Assessing the nutritional value of Australian Farmed Barramundi

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Abbreviations

ABFA – Australian Barramundi Farmers Association

AFB – Australian farmed barramundi

NQC - Norwegian quality cut

Executive Summary

Farmed Australian barramundi (*Lates calcarifer*) is a reasonably well-recognised fish product in the Australian marketplace, however, its nutritional value and health benefits compared to other animal protein and seafoods is not quantified and widely known by consumers. This study assessed the nutrient composition, specifically omega-3 long-chain polyunsaturated fatty acids (n-3 LC-PUFA) and minerals, in farmed barramundi fillets so that updated nutritional information could be provided to food agencies and to identify potential marketing advantages. Australian farmed barramundi were sourced from seven farms across three fish sizes (0.6 kg, 1.5 kg and 3 kg), between seasons (winter and summer) and from different production systems (low vs high salinities). To compare omega-3 levels in Australian farmed barramundi with other consumer fish products, wild caught Australian and imported barramundi, as well as Atlantic salmon (*Salmo salar*), tropical snapper (*Lutjanus spp*.), Nile perch (*Lates niloticus*) and Basa catfish (*Pangasius spp*.), were included in lipid, fatty acid and mineral analyses. Tasmanian farmed Atlantic salmon had higher levels (three-fold) of n-3 LC-PUFA than Australian farmed barramundi.

Levels of n-3 LC-PUFA in Australian farmed barramundi were similar to wild barramundi and saddletail and goldband snapper. However, Australian farmed barramundi had significantly higher levels of n-3 LC-PUFA than imported white flesh fish alternatives Nile perch (three-fold) and Basa (16-fold). One serving (150 g) of Australian farmed barramundi fulfils one person's daily n-3 LC-PUFA and selenium requirements, respectively. There was little difference in the nutritional composition of imported and Australian farmed barramundi.

There was a trend of increasing n-3 LC-PUFA as fish became larger, although further work may be needed here to determine the actual differences due to small sample sizes within each category. No differences were seen in levels of nutrients due to salinity of culture (except for phosphorus), or season.

These findings can be used in conjunction with marketing programmes that are focused on the nutritional benefits of Australian farmed barramundi to consumers and associated food agencies.

Keywords

Omega-3, Diet, Consumers, nutritional value, *Lates calcarifer*, Nutrient composition, Farmed fish

Introduction

There is significant interest in the development of Northern Australia which has been well recognised by the Federal Government through its 2015 White Paper on Developing Northern Australia. Aquaculture has been recognised as one of the prime industries capable of driving expansive growth in Northern Australia.

Consumers are increasingly aware of the link between improved health and a diet consisting of important nutrients such as omega 3 long chain polyunsaturated fatty acids (n3 LCPUFA) and minerals. Fish are major contributors to these nutritional requirements and, as such, demand for products high in n3 LCPUFA, like Atlantic salmon and fish oil supplements has risen. Barramundi is also included as a contributing fish species as it possesses high oil and n3 LCPUFA content. Based on samples collected in 2010, the absolute content of n3 LCPUFA of farmed barramundi was similar to that of Atlantic salmon and four times greater than that of wild barramundi (Nichols et al., 2014). However, this information was not reported to food agencies or health organisations. In fact, some such as the Australia Heart Foundation (NHFA, 2015) continue to use information generated 15 years ago to categorize farmed barramundi as of inferior quality to farmed salmon, or other market competitor species such as wild caught Australian snapper. Similarly, the National Health and Medical Research Council (NHMRC, 2017) encourages fish consumption as a major supplier of iron, zinc, iodine, calcium and magnesium to the human diet. However, the mineral content in fish fillets is poorly documented, differs across species and culture conditions (Prabhu et al., 2016), and has not been documented for Australian farmed barramundi.

Objectives

The objective of this project was:

To assess the variability in nutrient composition, specifically omega-3 long-chain polyunsaturated fatty acids (n-3 LC-PUFA) and minerals, in the fillet of farmed Australian barramundi and how it compares against of meat protein sources.

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Method

To reflect the current nutritive value of farmed Australian barramundi, Norwegian quality cut (NQC) samples from fresh and deskinned subcutaneous fat-free fillets of farmed barramundi were obtained from a total of seven farms situated in different regions of Australia. NQC (NS 9401, 1994) is an international scientific standard whereby the same region of the fillet is always analysed so that standard comparisons can be made. The NQC is the most appropriate cut to assess as the objective of this study was to compare nutritional quality of Australian barramundi against other fish species than.

The NQC was obtained from the left de-skinned fillet from each fish as follows;

1. The fillet was first cut vertically where the anterior dorsal fin ended (ended means the caudal end of the anterior dorsal fin).
2. The tail-cut was then taken and cut again vertically along 50 % of its length.
3. The anterior portion of the resultant cut is the NQC.

NQC samples were frozen, sent to James Cook University (JCU) by temperature-controlled shipping. Upon delivery to JCU, samples were immediately freeze dried, ground and then shipped to CSIRO Hobart for lipid and fatty acid analyses. Lipid and fatty acid analyses were performed as described by Nuez-Ortín et al. (2016). Mineral composition (Ca, P, Mg, K, Na, Cl, S, Mn, Zn, Cu, Fe, Se, I) was determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at the Advanced Analytical Centre at JCU.

Nutritive profiles between seasons were obtained through analyses of samples provided by these farms in winter (Table 1) and summer, 2018 (Table 2).

Table 1. Number of samples, farm origin, fish size and length, and production conditions (temperature and salinity) of winter Australian farmed barramundi samples.

Sample	Farm	Weight (kg)	Length (cm)	Temp (°C)	Salinity (ppt)
1	Humpty Doo Barramundi	0.562	35	26.5	6
2	Humpty Doo Barramundi	1.189	46	26.5	6
3	Humpty Doo Barramundi	3.361	63	26.5	6
4	MainStream Aquaculture	0.76	38	25	2.2
5	MainStream Aquaculture	1.54	46	25	2.2
6	MainStream Aquaculture	2.7	54.5	25	2.2
7	Coral Coast Barramundi	3	61	20	35
8	Coral Coast Barramundi	1.5	46.5	20	35
9	Coral Coast Barramundi	0.65	34.5	20	35
10	GFB Fisheries – Kelso Fishery	0.524	34.6	18	0
11	GFB Fisheries – Kelso Fishery	1.375	47.7	17.85	0
12	GFB Fisheries – Kelso Fishery	2.751	61.6	17.85	0
13	Sealord King Reef	2.95	57	20.3	0
14	Sealord King Reef	1.78	47	20.3	0
15	Sealord King Reef	0.775	35	20.3	0
16	Barramundi Gardens	2	54	21	0
17	Barramundi Gardens	1	37	21	0
18	Barramundi Gardens	0.5	32	21	0

19	Daintree Saltwater Barramundi	1.86	49	22.5	17
20	Daintree Saltwater Barramundi	2.78	59	22.5	15
21	Daintree Saltwater Barramundi	0.9	40	22.5	15

Table 2. Number of samples and farm origin of summer Australian farmed barramundi samples

Sample	Farm	Location
1	Humpty Doo Barramundi	Humpty Doo, NT
2	Humpty Doo Barramundi	Humpty Doo, NT
3	Humpty Doo Barramundi	Humpty Doo, NT
4	GFB Fisheries – Kelso Fishery	Kelso, QLD
5	GFB Fisheries – Kelso Fishery	Kelso, QLD
6	GFB Fisheries – Kelso Fishery	Kelso, QLD
7	Barramundi Gardens	Mossman, QLD
8	Barramundi Gardens	Mossman, QLD
9	Barramundi Gardens	Mossman, QLD
10	Coral Coast Barramundi	Bowen, QLD
11	Coral Coast Barramundi	Bowen, QLD
12	Coral Coast Barramundi	Bowen, QLD
13	Coral Coast Barramundi	Bowen, QLD
14	Coral Coast Barramundi	Bowen, QLD
15	Coral Coast Barramundi	Bowen, QLD
16	MainStream Aquaculture	Werribee, Vic
17	MainStream Aquaculture	Werribee, Vic
18	MainStream Aquaculture	Werribee, Vic
19	Sealord King Reef	Cowley, QLD
20	Sealord King Reef	Cowley, QLD
21	Sealord King Reef	Cowley, QLD
22	Daintree Saltwater Barramundi	Wonga Beach, QLD
23	Daintree Saltwater Barramundi	Wonga Beach, QLD
24	Daintree Saltwater Barramundi	Wonga Beach, QLD

Comparisons of fatty acid profiles were made between seasons (winter and summer) and between salinities ([0-6 ppt] and high salinities [15-35 ppt]. For comparisons of farmed barramundi with other fish products available to the consumer, the NQC analogous cut from commercial size fillets were obtained through purchase of fish available for sale in Townsville supermarkets (Table 3).

Table 3. Number of samples, species, origin and type of other fish products analyzed for their nutritive profile in the present study

Sample	Species	Likely source of product	Type
1	Barramundi	Burdekin, Qld	Wild
2	Barramundi	Burdekin, Qld	Wild
3	Barramundi	Burdekin, Qld	Wild
4	Barramundi	Taiwan	Farmed
5	Barramundi	Taiwan	Farmed
6	Barramundi	Taiwan	Farmed
7	Atlantic salmon	Tasmania	Farmed
8	Atlantic salmon	Tasmania	Farmed
9	Atlantic salmon	Tasmania	Farmed
10	Basa catfish	Vietnam	Farmed
11	Basa catfish	Vietnam	Farmed
12	Basa catfish	Vietnam	Farmed
13	Nile perch	Uganda	Wild
14	Nile perch	Uganda	Wild
15	Nile perch	Uganda	Wild
16	Saddle-tail snapper	East Coast, Australia	Wild
17	Saddle-tail snapper	East Coast, Australia	Wild
18	Saddle-tail snapper	East Coast, Australia	Wild
19	Gold-band snapper	East Coast, Australia	Wild
20	Gold-band snapper	East Coast Australia	Wild
21	Gold-band snapper	East Coast Australia	Wild

Results

<u>Comparison of Australian farmed barramundi (AFB) to common terrestrial meats available to the Australian consumer</u>

The nutritional profile of winter sampled Australian farmed barramundi fillets was compared to chicken, pork, beef and lamb (Table 4).

Table 4. The nutrient composition of Australian farmed barramundi in comparison to poultry, pork, beef and lamb products.

Nutrient/100 g wet weight	Barramundi	Chicken		Pork		Beef		Lamb	
	mean	mean	% diff	mean	% diff	mean	% diff	mean	% diff
Calcium (mg)	8.55	11	78	18	48	6	143	7	122
Chromium (µg)	21.0	ND	ND	ND	ND	ND	ND	ND	ND
Copper (µg)	23.6	ND	ND	ND	ND	ND	ND	ND	ND
Iron (mg)	0.29	0.56	52	1.1	26	2.1	14	1.5	19
Magnesium(mg)	28.0	21	133	19	147	26	108	21	133
Manganese (µg)	12.3	ND	ND	ND	ND	ND	ND	ND	ND
Phosphorus (mg)	162	192	84	182	89	219	74	185	88
Potassium (mg)	356	237	150	337	106	364	98	251	142
Sodium (mg)	34.0	50	68	68	50	55	62	54	63
Selenium (µg)	28.0	17.1	164	9.7	289	11.5	243	9.3	301
Zinc (mg)	0.38	1.0	38	2.6	15	3.6	11	2.6	15
EPA (mg)	117	2	5850	0	ND	41	285	20	585
DPA (mg)	66	10	660	17	388	49	135	80	83
DHA (mg)	218	8	2725	31	703	8	2725	9	2422
EPA+DHA (mg)	335	10	3350	31	1081	48	698	28	1196
EPA+DHA+DPA (mg)	401	19	2111	48	835	97	413	109	368
Total lipid (g)	7.2	12.8	56	13.2	55	9.3	77	22.9	31
n3LCPUFA% of lipid	5.6	0.2	2800	0.4	1400	1.0	560	0.5	1120
Total n-3 (mg)	565	ND	ND	ND	ND	ND	ND	ND	ND
Total n-6 (mg)	1035	ND	ND	ND	ND	ND	ND	ND	ND
n3/n6 ratio	0.54	ND	ND	ND	ND	ND	ND	ND	ND
Saturated fats (g)	2.0	3.9	51	5.0	40	3.7	54	10.2	20
Monounsaturated(g)	3.6	6.4	56	5.7	63	4.0	90	8.3	43
Polyunsaturated (g)	1.6	1.8	89	1.7	94	0.6	267	1.2	133

*% difference = amount in Australian farmed barramundi /amount in given meat * 100, and thus is the percentage of a given nutrient found in barramundi versus the given meat. Data are mean ± SEM, n=21 for Australian Farmed Barramundi. Data for other animals was obtained from the database of Food Standards Australia New Zealand. The specific meats used for comparison were; Chicken, whole, flesh, skin & fat, raw (Food ID, 08C10525); Pork, forequarter chop, untrimmed, raw (Food ID, 08A30432); Beef, fillet steak, untrimmed, raw (Food ID, 08A10968); Lamb, chop, untrimmed, raw, not further defined (Food ID, 08A20829). ND = no data.*

This comparison highlights several points of differentiation between Australian farmed barramundi and terrestrial meat products.

- Australian farmed barramundi has lower levels of fat (total lipid) than meats commonly consumed in Australia. Specifically, Australian farmed barramundi has around half the fat levels of chicken and pork, and around a third that found in lamb.
- Australian farmed barramundi also contains less saturated fat than meat. Australian farmed barramundi contains around half the saturated fat levels of chicken or beef, less than half the saturated fat levels of pork, and a fifth of the saturated fat levels found in lamb.
- Australian farmed barramundi contains more beneficial long chain fatty acids that are being increasingly associated with good health. Australian farmed barramundi contains

around four-fold more LC-PUFA than grass fed beef and lamb, eight-fold more than pork, and 21-fold more than chicken.
- Australian farmed barramundi contains higher levels of selenium than meat, with 1.6-fold more than found in chicken, 2.4-fold more than beef, and around 3-fold more than pork or lamb.
- Australian farmed barramundi contains less sodium than meat.

What the data also show is that in comparison to chicken, pork, beef and lamb general have greater or similar levels of essential minerals than found in Australian farmed barramundi, except for selenium (note: as the meat data presented in the database is represented as means without variance statistical comparisons were not possible).

Comparison of Australian farmed barramundi to commonly available seafood to the Australian consumer

The nutritive profile of Australian farmed barramundi was compared to that of fish product commonly available in Australian supermarkets. Specifically, farmed barramundi was compared to Tasmanian farmed Atlantic salmon (*Salmo salar*), Australian wild caught barramundi, imported farmed barramundi from Taiwan, imported Basa (*Pangasius bocourti*), imported Nile perch (*Lates niloticus*), wild caught Australian saddletail snapper (*Lutjanus malabaricus*) and wild caught Australian goldband snapper (*Pristipomoides spp*) (Table 5).

These results show that;

-Australian farmed barramundi was found to be essentially identical to that of imported barramundi fillets from Taiwan in relation to mineral and fatty acid levels. Statistically the two products only differed in mean Calcium levels, with the Taiwanese product higher in Calcium than its Australian equivalent

-The major domestically produced competitor for Australian farmed barramundi, Tasmanian farmed Atlantic salmon, has around 3-fold higher levels of n-3 LC-PUFA, and hence is a higher source of these nutrients.

-The n-3 LC-PUFA levels in Australian farmed barramundi were similar to the three wild fish species tested (which included Australian wild barramundi)
-Australian farmed barramundi had around 3-fold higher levels of n-3 LC-PUFA than Nile perch (although this was not statistically significant) and 16-fold higher levels than Basa catfish.

Table 5. Essential element, LC-PUFA and total lipid concentrations in Australian farmed barramundi versus other commonly available fish in the Australian marketplace. Numbers in shaded cells indicate fish samples which were higher or lower in that nutrient than Australian farmed barramundi (as indicated by arrow direction, p<0.05).

Nutrient/100 g WW fillet	Australian farmed barramundi	Australian wild barramundi		Australian farmed Atlantic salmon		Imported farmed barramundi (Taiwan)		Imported Basa		Imported Nile perch		Wild Australian Saddletail snapper		Wild Australian Goldband snapper	
	mean	mean	% diff.[1]	mean	% diff.	mean	% diff.	mean	% diff.	mean	% diff.	mean	% diff.	mean	% diff.
Calcium (mg)	8.55	5.88	145	6.23	137	13.8↑	62	4.95	173	9.25	92	14.2↑	60	9.47	90
Chromium (μg)	21.0	13.9	151	24.7	85	17.4	121	18.7	112	14.8	142	18.8	112	16.1	130
Copper (μg)	23.6	2.1	1124	13.6	174	<1.7	ND	<1.0	ND	<1.4	ND	15.0	157	2.7	874
Iron (mg)	0.29	0.38	76	0.27	107	0.18	161	0.11	264	0.18	161	0.20	145	0.20	145
Magnesium(mg)	28.0	26.0↓	108	31.1↑	90	28.0	100	14.6↓	192	25.6	109	34 ↑	80	33.3 ↑	84
Manganese (μg)	12.3	7.9 ↓	156	16.6↑	74	11.7	105	8.9 ↓	138	11.7	105	9.9	124	9.5	129
Phosphorus (mg)	162	175	93	229 ↑	71	159	102	164	99	141↓	115	156	104	184 ↑	88
Potassium (mg)	356	393	91	350	102	332	107	189 ↓	188	301↓	118	303 ↓	117	364	98
Sodium (mg)	34.0	22.6	150	21.9	155	28.4	120	384↑	9	33.0	103	139↑	24	94.7 ↑	36
Selenium (μg)	28.0	52.3↑	54	44.0↑	64	37.9	74	25.7	109	24.9	112	102↑	27	103↑	27
Zinc (mg)	0.38	0.40	95	0.37	103	0.41	93	0.22 ↓	173	0.38	100	0.36	106	0.32	119
EPA (mg)	117	37	316	324 ↑	36	124	94	5 ↓	2340	17	688	30	390	27	433
DPA (mg)	66	43	153	125 ↑	53	75	88	4 ↓	1650	37	178	13	508	19	347
DHA (mg)	218	159	137	585 ↑	37	232	94	17 ↓	1282	93	234	274	80	331	66
EPA+DHA (mg)	335	196	171	909 ↑	37	357	94	21 ↓	1595	110	305	304	110	358	94
EPA+DHA+DPA(mg)	401	239	168	1034↑	39	432	93	25 ↓	1604	147	273	316	127	377	106
Total lipid (g)	7.2	1.2↓	600	12	60	5	144	2.1 ↓	343	0.7 ↓	1029	1.0 ↓	720	1.1 ↓	655
n3LCPUFA% of lipid	5.6	22.2↑	25	8.6	65	8.7	64	1.3 ↓	431	22.7↑	25	30.8 ↑	18	35.6 ↑	16
Total n-3 (mg)	565	257	220	1595↑	35	645	88	41↓	1378	160	353	322	175	384	147
Total n-6 (mg)	1035	149 ↓	695	1831↑	57	1155	90	289 ↓	358	90 ↓	1150	144 ↓	719	133 ↓	778
n3/n6 ratio	0.54	1.91↑	28	0.87	62	0.56	96	0.15 ↓	360	1.82↑	30	2.25↑	24	2.87 ↑	19
Saturated fats (g)	2.0	0.4 ↓	500	1.8	111	1.2	167	0.9	222	0.2 ↓	1000	0.4 ↓	500	0.4 ↓	500
Monounsaturated (g)	3.6	0.3 ↓	1200	6.7 ↑	54	2.0	180	0.9 ↓	400	0.2 ↓	1800	0.2 ↓	1800	0.2 ↓	1800
Polyunsaturated (g)	1.6	0.4 ↓	400	3.4 ↑	47	1.8	89	0.3 ↓	533	0.3 ↓	533	0.5 ↓	320	0.5 ↓	320

*% difference = amount in AFB/amount in given seafood * 100, and thus is the percentage of a given nutrient found in barramundi versus the given seafood. Data are mean ± SEM, n=21 for Australian Barramundi, and n=3 for other fish. Data were statistically analysed to determine fish which were different in nutrient concentrations (one-way ANOVA with Tukey HSD post hoc, p<0.05). Only statistical differences to Australian farmed barramundi are shown, represented by shaded cells with arrows for directionality. ND = no data.*

Comparison of Australian farmed barramundi nutrient profiles across seasons.

Samples of barramundi were provided by farms based on different size grades and in both winter and summer and sent for nutrient analyses. Results highlight a trend of increasing n-3 LC-PUFA with increasing size of fish (Table 6a, Figure 1), however nutrient profiles of farmed barramundi were very similar among seasons with no statistical differences in any of the parameters evident (Table 6b). Note: values are reported on dry weight.

Table 6a. Nutrient profiles of Australian farmed barramundi fillets sampled in winter against size classes (<1 kg, 1-1.9kg, 2-4 kg).

Nutrient	**Size class**		
mg/100 g WW	500 – 999 (g)	1000 – 1999 (g)	2000 – 4000 (g)
EPA	90 ± 16	110 ± 27	150 ± 34
DPA	50 ± 8	60 ± 11	88 ± 14
DHA	177 ± 25	189 ± 30	288 ± 43
EPA+DHA	267 ± 41	299 ± 56	438 ± 75
EPA+DHA+EPA	318 ± 49	359 ± 67	526 ± 89

Table 6b. Nutrient profiles of Australian farmed barramundi fillets sampled between seasons (winter vs summer).

	Winter		Summer		
mg/100g dry weight fillet	Mean	SD	Mean	SD	Diff.
EPA	398.56	197.48	473.39	300.43	-18.78%
DPA	227.34	90.52	266.89	143.92	-17.40%
DHA	756.96	269.11	787.97	377.71	-4.10%
EPA+DHA	1155.52	454.18	1261.36	669.74	-9.16%
EPA+DHA+DPA	1382.86	542.18	1528.25	811.79	-10.51%
Total n3	1952.43	708.54	2121.18	1025.08	-8.64%
Total n6	3587.83	1116.18	3839.76	1756.05	-7.02%
n3/n6ratio	0.54	0.08	0.56	0.09	-3.81%
Saturated fat (g/100 g dry weight)	6.64	2.27	7.49	3.57	-12.83%
Monounsaturated fat (g/100 g dry weight)	12.18	4.26	12.77	6.28	-4.88%
Polyunsaturated (g/100 g dry weight)	5.33	1.68	5.96	2.74	-11.82%

*Winter (n=21), summer (n=24).). %Diff: ((amount in winter-amount in summer)/(amount in winter)*100). Statistical analysis by Independent t-test, SPSS; significance at p<0.05.*

Comparison of Australian farmed barramundi nutrient profiles between salinities.

Winter samples of barramundi were collected from farms producing under high (15-35 ppm, n=6) or low salinity conditions (0-6 ppm; n=15)) and sent for nutrient analyses. Phosphorus content was found to be significantly higher at high salinity. No significant differences were detected in the rest of nutrients due to salinity of production (Table 7).

Comparison of Australian farmed barramundi versus human nutritional requirements

There may be an advantage to marketing Australian farmed barramundi in relation to human health. Many health claims in Australia require scientific evidence to comply with legislation put forward by Food Standards Australia. Accordingly, the levels of long-chain polyunsaturated omega 3 fatty acids in Australian farmed barramundi were compared to daily recommended human consumption levels by the National Heart Foundation of Australia and the Australian National Health and Medical Research Council (NHMRC). This comparison highlights that as little as 100 g of Australian farmed barramundi fillet provides between 2 – 4.5 times the recommended daily intake for men and woman, respectively (Table 8).

Table 7. Nutrient profiles of Australian farmed barramundi fillets sampled during winter from high (15-35 ppm) vs low (0-6 ppm) salinity production systems.

	High salinity		Low salinity		
mg/100g dry weight fillet	Mean	SD	Mean	SD	Diff.
Calcium (mg)	31.54	6.69	30.64	7.43	2.87%
Chromium (μg)	83.72	30.50	72.17	20.51	13.79%
Copper (μg)	39.36	27.09	28.25	48.96	28.22%
Iron (mg)	1.04	0.36	1.03	0.30	0.83%
Magnesium(mg)	108.51	8.58	98.18	13.80	9.52%
Manganese (μg)	51.43	9.52	42.11	9.84	18.12%
Phosphorus (mg)	641.15	45.46	560.78	66.32	12.54%*
Potassium (mg)	1407.31	99.29	1231.81	153.41	12.47%
Sodium (mg)	86.01	21.58	134.99	99.86	-56.94%
Selenium (μg)	92.50	40.97	79.00	50.85	14.59%
Zinc (mg)	1.49	0.17	1.30	0.19	12.35%
EPA	300.69	113.02	437.71	213.08	-45.57%
DPA	195.31	87.49	240.15	91.41	-22.96%
DHA	666.51	308.03	793.14	254.28	-19.00%
EPA+DHA	967.21	411.56	1230.85	461.43	-27.26%
EPA+DHA+DPA	1162.51	491.97	1471.01	551.70	-26.54%
Total n3	1631.88	648.15	2080.65	710.98	-27.50%
Total n6	2942.41	1017.90	3845.99	1076.94	-30.71%
n3/n6 ratio	0.55	0.08	0.54	0.08	2.24%
Saturated fat (g/100 g dry weight)	5.41	1.97	7.13	2.25	-31.96%
Monounsaturated fat (g/100 g dry weight)	9.53	3.73	13.23	4.10	-38.85%
Polyunsaturated fat (g/100 g dry weight)	4.40	1.54	5.71	1.63	-29.79%

*High salinity (n=6), low salinity (n=15).%Diff: ((amount in high salinity-amount in low salinity)/(amount in high salinity)*100). Statistical analysis by Independent t-test, SPSS; * significance at p<0.05.*

Table 8. Long-chain polyunsaturated omega 3 fatty acid (n-3 LC-PUFA) concentrations in winter sampled Australian farmed barramundi (mg/100 g of fillet) versus the recommended daily intake of these nutrients (mean ± SEM, n = 21).

Nutrient	mg/100 g wet weight	Recommended daily intake (RDI)	% of RDI in 100 g barramundi	% of RDI in 200 g barramundi
EPA	117 ± 15			
DPA	66 ± 7			
DHA	218 ± 21			
EPA+DHA	335 ± 36	500[1]	67	134
EPA+DHA+DPA	401 ± 42	90[2]	445	891
		160[3]	250	500

[1] Recommended daily intake for adults by the National Heart Foundation of Australia (NHFA 2015) and the International Society for the Study of Fatty Acids and Lipids (ISSFAL 2004) to reduce the risk of coronary heart disease in adults.[2,3] Recommended daily intake for adult women[2] or men[3] by the Australian Governments National Health and Medical Research Council to prevent LC-PUFA deficiency (NRV 2006).

Similarly, essential nutrient concentrations present in Australian farmed barramundi were compared to levels recommended by the Australian National Health and Medical Research Council. Barramundi can be marketed as a good source of selenium, potassium, phosphorus and chromium. In particular, a 200 g portion of fillet will provide the daily requirements for selenium and chromium (Table 9).

Table 9. Essential element concentrations in Australian farmed barramundi (mg or µg /100 g of fillet), and the concentration in relation to the recommended daily intake of these nutrients. Nutrients for which Australian farmed barramundi are an appreciable source are shaded. Data are mean ± SEM, n = 21.

Nutrient	Per 100 g WW	Recommended daily intake (RDI)*	% of RDI in 100 g barramundi	% of RDI in 200 g barramundi
Calcium (mg)	8.55 ± 0.34	1000	1	2
Chromium (µg)	21.0 ± 1.3	25	84	168
Copper (mg)	0.02 ± 0.02	1.2	2	4
Iron (mg)	0.29 ± 0.02	18	2	3
Magnesium (mg)	28.0 ± 0.4	400	7	14
Manganese (mg)	0.01 ± 0.004	5	<1	<1
Phosphorus (mg)	162 ± 2	1000	16	32
Potassium (mg)	356 ± 5	2800	13	25
Sodium (mg)	34 ± 5.6	460	7	15
Selenium (µg)	28.0 ± 1.3	60	47	93
Zinc (mg)	0.38 ± 0.01	8	5	9

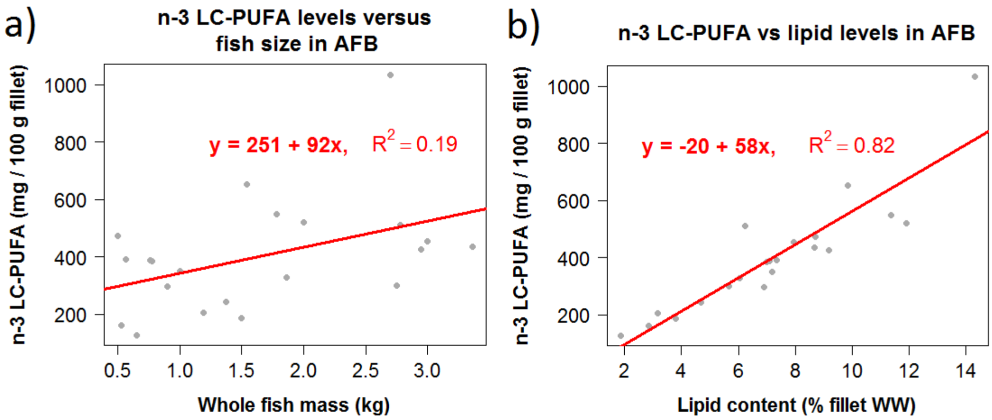
* Recommended daily intake for women between the ages of 31-50 years by the Australian Governments National Health and Medical Research Council for minerals.

Comparison of barramundi n3-LC-PUFA profiles against increasing fat levels and fish size

The profile of n3-LC-PUFA was compared across winter samples differing in fish size (Figure 1a) and against increased fat fillet levels (Figure 1b). Data indicates that increasing the fat levels in the fillet may have an additional benefit of increasing fillet n-3 LC-PUFA levels, as a strong positive relationship was found to exist between AFB fillet lipid content and n-3 LC-PUFA levels (Fig. 1b). Conversely, only a weak positive relationship exists between fish size and n-3 LC-PUFA content

(Fig. 1a). Regardless of size, increasing the n-3 LC-PUFA levels in feed will increase levels in fillet at the expense of higher feed cost.

Figure 1. The level of n-3 LC-PUFA (DHA+DPA+EPA) in Australian farmed barramundi (AFB) fillets versus fish size (a) or fish lipid levels (b). Equations explain the linear models (red lines) fitted.



Discussion

This project set out to establish the current nutrient profiles of Australian farmed barramundi against other commonly available animal protein sources (both terrestrial and seafood). It also examined if the nutrient profile of farmed barramundi varied significantly between seasons and salinity conditions. The results show that Australian farmed barramundi is a good source of long-chain polyunsaturated omega-3 fatty acids and other essential nutrients, and against some commonly consumed meats there may be advantageous marketing opportunities to highlight to consumers.

How is the nutritional quality of farmed Australian barramundi different from other market competitors?

The data demonstrate that farmed Australian Barramundi are qualitatively and quantitatively quite similar in micronutrient composition to many other, but not all, seafoods. Like many seafoods, Australian farmed barramundi is a rich source of n-3 LC-PUFA, selenium, phosphorus and potassium. Thus, one of the strengths of Australian farmed barramundi as a food probably resides in its place as a representative seafood *per se*. This grouping as a seafood comes with immediate advantages over other non-seafood groups such as pork or chicken, which are typically low in LC-PUFA, high in saturated fat and often have lower selenium levels.

In relation to individual terrestrial meat products the following points of difference are highlighted;

Australian farmed barramundi (AFB) versus chicken

- AFB has half the fat of chicken
- AFB has half the level of saturated fat of chicken
- AFB has over 20 times more n-3 LC-PUFA than chicken
- AFB has over one and a half times more selenium than chicken
- AFB has less sodium than chicken

Australian farmed barramundi (AFB) versus pork

- AFB has half the fat of pork
- AFB has less than half the saturated fat levels found in pork
- AFB has over 8 times more n-3 LC-PUFA than pork
- AFB has 3 times more selenium than pork
- AFB has half the sodium found in pork

Australian farmed barramundi (AFB) versus beef

- AFB has less fat than beef
- AFB has half the saturated fat levels found in beef
- AFB has over four time more n-3 LC-PUFA than beef
- AFB has around two and a half times more selenium than beef
- AFB has nearly three times more polyunsaturated fat than beef
- AFB has less sodium than beef

Australian farmed barramundi (AFB) versus lamb

- AFB has less than a third of the fat found in lamb
- AFB has five times less saturated fat than lamb
- AFB has around four times more n-3 LC-PUFA than lamb
- AFB has three times more selenium than lamb
- AFB has higher levels of polyunsaturated fat than lamb
- AFB has less sodium than lamb

Australian farmed barramundi (AFB) versus meat in general

- AFB has less fat than meat
- AFB has less saturated fat than meat
- AFB is a richer source of n-3 LC-PUFA than meat
- AFB is a richer source of selenium than meat
- AFB has less sodium than meat

In relation to commonly available and tested seafood in the Australian marketplace the following statements can be made (note: not all comparisons are statistically different);

Australian farmed barramundi (AFB) versus wild barramundi

- AFB has nearly twice as much n-3 LC-PUFA as wild barramundi
- AFB has more n-3 LC-PUFA than wild barramundi
- AFB has more omega-3 than wild barramundi
- AFB has 12 times more monounsaturated fats than wild barramundi
- AFB is a richer source of monounsaturated fat than wild barramundi
- AFB has 4 times more polyunsaturated fat than wild barramundi
- AFB is a richer source of polyunsaturated fat than wild barramundi

Australian farmed barramundi (AFB) versus salmon (Farmed Australian Atlantic salmon as available to Australian consumers)

- AFB has less omega-6 than salmon

Australian farmed barramundi (AFB) versus imported barramundi

- Currently no differences of importance

Australian farmed barramundi (AFB) versus imported Basa

- AFB has more manganese, magnesium, potassium, phosphorus and zinc than basa
- AFB has nearly twice as much zinc as imported basa
- AFB has twice as much magnesium as imported basa
- AFB has twice as much potassium as imported basa
- AFB has nearly twice as much zinc as imported basa
- AFB has more than double the level of iron as imported basa
- AFB has over 10 times less sodium than imported basa
- AFB is a better source of essential micronutrients than imported basa
- AFB has more than 16 times more n-3 LC-PUFA than imported basa
- AFB has more than 14 times more omega-3 than imported basa
- AFB has 4 times more monounsaturated fats than imported basa
- AFB is a richer source of monounsaturated fat than imported basa
- AFB has over 5 times more polyunsaturated fat than imported basa
- AFB is a richer source of polyunsaturated fat than imported basa

Australian farmed barramundi (AFB) versus imported Nile perch

- AFB has more potassium and phosphorus than imported Nile perch
- AFB has more iron than Nile perch
- AFB is a better source of essential micronutrients than imported Nile perch
- AFB has nearly three times more n-3 LC-PUFA than imported Nile perch
- AFB has over 3 times more omega-3 than imported Nile perch
- AFB has 18 times more monounsaturated fat than imported Nile perch
- AFB is a richer source of monounsaturated fat than imported Nile perch
- AFB has over 5 times more polyunsaturated fat than imported Nile perch
- AFB is a richer source of polyunsaturated fat than imported Nile perch

AFB versus wild Australian snapper (synonymous with "some wild caught Australian fish")

- AFB has slightly more EPA and DPA than wild caught snapper
- AFB has slightly more omega-3 than wild caught snapper
- AFB has 18 times more monounsaturated fat than wild caught snapper
- AFB is a richer source of monounsaturated fat than wild caught snapper
- AFB has over 3 times more polyunsaturated fat than wild caught snapper
- AFB is a richer source of polyunsaturated fat than wild caught snapper

Does the nutritional value of farmed Australian barramundi vary by season and salinity or production?

The absolute contents of nutrients in fillets of farmed fish, particularly n-3 LC-PUFA, is highly regulated by dietary composition and highly dependent on fish size. Given different feeds of unknown nutrient composition used across farms, seasons and water salinities, as well as the differences in weight of sampled fish across seasons and water salinities, it is not conclusive whether the nutritional value of farmed Australian barramundi was affected by season and water salinity as few differences were found among fish from the different sample groups. Further research should evaluate the effect of season and salinity in fillets of fish of similar size and fed with the same feed.

Does the current nutritional value of farmed Australian barramundi warrant research and efforts towards creating a tailored made feed that result in premium quality fillets?

An increasing amount of research has been directed towards creating more nutritionally beneficial foods to increase the overall health of the population and as a marketing advantage. In relation to aquaculture, the increase in the use of plant-based ingredients in aquafeeds has resulted in decreased n-3 LC-PUFA levels in aquaculture produce. This has prompted research efforts into tailoring feed and feeding regimes to maximise levels of beneficial nutrients in aquaculture produce, with the main focus being on these n-3 LC-PUFA. As such, much of the following discussion will focus on n-3 LC-PUFA in relation to tailored made feed for Australian farmed barramundi. The current report demonstrates a clear trend of decreasing levels of n-3 LC-PUFA in Australian farmed barramundi since 2002, which is without doubt, a direct consequence of decreased levels of these fatty acids in the formulated diets fed to the animals. Specifically, the n-3 LC-PUFA content of Australian farmed barramundi was 1966 mg per 100 g fillet in 2002 and 790 mg per 100 g fillet in 2010 (Nichols et al. 2014). Thus, the average n-3 LC-PUFA levels in Australian farmed barramundi (401 mg per 100 g fillet; Table 3) has decreased by 5-fold from 2002, and 2-fold from 2010. However, the data also demonstrate that Australian farmed barramundi currently has statistically similar levels of n-3 LC-PUFA as wild caught barramundi (401 versus 239 mg / 100 g fillet).

While limited, consumer research in Australia has found that those who purchased Australian farmed barramundi did so largely for the taste (68 %), with little mention of health benefits being a factor. This contrasted with those who bought salmon, whereby perceived health benefits was the second most prominent reason for purchasing this fish (FRDC 2011). Thus, without more research data on the Australian consumer's knowledge and desires on issues such as n-3 LC-PUFA levels in barramundi, it is difficult to determine if a tailor made feed designed to increase n-3 LC-PUFA levels in Australian farmed barramundi, and the associated production of nutritionally premium quality barramundi fillets, is economically justified.

The level of n-3 LC-PUFA in the diets of Australian farmed barramundi can be viewed at a number of levels. In relation to nutrition, there is an obvious case to ensure the animals dietary requirements are met, as this ensures good health and growth and the accompanying economic benefits to the farmer. Barramundi are unable to synthesise sufficient n-3 LC-PUFA to meet requirements (Salini et al. 2015), but requirements are low (for example <1 g DHA kg^{-1} diet (Morton et al. 2014)). As such, the overall n-3 LC-PUFA intake by the animals at one or more stages during the production cycle must be more than animal requirements, in order to match or maintain current fillet levels of n-3 LC-PUFA, and the loss of a portion of the fatty acids to metabolic oxidation within the animal must be accepted.

If a marketing advantage and/or price premium proves obtainable for tailored Australian farmed barramundi fillets then several strategies can be pursued for tailoring feeds and feeding regimes, replicating what has occurred in more mature industries such as in the international Atlantic salmon industry. These strategies are based largely on manipulating the n-3 LC-PUFA levels and the sensory qualities (colour, aroma, taste) of the fillet. Dietary n-3 LC-PUFA retention efficiency, and when possible *de nova* synthesis, increases with decreasing dietary levels (Salini et al. 2015, Callet et al. 2017). Thus, one strategy is to find a compromise between dietary levels of n-3 LC-PUFA and n-3 LC-PUFA retention in the fish, to ensure a minimum n-3 LC-PUFA level in Australian farmed barramundi that aligns with consumer preferences. The second strategy is to formulate a finishing diet that aims to elevate levels of beneficial nutrients and fillet sensory and storage qualities in the final stages of the animals growout. A finishing diet could be combined with a pre-finishing growout diet that contains only the n-3 LC-PUFA levels to meet barramundi requirements, which could help to balance out the economic costs of such a strategy over a production cycle.

The data also demonstrate little difference in nutritional composition between imported and Australian grown barramundi for the nutrients analysed. Thus, while Australian farmed barramundi may have a competitive advantage in relation to being delivered fresh to the consumer (among others), further advantage may be gained by tailoring feed to differentiate the two products and further justify the price difference to the consumer. The most obvious choice would be to develop a dietary regime which results in Australian farmed barramundi with a statistically greater level of n-3 LC-PUFA than the imported product (currently Australian farmed barramundi is 401 vs imported of 432 mg n-3 LC-PUFA/100 g fillet). As mentioned, Australian farmed barramundi in 2002 contained 1966 mg n-3 LC-PUFA / 100 g fillet, clearly demonstrating changes to diet composition can result in farmed barramundi with n-3 LC-PUFA that exceed the current levels found in imported barramundi, and even domestically produced Atlantic salmon (1034 mg n-3 LC-PUFA found in the current study).

How can this data be used to raise awareness at the household level and in health sectors via ABFA marketing and promotions through social media and future marketing campaigns?

There are three ways the data can be used to market Australian farmed barramundi to households and the health sector

1. Australian farmed barramundi can be marketed for its seafood qualities (high n-3 LC-PUFA and selenium) against common terrestrial meats (as highlighted above).
2. Australian farmed barramundi can be marketed as a healthier alternative against other seafoods, specifically imported white flesh fish such as Basa and Nile perch.
3. Australian farmed barramundi can be marketed for its general health qualities in isolation of other food types in relation to meeting Australian recommended dietary intakes.

In relation to (3) above, Australian farmed barramundi (AFB) has many attributes that are increasingly being associated with good health scientifically and in the minds of consumers, these attributes provide marketing opportunities. The following statements or similar are valid in this respect. Statements are followed by the clause and standard in Food Standards Australia required to make such a claim on the nutritional quality of a product (One serving is based on portion of 150 g).

- AFB is a good source of monounsaturated fat (or the synonymous omega-9) (<28 % saturated fat, >40 % mono unsaturated fat of total fat, Clause 12 of Standard 1.2.8, FSA)
- AFB is a good source of omega-3 (<28 % saturated fat of total fat, <5 g saturated fat / 100 g food, >60 mg EPA + DHA per serve, Clause 13 of Standard 1.2.8, FSA)
- AFB has a low proportion of saturated fat (<28 % saturated fat of total fat, must state 'low proportion of *saturated and *trans fatty acids of total fatty acid content'. See schedule 4, FSA)
- AFB is a good source of protein (>10 g protein per serve. See schedule 4, FSA)
- AFB is low in sodium (<120 mg / 100 g food, Clause 17 of Standard 1.2.8, FSA)
- AFB contains magnesium, potassium, phosphorus, selenium and zinc (The food must meet the general claim conditions for making a nutrition content claim, schedule 4, FSA)
- AFB is a good source of selenium (The food must meet the general claim conditions for making a nutrition content claim, schedule 4, FSA)
- One serve of AFB gives you all your daily n-3 LC-PUFA needs (synonymous with DHA+EPA, or DHA+DPA+EPA)(See Table 7)
- One serve of AFB gives you over half your daily Selenium needs (See Table 8)

Conclusion

The data obtained on the nutrient profile of Australian farmed barramundi through this study presents immediate marketing opportunities for the ABFA. The findings will become of greater value when more market research related to recognition of farmed barramundi is conducted with the Australian consumer. Market research will increase understanding of what the market, or potential market, understands about specific nutrients that are found in substantial amounts in Australian farmed barramundi.

Recommendations

1. Use the current data and associated statements for a marketing campaign.
2. Conduct market research to determine if consumers desire and/or are willing to pay a premium for tailor made fillets.
3. Develop studies that determine the appropriate composition and feeding regime for a finishing diet that results in fillets that meet or exceed market expectations.
4. Analyse Australian farmed barramundi for antibiotics, iodine and vitamin D levels.

Further development

Developing a strategy to tailor feeds could be further investigated.

Minimal research has been conducted in modifying diets to enhance the non n-3 LC-PUFA nutritional composition, or the sensory properties of fish. Many micronutrients are tightly regulated in the body, and it is difficult to manipulate their levels in the fillet using dietary levels within nutritionally relevant ranges. For instance, Zn levels in fish are tightly regulated, with fillet levels remaining the same as dietary levels increase (Moazenzadeh et al. 2018). This is true also for the majority of the other micronutrient elements that ultimately could be of interest to the consumer, i.e. Cu (Lin et al. 2010), Fe (Andersen et al. 1996), Mg (Shim and Ng 1988), Mn (Maage et al. 2000). Ultimately, this rules the majority of elements out as candidates for modifying beyond barramundi requirements in a tailormade feed. The exception to this rule is Se, which due to its presence in selenomethionine, can be increased in fillet levels in a dose dependent manner (Lin and Shiau 2005). Thus, if a marketing advantage is found in increasing the levels of Se in barramundi fillets, and legislation permits, it can quite easily be increased to levels similar to or higher than any other seafood, including imported barramundi.

Alongside Se and n-3 LC-PUFA, other areas can be an additional focus of a tailormade feed with the aim of improving product shelf life and sensory properties. There is some evidence that tailoring diets can increase post slaughter fillet quality. For instance increasing dietary vitamin E levels can increase fish fillet vitamin E levels, and may decrease fillet oxidation levels post slaughter (Kamireddy et al. 2011).

Extension and Adoption

ABFA will be responsible to send the final report to the Media Centre of Food Standards Australia New Zealand for the online publication of the report and update of food databases.

ABFA commits to consumer outreach by covering the cost of developing infographics that can be distributed to retailers around the country and shown at sale point. In addition, social media tools will be used by ABFA and JCU for marketing communication.

The ABFA will add the information gathered in this project into its marketing materials which will greatly assist consumer awareness of the health benefits of Australian farmed barramundi and assist in increasing sales volumes and price.

A major output of this project will be a report to communicate the updated nutritional composition of Australian farmed barramundi and other fish products to farmers, seafood marketers and feed companies.

ABFA has shown interest in the production of a premium barramundi fillet (i.e. enhanced content of n3 LC-PUFA in fillet), thus the information in this report is important for farmers and feed manufacturers to decide whether aquafeeds tailored to achieve a premium quality fillet are economically feasible and therefore worthwhile to be developed. This report will be also made available to health organizations and food agencies for the update of food composition databases and recommended intakes.

References

Andersen, F., A. Maage and K. Julshamn (1996). "An estimation of dietary iron requirement of Atlantic salmon, Salmo salar L., parr." Aquaculture Nutrition **2**(1): 41-47.

Callet, T., F. Médale, L. Larroquet, A. Surget, P. Aguirre, T. Kerneis, L. Labbé, E. Quillet, I. Geurden, S. Skiba-Cassy and M. Dupont-Nivet (2017). "Successful selection of rainbow trout (Oncorhynchus mykiss) on their ability to grow with a diet completely devoid of fishmeal and fish oil, and correlated changes in nutritional traits." PLOS ONE **12**(10).

Codabaccus, M. B., W.-K. Ng, P. D. Nichols and C. G. Carter (2013). "Restoration of EPA and DHA in rainbow trout (Oncorhynchus mykiss) using a finishing fish oil diet at two different water temperatures." Food Chemistry **141**(1): 236-244.

FRDC. (2011). "Understanding The Australian Seafood Consumer (and Chefs)." from http://www.frdc.com.au/-/media/Fish-FRDC/Education/Module6-Understanding_The_Australian_Seafood_Consumer_and_Chefs.ashx?la=en.

Grigorakis, K. (2007). "Compositional and organoleptic quality of farmed and wild gilthead sea bream (Sparus aurata) and sea bass (Dicentrarchus labrax) and factors affecting it: A review." Aquaculture **272**(1-4): 55-75.

ISSFAL (2004). Official Satement from the International Society for the study of fatty acids and lipids on Intake of PUFA in Healthy Adults. Brighton, International Society for the study of fatty acids and lipids.

Kamireddy, N., S. Jittinandana, P. B. Kenney, S. D. Slider, R. A. Kiser, P. M. Mazik and J. A. Hankins (2011). "Effect of Dietary Vitamin E Supplementation and Refrigerated Storage on Quality of Rainbow Trout Fillets." Journal of Food Science **76**(4).

Lin, Y.-H. and S.-Y. Shiau (2005). "Dietary selenium requirements of juvenile grouper, Epinephelus malabaricus." Aquaculture **250**(1-2): 356-363.

Lin, Y.-H., C.-C. Shih, M. Kent and S.-Y. Shiau (2010). "Dietary copper requirement reevaluation for juvenile grouper, Epinephelus malabaricus, with an organic copper source." Aquaculture **310**(1-2): 173-177.

Maage, A., B. Lygren and A. El-Mowafic (2000). "Manganese requirement of Atlantic salmon (Salmo salar) fry." Fisheries Science **66**(1): 1-8.

Moazenzadeh, K., R. H. Islami, A. Zamini and M. Soltani (2018). "Effects of dietary zinc level on performance, zinc status, tissue composition and enzyme activities of juvenile Siberian sturgeon, Acipenser baerii (Brandt 1869)." Aquaculture Nutrition **24**(4): 1330-1339.

Morton, K. M., D. Blyth, N. Bourne, S. Irvin and B. D. Glencross (2014). "Effect of ration level and dietary docosahexaenoic acid content on the requirements for long-chain polyunsaturated fatty acids by juvenile barramundi (Lates calcarifer)." Aquaculture **433**: 164-172.

Mourente, G. and J. G. Bell (2006). "Partial replacement of dietary fish oil with blends of vegetable oils (rapeseed, linseed and palm oils) in diets for European sea bass (Dicentrarchus labrax L.) over a long term growth study: Effects on muscle and liver fatty acid composition and effectiveness of a fish oil finishing diet." Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology **145**(3-4): 389-399.

Mraz, J., T. Zajic and J. Pickova (2012). "Culture of common carp (Cyprinus carpio) with defined flesh quality for prevention of cardiovascular diseases using finishing feeding strategy." Neuro Endocrinol Lett **33 Suppl 2**: 60-67.

NHFA (2015). Sources of Omega-3, The National Heart Foundation of Australia.
Nichols, P. D., B. Glencross, J. R. Petrie and S. P. Singh (2014). "Readily available sources of long-chain omega-3 oils: is farmed Australian seafood a better source of the good oil than wild-caught seafood?" Nutrients **6**(3): 1063-1079.

NS 9401 (1994). Atlantic salmon. In: Reference sampling for quality measurements. Norsk standard, 1st Ed. (p. 3). Oslo, Norway: Norges Standardiseringsforbund.

NRV (2006). Nutrient reference values for Australia and New Zealand including recommended dietary intakes, Australian National Health and Medical Research Council (NHMRC) and the New Zealand Ministry of Health (MoH).

Nuez-Ortin, W.G., Carter, C.C., Cooke, I., Wilson, R, Nichols, P. (2016). Preliminary Validation of a High Docosahexaenoic Acid (DHA) and alpha-Linolenic Acid (ALA) Dietary Oil Blend: Tissue Fatty Acid Composition and Liver Proteome Response in Atlantic Salmon (Salmo salar) Smolts. PlosOne. DOI:10.1371/journal.pone.0161513

Salini, M., S. Irvin, N. Bourne, D. Blyth, S. Cheers, N. Habilay and B. Glencross (2015). "Marginal efficiencies of long chain-polyunsaturated fatty acid use by barramundi (Lates calcarifer) when fed diets with varying blends of fish oil and poultry fat." Aquaculture **449**: 48-57.

Salini, M. J., G. M. Turchini, N. M. Wade and B. D. Glencross (2015). "Rapid effects of essential fatty acid deficiency on growth and development parameters and transcription of key fatty acid metabolism genes in juvenile barramundi (Lates calcarifer)." The British journal of nutrition **114**(11): 1784-1796.

Shim, K. F. and S. H. Ng (1988). "Magnesium requirement of the guppy (Poecilia reticulata Peters)." Aquaculture **73**(1-4): 131-141.

Torstensen, B. E., J. G. Bell, G. Rosenlund, R. J. Henderson, I. E. Graff, D. R. Tocher, Ø. Lie and J. R. Sargent (2005). "Tailoring of Atlantic Salmon (Salmo salar L.) Flesh Lipid Composition and Sensory

Quality by Replacing Fish Oil with a Vegetable Oil Blend." Journal of Agricultural and Food Chemistry **53**(26): 10166-10178.

Waschulewski, I. H. and R. A. Sunde (1988). "Effect of Dietary Methionine on Utilization of Tissue Selenium from Dietary Selenomethionine for Glutathione Peroxidase in the Rat." The Journal of Nutrition **118**(3): 367-374.