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SUMMARY – Wild-caught Mediterranean yellowtail, *Seriola dumerilii* were fed isonitrogenous (400 g/kg CP) extruded dry diets which contained four lipid levels (180, 220, 260, and 300 g/kg) for 118 days at an average temperature of 18°C. Growth, feed:gain ratio, and body composition were measured. Feed intake was measured on two occasions using an x-ray method. Growth rates (>1%/day) were not affected by diet composition however, feed:gain ratio and feed intake varied inversely with dietary energy level. In fish up to 500 g, the present study indicates that low protein, high energy dense diets similar to those used in the intensive salmonid production (*ca.* 17.5 g CP/MJ and 24.5 MJ GE/kg) gives high growth rates and feed conversion efficiency, as judged by values reported in the literature. Little effect of diet composition on relative organ size and body composition was observed, although visceral fat was elevated in fish fed the diet containing the highest lipid level. As protein is the most costly macro-nutrient in fish feeds, the relatively low protein requirement indicated by these trials is likely to prove more cost-effective than traditional, high protein diets. At the same time, a high energy density, which improved protein retention and feed:gain ratio, is likely to benefit the environment through reduced nutrient loading. Based on growth performance, and of the closely related Japanese yellowtail, *S. quinqueradiata*, *S. dumerilii* would appear to have considerable potential in aquaculture in the Mediterranean, as it has in other regions, notably in Japan.

Key words: *Seriola dumerilii,* diet composition, growth, body composition.

***RESUME* –** *"Ingestion alimentaire, croissance, et composition corporelle de la sériole couronnée méditerranéenne (*Seriola dumerilii*) recevant des régimes iso-azotés contenant différents niveaux lipidiques". Des sérioles méditerranéennes (*Seriola dumerilii*) provenant de captures en milieu sauvage, ont été alimentées avec des régimes secs extrudés iso-azotés (400 g/kg CP) qui contenaient quatre niveaux lipidiques (180, 220, 260 et 300 g/kg) pendant 118 jours à une température moyenne de 18°C. La croissance, le ratio aliment:gain, et la composition corporelle ont été mesurés. L'ingestion a été mesurée à deux reprises en utilisant une méthode de rayons X. Les taux de croissance (>1%/jour) n'étaient pas affectés par la composition du régime, cependant le ratio aliment:gain et l'ingestion alimentaire ont varié de façon inverse au niveau d'énergie alimentaire. Chez les poissons pesant jusqu'à 500 g, la présente étude indique que des régimes denses à faible protéine et énergie élevée semblables à ceux utilisés pour la production intensive de salmonidés (*ca. *17,5 g CP/MJ et 24,5 MJ GE/kg) donnent de forts taux de croissance et une efficacité de conversion alimentaire élevée, si l'on en juge par les valeurs rapportées dans la littérature. On n'a observé que peu d'effet de la composition du régime sur la taille relative des organes et la composition corporelle, bien que la graisse viscérale ait été élevée chez les poissons recevant le régime contenant le plus fort niveau en lipides. Etant donné que la protéine est le macronutriment le plus onéreux pour les aliments aquacoles, les besoins relativement faibles en protéine observés lors de ces essais tendent à indiquer que ces régimes seraient plus avantageux économiquement que les régimes traditionnels à protéine élevée. En même temps, une forte densité en énergie, qui a amélioré la rétention de protéines et le ratio aliment:gain, pourrait être bénéfique pour l'environnement à travers des rejets moindres en nutriments. En se basant sur les performances de croissance, et sur la sériole japonaise (*S. quinqueradiata*) qui est très proche,* S. dumerilii *semblerait avoir un potentiel considérable en aquaculture en Méditerranée, comme c'est le cas dans d'autres régions, notamment au Japon.*

Mots-clés : Seriola dumerilii*, composition du régime, croissance, composition corporelle.*

Introduction

Seriola dumerilii is a circum-global pelagic carnivorous species known by various names including the Mediterranean yellowtail, amberjack and kampachi. It is extensively cultivated, notably in Japan which has an annual production estimated to be around 20,000 tonnes per year (J. Kleine Staarman, pers. comm.). Most of this production is based on moist diets made by the farmers from raw fish and variable amounts of binder meals and vitamin premixes, although some dry extruded feeds are used. This species is a candidate for aquaculture in other regions, including the Mediterranean. *Seriola dumerilii* exhibits several desirable characteristics (García-Gómez, 1993) including a fast growth rate, potentially large body size (typically 3-5 kg at harvest), good survival, and is easily adapted to farming conditions, including readily accepting manufactured dry diets which are the basis of intensive fish farming in various species groups, notably the salmonids. Compared with salmonids, relatively little research has been conducted into nutritional requirements and practical formulations for dry extruded diets for this species. Shimeno *et al.* (1980), Takeuchi *et al.* (1992) and Jover *et al.* (1999) concluded that dietary crude protein (CP) levels of 500 to 550 g/kg and crude lipid (CL) levels of approximately 150 g/kg (*ca.* 35 g CP/MJ) gave optimal growth in both the Mediterranean yellowtail and the closely related Japanese yellowtail (*Seriola quinqueradiata*). Moist feeds typically contain, on an as-fed basis, 220 g/kg CP, 60 g/kg CL, 50 g/kg ash, 30 g/kg nitrogen-free extract, and a crude energy (CE) level of approximately 8 MJ/kg (equivalent dry matter values approximately 620, 170, 140 and 70 g/kg respectively, and 22 MJ/kg) (Talbot, 1998).

Commercial salmonid diets have developed towards relatively low protein (380 to 420 g/kg) and high fat (300 to 350 g/kg) levels, with protein:energy ratios typically around 18 g CP/MJ and CE levels around 25 MJ/kg. This composition reflects the well described "protein sparing" effect of high dietary energy levels which, together with the anabolic effect of increased energy intake *per se*, results in low feed:gain ratios (FGRs) and high growth rates (Talbot, 1993; Talbot and Hole, 1994). *Seriola* spp. eat largely similar food in nature to that consumed by salmon and it is likely that their nutritional requirements and physiological responses to dietary protein:energy ratios are similar. Shimeno *et al.* (1985) demonstrated that both carbohydrate and lipid could spare dietary protein in Japanese yellowtail. Depending on fish size and water temperature, various studies (e.g. Viyakarn *et al.*, 1992; Watanabe *et al.*, 1992, 1998b; Sakamoto *et al.*, 1995) have shown excellent growth rates with FGRs between 1 to 2 kg feed/kg fish growth, in Japanese yellowtail fed diets containing around 450 g/kg CP and 200 to 250 g/kg CL (*ca.* 20 g CP/MJ and 23-25 MJ/kg). Under intensive commercial rearing conditions in sea cages using dry extruded diets (*ca.* 420 g/kg CP and 300 g/kg CL) fed to satiation daily, *S. quinqueradiata* can grow from 5 g to 3 kg in approximately 12 months (Talbot, unpublished results). This paper reports the effects dietary protein:energy ratios similar to those used for salmonids on growth, feed conversion, and body composition in juvenile Mediterranean yellowtail.

Materials and methods

Wild fish weighing approximately 100 g were caught in September in the region of Murcia, Spain, by commercial fishermen using nets. The fish were transported to the Spanish Institute of Oceanography, Pto. de Mazarrón, where they were held in tanks for several weeks prior to the start of the trials. During this period, the fish were fed a commercial extruded fish feed (Trouw Spain S.A.) containing 530 g/kg CP and 220 g/kg CL, with a calculated gross energy (GE) level of 23.9 MJ/kg and 22.2 g CP/MJ CE.

Diets

Four extruded diets were made at the Nutreco Technology Centre, Stavanger Norway. The diets contained nominally, equal levels of CP (400 g/kg), and four CL levels (180, 220, 260, and 300 g/kg respectively). The raw material composition of the diets is shown in Table 1, together with the analysed chemical composition. Dietary CP [(mg nitrogen/g dry matter) x 6.25] was measured using a Tecator Kjeltec auto-analyser, and CL was determined gravimetrically following extraction in dichloromethane using a Soxtec HT-6 apparatus. The carbohydrate content of each diet was estimated as nitrogen free extract (NFE) by difference from the sum of the protein, lipid, and ash content. Ash content was determined gravimetrically following combustion at 540°C in a muffle furnace. Dietary GE (MJ/kg) content was calculated using energy equivalents for protein, lipid and carbohydrate of 23.6, 39.5, and 17.2 kJ/g respectively (Cho *et al.*, 1982). All diets contained 8 g/kg lead glass ballotini (*ca.* 450 μm diameter, British Optical Ltd, Walsall, UK) for the measurement of feed intake by the method of Talbot and Higgins (1983). The feed contained 12.4 ballotini per gram.

Table 1. Composition of the test diets[†]

Ingredient	18% lipid	22% lipid	26% lipid	30% lipid
Fishmeal	316	316	316	316
Full-fat soya meal	200	200	200	200
Corn gluten meal	115	126	134	142
Wheat	251	199	148	97
Di-calcium phosphate	0.12	0.41	0.71	1.01
Lysine HCl	0	0	1.62	3.40
DL methionine	0	0	0.01	0.48
Vitamin/mineral premix	5	5	5	5
Crude protein (CP)	424	427	429	43.6
Crude lipid (CL)	184	222	257	293
Gross energy (GE)	227	236	243	252
g CP/MJ GE	187	181	176	173

[†]All values are in g/kg dry matter except gross energy (MJ/kg).

Fish and husbandry

Twenty five fish (96 g average weight) were stocked into each of 12, 1 m^3 cylindrical tanks which were supplied with through-flowing sea water. The water temperature decreased from 20.5°C to 15.3°C over the first nine weeks of the trial. Thereafter, heated water at approximately 18°C was used. The average weekly temperature to during the 118 days of the trial was 17.9°C. Each diet was randomly allocated to three tanks. The fish were individually weighed (nearest 0.1 g) and the fork length was measured to the nearest millimetre at the start and end of the trial. Specific growth rate (SGR, %/day) for each tank was calculated from mean body weight as: SGR = [(ln end wt, g – ln start wt, g)/days] x 100. The fish were fed to apparent satiation twice per day, and the weight of feed dispensed to each tank was recorded daily. FGR was calculated as: feed:gain = feed delivered (g)/biomass gain (g). Protein efficiency ratio (PER) was calculated as: PER = increase in mean body weight (g)/protein consumption (g).

Feed intake

On two occasions during the last week of the trial, 10 fish from each of the tanks (30 fish per dietary treatment), were anaesthetised and x-rayed shortly after the morning meal. Two days separated each set of x-rays. Each x-rayed fish was individually weighed, and the quantity of food (g/kg fish) in the intestines of each fish was measured by counting the number of ballotini on the x-ray plate. Water temperature was 18°C on the days when feed intake was measured.

Body composition

Six fish were sampled at random from the stock population at the start of the trial for body composition analysis. At the end of the trial, two fish from each tank (six fish per dietary treatment) were sampled. The fish were killed using an overdose of anaesthetic. The whole body weight and fork length of each fish was measured, and the liver and gut were dissected and weighed. Liver somatic index (LSI) and viscero-somatic index (VSI, representing total gut cavity contents minus liver weight) were calculated as: LSI and VSI = 100 x [organ weight (g)/body weight (g)]. Condition factor (CF) was calculated as: CF = 100 x [body weight (g)/body length^3 (cm)]. The visceral organs (liver plus intestines) and a sample of epaxial muscle were analysed for fat and moisture content in individual fish. After drying at 105°C, fat was determined gravimetrically following extraction in dichloromethane using a Soxtec HT-6 apparatus.

Statistics

Dietary responses were analysed using ANOVA; percentage data was first subjected to an arcsine transformation. Significant differences between each treatment were tested for using Duncan's multiple comparison test. Differences were considered significant at $p < 0.05$. Statistical tests were performed using Unistat™ v. 4.53 software.

Results and discussion

The effects of the dietary treatments on growth, feed conversion, body traits, and body composition results are shown in Table 2. Growth and feed conversion was not significantly different between the dietary treatments however, there was some indication that FGR decreased with increasing dietary fat levels. This result suggests that all diets contained sufficient protein and energy, and other essential nutrients, to sustain the maximum growth rate achievable under the rearing and environmental conditions which prevailed during the trial.

Table 2. Effect of different dietary fat levels in isonitrogenous diets on growth, feed conversion, body traits, and body composition in *Seriola dumerilii*[†]

Parameter	Diet			
	18% fat	22% fat	26% fat	30% fat
Start wt (g)	95 ± 3.7^{a}	94 ± 3.9^{a}	97 ± 3.0^{a}	98 ± 2.8^{a}
End wt (g)	358 ± 29.0^{a}	353 ± 25.8^{a}	371 ± 12.7^{a}	370 ± 12.9^{a}
Wt gain (%)	377 ± 17.7^{a}	376 ± 14.2^{a}	384 ± 17.7^{a}	378 ± 22.1^{a}
SGR (%/day)	1.12 ± 0.04^{a}	1.12 ± 0.03^{a}	1.14 ± 0.04^{a}	1.12 ± 0.05^{a}
Feed:gain	1.74 ± 0.14^{a}	1.72 ± 0.16^{a}	1.55 ± 0.01^{a}	1.68 ± 0.17^{a}
Protein efficiency ratio	1.36 ± 0.10^{a}	1.37 ± 0.12^{a}	1.50 ± 0.01^{a}	1.37 ± 0.14^{a}
Condition factor	1.33 ± 0.01^{a}	1.33 ± 0.01^{a}	1.36 ± 0.03^{b}	1.38 ± 0.05^{b}
Muscle fat (%)	7.4 ± 0.7^{a}	8.4 ± 2.4^{ab}	8.7 ± 1.3^{ab}	9.4 ± 1.2^{b}
Muscle water (%)	70.4 ± 0.7^{a}	69.8 ± 2.0^{a}	69.2 ± 1.2^{a}	69.0 ± 1.5^{a}
Visceral fat (%)	15.9 ± 5.9^{a}	17.7 ± 4.7^{ab}	19.1 ± 5.6^{ab}	23.5 ± 5.4^{b}
Liver-somatic index	1.6 ± 0.3^{a}	1.6 ± 0.3^{a}	1.6 ± 0.5^{a}	1.8 ± 0.5^{a}
Viscero-somatic index	7.4 ± 1.3^{a}	7.2 ± 0.9^{a}	8.1 ± 2.3^{a}	8.2 ± 1.6^{a}

[†]Values are mean ± SD. Means in a row sharing the same letter are not significantly different (ANOVA, $p < 0.05$).

Feeding fish to apparent satiation in freely draining tanks is subjective and it is very difficult to measure FGR accurately due to unaccounted-for feed loss on the one hand (increasing the apparent FGR), and under-feeding on the other, due to difficulties in deciding when the feeding activity has ceased. Under-feeding leads to reduced growth and elevated FGR (Talbot and Hole, 1994). Actual feed intake measured by the x-ray method is shown in Fig. 1. On the first measurement day, feed intake was observed to decrease with increasing dietary lipid levels, being significantly lower in the diets containing 260 and 300 g/kg lipid compared to the diets containing 180 and 220 g/kg. Feed intake was lower in fish fed all diets on the second day of measurement, possibly reflecting the stress of handling during the x-raying two days earlier. No significant differences in feed intake were found on day 2, however a similar trend of decreasing intake with increasing dietary lipid levels was observed.

It is uncertain whether FGR (Table 1) or the direct measurement of feed intake (Fig. 1) gives the best indication of the effect of dietary energy on feed intake. However, both measurements suggest that weight-specific daily feed intake appeared to fall in relation increasing dietary energy levels. If this is the case, then protein intake in the isonitrogenous diets used in the present study will also decrease as the dietary energy increases. As growth remained constant, it appears that increasing dietary energy in otherwise nutritionally complete diets improves protein utilisation, and that the main effect of increasing energy density is a reduction in FGR. In general, the lower protein and higher energy diets used in the present trial compared to those used by Jover *et al.* (1999) resulted in lower FGRs (*ca.* 1.7 vs. 3.0). In nutrition studies, nutrient intake (nutrient inclusion level x feed intake) is a much more important parameter than diet composition *per se.* Although not significant, the diet containing 260 g/kg CL appeared to give the best overall performance in terms of FGR and growth. FGRs indicate that fish fed the diet containing 260 g/kg ingested 665 g CP per kilo gain (PER 1.50) whereas one kilo weight gain in fish fed the other diets required ingestion of between 732 g and 738 g CP (PER ≈1.37). In a study reported by Watanabe *et al.* (1998a), maximum growth rate (0.35%/day) in *S. quinqueradiata* of 440 g average weight at 14.5°C required 151 kJ and 3.6 g CP per kg body weight, while 600 g fish at 16°C required approximately 185 kJ and 4.1 g CP (SGR 0.16%/day). Comparisons between published reports of the performance in fish fed different diets is difficult due to many factors including differences in husbandry methods, environmental conditions, feeding rates, and undefined nutritional values of the various raw materials employed. Nevertheless, a number of indicators of performance in the Japanese yellowtail (which can serve as a "surrogate" species given the paucity of data for *S. dumerilii*), are reviewed in relation to diet composition, fish size, and water temperature (Table 3). This review is intended, in broad terms, to indicate the level of potential performance in these species in a captive rearing situation when fed formulated diets. Clearly, growth rate is strongly influenced by fish size and water temperature, but FGRs around 1.0, and PER values greater than 2.0 have been reported. The optimum temperature for growth of both the Mediterranean and Japanese yellowtail is approximately 26°C, and the lower tolerance level of this species is approximately 12°C. Given the relatively low water temperature in the present trial, the growth rate, at over 1% increase in body weight per day, was excellent, and SGR, PER and FGR values are comparable with *S. quinqueradiata*.

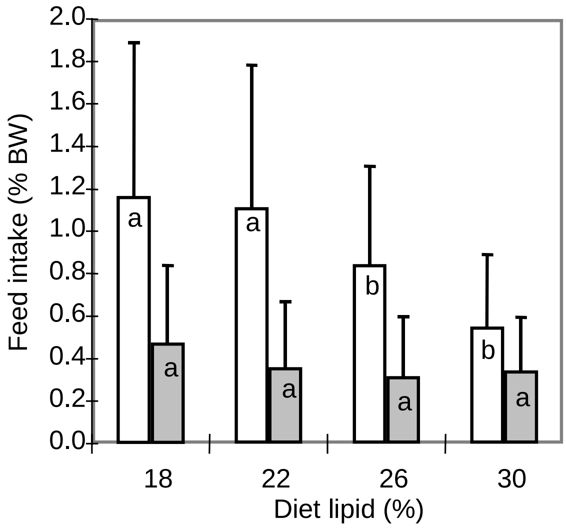

Fig. 1. Feed intake (mean ± SD; n = 30) in *Seriola dumerilii* in relation to dietary fat level. Measurements were taken on two days (day 1, open bars; day 2, shaded bars) separated by two days. For each day, treatments sharing the same letter were not significantly different (ANOVA, $p < 0.05$).

Within the range tested, dietary lipid levels did not significantly affect liver- or viscero-somatic index, or muscle water content. However, condition factor, and muscle and visceral fat increased significantly with increasing dietary fat levels, although the differences were small with the exception of visceral fat in the fish fed the diet containing 30% lipid. Most of the published reports which describe the effect of diet composition on body composition in *Seriola* spp. have tested diets with higher protein, and lower energy levels than those tested in the present trial. No significant effects on the proximate composition of muscle in *S. dumerilii* was found by Jover *et al.* (1999) in fish fed diets containing 25 and 28 g CP/MJ; the energy content of the diets being nearly identical (17.2 to 17.8 MJ/kg). Shimeno *et al*. (1985) found no significant effect of diet composition (15.5-18.1 MJ ME/kg, 30.5-43.6 g CP MJ ME/kg) on condition factor or relative organ size in *S. quinqueradiata*, although the trial period (28 days) was very short. In a study of soybean meal (SBM) inclusion level in diets ranging from approximately 370 g/kg CP and 250 g/kg CL to 500 g/kg CP and 190 g/kg CL, carcass lipid levels increased in fish fed high dietary lipid and SBM levels and increased with increasing body size (Viyakarn *et al.*, 1992). Liver lipid content also increased proportionally to dietary SBM level and lipid

Table 3. Literature values of the growth and conversion efficiency in *Seriola quinqueradiata* and *Seriola dumerilii* fed dry diets. The treatments giving the best growth rates in each study have been chosen. In general, best growth resulted in best FGR and PER. In compiling the diet composition values several assumptions, and estimations of some dietary parameters which were not given in the original publications, were made. To standardise the data, energy equivalents of dietary macro-nutrients were based on those given by Cho *et al.* (1982), and these may differ from those used by the authors. All dietary values have been re-calculated on a dry matter basis. Dietary raw material composition, other environmental parameters, and feeding rates, have not been considered. Due to variance around reported data, rounded-up values have been used

Reference	Temperature[†] (°C)	Days[††]	Start-end wt (g)	SGR[†††] (% BW/day)	FGR[††††]	PER[†††††]	CP[††††††] (g/kg)	CE[†††††††] (MJ/kg)	CP:GE[††††††††] (g/MJ)
S. quinqueradiata									
Sakamoto *et al.* (1995)	25	42	40-170	3.5	1.0	2.2	505	24.0	20.9
	27→16	78	425-1240	1.4	1.6	1.3	505	24.0	20.9
Shimeno *et al*. (1980)	26-29	30	106-290	3.4	1.4	1.3	530	15.5	34.2
Shimeno *et al.* (1985)	26-29	30	88-214	3.1	1.4	1.3	570	17.3	33.0
Takeuchi *et al.* (1992)	20-24	35	4-36	6.5	1.0	1.9	510	15.8	32.2
	19-22	30	2-16	7.4	0.9	2.3	500	13.9	36.0
Watanabe *et al.* (1992)	28→18	74	160-690	2.0	1.4	1.6	490	25.8	19.1
	21→28→18	143	1190-3240	0.7	2.1	1.1	480	26.7	18.1
Viyakarn *et al.* (1992)	26→21	70	365-760	1.1	2.6	0.8	540	23.0	23.7
	24-25	36	40-180	4.2	1.0	2.0	540	23.4	23.7
Watanabe *et al.* (1998b)	24	45	13-160	5.6	0.9	2.4	500	24.0	21.0
	27→22	50	130-340	1.9	1.4	1.5	500	24.0	21.0
S. dumerilii									
Jover *et al.* (1999)	14-28	307	150	0.7	2.5	0.9	490	21.2	23.0
Present trial	21→15→18	118	100-370	1.1	1.6	1.5	430	24.3	17.6

[†]Temperature range during trial. Arrow indicates direction of change when temperature varied.
[††]Duration of the trial. Intermediate monitoring points were not considered separately.
[†††]Specific growth rate calculated as [(ln end wt – ln start wt)/days duration] x 100.
[††††]Feed:gain ratio calculated as g feed given/g biomass gain.
[†††††]Protein efficiency ratio calculated as g wt gain/g protein fed.
[††††††]Crude protein re-calculated on a dry matter basis.
[†††††††]Crude energy re-calculated on a dry matter basis from given proximate composition using the energy equivalents in Cho *et al.* (1982).
[††††††††]Crude protein: crude energy ratio.

level. Takeuchi *et al.* (1992) observed elevated whole body and liver lipid levels with increasing dietary lipid content, especially in diets containing more than 150 g/kg CL in diets containing 450 and 500 g/kg CP. Body size, season, feeding rates, duration of feeding, and dietary amino acid levels are clearly important in determining the body lipid stores, in addition to diet CP, CL, and GE levels. The optimum diet composition with respect to carcass composition depends on consumer preferences. Market surveys and organoleptic tests require to be conducted before any diet recommendations can be given to produce fish with the desired body composition. The consequences of the effect of diet composition on body traits and body composition, including fish health and gutting losses, remains to be established, and long term trails require to be conducted.

Conclusions

Both *S. quinqueradiata* and *S. dumerilii* have been shown in this, and in other studies, to exhibit high growth rates and feed conversion efficiency when fed extruded dry diets with a composition similar to that used in the intensive production of salmonids. The present study suggests that for fish up to 500 g at temperatures around 18°C, a diet containing approximately 17.5 g CP/MJ and 24.5 MJ CE/kg gives good growth and feed conversion, and with minimal effects on body traits and body composition. A diet with this composition contains about 100 g/kg less CP than has been suggested from other studies, and some 200 g/kg less than traditional moist diets on a dry matter basis. As protein is the most costly macro-nutrient in fish feeds, lowering protein levels can reduce the formulation cost of commercial diets. At the same time, the relatively high energy density, which permits the improved protein retention and FGR, is likely to benefit the environment through reduced nutrient loading. In relation to productivity in aquaculture, the growth rate of the Mediterranean yellowtail compares very favourably with growth rates that are attained by the two predominant farmed species in the Mediterranean namely, sea bass (*Dicentrachus labrax*) and gilthead sea bream (*Sparus aurata*), at similar temperatures. The main constraint to the commercial production of *Seriola dumerilii* in the Mediterranean relates to the availability of juveniles and the development of a consumer market.

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