

Growth, feed conversion and faecal discharge of yellowtail kingfish (*Seriola lalandi*) fed three commercial diets

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Abstract A study was undertaken to provide data on growth, feed conversion ratio (FCR) and faecal discharge of yellowtail kingfish (*Seriola lalandi*) fed three commercial diets used previously to culture this species in New Zealand. Fish were raised in tanks from 0.4 to 1.2 kg over the spring (water temperature 14–17°C) and summer (17–22°C) periods. There were considerable differences in volumetric and mass-specific feed intake, and energy intake amongst diets. Daily crude protein intake was similar amongst diets, although it increased from the cold (4.05–4.50 g protein kg⁻¹ day⁻¹) to warm period (6.48–7.67 g protein kg⁻¹ day⁻¹). The biological and economical FCR varied with diet (BFCR 1.22–2.17, EFCR 1.30–2.62), as did the cost of feed per unit biomass produced (NZ\$2.38–3.78 kg⁻¹). Growth rates were broadly similar amongst diets, and the warmer summer temperature period greatly improved both growth (increase from 0.51–0.64% to 1.18–1.23% mass gain day⁻¹) and BFCR (decrease from 1.37–2.17 to 1.22–1.46). The Salmofood ESF diet resulted in only half of the faecal settleable solids and settleable

total nitrogen (TN) and total phosphorus (TP) output compared with Skretting NME, which was in turn only half or less of that of Reliance SF.

Keywords aquaculture; feed intake; growth; settleable solids; temperature

INTRODUCTION

Yellowtail kingfish (*Seriola lalandi* Valenciennes 1833) is a marine species of aquacultural importance in Australia (Hutson et al. 2007; Fernandes & Tanner 2008), New Zealand (Moran et al. 2008), Japan (Nakada 2002), and Chile, but one for which little has been published on the grow-out phase of the production cycle. The diets that have been used to raise this species in New Zealand to date have been chosen based on factors such as physical properties (e.g., floating or sinking), price, availability, ingredients, and nutritional profiles (D. Moran & S.J. Pether pers. obs.). The diets have been primarily manufactured for salmonids, and no data have been available to compare the environmental or production performance of these diets for yellowtail kingfish.

Some of the key factors used to assess the environmental impacts of land-based and sea cage production systems is the discharge of nitrogen, phosphorus and settleable solids into the surrounding water (Cho et al. 1994; Aubin et al. 2006). Excessive nutrient discharges from uneaten feed and excreta can lead to eutrophication of the area around sea cages or land-based farm discharge outlets (Gowen 1994), and settleable solids can accumulate on the sea floor and cause localised depletion of the epifauna (Gowen et al. 1991). A recent modelling study of nutrient discharges from Australian yellowtail kingfish farms indicates that this species may have a significantly higher eutrophication impact than other cultured finfish species (Fernandes & Tanner 2008). For this reason, there is a need to develop a better understanding of the relationship between nutrition, production, and environmental impact of yellowtail kingfish aquaculture.

To our knowledge there is no published information on the nutritional requirements of yellowtail kingfish, but there are several studies on the effect of different dietary formulations for Japanese yellowtail (*S. quinquerediata*) and Mediterranean yellowtail (*S. dumerili*) (Taki et al. 1989; Ukawa et al. 1994; Masumoto et al. 1996; Ruchimat et al. 1997a,b; Watanabe et al. 2000a; Tomás et al. 2005; Vidal et al. 2008). Most of these studies relate to the optimisation of protein inclusion rates, or substituting fish meal with other animal or plant protein sources. Japanese yellowtail are reported to require relatively high protein levels (52%) in feed for maximum growth (Masumoto et al. 1998), as are Mediterranean yellowtail (50%+) (Jover et al. 1999; Vidal et al. 2008), probably because *Seriola* spp. are highly reliant on protein for both growth and energy (Masumoto et al. 1998; Takakuwa et al. 2006).

The purpose of this study was to provide data on the effect of three commercial diets on yellowtail kingfish growth rate, feed intake, feed conversion ratio (FCR), cost of biomass production, and faecal discharge characteristics. The daily protein intake was calculated to assess whether yellowtail kingfish have a similar protein requirement to that reported in other *Seriola* spp. for maximum growth at different seasonal temperatures. Although the direct comparison of commercial diets is not widespread in nutritional aquaculture research, there are some published studies that have used this approach (e.g., Maage et al. 1989; Lee & Litvak 1996; Hung et al. 1998; Satoh et al. 2003; Fülberth et al. 2009). Independent testing of commercial diets used in aquaculture is important for farm managers and those carrying out environmental impact assessments of farming operations, and can also highlight areas where diets can be optimised and research is needed.

MATERIALS AND METHODS

Experimental subjects and feed types

The study was carried out between November 2006 and February 2007 at Ruakaka in the north of New Zealand (National Institute of Water and Atmospheric Research Limited (NIWA) Bream Bay Aquaculture Park). Yellowtail kingfish produced at the same facility (c. 0.4 kg) were fed a mixture of the three commercial diets to be tested for 1 month before the trial. The diets used in this study were as follows: Salmofood Estrategia SF (hereafter Salmofood ESF, Salmofood, Castro, Chile); Skretting Nova ME (hereafter Skretting NME, Skretting Australia,

Tasmania, Australia); and Reliance Salmon Food (hereafter Reliance SF, Reliance Feeds, Christchurch, New Zealand). These feeds were chosen as they have been used for the commercial on-growing of yellowtail kingfish in New Zealand (D. Moran pers. obs.). Pellet sizes used were 9 and 11 mm for Salmofood ESF and Skretting NME, and 8 and 11 mm for Reliance SF. To approximate the feed protocols used in New Zealand commercial grow-out operations, the pellet size was changed during the trial as the fish grew. From the beginning of the trial until 13 February 2007, 9 mm Salmofood ESF and Skretting NME pellets were fed (fish weight c. 1.0 kg), after which time 11 mm pellets were fed. Until 29 January 2007, 8 mm Reliance SF pellets were fed (fish weight c. 0.9 kg), after which time 11 mm pellets were fed. An independent macronutrient analysis was undertaken (AgriQuality Ltd, Auckland, New Zealand) for comparison with manufacturer information (Table 1). Ash was quantified according to Association of Official Analytical Chemists standard 923.03 (AOAC 1990); protein calculated by combustion (method 990.03, AOAC 1990); fat quantified according to AOAC standards 922.06, 950.54, 948.15, 954.02 (AOAC 1990); free fatty acids quantified using American Oil Chemist Society standard Ca 5a-40 (AOCS 1997) and an accelerated solvent extraction (ASE); peroxide value quantified using ASE and AOCS standard Cd 8b-90 (AOCS 1997). Sinking speed was measured by dropping a single pellet ($n = 20$ for each diet) into a tank 0.85 m deep and recording the time (to nearest 0.1 s) it took to sink to the bottom (water salinity 37 PSU, 20.8°C). Pellet density was calculated by measuring the dimension of a pellet ($n = 20$ for each diet) with callipers (to nearest 1 mm) and weighing it (to nearest 0.01 g).

Experimental setup and daily feeding regime

The three commercial diets were compared using four replicate tanks of fish per treatment (12 tanks in total). The tanks used were 1.50 m in diameter and 0.85 m deep plastic tanks (1500 litres) with water exiting from a surface drain. A drain and tap at the centre base of the tank allowed for the collection of uneaten feed and settleable solids. Sea water was pumped ashore (salinity 37 PSU, pH 8.3), filtered to 5 μm through a sand filter and supplied to each tank at a rate of 50–60 litres min^{-1} . Oxygen was added into the tanks by a wooden diffuser to maintain an oxygen concentration of 85–100% air saturation. Water temperature was that of the ambient incoming water (detailed below) and tanks were lit with diffuse sunlight (10 000–15 000 lux at water surface).

Temperature and dissolved oxygen were measured daily, and tanks cleaned (scrubbed) every 4 weeks without removing the fish.

The trial ran for 114 days from November 2006 to February 2007, which represents the austral spring and summer. To start the trial, fish were lightly sedated using Aqui-S (active ingredient isoeugenol, Aqui-S New Zealand Ltd, Lower Hutt, New Zealand), weighed in groups of 4–6 to the nearest 0.01 kg and 40 fish allocated to each trial tank. There were two re-weighing periods during the trial. The first was on 19 December 2007, 47 days after the start of the trial (hereafter termed the first period), which approximately coincided with a change in water temperature from spring temperatures to summer temperatures. This seasonal boundary was based on the transition of water temperatures from below 17°C to above 17°C, which represents the onset of increased feeding and spawning activity in yellowtail kingfish (Moran et al. 2007). The second weighing period was at the completion of the trial on 23 February 2007, 67 days after the previous weighing date (termed the second period). Before each weighing, the fish were starved for 36 h. At both sampling times, the fish were sedated using 15 ppm Aqui-S and groups of 4–6 fish were weighed to the nearest 0.01 kg. Mortalities were collected daily

and weighed. The daily water temperatures for the first period ranged from 14.2°C to 17.3°C (with a median of 15.7°C), and for the second period from 17.0°C to 21.6°C (with a median of 19.5°C).

Fish were fed twice a day at 0900 and 1500 h. Before feeding, tanks were partially drained from the bottom to remove settled solids. Fish were then fed by hand over a 15 min period until no more pellets were consumed, and the amount of feed administered recorded to the nearest 1.0 g. Thirty min after the cessation of feeding the uneaten feed was collected in a 1 mm mesh net held over the outlet of the bottom drain. Any uneaten floating feed was also removed. Uneaten Salmofood ESF and Skretting NME pellets were counted, and converted to an original feed mass equivalent using the mean pellet weights derived from the measurement of 20 pellets (mean \pm SD, Salmofood ESF 9 mm: 0.58 \pm 0.04 g, 11 mm: 1.10 \pm 0.06 g; Skretting NME 9 mm: 0.66 \pm 0.07 g, 11 mm: 1.12 \pm 0.11 g). Reliance SF pellets became swollen and broke into smaller pieces once in the water for longer than 5 min, so counting the number of uneaten pellets of this feed type was not possible. Tests showed that Reliance SF pellets left to soak in water reached a constant weight after 30 min and remained stable for a further 30 min. The hydration stability allowed the uneaten and broken-up Reliance SF, once collected

Table 1 Feed composition and properties of three commercial diets fed to yellowtail kingfish *Seriola lalandi* (% represents mass of nutrient per pellet mass).

	Salmofood ESF	Skretting NME	Reliance SF
Information supplied by manufacturer			
Manufacturing process	Extrusion	Extrusion	Steam pressed
Protein source	Fish meal, non-ruminant meal, plant protein meal	Fish meal, plant protein meal, poultry meal	Fish meal, meat and bone meal, dried animal blood, milk powder
Lipid source	Fish oil	Fish oil, poultry oil	Fish oil
Gross energy (MJ kg ⁻¹)	23.5	18.9	15.6
Ash (%)	not available	9.0	11.0
Protein (%)	43.0	45.0	45.0
Lipid (%)	26.0	20.0	15.0
Carbohydrate (%)	18.0	18.0	18.0
Moisture (%)	10.0	8.0	10.0
Independent analysis			
Ash (%)	7.3	6.8	12.7
Protein (%)	49.1	41.8	42.5
Lipid (%)	21.4	23.2	17.0
Free fatty acid (%)	3.8	3.1	6.4
Peroxide (meq O ₂ kg ⁻¹)	7.0	4.6	5.9
Delivered price (\$NZ kg ⁻¹)	2.75	1.79	1.69
Pellet size (mm)	9 11	9 11	8 11
Density (cm ³ g ⁻¹)	5.06 4.84	3.50 3.77	2.84 3.60
Sinking speed (cm s ⁻¹)	0 0	14 10	18 20

and strained through a 1 mm mesh, to be calculated as an original mass using the following hydration factors: hydrated Reliance SF 8 mm = original weight $\times 1.75$ (± 0.04 SD, $n = 10 \times 10$ g replicates); hydrated Reliance SF 11 mm = original weight $\times 1.72$ (± 0.05 SD, $n = 10 \times 10$ g replicates).

Faeces collection and analysis

In the final week of the trial, the amount of faeces (as settleable solids) produced over a 24 h period following feeding was quantified in three replicate tanks of each feed type. Before feeding in the morning, each tank was partially drained from the bottom and the settleable solids collected in a 180 μm mesh net. The contents in the net were drained of most water by squeezing and then repeatedly blotted on tissue paper until little water was wetting new tissue paper. The contents were then weighed to the nearest 1.0 g. Following measurement of settleable solids, the fish were fed once daily to satiation (feeding took approximately 10 min) and uneaten pellets collected immediately after feeding (as described above). The amount of faeces excreted during the feeding period was negligible. This process was repeated over 3 days, and the blotted wet weight of settled solids was calculated as a proportion of the mass of feed administered ($n = 9$ observations per feed type). Sub-samples of settled solids from a single feed period were frozen and analysed for total nitrogen (TN) and total recoverable phosphorus (TP) content (Hill Laboratories, Hamilton, New Zealand). The samples were lyophilised and TN analysed via catalytic combustion followed by gas chromatography (Bremner 1996). Total recoverable phosphorus was analysed via nitric acid/hydrochloric acid digestion (Martin et al. 1994) and inductively coupled plasma mass spectrometry (Creed et al. 1994). The behaviour of settleable solids can vary substantially depending on a number of factors, in particular the dynamics of the water currents (Elberizon & Kelly 1998; Chen et al. 1999). It is recognised that the amount of settleable solids recorded in the current study may not represent the absolute values that can be expected in a sea cage scenario, but as the water currents, temperature and salinity were similar in each rearing tank, the results are useful for comparative purposes.

Data analysis

For each replicate tank and measurement period the following variables were calculated. Daily feed consumption was calculated as both mass (% body weight (BW) consumed day⁻¹) and volume of feed

consumed (cm³ consumed kg⁻¹ biomass day⁻¹). The volume of feed eaten per meal was calculated from the mass of feed consumed and the pellet density (see Table 1). The percentage of the daily feed intake consumed in the first meal was used as an index of how daily feed consumption was divided between the twice-daily meals. Daily protein intake (g consumed kg⁻¹ biomass day⁻¹) was calculated using the crude nutritional composition data (from the independent analysis) and the mean daily feed intake. Daily energy intake (MJ consumed kg⁻¹ biomass day⁻¹) was calculated using dietary energy data supplied by the manufacturer and the mean daily feed intake. Specific growth rate (SGR, % weight gain day⁻¹) was calculated using the formula $\text{SGR} = (\exp^g - 1) \times 100$, where $g = (\ln W_{T_1} - \ln W_{T_0}) / (T_1 - T_0)$, where W = mean individual weight, and T = time. Relative daily feed consumption (%BW consumed day⁻¹) was estimated using the SGR data. In this study, both the biological feed conversion ratio (BFCR) and the economical feed conversion ratio (EFCR) were measured. The former provides an exact measure of the nutritional value of the diet for growth as it is calculated from the amount of feed that is ingested, whereas the latter accounts for the fact that not all feed is ingested *in situ* and there is a degree of wastage. The BFCR was calculated by dividing the mass of feed consumed by the biomass increase over the measurement period (with adjustments for any mortality that occurred). The EFCR was calculated by dividing the mass of feed administered by the biomass increase. The cost of biomass production (NZ\$ kg⁻¹ biomass produced) for each feed type was calculated using the delivered feed cost (see Table 1) and the BFCR and EFCR data for each replicate tank. Feed prices are contingent on volume ordered and delivery distance, and were used for comparative purposes only. Labour and infrastructure costs were not incorporated into the cost of biomass production. Settleable solids production was calculated as a function of the amount of feed (wet weight) ingested (g settleable solids produced kg⁻¹ feed). The data on the production of settleable solids per kg food consumed were not intended to be used for mass-balance purposes, as the comparative hydration of the settleable solids versus pellets were different. However, there was a need to standardise the mass of settleable solid faeces produced to some measure of feed input, hence the rationale for using the units chosen. Settled solids TN and TP output was calculated as a mass excreted per kg feed (wet weight) consumed (g TN or TP kg⁻¹ feed consumed), and also as a mass excreted per tonne of fish produced (kg TN or TP tonne⁻¹ fish produced) using the BFCR data for each replicate.

One of the trial tanks fed Reliance SF suffered a disease event mid-way through the first measurement period, resulting in the mortality of 10 fish in two weeks. Owing to the uncertainty about the effect of the disease event on the growth characteristics of the fish, this replicate was not included in the data analysis for the first period. The feeding rate was similar to that of other tanks for the second measurement period and the fish appeared healthy. All parameters measured in this tank were similar to that of the other replicates in the second period (0–14% of mean values), so the data of the 30 remaining fish were included in the analysis as it was assumed the surviving fish had recovered sufficiently to be comparable with other replicates.

Statistical analyses

A mean (\pm SD) was calculated from the replicate tanks for the aforementioned production attributes (i.e., individual weight, feed intake, protein intake, SGR, FCR, biomass cost) for each diet and time period. One-way ANOVA was used to compare variance amongst treatments for each measurement (Fowler et al. 1998). Significant differences between treatment means were evaluated using the unequal-N Tukey HSD test for period 1 (as the Reliance SF treatment had only 3 replicates), and a Tukey HSD test for period 2 (all n equal amongst treatments) (Fowler et al. 1998). The nonparametric Kruskal-Wallis test was used to compare variance between treatments when the assumptions of parametric analysis were not satisfied, and multiple comparisons of mean ranks were used for post-hoc comparisons (Siegel & Castellan 1988). Comparison of SGR for the second period was carried out using initial weight as a covariate (ANCOVA), as weight and SGR are correlated. Faecal production rates were compared by calculating a grand mean (\pm SD) from the 9 samples collected for each feed type. A Kruskal-Wallis test was then used to compare the variance amongst treatments. Faecal TN and TP content were analysed by ANOVA and Tukey HSD. All statistical comparisons were performed in Statistica (v. 7.1, StatSoft Inc, United States).

RESULTS

Feed intake, growth and FCR

There were highly significant differences in both mass-specific (ANOVA, $F_{2,8} = 40.77$, $P < 0.01$) and volume-specific feed intake (ANOVA, $F_{2,8} = 159.34$, $P < 0.01$) amongst diets for the first (14–17°C) and second period (17–22°C; mass-specific: ANOVA, $F_{2,9}$

$= 10.94$, $P < 0.01$; volume-specific: ANOVA, $F_{2,9} = 38.96$, $P < 0.01$) (Table 2). During both measurement periods, the mass-specific intake was highest for Reliance SF, followed by Skretting NME and then Salmofood ESF. The opposite pattern was evident for volume-specific intake, with the highest volume consumed using Salmofood ESF and the lowest using Reliance SF. Feed intake was higher in the second, warmer period by a factor of 1.6–1.7 for all diets. Diet type had no significant effect on the amount of feed consumed between the twice daily meals during the first period (Kruskal-Wallis, $H_{(2)} = 5.30$, $n = 11$, $P > 0.05$). Although there was a significant difference in the second period (ANOVA, $F_{2,9} = 7.70$, $P < 0.05$), the magnitude of the difference between diets was small. Overall, there was approximately equal feed intake between daily meals over the course of the trial. The amount of crude protein consumed per day during the first period was significantly different amongst diets (ANOVA, $F_{2,8} = 10.66$, $P < 0.01$), however, the magnitude of the difference was not great (4.20–4.50 g protein consumed kg^{-1} biomass day^{-1}). Crude protein intake was higher in the second period (6.48–7.67 g protein consumed kg^{-1} biomass day^{-1}). As was observed in the first period, there were statistically significant differences in crude protein intake between diets in the second period (ANOVA, $F_{2,9} = 5.45$, $P < 0.05$), however, the mean intake values were broadly similar. Daily energy intake amongst diets was significantly different for both time periods, with Salmofood ESF resulting in the highest daily energy intake and Reliance SF the lowest. Daily energy intake was higher in the second period, reflecting the increased feed intake (Table 2).

At the end of the first period, the highest average weights were achieved using Salmofood ESF, followed by Skretting NME then Reliance SF (Table 2). Salmofood ESF resulted in the highest mean SGR and lowest within-treatment variability compared with the other diets during the first period, though overall there was only a weak statistical difference in SGR between diets (Kruskal-Wallis, $H_{(2)} = 4.60$, $n = 11$, $P > 0.05$). The growth rates attained during the Second Period were similar amongst diets (1.18–1.23% day^{-1}), and were approximately twice that of the cooler first period. The average individual weights at the end of the trial for Salmofood ESF and Skretting NME were significantly higher (ANOVA, $F_{2,9} = 7.61$, $P < 0.05$) than the weight achieved using Reliance SF. There was a significant difference in the BFCR (ANOVA, $F_{2,8} = 12.07$, $P < 0.01$) and EFCR (ANOVA, $F_{2,8} = 6.93$, $P < 0.05$) amongst

Table 2 Results of feed trial for yellowtail kingfish (*Seriola lalandi*) raised on three commercial diets. Values represent mean \pm SD. Means followed by the same superscript do not differ at $P < 0.05$ (Tukey-HSD or multiple comparison of mean ranks). Significant test either ANOVA (AN), ANCOVA (AC) or Kruskal-Wallis (KW). One replicate tank for Reliance SF suffered a disease event during the first period, so data from this replicate were not included in the analysis. (SGR, specific growth rate; BFCR, EFCR, biological and economical feed conversion rates, respectively.)

n (replicate tanks)	First period, 14–17°C, 47 days, start weight 0.42 \pm 0.01 kg				Second period, 17–22°C, 67 days			
	Salmofood ESF		Reliance DF		Salmofood ESF		Reliance SF	
	4	4	3	P	4	4	4	P
Body weight at end (kg)	0.57 \pm 0.01 ^a	0.55 \pm 0.02 ^{ab}	0.51 \pm 0.03 ^b	0.01 AN	1.26 \pm 0.07 ^a	1.22 \pm 0.06 ^a	1.12 \pm 0.04 ^b	0.02 AN
Mass intake (% body weight day ⁻¹)	0.86 \pm 0.02 ^a	0.97 \pm 0.03 ^b	1.06 \pm 0.04 ^a	<0.01 AN	1.41 \pm 0.04 ^b	1.55 \pm 0.10 ^b	1.81 \pm 0.18 ^a	<0.01 AN
Volume intake (cm ³ kg ⁻¹ day ⁻¹)	43.32 \pm 0.85 ^c	33.90 \pm 1.14 ^b	30.01 \pm 1.10 ^a	<0.01 AN	68.43 \pm 2.14 ^b	45.46 \pm 3.10 ^a	53.96 \pm 5.46 ^c	<0.01 AN
First feed amount (% of daily intake)	51.38 \pm 2.41	48.62 \pm 4.16	45.13 \pm 3.68	0.07 KW	54.33 \pm 1.36 ^b	52.60 \pm 0.77 ^{ab}	50.79 \pm 2.13 ^a	0.01 AN
Protein intake (g protein kg ⁻¹ day ⁻¹)	4.20 \pm 0.08 ^b	4.05 \pm 0.14 ^b	4.50 \pm 0.16 ^a	<0.01 AN	6.94 \pm 0.22 ^{ab}	6.48 \pm 0.40 ^b	7.67 \pm 0.77 ^a	0.03 AN
Energy intake (MJ kg ⁻¹ day ⁻¹)	201 \pm 4 ^a	183 \pm 6 ^b	165 \pm 6 ^c	<0.01 AN	331 \pm 10 ^a	293 \pm 18 ^b	281 \pm 28 ^b	0.02 AN
SGR (% mass gain day ⁻¹)	0.64 \pm 0.01	0.58 \pm 0.08	0.51 \pm 0.11	0.10 KW	1.18 \pm 0.06	1.19 \pm 0.06	1.23 \pm 0.11	0.62 AC
BFCR	1.37 \pm 0.12 ^b	1.68 \pm 0.26 ^b	2.17 \pm 0.35 ^a	<0.01 AN	1.22 \pm 0.13	1.33 \pm 0.20	1.46 \pm 0.03	0.09 KW
Cost from BFCR (NZ\$ kg ⁻¹ produced)	3.78 \pm 0.35 ^a	2.98 \pm 0.27 ^b	3.67 \pm 0.59 ^{ab}	0.05 KW	3.37 \pm 0.24 ^b	2.38 \pm 0.36 ^a	2.47 \pm 0.05 ^a	0.02 KW
EFCR	1.84 \pm 0.22 ^a	2.04 \pm 0.21 ^a	2.62 \pm 0.04 ^b	0.02 AN	1.30 \pm 0.13 ^b	1.40 \pm 0.08 ^b	1.66 \pm 0.07 ^a	<0.01 AN
Cost from EFCR (NZ\$ kg ⁻¹ produced)	5.05 \pm 0.61 ^a	3.66 \pm 0.37 ^b	4.44 \pm 0.68 ^{ab}	0.03 AN	3.58 \pm 0.36 ^b	2.51 \pm 0.15 ^a	2.82 \pm 0.12 ^a	<0.01 AN

diets for the first period, ranging between 1.37–2.17 and 1.84–2.62, respectively (Table 2). Salmofood ESF resulted in the most efficient FCR, whereas Reliance SF was the least efficient. The BFCR and EFCR values in the second period were lower by 10–37% compared with the first period, and the magnitude of differences between and within feed types was reduced (Table 2). There was a weak statistical difference in BFCR amongst diets in the second period (Kruskal-Wallis, $H_{(2)} = 4.77$, $n = 12$, $P > 0.05$), but a stronger statistical difference in EFCR (ANOVA, $F_{2,9} = 13.90$, $P < 0.01$), and like in the first period, Salmofood ESF had the lowest EFCR (1.30) whereas Reliance SF had the highest (1.66). The feeding rate of the replicate Reliance SF tank that suffered a disease event during the first period was similar to that of the other replicates (1.01% BW day⁻¹), however, the BFCR and SGR were greatly affected (22.86 and 0.21% day⁻¹, respectively, versus a mean \pm SD of 2.17 \pm 0.35 and 0.51 \pm 0.11% day⁻¹ for the other replicates).

Overall biomass production costs were lower in the second period, reflecting the increased feed conversion efficiency observed during this time. The cost of production differed between diets during the first period, with Skretting NME the cheapest and Salmofood ESF the most expensive (Table 2). In the second period, Skretting NME and Reliance SF were significantly lower compared with Salmofood ESF for both BFCR (Kruskal-Wallis, $H_{(2)} = 7.42$, $n = 12$, $P < 0.05$) and EFCR (ANOVA, $F_{2,9} = 21.36$, $P < 0.01$) cost analyses (Table 2).

Faecal output

The mass of settleable solids resulting from faecal output was significantly different (Kruskal-Wallis, $H_{(2)} = 23.16$, $n = 27$, $P < 0.01$) amongst diets (Table 3). Salmofood ESF resulted in the lowest settleable solids output (55 g solids kg⁻¹ feed consumed), Skretting NME nearly twice this amount (99 g solids kg⁻¹ feed consumed), and Reliance SF 7.5 times that of Salmofood ESF (414 g solids kg⁻¹ feed consumed). Salmofood ESF also resulted in the lowest settleable solid nutrient output, with 0.61 and 0.17 g settled TN and TP kg⁻¹ feed consumed, respectively (Table 3). Skretting NME had approximately twice these values, whereas Reliance SF had 3.7 times the concentration of N and 10.3 times the concentration of P. The settled TN and TP output per tonne of fish followed a similar relationship, with Salmofood ESF resulting in considerably lower TN and TP excretion compared with Skretting NME, which in turn was lower than Reliance SF (Table 3).

Table 3 Effect of diet types on faecal output of yellowtail kingfish (*Seriola lalandi*). Values represent mean \pm SD. Means followed by the same superscript do not differ at $P < 0.05$ (Tukey-HSD or multiple comparison of mean ranks). Significant test either ANOVA (AN) or Kruskal-Wallis (KW). (TN, total nitrogen; TP, total phosphorus.)

<i>n</i>	Salmofood ESF 9	Skretting NME 9	Reliance SF 9	<i>P</i>
Settleable solids (g kg ⁻¹ feed)	55 \pm 16 ^c	99 \pm 18 ^b	414 \pm 67 ^a	<0.01 KW
<i>n</i>	3	3	3	
Settled TN (g TN kg ⁻¹ feed)	0.61 \pm 0.23 ^c	1.44 \pm 0.39 ^b	2.28 \pm 0.23 ^a	<0.01 AN
Settled TN (kg TN tonne ⁻¹ fish)	0.73 \pm 0.23 ^c	1.76 \pm 0.34 ^b	3.34 \pm 0.36 ^a	<0.01 AN
Settled TP (g TP kg ⁻¹ feed)	0.17 \pm 0.08 ^c	0.73 \pm 0.32 ^b	1.76 \pm 0.49 ^a	<0.01 AN
Settled TP (kg TP tonne ⁻¹ fish)	0.21 \pm 0.08 ^c	0.88 \pm 0.31 ^b	2.58 \pm 0.73 ^a	<0.01 AN

DISCUSSION

The increase in fish weight from approximately 0.42–1.20 kg over the 114 day course of the trial is a fast growth rate from an aquaculture perspective (SGR c. 0.9% mass gain day⁻¹), especially considering that the study had relatively cool water temperatures in the first period. If rearing temperature could be maintained at the upper range of that used in this study (i.e., 17–22°C), it should be possible to obtain growth rates of 1.2% day⁻¹ up to 1.2 kg. Although the use of tanks and hand feeding to rear the fish in the current study differs from sea cage or larger scale land-based commercial aquaculture, the data nevertheless show the growth potential of this species. Previous observations at the same facility indicate minimal gonadal development of fish up to 2.5 kg (S.J. Pether pers. obs.), so the majority of biomass that is accreted over this period is harvestable muscle. Some early development and spermiating males from 6 kg were observed at this research facility, and spermiating 3 kg males at a New Zealand land-based yellowtail kingfish farm (S.J. Pether pers. obs.). Poortenaar et al. (2001) report maturity in the wild does not occur until individuals are >700 mm total length or c. 7 kg, so it is possible that growth rates remain at or above 1.0% day⁻¹ to market size (3 kg) at 17–22°C. Growth rates reported for South Australian yellowtail kingfish farms range from 0.25–0.32% day⁻¹ for 1.3–3.3 kg fish (Fernandes & Tanner 2008) and c. 1.2% day⁻¹ for 0.01–3 kg fish (O'Sullivan 2005). The EFCR values for the better performing Salmofood ESF and Skretting NME diets (1.30–2.04) were below the values for South Australian yellowtail kingfish operations given by O'Sullivan (2005, EFCR = 2.2) and Fernandes & Tanner (2008, EFCR = 3.0–3.4). The commercial diets used in the current study varied considerably in ingredients, manufacturing method,

macronutrient profile, delivered price, and density. Salmofood ESF resulted in the best weight gain during the cooler first period (14–17°C), followed by Skretting NME and then Reliance SF. The mean growth rates showed a similar ranking, however, the within-treatment variability of Skretting NME and Reliance SF reduced the statistical significance of the differences in SGR amongst diets (ANOVA, $P < 0.05$). Growth rates and variance were similar amongst diets during the warmer second period (17–22°C). The differential effect of diet on weight gain and SGR between the two periods could mean that while the nutritional composition of the diets were adequate for biomass production at warmer temperatures, at lower temperatures nutritional differences in the diets may have affected growth. The higher protein content of Salmofood ESF compared with Skretting NME and Reliance SF (49% versus 42–43%) may have been an important factor in the greater average weight and growth rate and lower size variation of this diet at cooler temperatures. Support for this hypothesis comes from a study which found that the proportion of protein digested by Japanese yellowtail *S. quinqueradiata* (termed apparent protein digestibility, APD) decreased with water temperature (Kofuji et al. 2005). Kofuji et al. (2005) reported that while there was little difference in APD of Japanese yellowtail fed pellets of differing protein content at 22–25°C, at 16–18°C the fish could not as easily digest lower protein diets (41–43% protein) compared with higher protein ones (45% protein). Kofuji et al. (2005) also demonstrated that these differences were related to the temperature-specific activity of protein digesting enzymes in Japanese yellowtail. This finding could offer an explanation for the relationship between temperature, diet and growth found in the current study for yellowtail kingfish. In addition to the absolute content of protein in the diet,

the digestibility of the protein is also an important factor when considering growth differences between diets (Cho et al. 1982). According to information provided by the manufacturers, all three commercial diets used in the current study had differing protein sources, but included a combination of plant, fish and non-fish animal protein meal. The differing inclusion rates of these protein sources possibly contributed to the variation in growth performance amongst diets, however, a more in-depth nutritional analysis of protein quality is necessary to establish whether protein source affects digestion and growth.

From a feed management perspective, it is important to know how much fish can ingest in a single meal and the length of time it takes the fish to process the feed through the gut, so that another meal can be administered without risk of overfeeding. Reliance SF had the highest mass-specific consumption, followed by Skretting NME, then Salmofood ESF. On a volumetric basis, considerably more Salmofood ESF was consumed than the other two diets, which reflected the finding that Salmofood ESF pellets had a low density. The daily intake of all diets was divided equally between the first and second meals, which were separated by 5.5 h. The equal ingestion rates are unexpected given that the diets varied considerably in density ($2.84\text{--}5.06\text{ cm}^3\text{ g}^{-1}$) and, therefore, might be expected to pass from the stomach into the intestine at varying rates depending on how quickly the pellets can be digested in the stomach. Watanabe et al. (2001a) concluded that the physical properties of a pellet such as shape, hardness and stability greatly affect stomach and intestinal evacuation time in Japanese yellowtail.

If stomach fullness was not a predominant factor in determining feed intake rate in the current study, nutrient intake may have been. For most vertebrates studied to date, meal termination results from a combination of gastric and post-gastric signals about the chemical and physical qualities of feed (Ritter 2004). In the current study, the daily energy intake varied considerably amongst diets, meaning this parameter is unlikely to have influenced the cessation of feeding. In contrast, the daily crude protein intake was remarkably similar, despite significant differences in the nutritional profiles. The values for daily protein intake in the current study are similar to those published from more exhaustive research on maximum growth in Japanese yellowtail above 500 g weight during summer and winter temperatures (Watanabe et al. 2000b, 2001b). The similarities in voluntary protein intake in yellowtail kingfish,

despite the presentation of diets with different nutritional and physical properties, indicates that the main signal for satiation may be a chemical cue relating to the threshold of protein, which is consumed to a level required for maximum growth at a given temperature.

There were differences in the feed conversion ratio amongst diets, in particular at $14\text{--}17^\circ\text{C}$. Reliance SF generally had the highest BFCR and EFCR values, which was likely correlated with the comparatively high ash content of this diet (12.7% compared with 6.8–7.3% of the other diets). The finding that FCR was also strongly modified by temperature has been observed in other fish species (e.g., Jonassen et al. 2000; Bendiksen et al. 2002; Van Ham et al. 2003; Duston et al. 2004; Bailey & Alanärä 2006). There was a 10–37% decrease in BFCR and EFCR for all feed types associated with the increase in water temperature from $14\text{--}17^\circ\text{C}$ to $17\text{--}22^\circ\text{C}$, with Reliance SF showing the greatest decrease. Japanese yellowtail are known to have poorer protein digestion efficiency at lower temperatures (Kofuji et al. 2005), which may explain why feed conversion was less efficient in yellowtail kingfish during cooler temperatures. When the FCR data were translated into production costs per unit biomass, there was a degree of overlap in production costs amongst diets, however, in general, Skretting NME was the cheapest diet based on the delivered price of feed. Salmofood ESF was the most expensive diet, representing a 21–30% higher cost of production compared with Skretting NME.

Based on the BFCR and EFR values, faecal solids output and settled solids TN and TP content, Salmofood ESF was the best diet from an environmental impact perspective, followed by Skretting NME then Reliance SF. The floatation of the Salmofood ESF pellet is a positive aspect from an environmental perspective, as the pellets are longer available at or near the water surface than sinking pellets. Given that yellowtail kingfish are willing to feed at the surface, floating pellets make it easier to observe feeding without the use of underwater cameras, and can help minimise overfeeding and wastage of feed. Salmofood ESF resulted in significantly lower settleable solids output per unit feed consumed compared with Skretting NME, and both diets generated considerably less faecal solids than Reliance SF. Although the amount of settleable solids recorded in the current study were used for comparative purposes, the behaviour of settleable solids can vary substantially depending on salinity and water currents (Elberizon & Kelly 1998; Chen

et al. 1999), therefore, settlement characteristics may differ *in situ*. In addition to generating relatively little settleable solids, Salmofood ESF also had the lowest BFCR values, meaning it requires the lowest feed (and nutrient) input per unit biomass produced. As the faecal output study was carried out in the second period when water temperature was warmer and FCRs were relatively low, it is possible that the faecal discharge and nutrient load per unit feed administered would be greater at cooler temperatures (i.e., below 17°C).

The diets were ranked in a similar pattern of settleable TN and TP discharge as they were with the mass of settleable solids. Salmofood ESF generated less than half the amount of settleable TN and TP per unit biomass as Skretting NME, which in turn was half of that of Reliance SF. The TN and TP content of the faeces can disperse in ways that were not measured. For instance, Fernandes & Tanner (2008) showed that a significant percentage (43–47%) of N is leached from the faeces of yellowtail kingfish during the first 2–240 min after defecation, and that a large portion of the faeces has a low sinking rate and is prone to transport away from the rearing cage (or tank as in the current study). The same authors estimate that 70% of the ingested N is excreted as dissolved N from the gills, urine and faeces, 15% is retained in the fish biomass, and 15% is excreted as solid wastes (Fernandes & Tanner 2008). Of the solid waste portion, only 2–3% of N enters the sediment (Fernandes & Tanner 2008), although the exact quantity depends on the settling characteristics of the defecated meal. The faecal discharge reported in the present study only represents the fraction that is likely to accumulate directly underneath or within a close radius of an aquaculture sea cage. It is possible that there could be differences amongst diets in terms of the amount of faecal N and P released through leaching and particulate transport. Nevertheless, the current study demonstrated that the choice of commercial diet has a significant impact on the settleable solids discharge in yellowtail kingfish farms.

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