies that are directly relevant to the effects of hatchery rearing and stocking, we performed manual screening. In the screening, we eliminated purely theoretical, political and/or socio-economical papers as well as review papers without newly published data. To minimize artificial bias and inconsistency in the selection of papers, the screening was performed by both authors independently and then the results were merged. Some papers from the 1980s or earlier were manually added because they were not identified in the online database search above. Eventually we obtained 266 publications. Of these publications, 99 papers (37.5%) contained results from genetic analyses.

To summarize the temporal trend of the research activities, we plotted the number of peer-reviewed publications in the last 50 years (Fig. 2). The number of related publications increased significantly in the last two decades. In total, 74% of the studies were published in the last ten years (2000–2009), and 23% between 1990 and 1999. The pattern was consistent for genetic and non-genetic studies, and the fraction of genetic studies ranged between approximately 30 and 45% in the last 5 years (Fig. 2).

2.2. Species of interest

Among the 266 case studies, salmonid fish and flatfish species were most studied (17.3% and 15.1%, respectively. Fig. 3C). For aquatic invertebrates, lobsters, crabs and abalones were most studied (4.8–5.5% each). Between genetic and ecological studies, however, the results were different. Salmonid and bream species were particularly popular in the genetic studies, but not so much in the ecological studies (Fig. 3A and B). Aquatic invertebrates were rather popular in ecological studies. The species distribution in the studies does not reflect their contribution to the world food production during the study period (Fig. 3D), suggesting that research efforts were influenced by the other species-specific factors such as technical difficulties, local interest and study histories.