



Fisheries enhancement and restoration in a changing world



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ABSTRACT

Fisheries enhancement is an important strategy for maintaining and improving fisheries productivity, and addressing some of the other contemporary challenges facing marine ecosystems. Aquaculture-based enhancement includes stock enhancement, restocking, and sea ranching. Developments in aquaculture techniques, tagging, genetics, modelling and ecology have underpinned growth in this field in the 21st century, particularly in the context of marine recreational fisheries. Marine enhancement practice has now matured to the point that quantitative tools are frequently applied before any fish or shellfish are released into the natural environment, and pilot-scale enhancement scenarios and release strategies are evaluated before full implementation. Social and economic studies are also increasingly important components of this assessment. Here, several case studies from diverse geographic areas exemplify the union of aquaculture technology, quantitative modelling, social science, physiology and ecology to estimate enhancement potential, improve enhancement strategies, assess enhancement outcomes, and support adaptive management. Integrating aquaculture-based enhancement with habitat enhancement presents a remarkable opportunity for future research and development, and offers the potential to further increase the opportunities and associated socio-economic benefits that are available to a broad range of fisheries stakeholders.

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1. Introduction

Enhancement of fisheries productivity in the marine environment is an important challenge in the 21st century (Bell et al., 2008; FAO, 2014), especially for providing increased food security (e.g. Liao, 2004), opportunities for socioeconomic benefits (e.g. Whitmarsh, 2001) and supporting natural systems that have been negatively affected by anthropogenic stresses such as overfishing and habitat loss. Fisheries enhancement refers to the use of additional measures aimed at enhancing productivity beyond what is achievable by good harvest management alone, and can include management of habitats (e.g. Pollard, 1989) and management of populations (e.g. Leber, 2013; Lorenzen, 2008). These measures often encompass technical solutions that address natural or human-induced ecological limitations in natural systems, for

example, recruitment limitation (e.g., aquaculture-based enhancement), degraded natural habitats (e.g., habitat restoration and rehabilitation), and habitat limitation (e.g., deployment of artificial reefs and other man-made habitat). Such limitations are also addressed, less commonly, by restricting access of stakeholders to areas (e.g., fishing closures) or marine protected areas with sanctuary or no-fish zones, which have an intended fisheries outcome (e.g. Pérez-Ruzafa et al., 2008).

The term aquaculture-based enhancement is used here and by others to refer to stock enhancement (the release of hatchery seed to improve self-sustaining populations), restocking (the release of hatchery seed to rebuild severely depleted fish stocks), and sea ranching (release of hatchery seed in put, grow and take operations; Bell et al., 2008; Lorenzen et al., 2013). The science of these strategies has undergone major transformation over the past 20 years, with a concurrent dialogue on the way release programs should be developed, implemented and assessed (Bell, 2004; Bell et al., 2006, 2008, 2005; Blankenship and Leber, 1995; Blaxter, 2000; Laurec, 1999; Leber, 2013; Lorenzen, 2014; Lorenzen et al., 2013, 2010; Molony et al., 2003; Munro and Bell, 1997; Radonski and Loftus,

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1995; Sass and Allen, 2014; Taylor et al., 2005). The International Symposia on Stock Enhancement and Sea Ranching (ISSESR), and associated proceedings, have contributed greatly to this scientific development, providing a forum for the review and synthesis of work, regularly identifying emerging issues and novel areas for research, and leading the development of some of the fundamental principles in the field. The research presented at these Symposia and the ensuing debates have been published in books (1st ISSESR, Howell et al., 1999; 2nd ISSESR, Leber et al., 2004) and various journal Special Issues (3rd ISSESR, Bell et al., 2008; 4th ISSESR, Lorenzen et al., 2013).

Almost two decades after the 1st ISSESR in Bergen, Norway in 1997, the three major pressures of an increasing human population, a plateau in capture fisheries production, and the fundamental importance of aquatic derived protein to a healthy diet, still remain. Over this period, human population increased by almost 30% from 5.7 to 7.3 billion. Annual capture fisheries production remained stable at around 90 million tonnes (t), while aquaculture production increased by 150% from 28 to 70 million t, so that overall aquatic food production grew at a rate of 35%, marginally exceeding that of human population growth (FAO, 2014). Despite the impressive growth of aquaculture over this period, exploitation of capture fisheries has remained crucially important for many of the world's poorest coastal dwellers (Béné et al., 2010), and has increased in importance for recreational fisheries and the multi-billion dollar industries they support (Ihde et al., 2011). Environmental change at scales ranging from local to global is likely to impact increasingly on the productive capacity of fisheries (see Sale et al., 2014 for tropical coastal fisheries). Together with a growing global population and sustained pressures to maintain and increase current high levels of production, complementary approaches to traditional fisheries management practices (such as fisheries enhancement) remain important, and will play a key role in addressing fishery productivity limitations into the future. The 5th ISSESR, held in Sydney Australia in 2015, examined the advances in aquaculture-based enhancement over the last 5–10 years, and the implications of these developments for future research and management.

This article introduces the *Fisheries Research* Special Issue “Fisheries Enhancement and Restoration in a Changing World” arising from the 5th ISSESR. We summarise the main advances presented in this Special Issue, and integrate these with other relevant, recent literature. We start with a focus on recreational fisheries and the pressures to initiate release programs for this sector, examine the social and economic value of release programs, investigate developments in hatchery technology and release strategies, look at alternative forms of fisheries enhancements and conclude by identifying potential opportunities for future development. The research presented in the 18 publications within this issue covers aquaculture and ecological research to support more effective enhancement, mechanisms for increasing the survival of released individuals, models for evaluating release strategies and the potential success of releases, qualitative approaches to understand the social value of release programs, and the governance of these programs within an overall framework of managing fisheries. These topics are covered for a range of taxa with diverse life-history strategies, including crustaceans and echinoderms, as well as teleosts.

2. Recreational fisheries and increasing impetus for enhancement

Over the last twenty years, our understanding of the nature, volume, value and extent of recreational fishing has grown rapidly. Recently, Arlinghaus et al. (2015) estimated that about 118 million people participated in recreational fisheries in the industrialised

world. However, this figure does not include recreational fishing in some of the world's most populous developing countries, which may push this level as high as 11.5% of the global population (totalling more than 850,000,000 participants, as suggested by Cooke and Cowx, 2004). Recreational fishing exacerbates the pressures on many fishery resources, particularly species perceived as highly desirable that are also subject to commercial fishing, while providing multiple social and economic benefits (Ihde et al., 2011). Our growing understanding of the costs and benefits of recreational fisheries, and their interaction with other sectors using marine resources (e.g. commercial and indigenous fishers, and other groups utilising waterways and the marine environment) continues to provide challenges to fisheries management systems (Jordan et al., 2016).

Recognising the social and financial benefits of recreational fishing, many governments highlight the improvement of recreational fishing opportunities as a strategic objective. However, participation is decreasing in some developed countries, possibly due to real or perceived reductions in fishing opportunities or fishing quality, particularly in and around urban centres (Arlinghaus et al., 2015). Aquaculture-based enhancement is increasingly being employed as a strategy to improve the recreational fishing experience and provide greater opportunities to communities. Research and progress in the enhancement of recreational fisheries have been a hallmark of the last two ISSESR.

The responsible approach to marine stock enhancement provides an accepted framework of guiding principles for designing and implementing aquaculture-based enhancement (Blankenship and Leber, 1995; Lorenzen et al., 2010). Importantly, Leber (2013) points out that the elements of the responsible approach need to be adapted to the local circumstances, and Taylor et al. (2005) give some examples of how this can be achieved. Several examples of how the responsible approach can be adapted wholly or partially to the enhancement of recreational fisheries are presented here. These examples come mainly from the United States (Garlock et al., 2016) and Australia (Blount et al., 2016b; Broadley et al., 2016; Taylor, 2016). Blount et al. (2016b) summarises a process (Cardno, 2011) that integrates these principles with the requirements of local legislation, to design and assess a marine stocking strategy in New South Wales (NSW), Australia. The process was initiated through stakeholder engagement, and assessed priority species and locations against agreed, pre-determined criteria. The environmental, social and economic risks and potential outcomes from these scenarios were also assessed. Importantly, the associated Fishery Management Strategy, which now governs marine fish stocking in this jurisdiction (NSW Department of Primary Industries, 2014), highlights recruitment limitation as the rationale for stocking events, provides a comprehensive research plan to further develop stocking practices and minimise risks, and includes provisions for adaptive management of marine fish stocking into the future, based on research outcomes.

In Florida, USA, Garlock et al. (2016) quantitatively assessed current and potential release programs for five candidate, marine species, and evaluated the outcomes from stocking relative to other management measures that could be applied. This study applied readily available life-history and fishery model parameters, alongside constraints imposed by local regulatory policies. They identified that the contributions of stocked fish to fisheries are heavily influenced by the species' life history and its pattern of vulnerability to fishing, reinforcing the importance of biological attributes in species being released (Munro and Bell, 1997; Taylor et al., 2005) while highlighting the often overlooked importance of fisheries characteristics (see also Section 3 below). This study forms part of a wider set of biological-technical, social and economic assessments on Florida's marine recreational fisheries

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