Ministry for Primary Industries
Manatū Ahu Matua

LITERATURE REVIEW OF ECOLOGICAL EFFECTS OF AQUACULTURE

Effects from Genetic Modification or Polyploidy

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CAWTHRON INSTITUTE

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AUGUST 2013

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9.1 Introduction

Genetically modified organisms (GMO), also known as transgenic organisms, are those that have had foreign DNA artificially inserted into their own genomes (FAO 2000). Transgenics are either utilised or promoted as they show commercially advantageous properties, for example, disease or pest resistance, altered body composition, they can produce pharmaceutical proteins or have altered colour, which can act as a bioindicator for estrogenic pollutants (Dunham 2009). Increasing growth rate through transgenic strains of fish has been the most thoroughly researched of the possible transgenic alterations (Rasmussen & Morrissey 2007; Dunham 2009). Twenty-seven species of fish and eight species of transgenic invertebrates had been developed by 2007 (Rasmussen & Morrissey 2007). In 2007, the only strain progressed beyond the research phase was Atlantic salmon (*Salmo salar*), which contained a Chinook salmon growth hormone (patented and licensed to Aqua Bounty technologies in Canada and the United States of America that caused greater feed efficiency, enhanced growth and inheritance of these traits (see Table 2 in Rasmussen & Morrissey 2007).

A good description of how a transgenic fish is produced is contained in the review of Rasmussen and Morrissey (2007):

> ... a DNA construct containing genes for the desired trait(s) along with a promoter sequence is generally introduced into the pronuclei of fertilized eggs. This is followed by in vitro or in vivo (implanted into the uterus of a pseudopregnant female) incubation of the injected embryos and subsequent maturation into a fully developed transgenic organism (Chen et al. 1996). Once transgenes have become integrated into a host organism's DNA, they can be passed on to future generations (Chen et al. 1996), with the possibility of 100 percent transmission using stable isogenic transgenic lines (Nam et al. 2002).

The use of transgenics is currently not commercially practiced in aquaculture in New Zealand.

The main ecological concern with the use of these techniques is the potential impact of escapees from cages (rearing in land-based facilities may not pose the same risk). In addition to the concerns outlined in (Chapter 8 Escapee Effects) are also concerns about (Glare et al. 2001):

- altered interactions due to altered fish characteristics;
- genetically modified fish may have increased tolerance of physical factors and so fish may move to new regions;
- migratory and territorial behaviour may be altered and resistance to diseases may alter fish population dynamics.

The degree of ecological risk involved is greatly influenced by the scale and frequency of introductions of transgenic fish into a particular environment and is further influenced by the following factors (Galli 2002):

- the type of transgenic fish, namely the overall phenotypic effect of the transgene;
- the adaptive ability of the transgenic animals to the local environment;
- the fitness of the transgenic fish;
- the health of local populations;
- the normal ecological role of the host species (keystone species could have a profound potential to impact ecosystems);
- the potential for dispersal and persistence;
- the local environment itself.

It is difficult to predict the impact of these fish on ecological systems, especially as no specific work has been done on these issues in New Zealand. Overseas studies (mainly about transgenic salmon) and models can, however, provide some general information on risks. However, no research and risk assessment, no matter how comprehensive in scope, will cover all possible outcomes of introducing transgenic fish into natural ecosystems (Kapuscinski & Hallerman 1991).

Polyploid individuals have extra sets of chromosomes, beyond the normal two; in this chapter, we refer to polyploidy artificially induced in fish and shellfish through the manipulation of embryos (Rasmussen & Morrissey 2007). Polyploidy is one of a number of measures proposed as a potential control for breeding of escaped transgenic fish and as a method for changing an organism's phenotype, for example, stimulating growth. Polyploidy is being commercially used in shellfish aquaculture overseas, and the ecological risk of this will be addressed in Section 9.3.

9.2 Feed-added species (salmon, kingfish, hapuku)

9.2.1 Description of main effects and their significance

Table 9.1: Ecological effects of genetic manipulation.

Description of effect/s	The effects may range from none to significant, and results from studies on these effects are often contradictory. Any effect may depend on the magnitude of any changes to phenotype; for example, genetically modified fish may have changed tolerance to physical factors and move to new regions; migratory and territorial behaviour may be altered and resistance to diseases may alter fish population dynamics. Note: As each transgenic line is unique the changes to the phenotype and genotype-by-environment effects are unknown unless specific studies on each line are carried out. Risk assessments on a case-by-case basis for each unique transgenic line must be conducted before describing the effects.
Scale	Potentially up to *national* (or Australia as well in the case of kingfish – see Chapter 8 Escapee Effects).
Duration	Potentially *long term* and irreversible.
Management options	EPA presently controls the use of genetically modified organisms, and none are currently allowed to be used in aquaculture. Sterility has been proposed as a potential control on interbreeding (also mentioned in Chapter 8) but technology to achieve this has yet to be developed.
Research gaps	• Methodologies to conduct case-by-case risk analyses for each unique transgenic line, including under environmental conditions that are relevant to commercial and natural environments. • Unknown genotype-by-environment effects for each unique transgenic line. • Sterilisation methods that do not influence expression of the transgenic genes.

* Italicised text in this table is defined in chapter 1 – Introduction.

Summary

Escaped transgenic fish may out-compete native fish for food for juveniles or in competition for reproduction (Einum & Fleming 1997) and pass on their traits in the wild. The results from the work done in this area are variable, however, and are mostly from the laboratory or aquaria, so their application to the wild is questionable. Hypoxia negatively impacted egg mortality and larval mass more in transgenic fish than wild fish (Sundt-Hansen et al. 2007). Although transgenic fish are generally stated to have lower fitness than their wild counterparts (Dunham 2009), some studies show that transgenic early life stages may show better survival when escaped than wild fish (Hindar 1995; Sundstrom et al. 2010), while others show the opposite (Dunham et al. 1999b). Some escaped transgenic fish show relatively large appetites (Kapuscinski and Hallerman 1991; Sundstrom et al. 2009), are not susceptible to higher rates of predation (Tymchuk et al. 2005) and are larger than normal at a given age (in captivity); this may lead to increases in the size of their selected prey (Kapuscinski & Hallerman 1990). This means they have the potential to alter the dynamics of other fish populations that are interconnected in the food web (Zilinskas & Balint 1998). Two studies suggest transgenic fish have less effective camouflage, which should mean they are less likely to survive in the wild (Devlin et al. 1994; Rahman & Maclean 1999). Another study suggests that transgenic fish are likely to be poor breeders in the wild (Fitzpatrick et al. 2011). These studies show the importance of understanding genotype-by-environment interactions and stress the importance of naturalised environments when testing escapee effects for use in risk assessments (Sundstrom et al. 2007b; Fitzpatrick et al. 2011).

One study highlights the possibility of more serious consequences. A modelling study predicted that a small introduction of transgenic Japanese medaka, under a combination of increased mating success (due to larger size) and low viability of offspring, could eventually lead to extinction of both transgenic and non-transgenic fish (Muir & Howard 1999).

It is believed that released transgenic fish stocks may pose a risk to other species through niche[1] expansion (Kapuscinski

[1] A niche is the function or position of an organism or population within an ecological community. Also, the particular area within a habitat occupied by an organism.

& Hallerman 1990; 1991) and even speciation[2] (Knibb 1997). This was supported by a subsequent study showing that transgenic fish were more likely to explore than wild fish (Sundstrom et al. 2007a). For example, transgenic salmonids with introduced antifreeze protein genes could contribute to the range expansion of Atlantic salmon into areas previously too cold which would increase the risk to the resident fish in those rivers (Hindar 1995). However, antifreeze protein genes are unlikely to be utilised here in New Zealand.

The potential also exists (Fitzpatrick et al. 2011; Moreau et al. 2011) for GMO's interbreeding with wild populations to improve the fitness of wild populations (although other studies show decreased breeding success of transgenics), and enable better survival (Dunham 2004; Fitzpatrick et al. 2011). This change is likely to be valued by some sectors of society and opposed by others.

9.2.2 Impact mitigation and management strategies

At present the Environmental Protection Authority (EPA) is responsible for regulating all research, development, importation, field testing and release of genetically modified organisms in New Zealand, and it has not allowed any commercial use of GMO in aquaculture. The New Zealand Salmon Farmers Association Finfish Aquaculture Environmental Code of Practice also states that members shall not use transgenic or genetically modified salmon as broodstock for production purposes.

Sterilisation with polyploidy, hybridisation, transgenesis or a combination of these, together with the use of monosex stocks (Devlin et al. 2010), would be the ultimate way of decreasing environmental concerns about interbreeding of GMO and wild populations (Dunham 2004, 2009). Sterilisation has not yet been applied reliably at a commercial scale (Devlin et al. 2010). The success of this may depend on the mating behaviour of the fish: if the sterile transgenic fish could compete better for mates than the fertile non-transgenic fish, then the extinction effect predicted by Muir & Howard (1999) could be realised (Glare et al. 2001). Triploidy has also been seen to have variable effects on the growth rate of fishes, which decreases its desirability for use in aquaculture (Dunham 2004).

Good physical and biological containment measures are crucial for limiting the effects of escaped transgenic fish (Devlin et al. 2006). If these are adopted, the risks to biodiversity by GMO per se are probably extremely small (Beardmore & Porter 2003; Dunham 2009) and perhaps not different to those posed by the escape of traditional selectively bred fish, but environmental risk data is lacking to verify this hypothesis. (Dunham et al. 1999). However, in specific cases, the risks and consequences may be large and if a precautionary approach is favoured these risks should be assessed on a case-by-case basis (Beardmore & Porter 2003). This chapter should be read in association with Chapter 8 (Escapee Effects) as many effects and management options are common to both.

9.2.3 Knowledge gaps

Research is needed into better ways to assess genotype-by-environment interactions and ways to incorporate this data into risk assessments (Devlin 2006; Pennington 2011). More research into sterilisation methods to minimise environmental effects has also been proposed (Dunham & Liu 2006).

9.3 Filter feeders (green-lipped mussels and Pacific oysters)

9.3.1 Descriptions of main effects and their significance

See Table 9.1.

Summary

Transgenic technology is less advanced for marine invertebrates than fishes as it has been hindered by issues with several biological factors, such as growth rates and breeding properties (FAO 2000; Langdon et al. 2003). Transgenic dwarf surf clams (*Mulina lateralis*), oysters (species name not given) and eastern oysters (*Crassostrea gigas*) have been produced, but all are in the research phase (Rasmussen & Morrissey 2007).

Polyploidy has been studied in over 30 species of shellfish (Beaumont & Fairbrother 1991). The benefits of polyploidy have ranged from larger abductor muscles in scallops to increased survival in the Chinese pearl oyster (*Pinctada martensi*) (Allen 1998). Triploid oyster breeding has even developed into an industry in coastal China (Dunham 2004). Notably, these polyploidy treatments do not guarantee sterility (Dunham 2004).

No information could be found on the ecological consequences of the transgenic or polyploid shellfish. The risks involved with this are therefore unknown, and risk assessments would therefore need to be carried out on a case-by-case basis.

9.3.2 Impact mitigation and management strategies

See Section 9.2.2.

9.3.3 Knowledge gaps

See Section 9.2.2.

[2] Speciation is the evolutionary formation of new biological species, usually by the division of a single species into two or more genetically distinct ones.

9.4 Lower trophic level species

See Table 9.1.

Summary
Transgenic technology, as stated in the previous section, is less advanced for marine invertebrates than fishes as it has been hindered by issues with several biological factors, such as growth rates and breeding properties (FAO 2000; Langdon et al. 2003). Transgenic abalone (species name not stated), crayfish (*Procambarus clarksii*) and three shrimp species (one species name not given, *Litopenaeus vannamei* and *Penaeus monodon*) have been produced, but all are in the research phase (Rasmussen & Morrissey 2007). Since that review, triploid embryos of green urchins (*Strongylocentrotus droebachiensis*) have also been produced (Bottger et al. 2011).

No information could be found on the ecological consequences of the transgenic or polyploid lower trophic level species. The risks involved with this are unknown, and risk assessments would therefore need to be carried out on a case-by-case basis.

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