Environmental Research for Finfish Aquaculture in Australia

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Finfish aquaculture in Australia is presently dominated by two species: *Thunnus maccoyii* (southern bluefin tuna) in South Australia and *Salmo salar* (Atlantic salmon) in Tasmania. Other species farmed include yellowtail kingfish (*Seriola lalandi*), snapper (*Pagrus auratus*), and barramundi (*Lates calcarifer*) with others, such as striped trumpeter (*Latris lineata*) and mulloway (*Argyromonas holoepidotus*), in development. The finfish industry in Australia is comparatively small by world standards, but in the regional areas where the farms are located, it contributes hundreds of millions of dollars to the local economy (Table 1). Southern bluefin tuna (SBT) farming is unusual in that it relies on farming fish that have been obtained from wild capture of a quota-limited stock subject to international regulation.

Table 1. Australia's main finfish aquaculture industries.

Species	Location(s)	Tonnes (HOGG[a])	Value (AUD)
Atlantic salmon *Salmo salar*	Tasmania	17,600[b]	\$217M [b]
Southern bluefin tuna *Thunnus maccoyii*	South Australia	9,290[c]	\$151M[c]
Yellowtail kingfish *Seriola lalandi*	South Australia	2,000 [b]	\$17.5M [b]
Barramundi *Lates calcarifer*	Queensland, Western Australia, Northern Territory, South Australia	1,250[d]	\$11.2M [d]

[a]HOGG: head on, gilled, and gutted.
[b]2005/2006.
[c]2003/2004. The dollar value for SBT represents a dramatic decline on previous years due to a drop in price and exchange rate changes.
[d]2001/2002.

The responsibility for regulating aquaculture in Australia lies primarily with the States and Territories, but the Federal Government has responsibility for off-shore waters beyond 5.556 km (3 nautical miles) to the edge of the Exclusive Economic Zone. A framework has been developed to harmonize regulations and responsibilities between the States and Commonwealth.

Each State and territory has its own set of regulations for aquaculture; the Tasmanian approach is presented here as an example. In Tasmania, the finfish aquaculture industry is subject to regulation through two key pieces of legislation: the *Marine Farming Planning Act 1995* and the *Living Marine Resources Management Act 1995.* Marine Farming Development Plans are statutory documents, developed pursuant to the legislation, that specify marine farming zones, maximum lease area, and management controls for that region (Crawford 2003). Marine farming leases can be issued for 30 years with provision for renewal. The issue of a lease is conditional on the completion of a baseline environmental survey of the lease area. This includes the collection of baseline biological, physico-chemical, visual, bathymetric, and current flow data. Marine farming licenses are issued to leaseholders on an annual basis. Lease-specific environmental monitoring requirements are stipulated in the marine farming license.

In Tasmania, in relation to Atlantic salmon farming, license conditions state that there shall be no significant visual, physico-chemical, or biological impacts at, or extending beyond, 35 m from the boundary of the lease area. Visual impacts include the presence of any of the following: fish feed pellets, bacterial mats (e.g., *Beggiatoa* spp.), gas bubbling arising from the sediment, either with or without disturbance of the sediment, or numerous opportunistic polychaetes (e.g., *Capitella* spp., *Dorvilleid* spp.) on the sediment surface.

Unacceptable impacts *within the lease area* include visual evidence of excessive feed dumping, extensive bacterial mats on the sediment surface prior to restocking, or spontaneous gas bubbling from the sediment. License conditions require routine annual video surveys of the lease site to be performed to ascertain compliance with the above. More detailed biological and physico-chemical assessment may be required in the event that a visual impact is detected at or beyond 35 m from the lease boundary. In these cases, biological and physico-chemical parameters must not exceed specified limits or be significantly different to levels at reference sites.

Heavy metal, antibiotic, and chemical residues within or outside the lease area cannot exceed levels specified by the government. Other generic issues covered in licenses include the requirement for ecologically sustainable waste management practices, mesh size limits for bird netting, the reporting of seabird and mammal interactions, fish disease, mortality, and escapee events, chemical usage, introduced marine pest, and monthly feed input and stock management data.

The effects of SBT farming on the seafloor are much less evident, largely because whole baitfish are fed and consumed with minimal wastage and because farming zones are in high energy, wave-exposed environments.

The Australian Federal Government becomes involved in aquaculture when development actions come under the ambit of the Environment Protection and Biodiversity Conservation (EPBC) Act of 1999 (revised November, 2006). The EPBC Act relates to protection of the environment and heritage with a focus on matters of national environmental significance (NES) and ecologically sustainable development. Any action likely to have a significant impact on a matter of NES requires the approval of the Environment Minister. Matters of NES include world heritage properties, Ramsar wetlands, migratory species, threatened species and ecological communities, the Commonwealth marine area, nuclear actions, and national heritage. A 3-stage process is used involving referral, assessment, and approval. A decision by the department on whether approval will be required must be made within 20 business days. The implications for offshore aquaculture are described in a policy statement (Australian Government 2006).

Aquaculture research is carried out within university departments, State research laboratories, and Commonwealth research agencies around Australia. Much of this research is carried out more or less independently. To better meet the research and development needs of the finfish industries, the Australian Government agreed to the establishment of the Aquafin Cooperative Research Centre for Sustainable Finfish Aquaculture (CRC) in 2001. The CRC represents an investment of around $72 million Australia dollars (approx. $58,032,000) over 7 years from the Commonwealth, key industry sectors, and selected Universities and State and Federal research agencies. This coordinated multidisciplinary approach and sharing of expertise, skills, and facilities was deemed to be essential for the sustainable growth of finfish aquaculture in Australia given the wide geographic spread of research expertise and finfish farming locations.

The Aquafin CRC programs provide a research and development capability to address health, nutrition, and farming technologies including a broadly based environmental program essential to sustainable finfish farming (Cheshire and Volkman 2004). Details and research reports can be found on the Internet (*http://www.aquafincrc.com.au/*). These programs support the ongoing commercial development of the finfish industries while ensuring that they continue to perform in an environmentally sustainable manner.

Some of the environmental issues associated with finfish aquaculture world-wide include:

- Habitat and sediment degradation
- Reduced water quality and possible eutrophication
- Cultured fish escapees leading to genetic or disease transfer to wild stock
- Navigational hazards and restrictions to access
- Possible interactions with predatory marine species including entanglement and predators displacing protected species
- Chemical usage (e.g., net antifoulants) and therapeutic medicines
- Visual and noise impacts

Depending upon the location of the aquaculture operation, e.g., near-shore within 3 nautical miles of the coast versus offshore, the effects may vary and society's concern about these effects may differ.

Any aquaculture management framework has to recognize that unimpacted (natural) conditions are spatially and temporally distinct, and as a consequence, benthic (and system-wide) assimilative capacity varies. Unfortunately, many regulations attempt to define a one-size-fits-all baseline against which to measure effects. With increasing enrichment with organic matter, the chemistry and ecology of sediments under net pens becomes more similar, but for a given total input, the rates of change vary depending on sediment type, temperature, and composition (feeding mode) of the biota. Sediments can take a very long time (years in some cases) to recover completely to pre-farming conditions, but by monitoring sediment condition during the stocking cycle, most farms can use production schedules that enable the extent of recovery to be sufficient for re-use within months. Monitoring sediment condition allows farmers to effectively manage lease areas because there is usually a clear relationship between management practices on-farm and the scale of benthic impact.

Research by Macleod et al. (2004a, 2004b) for the Aquafin CRC has defined a 9-stage scale of impact, with six stages for increasing benthic impact and three stages for the recovery phase. This approach uses video scores that have been calibrated against more detailed benthic faunal counts. Alternatively, research for the SBT industry has resulted in the development of gene probes for specific benthic animal groups (*infauna*) as well as an innovative score-card reporting scheme, which promises to greatly speed up the annual tuna environmental monitoring program undertaken by this industry sector as a requirement of their license to farm fish issued by the relevant government regulatory agency, Primary Industries and Resources South Australia (PIRSA).

One key finding from the CRC research that is relevant to offshore temperate finfish farming is that the assimilative capacity of sandy organic-lean sediments can be quite low compared to organic-rich near-shore sediments dominated by silt and clay. A mitigating factor for benthic organic enrichment can be the presence of scavenger organisms such fish and crustaceans that quickly take advantage of any food arriving at the sediment. Thus, identical organic loads onto a sandy sediment may dramatically change the biogeochemical cycling, local flora, and fauna, while it may have much less effect at another location. This aspect is often insufficiently appreciated when interpreting simple nutrient budgets.

Within the Aquafin CRC, the general approach has been to establish detailed nutrient budgets for the ecosystem, including all significant natural and anthropogenic (including aquaculture) sources (Volkman et al. 2006). This is important in most Australian waters, because nutrients are often the limiting factor for phytoplankton growth in spring, summer, and autumn. The first stage is to develop a hydrodynamic model of the water body and then to capture ecosystem knowledge in linked biogeochemical and sediment transport models. The models require calibration and validation over several seasons. Finally, some ongoing monitoring is needed in conjunction with an adaptive management strategy. The monitoring is to inform not only the regulator and farmer about environmental effects, but also the modeling so that the models can be continuously improved. These models can also provide vital information about how natural environmental events, such as phytoplankton blooms, might impact on the industry and whether the aquaculture or other anthropogenic activities might affect these occurrences. A great advantage of the modeling approach is that it allows scenarios to be run to examine likely effects due to changing environmental conditions, including those related to climate variability or changing farming practices such as location of leases or stocking densities.

In Australia, and around the world, increasing inputs of organic matter and nutrients from agricultural runoff, sewage plants, urban inputs, etc. have created eutrophication problems and put the normal functioning of aquatic ecosystems at risk. There is a fundamental need to determine how sensitive the ecosystem might be to any additional nutrient loading. Symptoms of increasing eutrophication may include an increasing frequency or magnitude of algal blooms, increasing concentrations of ammonium in the water column, and decreasing dissolved oxygen (DO) in the water and sediments. Many indicators are available. A good indicator must be predictive (i.e., it indicates change before the change becomes too extreme). Indicators should provide information about issues of particular concern or about aspects of the ecosystem that have high conservation value. Chlorophyll *a* is good indicator of phytoplankton biomass. It can be rapidly measured by using vessel-mounted fluorometers or in the laboratory by spectrophotometry or high performance liquid chromatography. In many regions, the composition of the phytoplankton is also of interest due to the occurrence of harmful algal bloom species. Dissolved oxygen provides a direct indicator of water quality. Moored instruments are available to monitor DO continuously in the field with data telemetered back to a base station. The usual problems of biofouling, instrument drift, and potential tampering of moorings need to be considered. Measurement of the major nutrients (nitrate, phosphate, silicate) are essential for calibrating and validating models, but may not be a good predictor of problems apart from ammonia, which is directly excreted by fish and can be an indicator of high benthic remineralization. Given the natural variability of most ecosystems, careful assessment of the temporal and spatial frequency of sampling will be important to minimize the cost of monitoring while ensuring it has sufficient power to detect a specified degree of change.

A key element in any regulatory framework is the adoption of an adaptive management framework. This recognizes that current ecological knowledge of marine systems is imperfect and that ecosystem changes may be subtle and hard to detect among interannual variability. This approach includes formulation of an agreed set of environmental variables (including protected value indicators and system state indicators) and appropriate trigger values. These may be set relative to historical data or in comparison with control sites. The particular choice may vary from one ecosystem to the next. This is rather different from a regulatory regime where exceeding a specified value (e.g., of a contaminant in an effluent stream) leads to fines or even industry closure. If a trigger value is exceeded, this is a prompt for further measurement and evaluation to understand how the ecosystem is responding to the environmental challenge. The monitor and respond aspect of the adaptive management cycle may be quite short, perhaps after an annual review of the monitoring data or in response to a particular event. The process of formulating an agreed set of indicators also needs to be adaptive, but on a longer time scale. Achieving agreement is complex, because it requires cooperation across a range of agencies, companies, and other stakeholders with different roles and different priorities. In practice, it can work by having a team of scientists prepare a draft of a set of indicators and trigger values that is then negotiated with regulators, industry, and other stakeholders. Another approach is to carry out a risk assessment involving a broad stakeholder group, although sometimes this can fail to arrive at a common position.

Finally, research also needs to consider the possible effects of climate change on the environment and the aquaculture industry. Climate change will lead to variations in seawater and atmospheric temperatures, frequency, magnitude, and location of rainfall, and the frequency and magnitude of extreme weather events (e.g., winds). All of these can impact aquaculture operations. Possible environmental effects include changes in the frequency, magnitude, and composition of phytoplankton blooms, changes in the geographic ranges of temperature-sensitive species, changes to hydrodynamics and water circulation, increased rates of biological reactions (e.g., remineralization of organic matter) as temperatures rise, changes to river flows and surface run-off (system-flushing), and changes to water quality (e.g., turbidity) and salinity. This can have important effects on the productivity of species that are being farmed close to their environmental limits, as is the case for Atlantic salmon in Tasmania.

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