A Review of Research and Development Needs for Murray Cod Aquaculture in Australia

Report to the New South Wales Department of Primary Industries and the Fisheries Research and Development Corporation (FRDC)

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Summary

Murray Cod (*Maccullochella peelii*) aquaculture is undertaken in Victoria, New South Wales and Queensland and is expanding rapidly in New South Wales with several new entrant farmers. Production increases are primarily due to agricultural diversification on irrigated cropping farms.

In the last five years (2010–11 to 2014–15) Murray Cod farm gate production value increased on average 29% per annum. Farm gate production value in 2014–15 was over $3.6 million (an underestimate due to the non-availability of Queensland production data). Total capital investment value of the sector to date is roughly estimated at $20 million.

To assess the research and development (R&D) needs of the Murray Cod aquaculture sector, farmers were identified by the respective state fisheries agencies, and contacted to nominate their priorities for research and development to improve industry performance and overcome production and marketing constraints. A literature review was conducted to identify existing R&D information to better understand how new R&D could address identified production and marketing constraints without repetition or excessive overlap with previous R&D.

Based on farmer input, the following table lists researchable issues with an assigned priority.

Issue	Production system	Priority (H/M/L)
Optimising cage production systems	Pond	H
Chronic ulcerative dermatopathy (CUD) /'ratty tail'	RAS	H
Parasite infections (*Lernaea, Chilodonella,* etc.)	Pond	H
Bacterial infections	RAS, pond	H
Nutrition and feeds	RAS, pond	H
Growth variability	RAS	M
Fish colour	RAS	M
Off flavour	RAS	M
Slaughter (Aqui-S taste)	RAS	L
Product taste (from pellets)	RAS	L
Environmental aspects (effluent, etc.)	RAS, pond	L
Market	RAS, pond	L

Recommendations

Research priorities

The following topics, based on the high priorities nominated by farmers, are recommended for future R&D:

Management and treatment of parasitic infections, focussing on the parasitic copepod *Lernaea* and the ciliated protozoan *Chilodonella*:

- Integrated fish health management focussing on the role of water quality in controlling or reducing the impact of parasite outbreaks.
- Developing cost-effective and acceptable treatments to avoid the current reliance on Minor Use Permit chemicals.

Control of chronic ulcerative dermatopathy (CUD) or 'ratty tail':

- Identification of the physico-chemical factor(s) causing CUD.
- Development of cost-effective water treatment technology.

Reduction in off-flavours caused by geosmin and 2-methylisoborneol:

- Development of specialised compounded feeds to reduce off-flavours and improve product quality / taste.
- Development of more efficient post-harvest purging methodologies.

Nutrition and feeds

- Development of feeds that reduce off-flavours in Murray Cod in RAS systems.
- Development of functional feeds that improve fish flavour.

Industry development issues

The following recommendations are not strictly speaking researchable issues. However, these points were identified by the review as important to support continued development of Murray Cod aquaculture:

Document and extend 'lessons learned' by the Murray Cod aquaculture sector

- Document and extend 'lessons learned' by the Murray Cod aquaculture sector to reduce the failure rate of new entrant farmers. For example, culturing Murray Cod in large water storages has been shown to be unviable due to inability to control parasite outbreaks.

Capture 'lessons learned' by other aquaculture sectors

- Other Australian aquaculture production sectors have experience with production expansion that effectively saturates the domestic market, stimulating interest in export markets. Capturing these lessons would help Murray Cod farmers develop approaches to export market development.

Develop improved integrated management approached to Murray Cod aquaculture

- It is evident that there are strong interactions between Murray Cod growth and survival and environmental factors such as water quality, particularly temperature and dissolved oxygen levels, as well as fish nutrition, genetics, etc.
- Undertake a review of Murray Cod aquaculture management practices with a view to identifying or developing Better Management Practices.

Introduction

Production technologies for Murray Cod (*Maccullochella peelii*) were originally developed in the 1970s and 1980s to provide fingerlings for stocking in farm dams and for restocking Murray-Darling river systems which had seen an historical decline in Murray Cod numbers (Ingram et al., 2005; Rowland, 2004). By the late 1980's production of Murray Cod fingerlings was well established and there was increasing interest in farming this species (Ingram et al., 2005; Rowland, 2004). Aquacultured Murray Cod first entered the market in the early 1990s (Rowland, 2004).

Today, there are effectively two main production systems in use for Murray Cod farming: cages in freshwater ponds (hereafter shortened to 'pond farming') (Fig. 1) and recirculating aquaculture systems (RAS) (Fig. 2). Some farms use RAS for early-stage grow-out or to increase growth rates during winter (Ingram et al., 2005), then continue grow-out of fingerlings in cages in ponds. For simplicity, these combined systems are included in 'pond farming'. This report does not review production technologies for Murray Cod; there are several excellent published reviews on this topic, including those by Rowland (2004), Ingram et al. (2005) and Ingram (2009).

Figure 1 Pond production system - cages with bird exclusion netting in a freshwater pond.

Figure 2 RAS system for Murray Cod production.

Murray Cod aquaculture production and value

Murray Cod are produced in New South Wales, Victoria and Queensland. NSW and Victorian production data are shown in Figure 3. In Queensland, only a few growers produce Murray Cod and detailed production data are not available due to client confidentiality. There are some production data for South Australia for the period 1998-99 to 2002-03 but quantities produced were small (<8 tonne p.a.) (B.A. Ingram, pers. comm.). For NSW and Victoria, from 2002 to 2013 production was relatively stable at around 50–100 tonnes per annum (Fig. 3). In 2013 production increased dramatically, reaching about 150 tonnes in 2013-14 and 230 tonnes in 2014-15 with the increase attributable to increased production in NSW (Fig. 3). This increase reflects a substantial investment by new entrant farmers in Murray Cod aquaculture facilities, both RAS and pond-based, in NSW. A rough estimate of the capital investment in Murray Cod aquaculture at present, from discussions with industry representatives, is of the order of $20 million.

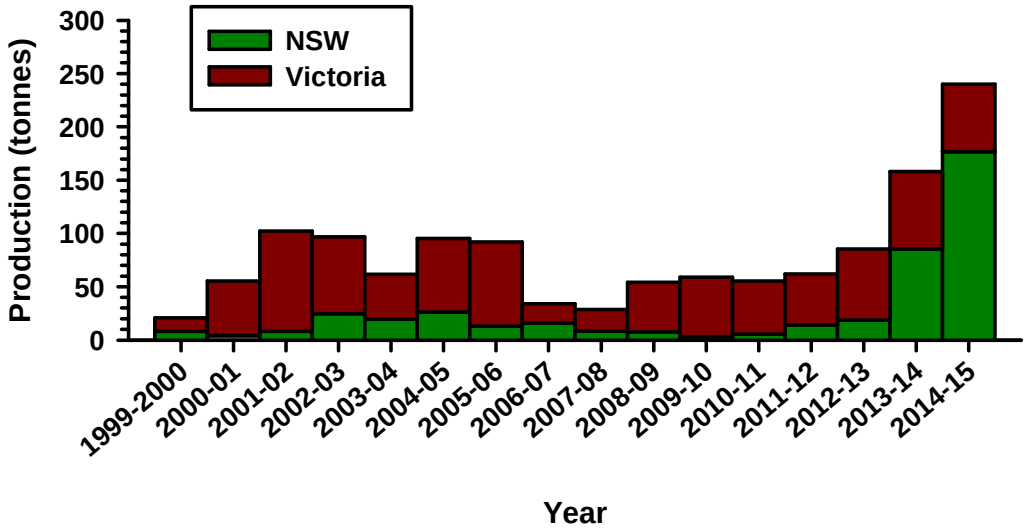

Figure 3 Annual aquaculture production of consumption-sized Murray Cod. NSW data from NSW Department of Primary Industries Aquaculture Production Reports. Victorian data from B.A. Ingram (Victoria DPI). Queensland data not included because of confidentiality issues.

Since Murray Cod breeding and larval rearing methods were developed, government and private hatcheries have produced large numbers of fingerlings for stocking public waterways and private impoundments (Ingram et al., 2005; Rowland, 2004). Since 2010 the production of Murray Cod fingerlings by private sector hatcheries in NSW has been around 2 million fingerlings, valued at over $1 million, per annum. In some years (e.g. 2010-11 and 2011-12) the value of fingerling production has been roughly equivalent to that of consumption-sized fish (Fig. 4). However, with the recent expansion of production in NSW the value of consumption-sized fish now surpasses the value of fingerling production (Fig. 4). There is a substantial, and reportedly expanding, market for Murray Cod fingerlings in China (Table 2, p.13).

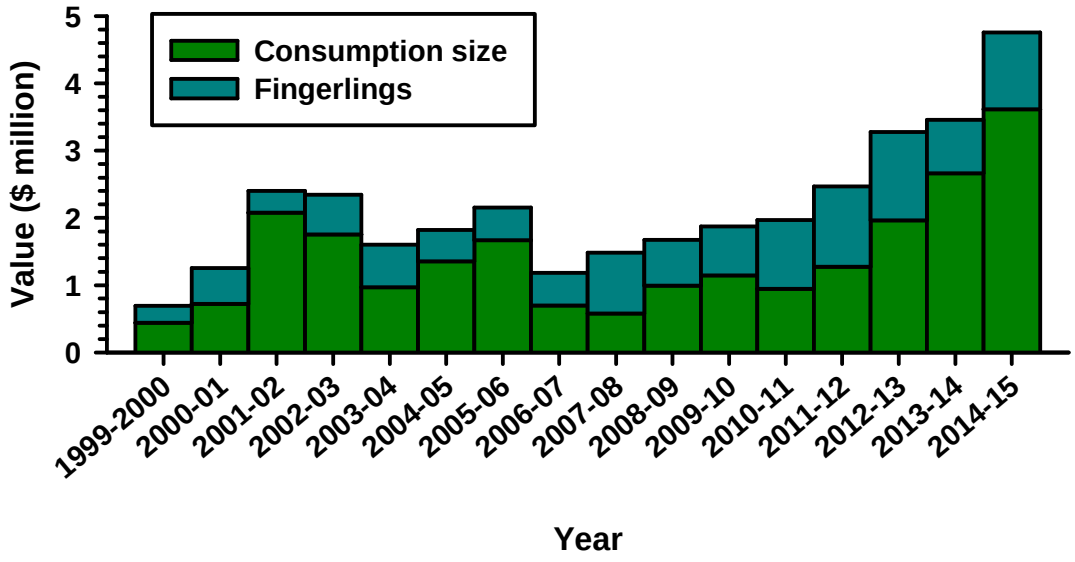

Figure 4 Value of production of consumption-sized and fingerling Murray Cod. NSW data from NSW Department of Primary Industries Aquaculture Production Reports. Victorian data from B.A. Ingram (Victoria DPI). Queensland data not included because of confidentiality issues.

Previous Fisheries Research and Development Corporation (FRDC) -funded research

FRDC has previously funded two research projects specifically on Murray Cod aquaculture:

1999/328: Development of intensive commercial aquaculture production technology for Murray Cod. The project undertook a range of research activities under these headings: industry status; fingerling production and grow-out, nutrition, water quality, fish health, markets and marketing, and economic analyses.

2010/036: Improved fish health management for integrated inland aquaculture through Better Management Practices (BMPs). This study evaluated the major causes of production losses

in integrated Murray Cod aquaculture and concluded that the greatest cause of mortality and reduced production could be ascribed to *Chilodonella* parasite infestations.

Final reports for both these projects (Bradley et al., 2014; Ingram and De Silva, 2004) are available on the FRDC website (www.frdc.com.au).

Additionally, FRDC have supported a range of research projects relating to the production of freshwater fish, particularly Silver Perch, that have focussed on and contribute to our general knowledge of freshwater fish husbandry, nutrition, health management, water quality and marketing, some aspects of which are pertinent to Murray Cod aquaculture.

Review methodology

Murray Cod farmers in New South Wales and Victoria were identified through the respective state Fisheries agencies. Dr Mike Rimmer and Dr Stewart Fielder (NSW DPI Fisheries) undertook a visit to Goulburn and Narrandera to speak with farmers in the Goulburn and the Wagga Wagga – Narrandera – Leeton areas. A meeting with four local farmers, government researchers and local DPI management was held at the Narrandera Fisheries Centre on 18 February 2016. Subsequently, these farmers were contacted by phone again to provide an opportunity for them to raise any issues that had not been discussed in the meeting at Narrandera. No additional issues were raised. Other farmers were contacted by phone and asked to provide their opinions on R&D needs for the industry. Murray cod farmers, researchers and fisheries managers contacted for this study are listed in Appendix 1.

A literature search was carried out to identify previous R&D on Murray Cod aquaculture. This literature review is not exhaustive – it is intended only to outline where R&D issues nominated by the industry have some pre-existing research findings.

Following review of a draft of this report by NSW DPI Fisheries staff, a revised draft was provided to farmers for further review and comment. All additional comments have been incorporated in this report.

R&D needs

For the purposes of this report, R&D topics nominated by farmers have been combined under the following headings:

- Production
- Feeds and nutrition
- Fish health
- Product quality
- Environmental aspects
- Markets
- Industry development

Production

RAS systems

A significant issue identified in RAS systems is high variability in growth rates, which results in a substantial proportion of smaller fish. Whereas many fish can be harvested at 10–12 months, these slower growing fish may take up to 18 months to reach harvest size and consequently their production cost is much higher.

In contrast, pond farms did not feel that this was a significant problem.

Cage systems

Pond farmers are interested in optimising their cage production systems. Topics include:

- cage dimensions and shape (square, rectangular);
- cage depth;
- optimising stocking density; and
- developing more cost-effective nursery and grow-out methods.

Another issue raised is developing culture, grading and harvest methods that reduce physical injury to operators (particularly back strain).

DPI Victoria has done some modelling of various culture systems, as well as interactions with temperature and water quality (nitrogen and phosphorus, and nutrient mass balance) to evaluate the impacts of water quality on Murray Cod production (B.A. Ingram, pers. comm. 2016).

Feeds and nutrition

Both RAS and pond farms nominated the development of dedicated feeds for Murray Cod as an issue. Currently, Murray Cod farms are using 'marine fish' (i.e. Barramundi and Yellowtail Kingfish) or Atlantic Salmon feeds (Table 1). There has been substantial previous research into Murray Cod nutrition at Deakin University, including: assessment of alternative proteins sources to fish meal; evaluation of dietary protein levels and optimal protein:energy ratios; and assessment of alternative lipid sources to fish oil (Appendix 2). Much of the early research on Murray Cod nutrition was supported through an FRDC-funded project (Ingram and De Silva, 2004).

Deakin University research using test diets specifically formulated for Murray Cod showed no difference in growth performance and feed utilization compared with fish fed commercial pellet diets (De Silva et al., 2004). However, feed conversion ratio and protein efficiency ratio were better in Murray Cod fed the experimental diets (De Silva et al., 2004). Importantly, there was significantly less lipid deposition in carcass and muscle of Murray Cod fed the experimental diets (De Silva et al., 2004) which is a negative attribute for consumers of Murray Cod.

Table 1 Examples of commercial pellet feeds used for Murray Cod culture, and the Deakin University test diets (De Silva et al., 2004).

Species	Pellet sizes	Crude protein	Crude lipid	Gross energy
Atlantic Salmon	1.2 – 1.5 mm	52%	20%	21.6 MJ
	2 – 3 mm	50%	21%	21.9 MJ
Barramundi, Yellowtail Kingfish	3–4 mm	50%	17%	21.0 MJ
	6–11 mm	45%	20%	21.7 MJ
Deakin Univ. experimental diets		49%	16 – 17%	20.9–22.2 MJ

Farmers expect significant gains to productivity arising from development of a specialised pellet feed for Murray Cod, including: lower FCRs, better water quality, and improved fish health. The author of this report does not share this view. Given the Deakin University results, it is unlikely that a pellet diet formulated specifically for Murray Cod will provide significant benefits over existing diets in terms of growth rate or cost of production. In addition, feed companies generally are reluctant to produce specific feeds for industries consuming relatively small quantities of pellet feeds, because of the high cost of production of small batches of specialised feeds and the cost of producing and storing many different types and sizes of pellets. A specialised Murray Cod feed would need to provide economic benefits commensurate with the expected higher cost of the feed compared with the currently used marine finfish feeds.

In the view of the author, greater benefits could be gained through focussing on product quality aspects, including reduction of off-flavours and improved fish taste, as discussed below. There has been some previous research on using finishing diets for production of Murray Cod in open-water systems, which included sensory evaluation. Although there were no significant differences found between treatments, the researchers felt that it was likely that small variations observed in the flavour profile of the Murray cod treatments were real, such as: colour evenness, moistness, and firmness in mouth (Turchini, 2011).

Fish health

RAS farms report few problems with fish health (note that chronic erosive/ulcerative dermatopathy is discussed under ‘product quality’ because it does not appear to have an infectious component (Schultz et al., 2011)). On the other hand, pond farms report significant problems with bacterial and parasitic infections.

A previous FRDC-funded research project (2010/032) concluded that infestations with *Chilodonella* are the greatest cause of mortality and reduced production in integrated Murray Cod production systems (Bradley et al., 2014). The interactions between water quality and fish health, particularly *Chilodonella* outbreaks, are recognised but not well understood. (Bradley et al., 2014) noted that Murray Cod mortality spikes during December and January was associated with lowered pH and DO. DPI Victoria has evaluated water quality interactions with fish health and concluded that improving water quality (e.g. dissolved oxygen) can reduce the impacts of *Chilodonella* outbreaks (B.A. Ingram, pers. comm. 2016).

An output from this project was fish health management guidelines for Murray Cod farming: Ingram et al. (2014).

Bacterial infections
Murray Cod in cages in ponds are reported to have some problems with bacterial infection, mainly in the posterior part of the body, especially the caudal peduncle and caudal fin. The problem is associated with low-level mortality, and can lead to ulceration which can affect fish marketability. Occurrence seems to be higher in winter than in the warmer months.

Parasites
Murray Cod are readily infected with the parasitic copepod *Lernaea* (anchor worm). *Lernaea* infestations cause unsightly red wounds on the fishes' skin which adversely affect marketability, and may lead to secondary bacterial infections. Treatment of *Lernaea* infections was nominated as a **high priority R&D issue** in regard to pond farming of Murray Cod. Current treatments rely on Minor Use Permits for treatment chemicals, and there is a need to develop cost-effective, acceptable treatments for *Lernaea* outbreaks as well as for protozoan outbreaks (see below).

Outbreaks of ciliated protozoans cause substantial mortalities in Murray Cod in hatcheries and in grow-out. In pond farms, most outbreaks are of *Chilodonella*, whereas in hatcheries *Trichodina* is more common. Dactylogyroid gill flukes are not commonly found on farmed Murray Cod. Outbreaks are strongly seasonal with most outbreaks occurring in spring and, to a lesser extent, in autumn. To reduce the incidence of protozoan outbreaks, fish are treated prophylactically with formalin in spring and – on some farms – in autumn as well. One published study suggests that sub-clinical infections of *Chilodonella* in Murray Cod may lead to increased mortality, slower growth and abnormal swimming behaviour (Baragahare et al., 2011).

Note that for treatments of external parasites the whole pond must be treated. Farmer experience is that simply treating the cages results in rapid reinfection from either resistant life-cycle stages in the pond, or from forage fish species acting as carriers.

Product quality

Chronic ulcerative dermatopathy (CUD)
CUD (formerly known as chronic erosive dermatopathy – CED) or 'ratty-tail' was nominated by farmers as a **high priority** for research. The main impact of CUD is on fish marketability. Although the symptoms are unsightly (Fig. 5), the overall impact on fish health appears to be minor.

CUD is seen in intensively farmed Murray Cod in RAS production systems using ground (bore) water (Baily et al., 2005; Schultz et al., 2014; Schultz et al., 2011). CUD results in focal ulceration of the skin overlying sensory canals of the head and flanks, and degeneration of the membranes between the fin rays (Baily et al., 2005; Schultz et al., 2011).

Development of lesions may begin after 2–3 weeks after initial exposure to groundwater and fin erosion after about 2 months (Baily et al., 2005). Degeneration of tissue around the pores communicating with the sensory canals leads to severe ulceration (Baily et al., 2005)

although this does not appear to compromise the ability of the fish to osmoregulate (Schultz et al., 2008). Erosion of the membranes of the fins leaves only the fin rays with a small amount of surrounding tissue (Baily et al., 2005), leading to the common name of ‘ratty tail’ (Fig. 5).

This syndrome is associated with the use of groundwater for grow-out culture. Murray Cod affected with CUD demonstrated regeneration of affected sensory canals after fish were transferred from bore water into river water (Baily et al., 2005). Schultz et al. (2011) found that pre-conditioning of groundwater using either a vegetated earthen pond or in the presence of artificial macrophytes drastically reduced both the incidence and severity of CUD, with more than 90% of fish exhibiting no visual signs.

Baily et al. (2005) specifically noted ‘the lack of notable or consistent internal changes associated with CUD-affected fish, despite the presence of marked external lesions’. Schultz et al. (2011) found no changes in haematology and blood parameters even in advanced CUD-affected fish, although Schultz et al. (2014) found greater number of rodlet cells in the gills and collecting ducts of the kidneys of CUD-affected fish than in control fish.

Figure 5 Murray Cod grown in a RAS production system showing 'ratty tail'.

Off-flavours

Off-flavours are a significant issue in RAS systems used for Murray Cod production, but not in pond systems. Off-flavours are generally caused by geosmin and 2-methylisoborneol, two highly odorous, earthy-musty metabolites of aquatic microorganisms, particularly cyanobacteria (Tucker, 2000). To reduce the level of off-flavours, Murray Cod produced in RAS systems are purged for 2–4 weeks prior to marketing. Purging involves placing the fish in a separate recirculation system which may be fitted with an activated charcoal filter to

remove organic compounds. The fish are not fed during the purging process. In research studies, this has led to weight loss in purged fish of around 4% and 9% during 2 and 4 weeks purging periods respectively (Palmeri et al., 2008a). However, aggression during the purging period is a problem with substantial damage to purged fish during this period.

Pond farms report that they have no significant problem with off-flavours in their product. To manage this issue they avoid harvesting fish if the ponds have a cyanobacterial bloom.

Palmeri et al. (2008b) concluded that off-flavours in Murray Cod were linked with water quality rather than the use of pelleted feed during the purging process, suggesting that water quality changes associated with metabolic waste products is the major factor contributing to off-flavours. Research on rainbow trout has demonstrated that off-flavours can be reduced through the reduction of dietary phosphorus in pellet feeds (Sarker et al., 2014), suggesting that specialised diets focussing on product quality could be useful in reducing off-flavours in Murray Cod aquaculture.

Slaughter
Some farms use the anaesthetic Aqui-S® (effective ingredient isoeugenol) as a component of the slaughter process. Some customers have indicated that they can taste the anaesthetic in the product. One farm is evaluating electric stunning as an alternative slaughter method.

Fish colour
Murray Cod reared in RAS systems are darker in colour than those reared in pond systems. Although there was not universal agreement on this issue, there is evidence that darker coloured fish are at a market disadvantage, and that lighter coloured fish attract a premium ($4–6 per kg higher) price on the domestic market.

Product taste
Pond farmers commented that RAS-reared Murray Cod ‘taste like pellets’. This would suggest that there are opportunities to develop a Murray Cod-specific feed that would improve the organoleptic attributes of the product along the lines of recent research on feeds to change the organoleptic properties of Barramundi (Jones et al., 2016). In these experiments, use of a ‘finishing diet’ incorporating the marine alga *Ulva* as an ingredient resulted in the end product being judged more ‘desirable’, ‘sweeter’, and ‘rich and complex’ when compared to fish finished on a standard commercial rearing diet (Jones et al., 2016).

Environmental aspects

No major issues were identified with regard to environmental impacts of Murray Cod aquaculture. Because Murray Cod are a freshwater species, waste water can be used for irrigation so farm effluent is not a significant issue. One RAS farms reports that the solid waste stream makes excellent plant fertiliser. In NSW, pond and RAS farming systems must not release culture water back to the environment, but treat and reuse, store and evaporate or integrate into other farming systems (e.g. irrigate).

There is potentially a market for solid waste streams as a garden fertiliser (cod poo?) but currently the quantities involved may be too small to pursue this option.

One aspect of Murray Cod farming discussed at the Narrandera meeting is that Murray Cod farming is the most cost-effective use of irrigation water, producing around $6,000 worth of crop per ML, compared with the second most profitable crop, cotton, which produces around ($200–300) per ML. This is a positive message regarding environmental stewardship in the current climate of debate about water usage, not to mention the generally negative perception of aquaculture in Australia.

Marketing

Currently most farmed Murray Cod are sold on the Australian domestic market. The larger farming operations are looking to China as a potential market for expansion of production. Based on Australian Department of Agriculture data (Table 2), since 2013 there have been relatively few consumption-size fish exported: a total of 7,020 to Vietnam and 747 to Japan. In contrast, large numbers of fingerlings have been exported, including a total of 2 million to China (Table 2).

Table 2 Exports of Murray Cod fingerlings and consumption-size fish from 2013 to 2015. Data provided by the Australian Department of Agriculture.

Product	Year	Number	Destination
Fingerlings	2013	600,000	China
		112,500	Malaysia
	2014	600,000	China
	2015	800,000	China
		20,000	Vietnam
Consumption size	2013	747	Japan
	2014	7,000	Vietnam
	2015	20	Vietnam

No specific issues apart from those listed under ‘product quality’ above were identified by farmers with respect to market development.

DPI Victoria has undertaken several studies related to market development, including assessment of overseas market potential. In 1999, a series of taste tests of Murray Cod dishes were undertaken at lunches held for local seafood industry representatives in Japan, Taiwan and Hong Kong, and in Melbourne with a Singaporean delegation. Taste test participants were positive in their assessment of Murray Cod, noting that it had a delicate, sweet flavour, with a special or distinctive flavour. There was an appropriate level of fat, and it was easily identifiable as a freshwater fish. Texture and colour were good, size was ideal, bone configuration good, and skin sheen regarded as a very positive attribute. There was good meat recovery and the fish suited a variety of preparations (Anonymous, 2001). Overall, these tests support the suitability of Murray Cod to be marketed to Asian consumers.

Assessment of markets for Murray Cod also formed part of the Our Rural Landscapes Extension (ORLe) Program under Project 08306 'Water Innovation Program – Multi water-use farming systems for a changing climate'. A case study on 'Market Development and Evaluation for Open-Water Farmed Murray Cod' (Gooley et al., 2008) undertook evaluations for both domestic and international markets. Domestic market evaluations undertaken in north-western Victoria provided positive consumer feedback and resulted in regular orders of product from selected restaurants. Export market evaluations in the form of surveys and taste tasting events were conducted in several Asian countries including Malaysia, Singapore, Japan, Thailand, Hong Kong, Indonesia and South Korea. Murray Cod was well received in all these countries and there was a preference for whole and filleted fish with quality and reliability of supply being important considerations for buyers. Short term export demand estimates ranged from hundreds of tonnes p.a. in the short term up to 500–1000 tonnes p.a. in the 5–10 year range. Preliminary post-harvest handling, market chain systems and logistics where also developed from this study.

NSW DPI has also undertaken several activities to support market expansion, particularly to Asia. Three Murray Cod farmers visited the Fine Foods Exhibition in Sydney in 2015 to evaluate opportunities for farmed Murray Cod, and to meet with other aquaculture sub-sector representatives. The industry generally appears to be making only tentative steps to engage with international markets because the domestic market is still strong and because of the complexities of engaging with distributors in China. One exception to this is Marionvale Blue (RAS farm near Goulburn) which has developed linkages with Chinese distributors, has developed translated marketing material, and has shipped some product live to China.

If production continues to increase in the immediate future – as appears likely – increased supply to the domestic market is likely to result in decreased prices, which in turn will stimulate interest in export markets. A proactive market development strategy would support firm farm-gate prices in the face of production expansion. From this perspective it may be useful for other aquaculture industry sectors that have faced the hurdle of developing and maintaining domestic and export markets to transfer their experiences to the Murray Cod farming sector.

Live fish transport

Marionvale Blue has shipped consumption-sized Murray Cod to China live using FloatPac® live fish transport systems. Shipment time is *ca*. 30 hours. Marionvale Blue feels that mortalities during shipping live Murray Cod are attributable to CO_2 build-up in the transport tanks.

Industry development issues

The following discussion deviates from the main focus of this report (i.e. sector R&D needs). However, it captures some issues that came up in discussion which – while perhaps not 'researchable issues' as such – more broadly support the continued development of Murray Cod aquaculture.

'Lessons learned' by the Murray Cod aquaculture sector

While Murray Cod aquaculture is developing rapidly, particularly in NSW, there have been a number of farms that have invested in Murray Cod aquaculture to diversify their farm

production, only to lose entire crops of fish. One indirect cause of these losses has been the use of large ponds for grow-out. Several farms utilised existing freshwater storages by placing net cages in existing large dams. As noted previously, Murray Cod are subject to outbreaks of protozoan parasites, particularly *Chilodonella*. To manage *Chilodonella* outbreaks, the entire pond needs to be treated and this is too costly to do in very large ponds. Farmer experience is that if the whole pond is not treated the outbreak will reoccur, presumably due to reinfection from other fish in the pond.

These lessons need to be explicitly captured and integrated into information packages for new entrant farmers.

'Lessons learned' from other sectors

It is likely that there are useful experiences that can be transferred from other finfish aquaculture production sectors (Atlantic Salmon, Barramundi, Yellowtail Kingfish) that have faced similar issues to those currently being faced by Murray Cod farmers. In particular, there are many aspects of market intelligence, product quality and market development where the experience of other sectors would be of relevance to the expansion of Murray Cod aquaculture. For example, the potential to expand domestic market demand to support increased production is an issue that has been faced by other Australian aquaculture sectors. Given the reported increasing demand from China for Murray Cod, lessons learned by other sectors (both positive and negative) on accessing international markets would also be valuable.

Murray Cod aquaculture management

Production management of Murray Cod in farms requires an integrated approach. It is evident that there are strong interactions between growth and survival and environmental factors such as water quality, particularly temperature and dissolved oxygen levels, as well as fish nutrition, genetics, etc. The Narrandera meeting proposed a review of Murray Cod aquaculture management practices with a view to identifying or developing Better Management Practices. Such an approach would build on Better Management Practices developed under FRDC project 2010/036 (Bradley et al., 2014).

Project outputs

1. This report.
2. Presentation on results of this review to the Australian Freshwater Native Fish Association at their planned conference in mid-2016.

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Literature cited

Abery, N.W., De Silva, S.S., 2005. Performance of murray cod, *Maccullochella peelii peelii* (Mitchell) in response to different feeding schedules. Aquaculture Research 36, 472-478.

Abery, N.W., Gunasekera, R.M., De Silva, S.S., 2002. Growth and nutrient utilization of Murray cod *Maccullochella peelii peelii* (Mitchell) fingerlings fed diets with varying levels of soybean meal and blood meal. Aquaculture Research 33, 279-289.

Anonymous, 2001. Preliminary market appraisal: Murray Cod taste testing for Asian markets. Department of Natural Resources and Environment, Box Hill, Victoria.

Baily, J.E., Bretherton, M.J., Gavine, F.M., Ferguson, H.W., Turnbull, J.F., 2005. The pathology of chronic erosive dermatopathy in Murray cod, *Maccullochella peelii peelii* (Mitchell). J. Fish Dis. 28, 3-12.

Baragahare, R., Becker, J.A., Landos, M., Šlapeta, J., Dennis, M.M., 2011. Gastric cryptosporidiosis in farmed Australian Murray cod, *Maccullochella peelii peelii*. Aquaculture 314, 1-6.

Bradley, T., McCowan, C., Cohen, S., Ingram, B., Green, C., Mansell, P., 2014. Improved fish health management for integrated inland aquaculture through Better Management Practices (BMPs). Final report for FRDC Project No. 2010/036. Department of Environment and Primary Industries, Melbourne.

De Silva, S.S., Gunasekera, R.M., Gooley, G., 2000. Digestibility and amino acid availability of three protein-rich ingredient-incorporated diets by Murray cod *Maccullochella peelii peelii* (Mitchell) and the Australian shortfin eel *Anguilla australis* Richardson. Aquaculture Research 31, 195-205.

De Silva, S.S., Gunasekera, R.M., Ingram, B.A., 2004. Performance of intensively farmed Murray cod *Maccullochella peelii peelii* (Mitchell) fed newly formulated vs. currently used commercial diets, and a comparison of fillet composition of farmed and wild fish. Aquaculture Research 35, 1039-1052.

De Silva, S.S., Gunasekera, R.M., Collins, R.A., Ingram, B.A., 2002. Performance of juvenile Murray cod, *Maccullochella peelii peelii* (Mitchell), fed with diets of different protein to energy ratio. Aquaculture Nutrition 8, 79-85.

Francis, D.S., Turchini, G.M., Jones, P.L., De Silva, S.S., 2006. Effects of dietary oil source on growth and fillet fatty acid composition of Murray cod, *Maccullochella peelii peelii*. Aquaculture 253, 547-556.

Gooley, G.J., Bailey, M., Abery, N., Olsen, L., O'Mahoney, N., Ingram, B., 2008. Final Report for Project 08306: Water Innovation Program - Multi water-use farming systems for a changing climate. Department of Primary Industries, Melbourne.

Gunasekera, R.M., De Silva, S.S., Collins, R.A., Gooley, G., Ingram, B.A., 2000. Effect of dietary protein level on growth and food utilization in juvenile Murray cod *Maccullochella peelii peelii* (Mitchell). Aquaculture Research 31, 181-187.

Ingram, B.A., 2009. Culture of juvenile Murray cod, trout cod and Macquarie perch (Percichthyidae) in fertilised earthen ponds. Aquaculture 287, 98-106.

Ingram, B.A., De Silva, S.S., 2004. Development of intensive commercial aquaculture production technology for Murray cod. Primary Industries Research Victoria, Marine and Freshwater Systems, Department of Primary Industries, Queenscliff, Victoria, 3225., 202 pp.

Ingram, B.A., Silva, S.S.d., Gooley, G.J., 2005. The Australian Murray cod - a new candidate for intensive production systems. World Aquaculture 36, 37...69.

Ingram, B.A., Gooley, G., Bradley, T., Ho, H.K., Cohen, S., 2014. Fish Health Better Management Practices for Murray Cod farming: Version 2.0. Fisheries Victoria Science Report Series No. 5

Jones, B., Smullen, R., Carton, A.G., 2016. Flavour enhancement of freshwater farmed barramundi (*Lates calcarifer*), through dietary enrichment with cultivated sea lettuce, *Ulva ohnoi*. Aquaculture 454, 192-198.

Palmeri, G., Turchini, G.M., Caprino, F., Keast, R., Moretti, V.M., De Silva, S.S., 2008a. Biometric, nutritional and sensory changes in intensively farmed Murray cod (*Maccullochella peelii peelii*, Mitchell) following different purging times. Food Chemistry 107, 1605-1615.

Palmeri, G., Turchini, G.M., Keast, R., Marriott, P.J., Morrison, P., De Silva, S.S., 2008b. Effects of starvation and water quality on the purging process of farmed Murray cod (*Maccullochella peelii peelii*). Journal of Agricultural and Food Chemistry 56, 9037-9045.

Rowland, S.J., 2004. Overview of the history, fishery, biology and aquaculture of Murray cod (*Maccullochella peelii peelii*), In: book of abstracts from the Management of Murray Cod in the Murray-Darling Basin, Workshop, 3-4 June 2004. Murray-Darling Basin Commission, Canberra, Australia.

Ryan, S.G., Smith, B.K., Collins, R.O., Turchini, G.M., 2007. Evaluation of weaning strategies for intensively reared Australian freshwater fish, Murray cod, *Maccullochella peelii peelii*. JWAS 38, 527-535.

Sarker, P., Pilote, A., Auffret, M., Proulx, É., Villemur, R., Deschamps, M.H., Vandenberg, G., 2014. Reducing geosmin off-flavor compounds and waste outputs through dietary phosphorus management in rainbow trout aquaculture. Aquaculture Environment Interactions 6, 105-117.

Schultz, A.G., Jones, P.L., Toop, T., 2014. Rodlet cells in Murray cod, *Maccullochella peelii peelii* (Mitchell), affected with chronic ulcerative dermatopathy. J. Fish Dis. 37, 219-228.

Schultz, A.G., Healy, J.M., Jones, P.L., Toop, T., 2008. Osmoregulatory balance in Murray cod, *Maccullochella peelii peelii* (Mitchell), affected with chronic ulcerative dermatopathy. Aquaculture 280, 45-52.

Schultz, A.G., Shigdar, S.L., Jones, P.L., Ward, A.C., Toop, T., 2011. Groundwater pre-treatment prevents the onset of chronic ulcerative dermatopathy in juvenile Murray cod, *Maccullochella peelii peelii* (Mitchell). Aquaculture 312, 19-25.

Tucker, C.S., 2000. Off-flavor problems in aquaculture. Reviews in Fisheries Science 8, 45-88.

Turchini, G.M., 2011. Murray Cod Open Water Nutrition - Final Report. Deakin University - DPI Fisheries Victoria.

Turchini, G.M., Gunasekera, R.M., De Silva, S.S., 2003. Effect of crude oil extracts from trout offal as a replacement for fish oil in the diets of the Australian native fish Murray cod *Maccullochella peelii peelii*. Aquaculture Research 34, 697-708.

Turchini, G.M., Francis, D.S., De Silva, S.S., 2006a. Fatty acid metabolism in the freshwater fish Murray cod (*Maccullochella peelii peelii*) deduced by the whole-body fatty acid balance method. Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology 144, 110-118.

Turchini, G.M., Francis, D.S., De Silva, S.S., 2006b. Modification of tissue fatty acid composition in Murray cod (*Maccullochella peelii peelii*, Mitchell) resulting from a shift from vegetable oil diets to a fish oil diet. Aquaculture Research 37, 570-585.

Appendix 1 – Persons contacted

The following table lists those contacted for this study. Communication: FV: field visit, February 2016; M: attended meeting at Narrandera Fisheries Centre on 18 February 2016; P: phone contact; E: e-mail contact.

Name	Company	Location	Type	Communication
Industry				
John Breen (Farm Manager)	Burjoe Pty Ltd *trading as* Marionvale Blue	Goulburn	RAS growout	FV
Noel Penfold	Murray Darling Fisheries	Wagga Wagga	Hatchery and pond growout	P
Ian Charles	Silverwater Native Fish	Grong Grong	Hatchery and pond growout	M
Mathew Ryan		Griffith	Cage growout and fingerlings	M
Brett and Lisa Ryan		Leeton	Cage / pond growout	M
George Commins	AquaComm Pty Ltd	Whitton	Cage / pond growout	P
Trentham Cliffs Fisheries Pty Ltd Jaeben & Glenek Underhill	Trentham Cliffs Fisheries Pty Ltd	Mildura	Fingerlings Growout	E
Colin Dickson	Ishwinroo Enterprises	Mildura	Hatchery / growout	E
Brad Beasley	Thurla Farms	Red Cliffs		
Government				
Matthew McLellan	NSW DPI	Narrandera Fisheries Centre	Government hatchery - restocking	M
Giles Butler (Regional Director South West)	NSW DPI			M
Stewart Fielder	NSW DPI	Port Stephens Fisheries Institute		FV, M
Helen Chen (International Engagement)	NSW DPI	Biosecurity and Food Safety, Sydney		P
Brett Ingram	Victoria DPI	DPI Queenscliff		P

Appendix 2 – Overview of nutritional research on Murray Cod

The following table is a partial list of published research on Murray Cod nutrition. It is intended only to give an overview of previous research on this topic.

Topic	Reference
Diet composition	
Fish meal replacement with blood meal and defatted soybean meal	Abery et al. (2002)
Effects of different protein:energy ratios in feeds	De Silva et al. (2002)
Fish meal replacement with soybean meal, shark meat meal waste and meat meal	De Silva et al. (2000)
Effect of dietary protein on growth and feed utilisation	Gunasekera et al. (2000)
Fatty acid metabolism re. dietary lipid sources	Turchini et al. (2006a); (Turchini et al., 2006b)
Use of trout oil as dietary lipid source; optimal n-3:n-6 ratio	Turchini et al. (2003)
Substitution of fish oil with alternative dietary lipids	Francis et al. (2006)
Feed management	
Weaning of juvenile fish to compounded diets	Ryan et al. (2007)
Feeding schedules (satiation / ration feeding; hand / belt feeding)	Abery and De Silva (2005)
Comparison of experimental diets for Murray Cod with commercial (salmon and barramundi) diets	De Silva et al. (2004)