**Interactions between Offshore Aquaculture and Fisheries**

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**EXTENDED ABSTRACT**

Offshore cage aquaculture offers substantial untapped potential to increase seafood production (Bostock et al. 2010; Gentry et al. 2017; Lester et al. 2018). However, offshore aquaculture can interact with wild fish stocks and capture fisheries and this presents significant concerns for the aquaculture, fisheries and conservation communities (Knapp & Rubino 2016; Gentry et al. 2017). Potential interactions and issues of controversy include loss of access to fishing grounds, pollution, interactions between escaped farmed fish and wild fish, attraction of wild fish to cage sites, disease transmission, fisher responses to altered fishing opportunities, and market interactions between products from aquaculture and capture fisheries (Lorenzen et al. 2012; Clavelle et al. 2018).

Here, we focus primarily on biological interactions between cultured and wild fish. The nature and outcome of such interactions depends on a variety of factors including the abundance and conservation status of wild fish populations, the number of fish being farmed, husbandry and genetic management of farmed fish, escape rates of farmed fish, health management of farmed fish, behavioral responses of wild fish to cage aquaculture, and responses of fishers to altered fish abundance and distribution (Lorenzen et al. 2012). The relative abundance of the interacting fish populations is a major factor: most interactions (except those involving introductions of invasive fish or pathogens) are strongest when farmed fish are abundant relative to wild fish. Furthermore, wild populations that are small or endangered may be particularly vulnerable to such interactions.

Rearing of fish in aquaculture implies radical modifications of the organism’s environment and often deliberate manipulations of its biology, e.g. through selective breeding. Cultured fish thus enter a process of domestication: a process of developmental and genetic change in response to culture. Domestication gives rise to organisms that perform well in culture but tend to perform less well than their wild conspecifics following escape into natural environments. Domestication effects usually become apparent within the first generation in captivity and become more pronounced in subsequent generations.

Population-level ecological interactions between farmed and wild fish occur as a result of the increase in population abundance following escapes, and from differences in the biology of cultured and wild fish which have a modifying effect on the nature and strength of interactions. Ecological interactions have genetic consequences where cultured and wild fish interbreed (direct genetic interactions), or where the ecological interactions alter the selection regime (indirect genetic interactions). Interactions can be analyzed and their outcomes predicted using population dynamics models that account for fitness differences between farmed and wild fish, such as those used for assessing intentional releases of hatchery fish in fisheries enhancements (Lorenzen 2005). The strongest population-level interactions occur when farmed fish abundance is high relative to the wild population and when maladaptation of farmed fish to life in the wild is only moderate and genetically based. When farmed fish abundance is very low relative to wild fish, interactions are minimal regardless of farmed fish fitness in the wild. When farmed fish abundance is high relative to the wild, there are two alternative husbandry and genetic management approaches to minimizing impacts on wild fish (Lorenzen et al. 2012). Management to minimize domestication, if successful, would lead to interactions that are strong but inconsequential because wild and farmed fish would be effectively identical. However, this approach is unrealistic because it is virtually impossible to avoid inadvertent domestication effects and moreover, it negates the production benefits to aquaculture that result from domestication. The alternative approach, advancing domestication while inadvertently or intentionally reducing the fitness of farmed fish in the wild, is likely to be a more promising approach. In any case, it is important to take measures to minimize escapes and facilitate recovery of escaped fish. Escapes are typically in the order of 2-5% of stock per year in cage operations, but can be effectively minimized integrated approaches.

Cage aquaculture operations have impacts on the behavior of wild fish, often attracting and aggregating fish in ways similar to fish aggregation devices or artificial reefs (Sanchez-Jerez et al. 2011; Sims 2013; Calllier et al. 2018). This behavior may enhance the scope for certain biological interactions such as disease transmission, but also amplify harvesting opportunities for fishers.

Confinement of fish in culture facilities greatly reduces transmission of metazoan parasites with complex life cycles (because intermediate or final hosts are typically absent), but provides ideal conditions for transmission of parasites with direct life cycles including bacteria, viruses, many protozoa and some metazoans such as sea lice (Murray & Peeler, 2005). Impacts on wild stocks from disease interactions may occur via three mechanisms: (1) introductions of alien parasites (2) transfer of parasites that have evolved increased virulence in culture, (3) changes in host population density, age/size structure or immune status that affect the dynamics of established parasites (Lorenzen et al. 2012). Controlling parasites in cultured fish is crucial to minimizing disease interactions with wild fish, but is not always effective and may not be sufficient. It is therefore important to implement an epidemiological, risk-based approach to managing disease interactions that accounts for ecological and evolutionary dynamics of transmission and host population impacts (Murray & Peeler, 2005).

Fishers may seek out and benefit from harvesting opportunities provided by escaped farmed and aggregated wild fish (Sims 2013; Dempster et al. 2018). This can reduce interactions between farmed and wild fish, but also affect the exploitation level of wild stocks in ways similar to fish aggregating devices. Offshore cage aquaculture therefore has the potential for complex interactions with fisheries that require concerted attention from both sectors.

Recent research advances provide us with a good conceptual understanding of potential interactions between offshore aquaculture and fisheries and with increasingly sophisticated quantitative models and tools for risk assessment and management planning. Small-scale pilot projects for the culture of native species that are abundant in the wild pose limited risks and can provide important empirical information on interactions with fisheries that can help to test and refine models, risk assessments and management plans. We strongly recommend that fisheries interaction studies should complement pilot aquaculture projects. Such studies should be accompanied by a stakeholder process involving fisheries and aquaculture stakeholders including regulators in order to develop sound management approaches for such interactions.

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