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Problems and solutions for hatchery release: a framework

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1 Hatchery release

Hatchery release is a method of breeding fingerlings in artificial environments and then releasing them into natural water bodies (Kitada, 2018). Commonly, the application scenario of hatchery release is categorized into five types in a sequence ranging from the most production-centered to the most conservation-oriented aims: culture-based fisheries, stock enhancement, restocking, supplementation, and reintroduction (Lorenzen et al., 2021). Over the past century, hatchery release has been widely used as a tool to enhance, restore, and rebuild fishery resources (Blaxter, 2000; Svåsand et al., 2000). In their update to the responsible approach to marine stock enhancement, which integrated biological, economic, social, and governance aspects of captive propagation programs, Lorenzen et al. (2010) established the implementation framework of hatchery release (Lorenzen et al., 2010). However, the public and scientific community are still concerned about the effectiveness and sustainability of hatchery release initiatives, especially in light of assessments that suggested that many programs have not achieved the desired outcomes (Johnsson et al., 2014; Näslund, 2021). A contrasting perspective is that hatchery release is implemented at a large scale in several countries and these programs should not be cancelled lightly until other tools are demonstrated to be more effective in restoring fishery resources (Armstrong and Seddon, 2008; Taylor et al., 2017). To say the least, there is no necessity to abolish the activity that supports livelihood fisheries (especially in developing countries) and is endowed with a cultural or religious significance (e.g., the Buddhist practice of releasing fish) (Lorenzen et al., 2010). The alternative and maybe more sensible course of action is to identify potential problems existing in hatchery release and find effective approaches to solve them (Brown and Day, 2002).

2 Problems with hatchery release

From the perspective of biology, the main problems of hatchery release fall into the following categories. Firstly, the fitness of released fish is low. Regardless of the hatchery release application scenario, the primary objective is that the released fish can survive in the wild (Wiley et al., 1993). If a released fish is not expected to survive in the wild, it undoubtedly undermines their most basic right to life and welfare (Brown and Day, 2002). The reasons for the low fitness of hatchery fish are mainly low behavioral adaptability and severe stress responses caused by release procedures (Näslund, 2021). Compared to wild fish, hatchery fish have poor predatory and anti-predatory abilities, tend to behave boldly and rigidly, are equipped with weak competitive ability in natural environments, and express low behavioral flexibility and diversity (Salvanes and Braithwaite, 2006). These differences between wild fish and hatchery fish originate from ontogenetic and genetic mechanisms (Olla et al., 1998). The ontogenetic deficiency is directly caused by the great differences in the structural, social, and sensory environment between the culture units and natural habitats, while the genetic discrepancy is mainly driven by deliberate or unintentional multi-generation artificial selection (Huntingford, 2004). Secondly, release may result in undesirable ecological and genetic interactions between wild and hatchery populations (Lorenzen et al., 2021). The ecological interaction is mainly mediated by a density-dependent mechanism, which is related to stocking number, release strategy (such as release time and location), wild population size, and environmental carrying capacity (Lorenzen et al., 2012). Genetic interaction can be direct (i.e., introgression due to reproductive activities) or indirect (e.g., reduction of wild population size through intraspecies competition) (Le Vay et al., 2007). Excessive gene flow may lead to changes in the genetic structure of the wild population, decrease in their genetic diversity, and thus weakening of their adaptive potential (Kitada, 2018). Thirdly, hatchery release may also promote interactions at higher ecological levels (Lorenzen et al., 2012). For example, released fish may compete for limited ecological niches, alter food web structure, influence energy flow through trophic relationships (i.e., eat and be eaten), and trigger cascade reactions (Lorenzen et al., 2021). Fish activities may also affect ecosystem function by modifying their habitats. Fourthly, releasing fish may cause disease transmission. It can be done either by introducing alien or evolved pathogens or by affecting the dynamics of established pathogens through changes in host population demography or immune status (Lorenzen et al., 2010). Fifthly, release procedures may also lead to technical interactions, such as the disturbance to the benthic ecosystem caused by broodstock capture and the changes in fishing pressure after the hatchery release activities (Lorenzen et al., 2010). In total, released fish have great ecological and genetic interactions with wild fish, and hatchery release may have technical and ethical interactions with ecosystems (including humans) (Le Vay et al., 2007). In the process of these interactions, the behavioral defects (and subsequent poor fitness) and decreased genetic diversity of released fish caused by limited sources of broodstock, captive environment, and release procedure are of great importance.

3 Finding solutions

Classical theories and practices offer several approaches to overcome the problems identified above. Genetic management is essential and needs to be addressed from the very beginning of a program because damage due to genetic impacts can be long-lasting and difficult to undo. Broodstock should be captured in the waters intended for release so as to avoid introducing non-native genotypes in the area and avoid disrupting the genetic background of the target wild population. Broodstock number should be as large as possible to minimize the risks of genetic diversity loss (Le Vay et al., 2007; Laikre et al., 2010). The first-generation fingerlings of native broodstock should be used to reduce the influence of artificial selection on the genome and epigenetics of hatchery fish and to avoid possible outbreeding depression (Johnsson et al., 2014). The second approach is to provide life skills training. It means that in the short term before release, hatchery fish undergo the key factors affecting their survival in the natural environment (such as predation, temperature change, etc.) so that they can acquire essential experience and adapt to the wild efficiently (Griffin et al., 2000; Brown and Day, 2002). As early as the beginning of this century, many related studies have been reported, and life skills training has been applied to the practice of hatchery release (Suboski and Templeton, 1989; Brown and Laland, 2001; Kelley and Magurran, 2003). Third, practitioners highlight the importance of optimizing release strategy. Various environmental factors should be considered to select the time and place suitable for individual species and specific developmental stages within a species (Lorenzen et al., 2010). At the same time, the beneficial effect of a larger size on fish survival, the detrimental effect of the captive environment on behavioral phenotype, and the economic cost involved in rearing fish to a large size in the hatchery prior to release should be comprehensively considered to select the appropriate fish size at release (Brown and Day, 2002). In addition, the soft release, which refers to the practice of providing an acclimatization period at the release site prior to actual release, is a promising method to help fish recover from various stresses involved in transportation, handling and change of environment (Tetzlaff et al., 2019).

How to optimize the hatchery environment to improve fish fitness has attracted wide attention in recent years (Ebbesson and Braithwaite, 2012; Johnsson et al., 2014). A basic principle is to introduce cues that fish receive in the wild to the captive environment to increase heterogeneity and complexity, in other words, simulate natural habitats (Johnsson et al., 2014). Projects based on this principle are often called environmental enrichment (Arechavala-Lopez et al., 2022). Most evidence shows that environmental enrichment can significantly improve the adaptive behaviors of hatchery fish by enhancing responses to behavioral and physiological stress as well as neural development and neurogenesis, although the mechanisms are not fully understood (Näslund and Johnsson, 2016; Zhang et al., 2022; Zhang et al., 2023a; Zhang et al., 2023b). More importantly, environmental enrichment can improve the learning ability of fish (Zhang et al., 2022). Considering that the nature of life skills training is associative learning behavior, it is expected that life skills training based on environmental enrichment will present an additive effect and equip hatchery fish with higher fitness (Brown and Laland, 2001; Kelley and Magurran, 2003). Interestingly, environmental enrichment can affect the level of DNA methylation in fish brains (Berbel-Filho et al., 2020). Although the ecological consequences of these modifications remain unclear, these observations suggest that environmental optimization may be beneficial to the normal development of the epigenetic spectrum. A recent meta-analysis showed that introducing physical structures alone could not significantly improve fish survival rate, suggesting that the desired effect of environmental enrichment depends on whether the introduced cues match the target fish species, including the type, intensity, and duration of enrichment (Zhang et al., 2022). For examples, bottom-based structures (such as cobbles) are more suitable for demersal fish, longer duration of enrichment may be needed for species featuring greater longevity (such as Atlantic salmon vs. zebrafish), and fishes whose natural habitats have complex water flow fields (such as rocky fishes) may benefit from flow exercise (Arechavala-Lopez et al., 2022; Zhang et al., 2023a). In this case, a preference test is an appropriate candidate to determine these factors (Näslund and Johnsson, 2016; Zhang et al., 2023a). Generally, conditioning strategies are still evaluated primarily at the behavioral level, and there are few long-term *in-situ* monitoring studies on their effects on fitness. Furthermore, assessments of the effectiveness of conditioning on fish fitness are sharply contradictory among studies, and the causes of these discrepancies should be deeply investigated in the future.

Except for the considerations mentioned above, practitioners should particularly pay attention to the specificities of target environments where fish are to be released. A good example is provided by the constraints related to releases in marine versus freshwater environments. Freshwater ecosystems, generally, have higher habitat heterogeneity, more ecosystem-human interactions, but a lower spatial scale compared to marine ecosystems. These characteristics mean that the fish that will be released into freshwater may need to be equipped with higher cognitive abilities so they can cope with complicated physical and social situations. In contrast, released marine fish may need stronger swimming ability (but this does not mean that one does not need to train their cognitive abilities). However, information on these questions is very scarce to date.

4 Conclusions, suggestions and future directions

In conclusion, I summarize below a framework that emerged from this and other investigations on hatchery release. Stakeholders should consider the following aspects when designing and developing a hatchery release project. (1) Decision-makers should select species based on comprehensive considerations of ecological, economic, and social effects and then calculate the environmental capacity of the target water to determine the stocking number. (2) Practitioners should increase the number of broodstock as much as possible and release only first generation offspring. (3) Environmental enrichment during the captive period should be conducted to ensure hatchery fish develop phenotypic and epigenetic characteristics that will maximize their fitness in the wild environment. (4) Life skills of hatchery fish should be developed by training before release to provide them with essential experience that will improve their fitness. (5) Soft release should be implemented as much as possible, and the release area and time as well as fish size should be determined accounting for the specific context and objectives of a program.

Hatchery release is not an all-in-one solution to manage fishery resources, and past and on-going programs have illustrated shortfalls of this approach to population management and enhancement, such as high release mortality, genetic impacts, and low economic return relative to input. However, at present, hatchery release is still implemented in some programs in several countries, and the potential problems can be addressed through various ways. Overall, I believe that the integration of these environmental and genetic management tools can lead to success effectively restoring resources, boosting production, and reducing ecological and genetic risks of hatchery release. Hatchery release should be conducted in combination with other methods, such as habitat restoration, fisheries regulation, and establishment of marine protected areas, but this is another question beyond the scope of this paper. I encourage decision-makers and practitioners to comprehensively consider all available management tools, compare their specific strengths, and choose the most optimal strategy based on the trade-offs between biological, social, economic, and ethical effects.

This paper also aims to point to knowledge gaps and research needs. Since epigenetic modifications are an important mechanism by which fish adapt to their environment, it is urgent to explore the ecological consequences of these molecular changes induced by environmental enrichment. The impact of released fish on wild ecosystems at various levels and the effects of pre-release conditioning on these interactions should be studied more extensively. Finally, the rising number of studies on environmental conditioning could be exploited to assess the effectiveness of parameters of the conditioning process through a meta-analysis approach.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of interest

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