The effects of swimming exercise on growth and whole-body protein and fat contents of fed and unfed fingerling yellowtail

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SUMMARY: Fingerling yellowtail *Seriola quinqueradiata* (initial mean body weight 4.3 g), an active pelagic fish, were reared under fed (4 weeks) and unfed (1 week) conditions to investigate the effects of swimming exercise on growth performance and whole body composition. The fish were raised in three water velocities: <0.3 body length/s (bl/s), 1.0 bl/s, and 2.25 bl/s and fed diets containing two fat levels (13.2 and 20.3%). The exercised fish had significantly higher weight gains and feed efficiencies than the unexercised fish in both dietary fat levels. A second-order polynomial suggested that the optimum water velocity for the growth occurred at about 1.6 bl/s. The whole-body crude protein and fat contents were higher in the exercised fish than in the unexercised fish, and consequently apparent body protein and fat retentions were improved in both dietary fat levels by swimming. However, during 1 week starvation, body fat loss/g body weight loss was higher in the exercised fish than in the unexercised fish. The results of the present study clearly show that swimming condition improves growth performance of fingerling yellowtail, and suggest that swimming exercise stimulates both anabolism and catabolism of protein and fat; however, under fed conditions anabolism appears superior to catabolism.

KEY WORDS: exercise, growth, seriola, starvation, swimming, yellowtail.

INTRODUCTION

Rearing fish under an optimum and continuous exercise condition, generally at a rate of one to two body length/s (bl/s), improves growth performance in brown trout *Salmo trutta*,¹ brook char *Salvelinus fontinalis*,²,³ rainbow trout *Oncorhynchus mykiss*,⁴,⁵ Atlantic salmon *Salmo salar*,⁶,⁷ Arctic char *Salvelinus alpinus*,⁸–¹⁰ ayu *Plecoglossus altivelis*,¹¹,¹² and striped bass *Marone saxatilis*.¹³–¹⁵ However, the growth of Chinook salmon *Oncorhynchus tshawytscha* has been found to be negatively related to swimming exercise.¹⁶ Studies on the effects of swimming exercise on marine species other than salmonids have been relatively scarce.¹⁷–¹⁹ We have conducted a series of studies on the effects of exercise on growth performance of red sea bream *Pagrus major*,²⁰ Japanese flounder *Paralichthys olivaceus*²¹ and yellowtail *Seriola quinqueradiata* (present study), which are important species in aquaculture of Japan. Of these, yellowtail is the most economically important species. Moreover, this species is an active pelagic fish, while red sea bream is a less active midwater species, and Japanese flounder is a relatively sedentary benthic species. Thus, rearing yellowtail under conditions of constant exercise seems promising. In the present study, a 4 week feeding trial was undertaken to investigate whether swimming exercise could improve the growth and other nutritional parameters of fingerling yellowtail. Following the feeding trial, the fish were starved for 7 days under each exercise condition to estimate the whole-body protein and fat expenditures associated with swimming exercise. The present study used only yellowtail fingerlings and did not investigate fish approaching market size.

MATERIALS AND METHODS

Fingerling yellowtail were transported from a hatchery of the Japan Sea Farming Association (Yashima, Kagawa, Japan) to the facilities of the National Research Institute of Aquaculture (Nansei, Mie, Japan). The fish were raised in indoor tanks for several weeks prior to the beginning of the feeding trial by feeding commercial dry pelleted feeds (C-series; Kyowa Hakko Co. Ltd, Tokyo, Japan). After sorting by body weight, 15 fish were ran-
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domly assigned to each of 15 tanks: cylindrical artemia culture tank of 50 L capacity (filled with 40 L seawater), with a large diameter polyvinyl pipe in the middle of each tank. The tanks were supplied with 4–5 L/min seawater from Gokasho Bay (Nansei, Mie, Japan). The fish were adapted to the experimental tanks for 1 week. The mean body weight and mean body length of the fish at the start of the trial were 4.3 g and 7.3 cm, respectively. A sample from the initial pool of fish was taken and frozen (–80°C) for later analyses. The water temperature rose from 22.0°C to 24.6°C over the course of the feeding and starvation trials.

Two diets were used in this study: the low fat diet (LF) was a commercial dry feed (C-series; Kyowa Hakko Co. Ltd) and the high fat diet (HF) was prepared by top dressing the LF diet with 8% pollack viscera oil (Riken Vitamin Co Ltd, Tokyo, Japan). The LF and HF diets contained 58.6% and 54.0% crude protein, 13.2% and 20.3% crude fat, and 5.1% and 4.4% moisture, respectively. The fish were fed by hand to apparent satiation twice daily 6 days per week. For the HF diet, three water velocities: <0.3 bl/s (control), 1.0 bl/s (slow) and 2.25 bl/s (moderate) were tested. For the LF diet, only <0.3 bl/s and 1.0 bl/s water velocities were tested. The water current in the tanks was generated by adjusting the angle of the incoming water, as previously reported, and the water flow in each tank was adjusted biweekly. Each treatment was assigned to three replicate tanks in a completely random design. However, the fish in one tank of the control LF diet were lost due to a water supply accident during the feeding trial.

The feeding trial was terminated at 4 weeks due to the rapid growth of the fish. Training time of 4 weeks seemed adequate, although the time was the minimum training period to see the effects of exercise on fish performance. Fish were anesthetized with 0.01% ethyl 3-aminobenzonate methanesulfonic acid salt solution (Aldrich Chemical Company Inc., WI, USA) and individually weighed initially and after 2 and 4 weeks. Feed was withheld for 1 day prior to weighing. At 4 weeks, eight fish from each tank were sampled and frozen at –80°C for subsequent analysis. Following the feeding trial, the remaining fish were maintained under each exercise condition without feed for 1 week to investigate the effects of starvation on fat and protein expenditures by swimming. At the end of the starvation trial, all the remaining fish were weighed and collected for subsequent analysis.

Analyses were performed on pooled samples, four fish pooled to one and two samples in each tank for the feeding trial and three fish pooled to one and two samples in each tank for the starvation trial. Crude protein was analyzed by the Kjeldahl method, crude fat by soxlet using diethyl ether, and moisture by drying for both the diets and fish. Statistical analyses of significance (P < 0.05) of differences among treatment means were carried out by protected least significant difference (StatView 5.0 Jpn version; SAS Institute Inc., Cary, NC, USA), without any transformations of percentage data prior to the analyses. Second-order polynomial regression analysis (CA-Cricket Graph III Jpn version; Computer Associates International, Inc., Malvern, PA, USA) was applied to estimate the optimum tank water velocity for juvenile yellowtail.

RESULTS

No mortality was observed in any of the treatment groups through the feeding and starvation trials (except as noted previously). The effects of water velocity on growth parameters are shown in Table 1. Mean final body weights and mean final body lengths over the course of the feeding trial were 22.8 g and 12.2 cm for the control, 30.6 g and 13.0 cm for the slow group, 30.5 g and 13.0 cm for the moderate group of the fish fed on the HF diet, and 24.0 g and 12.5 cm for the control and 29.9 g and 13.0 cm for the slow group of the fish fed on the LF diet, respectively. The differences in the weight and length between the exercised groups and the controls were significant. In the 4-week feeding trial, swimming exercise at either 1.0 bl/s or 2.25 bl/s significantly improved weight gain and feed efficiency in both dietary fat levels. The weight gain of the fingerling yellowtail in the exercised groups was about 600%, while the weight gain of the unexercised groups was 440–490%. Feed efficiency increased from 1.35 to 1.40 for the control fish to more than 1.5 for the exercised groups. By contrast, food intake tended to decrease in the exercised groups (4.21–4.30% of wet biomass/day) compared to the unexercised groups (4.36–4.44%). The whole-body fat level (%) was significantly higher in the exercised groups (4.6 and 4.7% for the HF diet and 3.1% for the LF diet) than in the unexercised groups (3.9% for the HF diet and 2.5% for the LF diet), and the protein level was similarly, but to a lesser degree, affected by swimming speed (Table 1). Apparent protein and fat retentions were significantly and clearly improved by swimming exercise (Table 1): protein and fat retentions were about 46–49% and 38% for the exercised groups and 42% and 28% for the unexercised groups, respectively. When compared in each swimming condition, dietary fat level did not affect weight gain, feed efficiency, food consumption ratio or fat retention, but tended to elevate protein retention, especially in the slow (1.0 bl/s) group (Table 1). When the weight gain data for both dietary fat levels in each swimming group were combined, a second-order polynomial suggested that the optimum water velocity for the growth occurred at about 1.6 bl/s (Fig. 1).

The effects of 1 week starvation and swimming speed on body condition are listed in Table 2. There were no effects of swimming speed on body weight loss (1.48–1.91 g/fish) or percentage weigh loss (5.1–7.8%); however, weight loss seemed to decrease as swimming
speed increased: from 6.1% to 5.1% in the HF diet and from 7.8% to 6.9% in the LF diet, but these differences were not significant due to the wide variability. The whole-body crude protein and fat levels clearly decreased in each treatment after the 1 week starvation (Tables 1,2). Starvation reduced slightly the whole-body crude protein levels from a range of 16.9–17.5% (average 17.2%) to a range of 16.0–16.6% (average 16.4%) and the whole-body crude fat levels from a range of 2.5–4.7% (average 3.8%) to a range of 1.0–2.8% (average 2.0%). Swimming exercise did not affect body protein loss per g of body weight loss with a range of 0.27–0.31 g during the 1 week starvation. By contrast, body fat loss per g of body weight loss was larger in the exercised groups than in the controls, especially in the fish fed the HL (0.38–0.40 g for the exercised groups and 0.25 g for the control). The control groups (0.52 g) tended to have a larger body moisture loss per g of body weight loss than the exercised groups (0.32–0.42 g) for the both dietary treatments.

**DISCUSSION**

Swimming exercise at the water velocity of 1–2 bl/s generally shows better growth and feed efficiency in salmonids, ayu and striped bass if the fish are fed to satiety,17–19 although not in all studies.16 The species used in the swimming study must be an important variable.17 Yellowtail, red sea bream and Japanese flounder are the most commonly cultured marine fish in Japan, and they represent considerably different natural ecologies. Yellowtail is a pelagic fish and the most active, followed by the less actively swimming red sea bream and the mostly sedentary Japanese flounder. Indeed, a water current in tanks did not markedly improve growth performance of the latter two species.20,21 Continuous swimming exercise impaired the growth of goldfish Carassius auratus, an

**Table 1** Growth performance of fingerling yellowtail raised under different water velocities and dietary fat levels for 4 weeks (mean±SE)

<table>
<thead>
<tr>
<th>Water velocity (bl/s)</th>
<th>No. tanks</th>
<th>&lt;0.3</th>
<th>1.0</th>
<th>2.25</th>
<th>&lt;0.3</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial body weight (g)</td>
<td>3</td>
<td>4.22±0.02</td>
<td>4.30±0.02</td>
<td>4.37±0.02</td>
<td>4.38±0.04</td>
<td>4.31±0.05</td>
</tr>
<tr>
<td>Final body weight (g)</td>
<td>3</td>
<td>22.84±0.80</td>
<td>30.55±1.72</td>
<td>30.50±1.09</td>
<td>25.06±0.92</td>
<td>29.94±0.66</td>
</tr>
<tr>
<td>Initial body length (cm)</td>
<td>3</td>
<td>7.3±0.0</td>
<td>7.3±0.0</td>
<td>7.3±0.0</td>
<td>7.4±0.1</td>
<td>7.3±0.0</td>
</tr>
<tr>
<td>Final body length (cm)</td>
<td>3</td>
<td>12.2±0.1</td>
<td>13.0±0.2</td>
<td>13.0±0.1</td>
<td>12.5±0.0</td>
<td>13.0±0.1</td>
</tr>
<tr>
<td>% weight gain</td>
<td>3</td>
<td>441±17</td>
<td>610±41</td>
<td>598±24</td>
<td>468±1</td>
<td>595±22</td>
</tr>
<tr>
<td>Feed efficiency</td>
<td>3</td>
<td>1.41±0.03</td>
<td>1.59±0.01</td>
<td>1.62±0.03</td>
<td>1.47±0.00</td>
<td>1.61±0.02</td>
</tr>
<tr>
<td>Food consumption ratio (%)</td>
<td>3</td>
<td>4.44±0.05</td>
<td>4.30±0.07</td>
<td>4.21±0.04</td>
<td>4.36±0.01</td>
<td>4.27±0.03</td>
</tr>
<tr>
<td>Whole-body composition (%)</td>
<td>3</td>
<td>Moisture 76.5±0.2</td>
<td>75.2±0.1</td>
<td>75.3±0.2</td>
<td>77.4±0.1</td>
<td>76.6±0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crude protein 16.9±0.1</td>
<td>17.2±0.1</td>
<td>17.0±0.1</td>
<td>17.2±0.0</td>
<td>17.5±0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crude fat 3.9±0.1</td>
<td>4.6±0.2</td>
<td>4.7±0.2</td>
<td>2.5±0.0</td>
<td>3.1±0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Protein retention (%) 42.3±1.1</td>
<td>48.6±0.6</td>
<td>49.0±1.0</td>
<td>41.2±0.1</td>
<td>45.9±0.4</td>
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<tr>
<td></td>
<td></td>
<td>Fat retention (%) 28.5±0.6</td>
<td>37.7±1.1</td>
<td>39.6±2.1</td>
<td>27.6±0.0</td>
<td>38.4±0.4</td>
</tr>
</tbody>
</table>

Values followed by the different letter on the row are significantly different (P<0.05, by PLSD).1 High fat diet: crude protein 54.0%, crude fat 20.3% and moisture 4.4%.2 Low fat diet: crude protein 58.6%, crude fat 13.2% and moisture 5.1%.3 Weight gain/feed intake (dry basis).4 % of wet biomass/day.5 The initial whole-body composition was as follows: moisture 78.8%, crude protein 16.7% and crude fat 2.0%.

**Fig. 1** Relationship between water velocity (body length/s) and weight gain of fingerling yellowtail at three different water velocities for 4 weeks (y=-112x^2 + 361x + 333; r=0.886).

(Tables 1,2). Starvation reduced slightly the whole-body crude protein levels from a range of 16.9–17.5% (average 17.2%) to a range of 16.0–16.6% (average 16.4%) and the whole-body crude fat levels from a range of 2.5–4.7% (average 3.8%) to a range of 1.0–2.8% (average 2.0%). Swimming exercise did not affect body protein loss per g of body weight loss with a range of 0.27–0.31 g during the 1 week starvation. By contrast, body fat loss per g of body weight loss was larger in the exercised groups than in the controls, especially in the fish fed the HL (0.38–0.40 g for the exercised groups and 0.25 g for the control). The control groups (0.52 g) tended to have a larger body moisture loss per g of body weight loss than the exercised groups (0.32–0.42 g) for the both dietary treatments.
inactive swimmer.\textsuperscript{22} By contrast, the present study clearly shows that swimming exercise produced positive effects on weight gain, feed efficiency, and protein and fat retention in fingerling yellowtail. It seems obvious that active swimmers like yellowtail are good subjects for the study of the relationship between growth and swimming exercise, and that the manner in which swimming exercise affects growth is dependent on swimming ability of the fish tested.

Fish expend more energy while swimming than while resting, and elevated oxygen consumption has been shown in swimming yellowtail.\textsuperscript{23} However, swimming fish do not always have higher oxygen and energy expenditures than resting fish when the fish are grouped.\textsuperscript{6,13} It has been indicated that oxygen consumption differs when fish are reared as individuals and when fish are reared in groups.\textsuperscript{8–10} Swimming decreases aggressive behavior among individuals and swimming fish tend to school.\textsuperscript{3–7,10} The decreased aggressive behavior by swimming seems to lead to a reduction of energy expenditure due to a relief from chronic stress.\textsuperscript{3–7,10} Growth acceleration by swimming may partially stem from the diminished energy demands of stressful aggressive interactions.\textsuperscript{3–7,10} Grouped and unexercised fish seem to suffer a higher energetic compensation for chronic stress resulting from aggression, compared with exercised fish that school and decrease their aggressive behavior.\textsuperscript{3–7,10} Unexercised Arctic char in standing water (0 bl/s) required an energy input of more than three times that of exercised fish at 2 bl/s for holding their body weight constant.\textsuperscript{8} Christiansen and Jobling inferred that under certain circumstances adaptations, decreased agonistic behavior promoted efficient ram ventilation and increased net protein synthesis by swimming, which may lead to energy savings that surpass the increased energy costs of swimming exercise.\textsuperscript{8} However, in the present study, body fat loss during the period of 1 week starvation was clearly high in the exercised group compared with the unexercised group. This result suggests that energy expenditure was higher in the exercised groups than in the unexercised groups under the unfed condition. Indeed, if energy loss/g weight loss during the 1 week starvation was estimated based on the values of protein and fat loss, the energy loss of the exercised group was 1.3 times higher than that of the unexercised group (Table 2). Nevertheless, feed efficiency, protein and fat retention were improved by swimming exercise under the fed condition for 4 weeks. There may be a difference in energy consumption in response to swimming between fed and unfed conditions.\textsuperscript{24} The growth increase observed in the present study seems not to be due to the diminished energy demands of less stressful aggression and efficient ram ventilation but due to a metabolic reason as will be discussed elsewhere.

An optimum swimming exercise seems to generally affect muscle morphology and body lipid content, although the responses were variable.\textsuperscript{6,13,25} When swimming exercise improves growth performance, the improved growth appears to be accompanied by an increase of body lipid content.\textsuperscript{1,3,6,14} By contrast, when the exercise either improves or fails to improve growth, body lipid content usually decreases.\textsuperscript{20,21} Increased protein synthesis rates\textsuperscript{4} and increased growth hormone (GH) levels were observed with growth increases in fish exercise-conditioned at an optimum velocity.\textsuperscript{26–28} Houlihan and Laurent reported that exercised rainbow trout had both increased protein synthesis and degradation compared to unexercised fish, and concluded that the increased growth rates resulted from the proportionately greater increase in the protein synthesis rate.\textsuperscript{4} Plasma GH level began to rise significantly 4 h after the onset of moderate exercise (1.5 bl/s) and reached a maximum level at 24 h in steelhead trout and coho salmon.\textsuperscript{26} During a moderate exercise (1.5 bl/s) for 24 h plasma GH level elevated only

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**Table 2** Effects of 1 week starvation on body condition of fingerling yellowtail reared at different water velocities (mean±SEM)

<table>
<thead>
<tr>
<th>Water velocity (bl/s)</th>
<th>Initial body weight (g)</th>
<th>Final body weight (g)</th>
<th>Weight loss (g)</th>
<th>% weight loss</th>
<th>Final whole-body composition\textsuperscript{1}</th>
<th>Energy loss/g weight loss (KJ)</th>
<th>Moisture loss/g weight loss (g)</th>
<th>Fat loss/g weight loss (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High fat diet 1.0</td>
<td>2.25</td>
<td>2.25</td>
<td>Crude protein (%)</td>
<td>Crude fat (%)</td>
<td>Protein/g weight loss (g)</td>
<td>Fat loss/g weight loss (g)</td>
</tr>
<tr>
<td></td>
<td>24.30±0.87</td>
<td>25.87±0.22</td>
<td>28.86±0.47</td>
<td>3.14±0.03</td>
<td>16.0±0.00</td>
<td>2.5±0.1</td>
<td>0.31±0.02</td>
<td>0.25±0.02</td>
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<td></td>
<td>22.83±0.93</td>
<td>27.93±2.55</td>
<td>27.38±0.34</td>
<td>4.39±0.03</td>
<td>16.5±0.2b</td>
<td>2.6±0.0b</td>
<td>0.30±0.01</td>
<td>0.38±0.04</td>
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<td></td>
<td>1.48±0.12\textsuperscript{a}</td>
<td>1.64±0.07\textsuperscript{a}</td>
<td>1.48±0.17\textsuperscript{a}</td>
<td>1.0±0.01\textsuperscript{a}</td>
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<td>5.1±0.5\textsuperscript{a}</td>
<td>0.8±0.5\textsuperscript{a}</td>
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</table>

Values followed by the different letter on the row are significantly different (P<0.05, by PLSD). \textsuperscript{1}Initial whole-body composition of each group at the beginning of the starvation trial is shown in Table 1. \textsuperscript{2}Calculated energy (KJ/g weight loss): protein, 4.5; fat, 8.0 kcal/g; 331 kcal=4.184 Joule.
at 2 h after the commencement of exercise in rainbow trout. Moreover, steelhead trout trained at 2.0 bl/s for 4 h/day for 5 weeks showed a greater increase of plasma GH level following 24 h of exercise than did the control fish. In the present study, the whole-body protein and fat contents were significantly higher in the exercised groups than in the controls in both HF and LF diets, and consequently the body protein and especially fat retentions were clearly improved in the exercised groups. This result shows that in fingerling yellowtail swimming at optimum water velocities enhanced the anabolism of protein and fat. It is probable that the observed benefits in growth of fingerling yellowtail resulting from exercise may have stemmed from the enhanced anabolic activity. During the 1 week starvation body protein reduction was not related to the swimming condition, yet body fat reduction was larger in the exercise groups than in the controls. This result shows that under unfed condition fingerling yellowtail consumed body fat in preference to body protein for swimming energy, and suggests that body fat catabolism was promoted by exercise. Thus, swimming exercise seems to stimulate both anabolism and catabolism but the former seems to be greater than the latter in fed fingerling yellowtail.

Growth of juvenile Arctic char was maximized at a swimming speed corresponding to approximately 1.75 bl/s, and it was indicated that this swimming speed was close to a threshold swimming speed (1.8 bl/s) for recruitment of white fibers in brook char *Salvelinus fontinalis*. Tsukamoto reported, based on electromyographical studies, that white muscles recruited at a water velocity of 62 cm/s but not at 49 cm/s in yellowtail with body weight of 765 g and body length of 35.8 cm, that white muscles were inactive below 61 cm/s in yellowtail with body weight of 750 ± 75 g and body length of 36.0 ± 1.3 cm, and that white muscles began to work at 65 cm/s in yellowtail with body weight of 750 g and body length of 36 cm. Tsukamoto established the concept of the ignition point of white muscle (IPW) as a threshold swimming speed at which white muscles critically recruit to produce swimming power. Considered all together, the IPW of yellowtail seems to range from 1.69 to 1.81 bl/s. Although the IPW may be affected by biotic and abiotic factors, the IPW determined by Tsukamoto approximately coincides with a water velocity of 1.6 bl/s at which the growth of fingerling yellowtail was estimated to be maximized in the present study. Thus, the concept of IPW seems a useful index to estimate the optimum water velocity for the growth of fish. Most of the energy for swimming is aerobically produced in red muscle around the water velocity of IPW. A balance between increased energy expenditure by swimming and decreased energy expenditure by swimming may be maintained at a maximum level around the water velocity of IPW, which may improve feed efficiency and consequently the growth, as inferred by Christiansen and Jobling.

Yellowtail have a high capacity for using dietary lipid as an energy source with a high-protein sparing effect. In the present study, dietary lipid supplementation failed to improve growth and other nutritional parameters of the small-size (4–30 g) yellowtail. The optimum protein and fat levels for fingerling yellowtail have been reported to be around 50 and 15–20%, respectively. Yellowtail fingerlings with initial mean body weight of 3.7 g fed a diet (crude protein 52% and crude fat 10%) for 35 days showed a daily specific growth rate of 6.49% (water temperature 20.2–24.1°C). The growth rate of 6.03–6.99% attained in the present study (initial mean body weight 4.3 g) was comparable to the value of 6.49%. The total loss of protein, fat and moisture accounted for 100–104% of the body weight loss for the 1 week starvation (Table 2). If energy loss during the 1 week starvation was estimated based on the values of protein and fat loss (Table 2), the energy loss was 157–189 KJ/kg fish per day. The estimated energy loss of the present study was relatively comparable to an energy loss of 155 KJ/kg fish per day determined by Masumoto et al. It is difficult to interpret the result of the present study that feed intake (% of wet biomass/day) was slightly but significantly lower in the exercise groups than in the controls. Swimming exercise seems to usually stimulate feed intake in fish. Indeed, the absolute amount of feed intake in the exercised groups (average 252.8 g) was higher than that in the controls (average 208.9 g), during the feeding trial. Perhaps when the feed intake was expressed as the feed intake per body weight unit per day, the feed intake may have become apparently higher in the controls than in the exercised groups, since the final fish size was smaller in the former than in the latter.

The findings of the present study show clearly that rearing fingerling yellowtail under a water current improves growth performance, and suggest that the concept of IPW is useful to predict optimum water flow condition of other species. The present study did not examine the effect of swimming exercise on market-size yellowtail. Further work with different fish size and species is required to clarify the effects of swimming exercise on growth.

ACKNOWLEDGMENTS

We wish to thank Dr Ian P. Forster of the Oceanic Institute, HI, USA, for his critical reading of the manuscript. This work was supported by a grant from the Ministry of Agriculture, Forestry and Fisheries, Japan.

REFERENCES

Growth and exercise in yellowtail

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