AperTO - Archivio Istituzionale Open Access dell'Università di Torino

The State of *Seriola* spp. Other Than Yellowtail (*S. quinqueradiata*) Farming in the World

This is a pre print version of the following article:

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/1578143> since 2016-06-30T14:41:40Z

Published version:

DOI:10.1080/23308249.2016.1187583

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

The state of *Seriola* spp. other than Yellowtail (*S. quinqueradiata*) farming in the world.

Journal:	<i>Reviews in Fisheries Science & Aquaculture</i>
Manuscript ID	BRFS-2016-0012.R1
Manuscript Type:	Review
Date Submitted by the Author:	n/a
Complete List of Authors:	Sicuro, Benedetto; University of Torino, Animal Production, Ecology and Epidemiology Luzzana, Umberto; Skretting
Keywords:	Amberjack, <i>Seriola dumerili</i> , <i>Seriola lalandi</i> , Carangids, Yellowtail farming

SCHOLARONE™
Manuscripts

The state of *Seriola spp.* other than yellowtail (*S. quinqu radiata*) farming
in the world

Benedetto Sicuro¹, Umberto Luzzana²

¹ Department of Veterinary Sciences, University of Torino, Grugliasco (TO), Italy

² Skretting, Mozzecane (VR), Italy

Corresponding author:

Benedetto Sicuro

Department of Veterinary Sciences, University of Torino

Largo Paolo Braccini, 2

10095 Grugliasco (Torino) - Italy

Email: benedetto.sicuro@unito.it

Tel.: +390116709260

Fax: +390116709240

Abstract

The aim of this review is to provide an update of *Seriola spp.* farming in the world, excluding yellowtail (*S. quinqueradiata*), and to identify strengths and weaknesses of these species as candidates for aquaculture diversification in different areas of the world. Farmed *Seriola* species other than yellowtail are yellowtail kingfish (*S. lalandi*) in Japan and Australia, longfin yellowtail (*S. rivoliana*) in the United States, greater amberjack (*S. dumerili*) in Japan, the Mediterranean and more recently Vietnam, and Pacific yellowtail (*S. mazatlana*) in North and Central America. Candidate countries for *Seriola spp.* farming development are China (although there are no published production statistics to date), New Zealand and the Canary Islands. The main bottlenecks for further expansion of *Seriola spp.* farming appear to be disease impact, lack of genetic improvement programs and incomplete knowledge of nutrient requirements. Extensive experience from Japan, where the success of *Seriola spp.* farming has been based on an integrated system between producer associations, research institutes and central government, it is clear that the aforementioned technical bottlenecks need to be addressed within a framework of medium-term public policies supporting aquaculture development.

Key words: Aquaculture diversification, Amberjack, Carangids, *Seriola dumerili*, *Seriola lalandi*, yellowtail

Introduction

Diversification is an urgent need for aquaculture (Teletchea and Fontaine, 2014) and new candidate species must be highly appreciated by consumers so to get high prices on the market. *Seriola spp.*, belonging to the *Carangidae* family, are one such group of fish with exceptional consumer acceptance. The species within this family with the longest history of commercial farming is yellowtail (*Seriola quinqueradiata* Temminck & Schegel, 1844) which has been farmed in Japan since the 1960's (Masumoto, 2002). *Seriola spp.* farming in Japan initially relied on collection of wild juveniles, caught in Spring and grown until they reached market size (2-5 kg) (Masumoto, 2002). Following the experience of yellowtail, other species have been considered for artificial rearing such as greater amberjack (*Seriola dumerili*, Risso 1810), yellowtail kingfish (*S. lalandi* Valenciennes, 1833) and longfin yellowtail (*S. rivoliana* Valenciennes, 1833). In 2014 the production of *Seriola spp* in Japan was of 150387 tonnes, with 107059 tonnes of yellowtail and 38770 tons of greater amberjack (http://www.maff.go.jp/j/tokei/kouhyou/kaimen_gyosei/index.html). World production of *Seriola spp.*, largely dominated by yellowtail, peaked at 160477 tonnes in 2011 (Lovatelli et al., 2013) with Japan and China (figures for the latter reported in FAO Fishstat as *Seriola nei* but likely to be *Seriola quinqueradiata*) as the major producers (Fig. 1). Yellowtail kingfish (*S. lalandi*) has the second highest production volume within *Seriola* species, with an annual production estimated at 4558 tonnes in Japan in 2013 and 3000-4000 tonnes (expected to increase in the near future to ≥ 5000 t) in South Australia (Miller et al., 2011) (Fig. 1). Yellowtail kingfish is a temperate and subtropical epipelagic species naturally occurring in the Australasian region, Southern Japan and East China Sea. It has a good adaptability to cage culture conditions. *Seriola lalandi* is currently farmed in Japan (Nakada, 2008; Shiraishi et al., 2010), New Zealand (Kolkovski and Sakakura, 2004, Camara and Symonds, 2014; Symonds et al., 2014), California (Buentello et al., 2015; Stuart and Drawbridge, 2011), Australia (Kolkovski and Sakakura, 2004, Hutson et al., 2007; Miegel et al., 2010), Chile (Aguilera et al., 2013; Orellana et al., 2014) and, in limited amount, in the Netherlands in recirculation aquaculture systems RAS (Abbink et al., 2011; Orellana et al., 2014; Garcia et al., 2015) .

Recently, *S. lalandi* has been targeted as potential new species for aquaculture in South Africa and Namibia (O'Neill et al., 2015). Limited production of other *Seriola spp.* species is reported, with *S. rivoliana* at 400 – 500 tonnes/year in southern US and Hawaii (Fig. 2), (Sims, 2013) and possibly similar volumes for greater amberjack in the Mediterranean (De la Gándara, 2006; Ottolenghi et al., 2004) and Taiwan (Lu et al., 2012) (Fig. 3). Greater amberjack is an epipelagic fish species diffused in the circumglobal temperate area, showing high growth rate (reaching 6 kg within 2.5 years of culture), excellent flesh quality and high economic value (Mazzola et al., 2000). Greater amberjack has the second longest history as a farmed *Seriola* species; its culture started in 1978 in Japan where it is still considered an important species (Miwa et al., 2011; Matsunari et al., 2013a), with a production volume of 38770 tons in 2013. Greater amberjack farming further developed in the Mediterranean region in the second half of the 1980's, and more recently in Vietnam (Ottolenghi et al., 2004), Korea, some coastal areas of China (Wu and Pan, 1997; Rongxing et al., 2008; Yokoyama et al., 2013; Ouqin et al., 2014) and in Taiwan (Lu et al., 2012). Major producers of greater amberjack in the Mediterranean have been Spain (in Balearic Islands, Murcia and Tarragona) (Grau 1999) and Italy (Giovanardi et al., 1984; Pipitone and Andaloro 1995; Lazzari et al., 2000), followed by Malta (http://www.fao.org/fishery/countrysector/naso_malta/en), Croatia (Benovic, 1980), Turkey (Yilmaz and Şereflişan, 2011) and Saudi Arabia. Longfin yellowtail (*S. rivoliana*) can be found in the East Atlantic coasts from Portugal to Azores and Madeira (Smith-Vaniz, 1986) and, less frequently, in Galicia (Spain) (Bañón and Garazo, 2006), the British Isles (Wheeler, 1986) and Mediterranean Sea (Castriota et al., 2004). This species is commercially cultured in Hawaii (Verner- Jeffreys et al. 2006) and it shows good potential for aquaculture diversification. Longfin yellowtail (*Seriola rivoliana*) in fact adapts well to rearing conditions and to dry commercial feeds. This species also responds positively to hormonal treatments to induce reproduction, although broodstock are reported to give poor spawns and low larval survival (Roo et al., 2012; Roo et al., 2014; Roo et al 2015). A further amberjack species, the Pacific yellowtail (*Seriola mazatlanana*) has been reported to spawn in Ecuador (Benetti 2000; Venizelos and Benetti, 1996), USA and Latin America (Tucker 2012). Recently, Florida Pompano

(*Trachinotus carolinus*) has been introduced in commercial farm in Florida, thus confirming the high commercial interest in Carangid fish (Schrandt and Powers, 2015).

The aim of this review is to provide an update of *Seriola spp.* farming in the world, excluding yellowtail, and to identify strengths and weaknesses of these species as candidates for aquaculture diversification in different areas of the world.

Feeding

In the early years of amberjack farming, farmed amberjack were fed raw frozen fish. Today extruded pellets are successfully used to grow this species (Garcia-Gomez, 2000), while trash fish is still occasionally used for broodstock feeding (Tab. 1). The higher efficiency of formulated feeds versus trash fish for amberjack feeding is reflected in the improved feed conversion rate (FCR), reported to decrease from 5 to 1,22 (Mazzola et al., 2000). This is similar to data reported for yellowtail, where FCR ranges from 0.9-2.6 with extruded pellets, compared to figures ranging up to 17.5 in the case of raw fish, depending on fish size (Talbot et al., 2000; Nakada, 2008). In terms of nutrient levels in amberjack feeds, research efforts have been devoted to quantify macronutrient (Garcia-Gomez, 2000; Jover et al. 1999; Talbot et al. 2000, Ottolenghi et al., 2004), amino acid (Limin et al. 2006) and gross energy requirements (Vidal et al., 2008) (Tab. 1). With respect to *S. lalandi*, optimal crude protein and fat levels (Jirsa et al., 2011; Jirsa et al., 2014) and gross energy requirements (Aguilera et al. 2013) have been quantified (Tab. 1), while nitrogen loading from cage operations has also been investigated (Fernandez and Tanner 2008). Being the most recent candidate for aquaculture, little information is available on *S. rivoliana* artificial feeding; Fernández-Palacios et al (2015) used mackerel at 2% of body weight for broodstock feeding, while requirements for growout should be presumably comparable with those reported for other *Seriola spp.* species. In order to reduce production costs and improve sustainability of the *Seriola spp.* aquaculture industry, extensive research has been carried out to quantify optimal inclusion levels of vegetable proteins (Ottolenghi et al., 2004). Following the experiences on several piscivorous fish species, different fish meal substitutes have successfully been tested, such as soybean meal at 10%

inclusion level in feeds for *S. lalandi* (Bowyer et al., 2013a) and at 20-30% for *S. dumerili* (Tomas et al., 2005). A novel non-GM soybean cultivar with reduced levels of heat-resistant oligosaccharides (raffinose and stachyose) and protease inhibitors has been tested at levels up to 40 – 48% inclusion in feeds for *S. lalandi* (Buentello et al., 2014; Jirsa et al., 2011) and soy protein concentrate (SPC) up to 20% inclusion again in feed for *S. lalandi* (Bowyer et al., 2013b). Recently, 80% replacement of fish meal with squid meal, defatted *Haematococcus pluvialis* and *Schizochytrium limacinum* meals has also been successfully achieved in *S. rivoliana*, thus showing potential application for single-cell protein (SCP) utilization (Kissinger et al 2016). Animal by-products such as poultry meal have also been successfully tested in Japanese amberjack (Nakada, 2008) and yellowtail (Bowyer et al 2012a). Less information is available on the substitution of fish oil with alternative lipid sources: in *S. lalandi* the use of canola oil and poultry oil, alone or in combination, to replace fish oil led to reduced activity of digestive enzymes (Bowyer et al 2012a; Bowyer et al 2012b). Among micronutrients, only selenium has been investigated in *S. lalandi* for possible toxic effects (Le and Fotedar, 2014). Feeding is known to significantly impact product quality of farmed fish and in this respect, O'Neil et al (2014) stated that nutritional characteristics of farmed *S. lalandi* can be potentially better respect to their wild counterpart. Broodstock nutrition impacts reproductive success and juvenile quality (Talbot et al., 2001; Fernández-Palacios et al., 2013). Rodríguez-Barreto et al (2014) found that gonad maturation of female broodstock is improved by increasing dietary eicosapentaenoic to arachidonic acid ratio up to 9. Inclusion of krill meal and astaxantin in *S. lalandi* broodstock feeds improved egg quality (Kolkovski and Sakura, 2004), while feeding *S. lalandi* broodstock feeds improved egg quality (Kolkovski and Sakura, 2004), while feeding *S. dumerili* and *S. rivoliana* broodstock with raw fish such as mackerel and squid are reported to have positive effect on artificial spawn induction and fecundity (Roo et al 2015; Fernández-Palacios et al., 2015b). Larval rearing has been successfully achieved by feeding *Artemia* and rotifers appropriately enriched or by mesocosm technology (Papandroulakis et al., 2005; Hamasaki et al 2009; Matsunari et al., 2013; Yamamoto et al., 2013). *Artemia* replacement will certainly be a further step to improve sustainability of *Seriola spp.* farming. Supplemental inclusion of Vitamin E and C (Kolkovski and Sakakura 2004), increase of temperature of larval

culture water for *S. lalandi* (Cobcroft et al., 2013) and supplemental inclusion of docosahexaenoic acid (DHA) in feeds for *S. rivoliana* (Mesa-Rodríguez A, Hernández et al., 2013) are reported to decrease the incidence of skeletal deformities during larval rearing. The natural predatory behavior of these fish sometimes causes cannibalism, particularly at larval stages, which has even been observed at low density for *S. lalandi* and *S. quinquerediata* (Stuart and Drawbridge, 2012; Kolkovski and Sakakura 2004). Light intensity, water temperature and turbidity are all reported to affect larval predatory behavior (Carton 2005; Ma, 2014; Stuart and Drawbridge 2012). Feeding management also needs optimization in order to ensure full utilization of feed and reduce competition in rearing cages (De la Gandara et al., 2004; Talbot et al., 1999).

Feed additives

Feed additives are a heterogeneous category of compounds traditionally utilized in fish feeds such as feeding stimulants, immunostimulants, probiotics and prebiotics (Zhang et al., 2014). Different additives have been tested for amberjack feeding. Considerable work has been reported on feeding stimulants. Hidaka et al (2000) tested squid and jack mackerel muscle extracts on Japanese amberjack and found that amino acids were the main palatability enhancers together with inosine-5'-monophosphate (IMP) and inosine. Taurine is an organic acid acting as an osmolyte and cytoprotectant as well as being involved in bile acid conjugation and bile flow. Recent studies demonstrated that the ability of taurine synthesis greatly differs between fish species (Yang et al., 2013; Salze and Davis, 2015). Matsunari and coll. extensively investigated the role of taurine in Japanese amberjack (Matsunari et al. 2003; Matsunari et al. 2005; Matsunari et al. 2006; Matsunari et al. 20013b), which is reported as having low or negligible ability of taurine synthesis due to the low cysteinesulphinatase decarboxylase activity during metabolism from methionine to cystathionine (El-Sayed 2014). Research suggests that fish fed artificial feeds with significant inclusion of plant proteins— mainly from soybean which is known to reduce enterohepatic circulation of taurine in higher vertebrates — may require

1
2
3 taurine supplementation. In fact, supplemental taurine has been reported to be needed for
4
5 Japanese amberjack fed soybean-based diets (Takagi et al., 2008), while a recent study suggests
6
7 that somewhere between 0.20% and 0.32% dietary taurine is required for *S. lalandi* fed a diet
8
9 containing soybean protein concentrate as the major protein raw material (Jirsa et al., 2014).
10
11 The importance of intestinal microbiota is increasingly recognized in fish nutrition, and has also
12
13 been subject of research in some *Seriola spp.* species, such as *S. dumerili* (Buntuello et al 2015;
14
15 Aguilera, 2013) and *S. lalandi* (Aguilera et al., 2013).
16
17
18
19

20 21 Pathology

22
23 Many pathogens are reported to affect *Seriola spp.* under farm conditions (Tab. 2). In Japan
24
25 amberjack farming has been hardly constrained by disease diffusion since its beginning and
26
27 yellowtail culture industry periodically experiences epidemic diseases and mass mortalities,
28
29 caused by encephalomyelitis (Yokoyama et al., 2010), pseudotuberculosis from *Photobacterium*
30
31 *damselae* (Nagano et al., 2011), lactococciosis and meningoencephalitis from *Lactococcus*
32
33 *garvieae* (Ooyama et al., 1999; Nakaima et al., 2014). Considering the high mobility of these
34
35 species and their diffusion in the temperate area, climate change could impact the future disease
36
37 diffusion as reported with *S. lalandi* in southern Australia (Doubleday et al., 2013). In the
38
39 Mediterranean region the most dangerous pathogens for greater amberjack are *Photobacterium*
40
41 *damsella* subsp. *piscicida*, which induces symptoms in both acute and chronic patterns (Crespo
42
43 et al. 1994) and *Vibrio harveyi* (Rigos and Katharios, 2010). In Spain, mycosis from
44
45 *Ichthyophonus hoferi* caused mortalities up to 23% (De la Gandara 2006). The digeneid
46
47 *Paradeontacylix sp.* caused up to 80% mortality together with *Zeuxapta seriola*
48
49 (Heteraxinidae) or *Cryptocaryon irritans* (Ciliophora) (De la Gandara 2006). Gill fluke
50
51 infections caused by monogeneans such as *Heteraxine heterocerca* caused mortalities in greater
52
53 amberjack (Grau et al., 1999; Shirakashi et al., 2013) and other parasites such as the copepod
54
55 *Caligus curtus* and the isopod *Gnathia vorax* have also been reported to cause mass mortalities
56
57 (Grau et al., 1999). Transfer of juveniles between countries has been reported to spread
58
59
60

pathologies to native areas, for example the spread of encephalomyelitis into Japan when *S. dumerili* juveniles were imported from China or tropical areas (Yokoyama et al., 2013; Nakada 2008; Yoshinaga et al., 2006). Also in China diseases outbreak is a major constraint to the potential of greater amberjack farming, in particular vibriosis (Rongxing et al., 2008). The main diseases of *S. lalandi* in Australia and New Zealand include flatworm parasites (*Benedenia seriolae*) and *Zeuxapta seriolae*, which inhabit the gills and the skin, respectively (Kolkovski and Sakakura 2004), facilitating secondary microbial infections. These infestations are typically treated with hydrogen peroxide disinfection baths but an anthelmintic orally administered, praziquantel, has also been tested (Williams et al., 2007). Metazoan parasite infestations in *S. lalandi* in southern Australia are a major threat to sea-cage aquaculture, in particular *Paradeontacylix spp.*(Digenea), *Kudoa sp.* and *Unicapsula seriolae* (Myxozoa) (Hutson et al 2007). In California, the presence of *Anisakis sp.* and the first case of cutaneous myxoma in fish has been reported in *S. lalandi* (Keller et al. 2011). In *S. rivoliana*, disease caused by a monogenean (*Neobenedia sp.*) is reported as the main cause of broodstock mortality (Roo et al., 2014). In Ecuador, epitheliocystis was found in *S. mazatlana* when first farming attempts started at the end of 1990's (Venizelos and Benetti, 1996). Vaccination has proven effective in modern *Seriola sp.* farming, since its early application in Japan with the use of oral vaccine against *Listonella garvieae* in 1997 (Ooyama et al., 1999). In the following years, monovalent, divalent and trivalent vaccines, water-based injection vaccines containing iridovirus, *L. anguillarum* and *L. garvieae* or *L. garvieae*, *L. anguillarum* and *Streptococcus dysgalactiae*, were introduced (Brudeseth et al., 2013). Yellowtail vaccination against pasteurellosis (Gravningen et al., 2008) and lactococciosis (Nakaima et al., 2014) has been very effective, leading to decreased antibiotic use. Vaccination has been suggested as the best strategy to prevent vibriosis in Chinese greater amberjack farming (Rongxing et al., 2008). Most of the vaccines currently available are based on classical fermentation, cultivation or recombinant technologies, while it is likely that future vaccines will be inactivated vaccines, live-attenuated vaccines and DNA vaccines (Brudeseth et al., 2013). Environmental factors such as water temperature influence fish health, and in fact water temperature below 10 °C can lead to inflammation of distal

intestine that can cause in turn mortality in *S. quinquerradiata* and *S. lalandi* (Miegel et al., 2010), while the decrease of water temperature from 22 °C to 18 °C is related with increase of sub-acute enteritis in *S. lalandi* (Bansemer et al., 2015). *S. lalandi* reared at 18 °C reduced growth, feed efficiency and nutrient retention respect those held at 22 °C of water temperature (Bowyer et al., 2012a; Bowyer et al., 2012b).

Artificial reproduction

In Japan the artificial reproduction of *S. dumerili* was first obtained in the Aquaculture Research Laboratory of Nagasaki Prefectural Institute of Fisheries in the early 1990's (Tachihara et al., 1993, Garcia and Diaz, 1995) and several years later it was accomplished in other regions, such as Mediterranean (Mazzola et al., 2000; Muraccioli et al., 2000) and Australia (Poortenaar et al., 2001). The first reports of spontaneous reproduction of greater amberjack came from fish held in large tanks (500 mc) (Jerez et al., 2006). In following trials tank volumes were reduced, still obtaining high quality spawns as long as good broodstock nutrition and health were maintained (Fernández-Palacios et al., 2013). *S. dumerili* females reared in captivity reach sexual maturity later compared to wild fish and inappropriate rearing conditions may negatively affect spawning activities and reproductive physiology (Kozul et al 2001; Micale et al., 1999). For these reasons hormonal treatments are used, initially based on human chorionic gonadotropin (Kozul et al 2001). Roo et al (2013) obtained gonadal maturation induction with intramuscular injections of GnRHa (20 µg/kg-1 of body weight) in broodfish of *S. dumerili* under controlled conditions. Mylonas et al (2004) then demonstrated the existence of a reproductive dysfunction of greater amberjack in captivity and proved that releasing-hormone agonist (GnRHa) implants can be successfully used for the induction of multiple spawns of viable eggs. Fernández-Palacios et al (2015b) recently developed a protocol based on intramuscular injections of GnRHa (20 µg/kg-1 of body weight) administered every 10 days to *Seriola dumerili* fluent males and 500 µm oocyte-bearing females. In other amberjack species, the control of artificial reproduction has been achieved only recently. The first studies on *S. lalandi* artificial reproduction aimed to understand the spawning behavior of wild caught broodstock and early larval development

(Moran et al 2007). Temperature-induced spawning was demonstrated in California in 2010 (Stuart and Drawbridge 2013). Muncaster et al (2013) showed that GnRHa (500 µg/kg-1 of body weight) implants did not stimulate reproduction or spawning of this species, while Nocillado et al. (2013) showed that kisspeptin treatment stimulate gonadal development in pre-pubertal male *S. lalandi*. As with other *Seriola* species, skeletal deformities are also described in hatchery-reared *S. lalandi* (Martinez-Montano et al 2014). First successful attempt of artificial reproduction of *S. rivoliana* was obtained in Hawaii in 2003 (Laidley et al., 2004), while more recently protocols for artificial spawning of this species have been described by Roo et al (2014) and Fernández-Palacios et al (2015a).

Bottlenecks and needs

In the light of the literature consulted, the main bottlenecks for further expansion of *Seriola* spp. farming appear to be disease impact, lack of genetic improvement programs and incomplete knowledge of nutrient requirements for these species. The availability of modern vaccines, as the one used against Lactococciosis (Nakaima et al 2014) represents a potential tool for reducing disease impact in *Seriola* spp. farming. From the technological point of view, some best practices have also been suggested for *S. dumerili* rearing, such as deeper cage submersion. In fact Shirakashi et al (2013) obtained a reduction up to 80% and 95% in the incidence of skin fluke infection when *S. dumerili* cages were submerged at a depth of 2 and 4 m, respectively. These results can be explained by positive phototactic behavior of parasite larvae, more concentrated in the superficial water layers and more active during the central part of the day. The most innovative and promising research on different *Seriola* spp. species are focused on modern genetic techniques, such as parentage allocation and pedigree reconstruction, focused on disease resistance and better growth (Whatmore et al., 2013; Kolkovski and Sakakura 2004). Genomic techniques are also considered a promising perspective for yellowtail farming. In Japan a whole genome radiation hybrid panel for *Seriola quinqueradiata* gene mapping has been recently obtained (Aoki et al., 2014), which is considered as an important step for the

identification of genes related to important farming traits. Selective breeding and genome selection approaches are used in New Zealand at the National Institute of Water and Atmospheric Research (NIWA), in order to provide the industry high-performance *S. lalandi* offspring (Camara and Symonds, 2015). A better understanding of the nutrient requirements and of the nutritional value of different raw materials for *Seriola* spp. is also needed, in order to allow sustainable farming of these species. Application of experimental models already used for other species may allow rapid development in the area of nutrition of *Seriola* spp.

Conclusions

It is very well known that world aquaculture production is dominated by species on the lower end of the food chain, but from a realistic point of view, production of piscivorous, high value fish species for international markets, like amberjacks, will presumably continue (Subasinghe and Hishamunda 2012). Developed and developing countries can benefit from aquaculture of high value species since it has been estimated that fishery and aquaculture trade in some cases can reach more than half of the total of traded commodities (FAO 2014). The investments needed to resolve the current bottlenecks to increased *Seriola* production are far below the capacity of single commercial operators, and may benefit from cooperative organizational systems that align the priorities of fish producers, research associations and regulatory bodies. Such policies have successfully been implemented in Japan, where the aquaculture industry is an integrated and efficient system based on such cooperation between stakeholders, combined with a central government that has been supporting Japanese amberjack farming since its beginning (Nakada 2008). Similarly, governmental may facilitate development of *Seriola* spp. farming in other countries. In New Zealand for instance, significant investments from the Foundation for Research Science and Technology and the Ministry of Business, Innovation and Employment have highlighted the potential for *S. lalandi* farming (Martinez-Montano et al., 2014; McKenzie 2014; Symonds et al., 2014). In the Canary Islands (Spain), during the last decade the Autonomic Government of Canary Islands has started an intensive program aiming

at development of farming techniques for *S. rivoliana* and *S. dumerili*. New Zealand and the Canary Islands are, in fact, areas where further development of *Seriola spp.* farming is expected. Looking at world production figures (Fig. 1), a further obvious candidate for *Seriola spp.* farming development is China, due to its geographical proximity to Japan and being first country in the world for aquaculture production, although the lack of published production statistics make it difficult to derive a clear perspective of the progress to date. Considering that most of modern high-value farmed fish species need significant technological development, the case of amberjack farming can be used as an example for further emerging piscivorous species.

Acknowledgments

We would like to thank Rhys Hauler, Yuta Hamasaki, Leo Nankervis and Giovanni Turchini for their critical revision and helpful suggestions on our paper. We also thank Leo Nankervis for the English revision of the manuscript.

References

Abbink, W., Blanco, Garcia A., Roques, J. A. C., Partridge, G. J., Kloet, K. and O. Schneider. The effect of temperature and pH on the growth and physiological response of juvenile yellowtail kingfish *Seriola lalandi* in recirculating aquaculture systems. *Aquaculture* **330**: 130–135 (2011)

Aguilera, E., Yany G. and J. Romero. Cultivable intestinal microbiota of yellowtail juveniles (*Seriola lalandi*) in an aquaculture system. *Lat. Am. J. Aquat. Res.*, **41**(3): 395-403 (2013)

Aoki J., Kai W., Kawabata Y., Ozaki A., Yoshida K., Tsuzaki T., Fuji K., Koyama T., Sakamoto T and K. Araki. Construction of a radiation hybrid panel and the first yellowtail (*Seriola quinqueradiata*) radiation hybrid map using a nanofluidic dynamic array. *BMC Genomics* **15** (165): 1-10 (2014)

Arimoto M., Mori K., Nakai T., Muroga K and I. Furusawa. Pathogenicity of the causative agent of viral nervous necrosis disease in striped jack, *Pseudocaranx dentex* (Bloch & Schneider). *J. Fish Dis.* **16** (5): 461–469 (1993)

Bansemmer M.S., Forder R.E.A., Howarth G.S., Sutor G.M., Bowyer J and D.A.J. Stone. The effect of dietary soybean meal and soy protein concentrate on the intestinal mucus layer and development of subacute enteritis in yellowtail Kingfish (*Seriola lalandi*) at suboptimal water temperature. *Aquacult. Nutr.* **21** (3): 300-310 (2014)

Barnes A. Preventing diseases in Fish by Vaccination. In Lucas JS, Southgate PC (eds) *Farming Aquatic Animals and Plants, 2nd Edition, Wiley-Blackwell* pp 445 – 459. (2012)

Benovic A. The problems and perspectives of mariculture in the southern Adriatic region. *Nova Thalassia* **4**: 105–111 (1980)

Benetti D.D. Aquaculture of Pelagic Marine Fish. *The advocate* **23**: 20(2000)

Benetti D. D. Spawning and larval husbandry of flounder (*Paralichthys woolmani*) and pacific yellowtail (*Seriola mazatlanensis*), new candidate species for aquaculture. *Aquaculture* **155** (1–4): 307–318 (1997)

Bowyer J.N., Qin J.G., Smullen R.P and D.A.J. Stone. Replacement of fish oil by poultry oil and canola oil in yellowtail kingfish (*Seriola lalandi*) at optimal and suboptimal temperatures *Aquaculture* **356–357**: 211–222 (2012a)

Bowyer J.N., Qin J.G., Adams L.R., Thomson M.J.S and D.A.J. Stone. The response of digestive enzyme activities and gut histology in yellowtail kingfish (*Seriola lalandi*) to dietary fish oil substitution at different temperatures. *Aquaculture* **368–369**: 19 - 28 (2012b)

Bowyer J.N., Qin J.G., Smullen R.P., Adams L.R., Thomson M.J.S and D.A.J. Stone. The use of a soy product in juvenile yellowtail kingfish (*Seriola lalandi*) feeds at different water temperatures: 1. Solvent extracted soybean meal. *Aquaculture* **384–387**: 35–45 (2013a)

Bowyer J.N., Qin J.G., Smullen R.P., Adams L.R., Thomson M.J.S and D.A.J. Stone. The use of a soy product in juvenile yellowtail kingfish (*Seriola lalandi*) feeds at different water temperatures: 2. Soy protein concentrate. *Aquaculture* **410–411**: 1–10 (2013b)

Brudeseth B.E., Wiulsrød R., Fredriksen B.N., Lindmo K., Løkling K.E., Bordevik M., Steine N., Klevan A and K. Gravningen. Status and future perspectives of vaccines for industrialised fin-fish farming. *Fish Shellfish Immunol.*, **35**: 1759-1768 (2013)

Buentello A., Jirsa D., Barrows F.T and M. Drawbridge. Minimizing fishmeal use in juvenile California yellowtail, *Seriola lalandi*, diets using non-GM soybeans selectively bred for aquafeeds. *Aquaculture* **435**: 403–411 (2015)

Camara M.D and J.E. Symonds. Genetic improvement of New Zealand aquaculture species: programmes, progress and prospects. *New Zeal. J. Mar. Fresh.* **48**(3) 466–491 (2014)

Campora C.E., Hokama Y., Tamaru C.S., Anderson B and D. Vincent. Evaluating the Risk of Ciguatera Fish Poisoning from Reef Fish Grown at Marine Aquaculture Facilities in Hawai'i. *J. World Aquacult. Soc.*, **41** (1) 61-70 (2010)

Carton A. G. The impact of light intensity and algal-induced turbidity on first-feeding *Seriola lalandi* larvae. *Aquac. Res.* **36**, 1588-1594 (2005)

Cobcroft J.M., Battaglene S.C., Biggs J.C.G and D.S. Fielder. Investigating causal factors of skeletal malformation in yellowtail kingfish *Seriola lalandi*. In: C.I. Hendry (Ed), Larvi, '13 – Fish & Shellfish Larviculture Symposium. European Aquaculture Society, Special Publication No. XX, pp 81 – 85 Oostende, Belgium (2013)

Crespo S., Grau A and F. Padro. The intensive culture of 0+ amberjack in the western Mediterranean is compromised by disease problems. *Aquacult. Int.* **2**:1–4. (1994)

De La Gandara F., Jover M and A. Garcia-Gomez. Effect of continuous food supply on the oxygen consumption of young Mediterranean yellowtail (*Seriola dumerili* Risso, 1810). *Aquacult. Int.* **12**: 205–213 (2004)

De la Gándara F. ¿Por qué no se ha desarrollado el cultivo de *Seriola dumerili* en el Mediterráneo? Actav IV Congreso Iberoamericano Virtual de Acuicultura CIVA 326 – 340 (2006)

Di Cesare A., Luna G. M., Vignaroli C., Pasquaroli S., Tota S., Paroncini P and F. Biavasco. Aquaculture Can Promote the Presence and Spread of Antibiotic-Resistant Enterococci in Marine Sediments. *PLoS ONE* **8**(4): 1-8 (2013)

Doan H., Doolgindachbaporn S and A. Suksri. Effect of *Lactobacillus plantarum* and Jerusalem artichoke (*Helianthus tuberosus*) on growth performance, immunity and disease resistance of *Pangasius catfish* (*Pangasius bocourti*, Sauvage 1880) *Aquacult. Nutr.* **21**: 1-13 (2015)

Doubleday Z.A., Clarke S.M., Li X., Pecl G.T., Ward T.M., Battaglene S., Frusher S., Gibbs P.J., Hobday A.J., Hutchinson N., Jennings S.M., R. Stoklosa. Assessing the risk of climate change to aquaculture: a case study from south-east Australia. *Aquac. Environ. Interact.* **3**: 163–175 (2013)

El-Sayed A.F.M. Is dietary taurine supplementation beneficial for farmed fish and shrimp? a comprehensive review. *Rev. Aquacult.* **6**: 241–255 (2014)

FAO. The State of World Fisheries and Aquaculture 2014. 223 pp. Rome (2014)

FAO. Fishery and Aquaculture Statistics. Global production by production source 1950-2012 (Fishstat). In: FAO Fisheries and Aquaculture Department. Rome. Updated 2014. <http://www.fao.org/fishery/statistics/software/fishstatj/en> (2014)

Fernandes M and J. Tanner. Modelling of nitrogen loads from the farming of yellowtail kingfish *Seriola lalandi* (Valenciennes, 1833) *Aquac. Res.* **39**: 1328-1338 (2008)

Fernández-Palacios H., Schuchardt D., Roo J., Hernández-Cruz C and M. Izquierdo. Multiple GnRHa injections to induce successtul spawning on wild caught greater amberjack (*Seriola dumerili*) matured in captivity. *Aquac. Res.* **1**: 1-12 (2013)

Fernández-Palacios H., Schuchardt D., Roo J., Hernández-Cruz C and M. Izquierdo. Spawn quality and GnRHa induction efficiency in longfin yellowtail (*Seriola rivoliana*) broodstock kept in captivity. *Aquaculture* **435**: 167–172 (2015a)

Fernandez-Palacios H., Schuchardt D., Roo J., Hernandez-Cruz C.M and M. Izquierdo. Multiple GnRHa injections to induce successful spawning of wild caught greater amberjack (*Seriola dumerili*) matured in captivity. *Aquac. Res.* **46**: 1748–1759 (2015b)

García A and M. Díaz. Culture of *Seriola dumerili* *Cahiers Options Méditerranéennes* **16**: 103 – 114 (1995)

Garcia A.B., Partridge G.J., Flik G., Roques J.A.C and W. Abbink. Ambient salinity and osmoregulation, energy metabolism and growth in juvenile yellowtail kingfish (*Seriola lalandi* Valenciennes 1833) in a recirculating aquaculture system. *Aquac. Res.* **46**: 2789–2797 (2015)

Garcia-Gomez A. Recent advances in nutritional aspects of *Seriola dumerili*. In: Basurco B (ed) *Cahiers options Meditteraneennes, vol 47. Recent advances in Mediterranean aquaculture finfish species diversification*. CIHEAM, 249–257 Zaragoza (2000)

Grau A., Crespo S., Sarasquete M.C and M.L.G. de Canales. The digestive tract of the amberjack *Seriola dumerili*, Risso: a light and scanning electron microscope study. *J. Fish Biol.* **41**: 287–303 (1992)

Grau A., Riera F and E. Carbonell. Some protozoan and metazoan parasites of the amberjack from the Balearic Sea (western Mediterranean). *Aquacult. Intern.* **7**: 307–317 (1999)

Gravningen K., Sakai M., Mishiba T and T. Fujimoto. The efficacy and safety of an oil-based vaccine against *Photobacterium damsela* subsp. *piscicida* in yellowtail (*Seriola quinqueradiata*): a field study. *Fish Shellfish Immunol.* **24**:523-529 (2008)

Hamasaki K., Tsuruoka K., Teruya K., Hashimoto H., Hamada K., Hotta T and K. Mushiake. Feeding habits of hatchery-reared larvae of greater amberjack *Seriola dumerili*. *Aquaculture* **288**: 216–225 (2009)

- Haouas W.G., Zayene N., Guerbe H and Hammami M., L. Achour. Fatty acids distribution in different tissues of wild and reared *Seriola dumerili*. *Int. J. Food Sci. Tech.* **45**: 1478–1485 (2010)
- Hidaka I., Kohbara J., Araki T., Morishita T., Miyajima T., Shimizu S and S. Kuriyama. Identification of feeding stimulants from a jack mackerel muscle extract for young yellowtail *Seriola quinqueradiata*. *Aquaculture* **181** (1-2) 115-126 (2000)
- Hutson K.S., Ernst I and I.D. Whittington. Risk assessment for metazoan parasites of yellowtail kingfish *Seriola lalandi* (Perciformes: Carangidae) in South Australian sea-cage aquaculture. *Aquaculture* **271**: 85–99 (2007)
- Iida T., Endo M., Fukutome M and Y. Fukuda. Meningoencephalitis caused by a gram-negative bacterium in yellowtail and amberjack. *Gyobyo Kenkyu* **33** (5): 455-458 (1998)
- Jirsa D., Davis A., Stuart K and M. Drawbridg. Development of a practical soy-based diet for California yellowtail, *Seriola lalandi*. *Aquacult. Nutr.* **17** (4): 869-E874 (2011)
- Jirsa D.O., Stuart K.R., Salze G.P., Rhodes M.A., Davis D.A and M.A. Drawbridge. Limiting Amino Acids in Practical Diets for California yellowtail, *Seriola lalandi*. *J. World Aquacult. Soc.*, **45** (6): 681-690 (2014)
- Jerez S., Samper M., Santamaria F.J., Villamandos J.E., Cejas J.R and B.C. Felipe. Natural spawning of greater amberjack (*Seriola dumerili*) kept in captivity in the Canary Islands. *Aquaculture* **252** 199– 207 (2006)
- Jover M., Garcia-Gomez A., Tomas A., De la Gandara F and L. Perez. Growth of mediterranean yellowtail (*Seriola dumerilii*) fed extruded diets containing different levels of protein and lipid. *Aquaculture* **179**: 25–33 (1999)
- Kissinger K.R., García-Ortega A and J.T. Trushenski. Partial fish meal replacement by soy protein concentrate, squid and algal meals in low fish-oil diets containing *Schizochytrium limacinum* for longfin yellowtail *Seriola rivoliana*. *Aquaculture* **452**: 37–44 (2016)

Kolkovski S and Y. Sakakura. Yellowtail kingfish, from larvae to mature fish – problems and opportunities. In: Cruz Suárez, L.E., Ricque Marie, D., Nieto López, M.G., Villarreal, D., Scholz, U. and M. González. 2004. Avances en Nutrición Acuícola VII. Memorias del VII Simposium Internacional de Nutrición Acuícola. Hermosillo, Sonora, México p 109 – 125 (2004)

Komatsu T., Mizuno S., Natheer A., Kantachumpoo A., Tanaka K., Morimoto A., Hsiao S.T., Rothausler E.A., Shishidou H., Aoki M and T. Ajisaka. Unusual distribution of floating seaweeds in the East China Sea in the early spring of 2012. *J. Appl. Phycol.*, **26** (2): 1169-1179 (2014)

Keller M., Han S and K. Snekvik. Severe anisakiasis and cutaneous myxoma in a California yellowtail, *Seriola lalandi* Valenciennes. *J. Fish Dis.*, **34**, 635–639 (2011)

Kozul V., Scaramuca B., Glamuzina B., Glavic N and P. Tutman. Comparative gametogenesis and hormonal induction of spawning of cultured and wild Mediterranean amberjack (*Seriola dumerilii*, Risso 1810) *Sci. Mar.*, **65**(3): 215 – 220 (2001)

Lackenby J.A., Chambers C.B., Ernst I and I.D. Whittington. Effect of water temperature on reproductive development of *Benedenia seriola* (Monogenea: Capsalidae) from *Seriola lalandi* in Australia. *Dis. Aquat. Organ.*, **74**: 235–242 (2007)

Laidley C.W., Shields R.J and A.O. Ostrowski. Progress in amberjack culture at the Oceanic Institute in Hawaii. *Glob. Aqua. Advoc.*, **7**, 42–43 (2004)

Lazzari A., Fusari A., Boglione A., Marino G and M. Di Francesco. Recent advances in reproductional and rearing aspects of *Seriola dumerilii*. In: Basurco B (ed) *Cahiers options Mediterraneennes*, vol 47. *Mediterranean marine aquaculture finfish species diversification*. CIHEAM, Zaragoza, pp 241– 247 (2000)

Le K.T and R. Fotedar. Toxic effects of excessive levels of dietary selenium in juvenile yellowtail kingfish (*Seriola lalandi*). *Aquaculture*, **433**: 229–234 (2014)

1
2
3 Lovatelli A., Aguilar-Manjarrez J and D. Soto. Expanding mariculture farther offshore:
4 technical, environmental, spatial and governance challenges. FAO Technical Workshop, 22–25
5 March 2010, Orbetello, Italy. FAO Fisheries and Aquaculture Proceedings No. 24. Rome, FAO.
6
7 73 pp. (2013)
8
9

10
11 Lu C.H., Ku C.C., Wen C.M and S.N. Chen. Effects of the Gill Parasite *Zeuxapta seriolae*
12 (Monogenea: Heteraxinidae) on the Sea Cage-cultured Amberjack *Seriola dumerili* (Risso,
13 1810) at Penghu Island (Pescadores), Taiwan. *J. Fish. Soc. Taiwan* **39** (2): 107-114 (2012)
14
15
16

17
18 Ma Z. Food ingestion, prey selectivity, feeding incidence, and performance of yellowtail
19 kingfish *Seriola lalandi* larvae under constant and varying temperatures. *Aquaculture*
20 *International* **22**:1317–1330(2014)
21
22
23

24
25 Mansour S., Azzouz K., Boumaiza M., Ben Amor M.M and C. Capape. First record of a rare
26 carangid species, the Almaco Jack, *Seriola rivoliana* (Osteichthyes: Carangidae) in Tunisian
27 marine waters (central Mediterranean). *Cah. Biol. Mar.* **52** (2): 187-192 (2011)
28
29
30

31
32 Martinez-Montano E., Gonzalez-Alvarez K., Lazo J.P., Audelo-Naranjo J.M and A. Velez-
33 Medel. Morphological development and allometric growth of yellowtail kingfish *Seriola lalandi*
34 V. larvae under culture conditions. *Aquac. Res.* **3**: 1–11 (2014)
35
36
37

38
39 Masumoto T. Yellowtail, *Seriola quinqueradiata*. In: Webster C.D., Lim C. (eds) *Nutrient*
40 *requirements and feeding of finfish for aquaculture*. CAB Int, Wallingford, pp 131–146 (2002)
41
42
43

44
45 Matsunari H. , Takeuchi T., Murata Y., Takahashi M., Ishibashi N., Chuda H and T.
46 Arakawa. Changes in the taurine content during the early growth stages of artificially produced
47 yellowtail compared with wild fish Nippon. *Suisang Gakkaishi*, **69** (5): 757-762 (2003)
48
49
50

51
52 Matsunari H., Takeuchi T., Takahashi M and K. Mushiake. Effect of dietary taurine
53 supplementation on growth performance of yellowtail juveniles *Seriola quinqueradiata*.
54 *Fisheries Sci.* , **71**: 1131-1135 (2005)
55
56
57

Matsunari H., Hamada K., Mushiake K and T. Takeuchi. Effects of taurine levels in broodstock diet on reproductive performance of yellowtail *Seriola quinqueradiata*. *Fisheries Sci.* **72**: 955–960 (2006)

Matsunari, H., Hashimoto, H., Oda, K., Masuda, Y., Imaizumi H., Teruya K., Furuita H., Yamamoto, T., Hamada, K and K. Mushiake. Effects of docosahexaenoic acid on growth, survival and swim bladder inflation of larval amberjack (*Seriola dumerili*, Risso). *Aquac. Res.* **44**: 1696–1705 (2013a)

Matsunari H., Hashimoto H., Iwasaki T., Oda K., Masuda Y., Imaizumi H., Teruya K., Furuita H., Yamamoto T., Hamada K and K. Mushiake. Effect of feeding rotifers enriched with taurine on the growth and survival of larval amberjack *Seriola dumerili*. *Fisheries Sci.* **79**, (5): 815-821 (2013b)

McKenzie J.R. Review of productivity parameters and stock assessment options for kingfish (*Seriola lalandi lalandi*). *New Zealand Fisheries Assessment Report* 2014/04: 1-21 (2014)

Mesa-Rodríguez A., Hernández-Cruz C.M., Izquierdo M.S., Fernández-Palacios H and J. Roo. Effect of increasing DHA content in new weaning diets for longfin yellowtail (*Seriola rivoliana*). In Larvi 2013: 6th fish & shellfish larviculture symposium. Book of abstracts. pp 275 – 279 Gant, Belgium (2013)

Mazzola A., Favaloro E and G. Sarà. Cultivation of the Mediterranean amberjack, *Seriola dumerili* Risso, 1810 , in submerged cages in the Western Mediterranean Sea. *Aquaculture* **181**: 257–268 (2000)

Micale V., Maricchiolo G., L. Genovese. The reproductive biology of the amberjack, *Seriola dumerilii* (Risso 1810). I. Oocyte development in captivity. *Aquac. Res.* **30**: 349-355 (1999)

Miegel R.P., Pain S.J., van Wettene W.H.E.J. , G.S. Howarth and D.A.J. Stone. Effect of water temperature on gut transit time, digestive enzyme activity and nutrient digestibility in yellowtail kingfish (*Seriola lalandi*). *Aquaculture*, **308**: 145–151 (2010)

- 1
2
3 Miller P.A., Fitch A.J., Gardner M., Hutson K.S and G. Mair. Genetic population structure of
4 Yellowtail Kingfish (*Seriola lalandi*) in temperate Australasian waters inferred from
5 microsatellite markers and mitochondrial DNA. *Aquaculture* **319**: 328–336 (2011)
6
7
8
9
10 Miwa S., Kamaishi T., Hirae T., Murase T and T. Nishioka. Encephalomyelitis associated with
11 microsporidian infection in farmed greater amberjack, *Seriola dumerili* (Risso). *J. Fish Dis.* **34**:
12 901–910 (2011)
13
14
15
16
17 Mooney A.J and Ernst I., I.D. Whittington. An egg-laying rhythm in *Zeuxapta seriolae*
18 (Monogenea: Heteraxinidae), a gill parasite of yellowtail kingfish (*Seriola lalandi*). *Aquaculture*
19 **253**: 10– 16 (2006)
20
21
22
23
24 Moran D., Smith C.K., Gara B and C.W. Poortenaar. Reproductive behaviour and early
25 development in yellowtail kingfish (*Seriola lalandi* Valenciennes 1833). *Aquaculture* **262**: 95–
26 104 (2007)
27
28
29
30
31 Mylonas C.C., Papandroulakis N., Smboukis A., Papadaki M and P. Divanach. Induction of
32 spawning of cultured greater amberjack (*Seriola dumerili*) using GnRH α implants. *Aquaculture*
33 **237**: 141–154 (2004)
34
35
36
37
38 Muncaster S., Pether S.M.J., Van de ven I., Marchant A., Irvine G., Johnson S.L., Rosengrave
39 P., Lokman P.M and J.E. Symonds. Gonadotropin-releasing hormone implants induce spawning
40 in female yellowtail kingfish *Seriola lalandi*. *World Aquaculture* **44** (4): 42–44 (2013)
41
42
43
44
45 Muraccioli P., Gándara F. de la, A. García-Gómez. Intensive farming potential of *Seriola*
46 *dumerilii* (Risso 1810) in Corsica. Recent advances in Mediterranean aquaculture finfish species
47 diversification. Zaragoza : CIHEAM, 2000. p. 267–273. *Cah. Opt. Médit.* **47**: 24–28 (2000)
48
49
50
51
52 Nakada M. Yellowtail Culture Development and Solutions for the Future. *Rev. Fish. Sci.* **10**(3–
53 4): 559–575, DOI: 10.1080/20026491051794 (2002)
54
55
56
57
58
59
60

Nakada M. Capture – based aquaculture of yellowtail. In A. Lovatelli; P.F. Holthus (eds). Capture – based aquaculture. Global overview. FAO Fisheries Technical Paper. N **508**. Rome FAO pp. 199 - 215 (2008)

Nakajima N., Kawanishi M, Imamura S., Hirano F., Uchiyama M., Yamamoto K., Nagai H., Futami K., Katagiri T., Maita M and M. Kijima. Development of a serology-based assay for efficacy evaluation of a lactococciosis vaccine in *Seriola* fish. *Fish Shellfish Immunol.* **38**(1):135-139 (2014)

Nagano I., Oshima S and M. Kawai. In vivo analysis on the adherence and infection route of *Photobacterium damsela* subsp. *piscicida* in yellowtail. *Fish Pathol.* **46** (2): 45-50 (2011)

Nocillado J.N., Zohar Y., Biran J., Levavi-Sivan B and A. Elizur. Chronic kisspeptin administration stimulated gonadal development in pre-pubertal male yellowtail kingfish (*Seriola lalandi*; Perciformes) during the breeding and non-breeding season. *Gen. Comp. Endocrinol.* **191**: 168–176 (2013)

O'Neill B., Le Roux A and L.C. Hoffman. Comparative study of the nutritional composition of wild versus farmed yellowtail (*Seriola lalandi*). *Aquaculture* **448**: 169–175 (2015)

Ooyama T., Kera A., Okada T., Inglis V and T. Yoshida. The protective immune response of yellowtail *Seriola quinqueradiata* to the bacterial fish pathogen *Lactococcus garvieae*. *Dis. Aquat. Organ.* **37**(2): 121-126 (1999)

Orellana J., Waller U and B. Wecker. Culture of yellowtail kingfish (*Seriola lalandi*) in a marine recirculating aquaculture system (RAS) with artificial seawater. *Aquacult. Eng.* **58**: 20–28 (2014)

Ottolenghi F., Silvestri C., Giordano P and A. Lovatelli. New MB Capture-based aquaculture. The fattening of eels, groupers, tunas and yellowtails. Rome, FAO. 308p (2004)

Ouqin C., Cunbin S., Yan R., Fang W and W. Shuqin. Histopathological observations on Pseudotuberculosis of *Seriola dumerili*. *J. Fish. China* **37**: (6) 936-943 (2013)

- Papadakis, I.E., Chatzifotis, S., Divanach, P and M. Kentouri. Weaning of greater amberjack (*Seriola dumerilii* Risso 1810) juveniles from moist to dry pellet. *Aquacult. Intern.* **16**:13–25 (2008)
- Papandroulakis N., Mylonas C.C., Maingot E and P. Divanach. First results of greater amberjack (*Seriola dumerili*) larval rearing in mesocosm. *Aquaculture* **250**:155–161 (2005)
- Pipitone, C., F. Andaloro. Food and feeding habits of juveniles greater amberjack, *Seriola dumerili* (OSTTEICHTHYES, CARANGIDAE) in inshore waters of the central Mediterranean sea. *Cybium* **19**(3): 3015-310 (1995)
- Pizzicori P., Castriota L., Marino G and F. Andaloro. *Seriola carpenteri*: a new immigrant in the Mediterranean from the Atlantic Ocean. *J. Fish Biol.* **57** (5): 1335-1338 (2000)
- Poortenaar C.W., Hooker, S.H and N. Sharp. Assessment of yellowtail kingfish (*Seriola lalandi lalandi*) reproductive physiology, as a basis for aquaculture development. *Aquaculture* **201**: 271–286 (2001)
- Rigos G., P. Katharios. Pathological obstacles of newly-introduced fish species in Mediterranean mariculture: a review. *Rev. Fish Biol. Fisher.* **20**:47–70 (2010)
- Rodríguez-Barreto, D., Jerez S., Cejas J.R., Martin M.V., Acosta N.G., Bolaños, A and A. Lorenzo. Ovary and egg fatty acid composition of greater amberjack broodstock (*Seriola dumerili*) fed different dietary fatty acids profiles. *Eur. J. Lipid Sci. Tech.* **116**: 1-12 (2014)
- Rodríguez-Barreto D., Jerez S., Cejas J.R., Martin M.V., Acosta N.G., Bolaños A and A. Lorenzo. Comparative study of lipid and fatty acid composition in different tissues of wild and cultured female broodstock of greater amberjack (*Seriola dumerili*). *Aquaculture* **360–361**: 1–9 (2012)
- Rongxing, J.I., Wenzheng, Z., Shiliu, H and Y. Qingpi. Vaccination in three different ways against vibriosis of *Seriola dumerili* caused by *Vibrio hollisae*. *Chin. J. Ocean. Limn.* **26**(3): 233-237 (2008)

Roo, J., Fernandez-Palacios, H., Hernandez-Cruz, C.M., Mesa-Rodriguez, A., Schuchardt, D and M. Izquierdo. First results of spawning and larval rearing of longfin yellowtail *Seriola rivoliana* as a fast-growing candidate for European marine finfish aquaculture diversification. *Aquacult. Res.*, **45**: 689–700 (2014)

Roo, J., Mesa-Rodriguez, C., Hernández-Cruz, C.M., Izquierdo, M.S and H. Fernández-Palacios. Recent advances in *Seriola dumerilii* culture. In Larvi 2013: 6th fish & shellfish larviculture symposium. p 398 Gant, Belgium. (2013)

Roo, J., Fernández-Palacios H., Schuchardt D., Hernández-Cruz C.M and M.S. Izquierdo. Influence of hormonal induction and broodstock feeding on longfin yellowtail *Seriola rivoliana* maturation, spawning quality and egg biochemical composition. *Aquacult. Nutr.* **21**: (5): 614 - 624 (2015)

Salze G.P and D.A. Davis. Taurine: a critical nutrient for future fish feeds. *Aquaculture* **437**: 215–229 (2015)

Schrandt, M.N and S.P. Powers. Facilitation and Dominance in a Schooling Predator: Foraging Behavior of Florida Pompano, *Trachinotus carolinus*. *PLoS ONE* **10**(6): e0130095. doi:10.1371/journal.pone.0130095 (2015)

Shiraishi T., Ohshimo, S and R. Yukami. Age, growth and reproductive characteristics of gold striped amberjack 1 *Seriola lalandi* in the waters off western Kyushu, Japan. *New Zeal. J. Mar. Fresh.* **44** (2): 117-127 (2010)

Shirakashi, S., Hirano C., Ishitani H and K. Ishmaru. Diurnal pattern of skin fluke infection in cultured amberjack, *Seriola dumerili*, at different water depths. *Aquaculture* **402**: 19-23 (2013)

Sims, N.A. Kona Blue Water Farms case study: permitting, operations, marketing, environmental impacts, and impediments to expansion of global open ocean mariculture. In A. Lovatelli, J., Aguilar-Manjarrez, & D. Soto (Eds) *Expanding mariculture farther offshore: Technical, environmental, spatial and governance challenges. FAO Technical Workshop*, 22–25

March 2010, Orbetello, Italy. *FAO Fisheries and Aquaculture Proceedings No. 24*. Rome, FAO. pp. 263–296. (2013)

Stephens, F.J and A. Savage. Two mortality events in sea-caged Yellowtail Kingfish *Seriola lalandi* Valenciennes, 1833 (Nannoperidae) from Western Australia. *Aust. Vet. J.*, **88**: 414–416. (2010)

Stuart, K.R and M.A. Drawbridge. The effect of light intensity and green water on survival and growth of cultured larval California yellowtail (*Seriola lalandi*). *Aquaculture* **321**: 152–156

Stuart, K.R. and M.A. Drawbridge. Captive spawning and larval rearing of California yellowtail (*Seriola lalandi*). *Aquacult. Res.* **44**: 728–737. (2011)

Skaramuca, B., Kozul, V., Teskeredzic, J., Bolotin, B and V. Onofri. Growth rate of tank-reared Mediterranean Amberjack, *Seriola dumerilii* (Risso 1810) fed on three different diets. *J. Appl. Ichtyol.* **17**:130–133 (2001)

Stride, M.C., Polkinghorne, A., Miller, T.L., Groff, J.M., La Patra, S.E and B.F. Nowak. Molecular Characterization of “Candidatus Parilichlamydia carangidicola,” a Novel Chlamydia-Like Epitheliocystis Agent in Yellowtail Kingfish, *Seriola lalandi* (Valenciennes), and the Proposal of a New Family, “Candidatus Parilichlamydiaceae” fam. nov. (Order Chlamydiales). *Appl. Environ. Microbiol.* **79** (5): 1590-1597 (2013)

Stuart, K.R and M. Drawbridge. The effect of photoperiod on larval culture performance of two marine finfish species. *Aquaculture* **360**: 54–57 (2012)

Symonds, J.E., Walker, S.P., Pether, S., Gublin, Y., McQueen, D., King, A., Irvine, G.W., Setiawan, A.N., Forsythe, J.A and M. Bruce. Developing yellowtail kingfish (*Seriola lalandi*) and hāpuku (*Polyprion oxygeneios*) for New Zealand aquaculture. *New Zeal. J. Mar. Fresh.* **48**(3): 371–384 (2014)

Subasinghe, R and N. Hishamunda. The Next 20 Years 606 in Aquaculture. In : Lucas JS, Southgate PC (eds) *Farming Aquatic Animals and Plants, 2nd Edition, Wiley-Blackwell* pp 606 – 616. (2012)

Tachihara, K., Ebisu, R and Y. Tukashima. Spawning, eggs, larvae and juveniles of the purplish amberjack *Seriola dumerilii*. *Bull. Jpn. Soc. Sci. Fish.* **59**:1479–1488 (1993)

Takagi, S., Murata, H., Goto, T., Endo, M., Yamashita, H and M. Ukawa. Taurine is an essential nutrient for yellowtail *Seriola quinqueradiata* fed non-fish meal diets based on soy protein concentrate. *Aquaculture* **280**: 198–205 (2008)

Takeuchi, T., Shiina Y., Watanaba T, Sekiya S and K. Imaizumi. Suitable protein and lipid levels in diet for fingerlings of yellowtail. *Nippon Suisan Gakkaishi* **58**:1333-1339. (1992)

Talbot, C., Corneillie S and O. Korsoen. Pattern of feed intake in four species of fish under commercial farming conditions: implications for feeding management. *Aquacult. Res.* **30**: 509-518 (1999)

Talbot, C., Garcia-Gomez, A., De La Gandara, F and P. Muraccioli. Food intake, growth and body composition in Mediterranean yellowtail (*Seriola dumerilii*) fed isonitrogenous diets containing different lipid levels. In: Basurco B (Eds) *Cahiers options Mediterraneennes, vol 47. Recent advances in Mediterranean aquaculture finfish species diversification*. CIHEAM, Zaragoza, pp 259–266 (2000)

Tanner, J.E and M. Fernandes. Environmental effects of yellowtail kingfish aquaculture in South Australia. *Aquacult. Env. Interac.* **1**: 155–165 (2010)

Teletchea, F and P. Fontaine. Levels of domestication in fish: implications for the sustainable future of aquaculture. *Fish Fish.* **15**: (2): 181-195 (2014)

Tomas, A., De La Gandara, F., Garcia-Gomez, A., Perez, L and M. Jover. Utilization of soybean meal as an alternative protein source in the Mediterranean yellowtail, *Seriola dumerili*. *Aquacult. Nutr.* **11**; 333–340 (2005)

- 1
2
3 Tucker, J. Marine fish. In : Lucas JS, Southgate PC (eds) *Farming Aquatic Animals and Plants*,
4
5 *2nd Edition*, Wiley-Blackwell pp 384 – 444. (2012)
6
7
8 Valls, M., Grau, A.M., Massuti, E., Tobaruela, A and F. Riera. First record of *Seriola rivoliana*
9
10 (Osteichthyes: Carangidae) in the western Mediterranean. *Mar. Biodivers. Rec.* **4**: 5-8 (2011)
11
12
13 Venizelos, A and D.D. Benetti. Epitheliocystis Disease in Cultured Yellowtail *Seriola*
14 *mazatlanensis* in Ecuador. *J. World Aquacult. Soc.* **27**, (2): 223-235 (1996)
15
16
17 Verner-Jeffreys, D.W., Nakamura, I and R.J. Shields. Egg-associated microflora of Pacific
18 threadfin, *Polydactylus sexfilis* and amberjack, *Seriola rivoliana*, eggs. Characterisation and
19 properties. *Aquaculture* **253**: 184–196 (2006)
20
21
22
23
24 Vidal, A., De la Gandara Garcia F., Garcia Gomez, A and M.J. Cerda. Effect of the
25 protein/energy ratio on the growth of Mediterranean yellowtail (*Seriola dumerili*) *Aquaculture*
26 *Research*, **39**: 1141-1148 (2008)
27
28
29
30
31 Watanabe, T., Verakunpiriya, V., Mushiake, K., Kawano, K and I. Hasegawa. The first spawn-
32 taking from broodstock yellowtail cultured with extruded dry pellets. *Fisheries Sci.* **62**: 388–
33 393. (1996)
34
35
36
37
38 Watanabe, K., Hara, Y., Ura, K., Yada, T., Kiron, V., Satoh, S and T. Watanabe. Energy and
39 protein requirements for maximum growth and maintenance of bodyweight of yellowtail.
40 *Fisheries Sci.* **66**: 884-893. (2000)
41
42
43
44
45 Whatmore. P., Nguyen N.H., Miller, A., Lamont, R., Powell, D., D'Antignana, T., Bubner, E.,
46 Elizur, A and W. Knibb. Genetic parameters for economically important traits in yellowtail
47 kingfish *Seriola lalandi*. *Aquaculture* **400**: 77–84 (2013)
48
49
50
51
52 Williams, R.E., Ernst, I and Chambers, C.B., I.D. Whittington. Efficacy of orally administered
53 praziquantel against *Zeuxapta seriolae* and *Benedenia seriolae* (Monogenea) in yellowtail
54 kingfish *Seriola lalandi*. *Dis. Aquat. Organ.* **77**, 199–205 (2007)
55
56
57
58
59
60

- Wu, H and J. Pan. Studies on the pathogenic bacteria of the vibriosis of *Seriola dumerili* in marine cage culture. *J. Fish. China* **21** (2): 171-174 (1997)
- Yamamoto, T., Matsunari, H., Iwasaki, T., Hashimoto, H., Kai, I., Hokazono, H., Hamada, K., Teruya, K., Hara, T., Furuita, H and K. Mushiake. Changes in mineral concentrations in amberjack *Seriola dumerili* larvae during seed production: high concentrations of certain minerals in rotifers do not directly affect the mineral concentrations in larvae. *Fisheries Sci.* **79** (2): 269-275 (2013)
- Yokoyama, H., Yanagida, T., Freeman, M.A., Katagiri, T., Hosokawa, A., Endo, M., Hirai, M and S. Takagi. Molecular diagnosis of *Myxobolus spirosulcatus* associated with encephalomyelitis of cultured yellowtail, *Seriola quinqueradiata* Temminck & Schlegel. *J. Fish. Dis.* **33**, (12): 939-946 (2010)
- Yokoyama, H., Miyazaki, Y., Yoshinaga, T and H. Tomoyoshi. Microsporidian Encephalomyelitis in Cultured Yellowtail *Seriola quinqueradiata*. *Fish Pathol.*, **48** (4): 119-125 (2013)
- Yoshinaga, T., Kinami, R., Hall, K.A and K. Ogawa. A Preliminary Study on the Infection of Anisakid Larvae in Juvenile Greater Amberjack *Seriola dumerili* imported from Japan to China as Mariculture Seedlings. *Fish Pathol.*, **41** (3): 123-126 (2006)
- Yang, H.J., Tian, L.X., Huang, J.W., Liang, G.Y and Y.J. Liu. Dietary taurine can improve the hypoxia-tolerance but not the growth performance in juvenile grass carp *Ctenopharyngodon idellus*. *Fish Physiol. Biochem.*, **39** (5): 1071-1078 (2013)
- Yilmaz, E and H. Şereflişan. Offshore Farming of the Mediterranean Amberjack (*Seriola dumerili*) in the Northeastern Mediterranean. *Isr. J. Aquacult-Bamind*, **63**: 575 – 582 (2011)
- Zhang, Q., Yu, H., Tong, T., Tong, W., Dong, L., Xu, M. and Z. Wang. Dietary supplementation of *Bacillus subtilis* and fructooligosaccharide enhance the growth, non-specific

immunity of juvenile ovate pompano, *Trachinotus ovatus* and its disease resistance against
Vibrio vulnificus. *Fish Shellfish Immunol.* **38**: 7–14. (2014)

For Peer Review Only

Fig. 1

Fig. 2

Fig. 3

Tab. 1 - Composition of feeds used for *Seriola spp.* in experimental trials

Species	Feed composition	Stage	Reference
<i>S. dumerili</i>	Raw mackerel	Broodstock	Jerez et al., 2006
<i>S. dumerili</i>	Horse mackerel, Atlantic mackerel, European anchovy, European pilchard, European hake, cephalopods	Broodstock and juveniles	Fernández-Palacios et al., 2013
<i>S. dumerili</i>	54% CP; 18% CL	Broodstock	Fernández-Palacios et al., 2013
<i>S. dumerili</i>	54- 52% CP; 20.2 – 21.2% CL	Broodstock	Rodríguez-Barreto et al., 2014
<i>S. dumerili</i>	45 - 50% CP; 14 – 17% CL	Growth out	Jover et al., 1999
<i>S. dumerili</i>	47 – 48% CP; 10.5 – 18 % CL; fish scraps	Growth out	Mazzola et al., 2000
<i>S. dumerili</i>	42.4 – 43.6% CP; 18.4 – 29.3% CL	Growth out	Talbot et al., 2000
<i>S. dumerili</i>	42% CP; 20% CL	Growth out	Papadakis et al., 2008
<i>S. dumerili</i>	50% CP; 17% CL	Growth out	Haouas et al., 2010
<i>S. lalandi</i>	Fresh and frozen fish, mussels with	Broodstock	Kolkovski and Sakakura 2004

	inclusion of HUFA		
	and vitamins		
<i>S. lalandi</i>	41.7% - 46.2% CP;	Growth out	Jirsa et al., 2011
	10.6% – 18.8% CL		
<i>S. lalandi</i>	48.2% - 50.6% CP;	Growth out	Jirsa et al., 2014
	12.8% - 14.7% CL		
<i>S. rivoliana</i>	Raw mackerel	Broodstock	Fernández-Palacios et al., 2015
<i>S. rivoliana</i>	50% CP; 15% CL	Growth out	Kissinger et al., 2016
CP = crude protein; CL = crude lipids			

Tab. 2 - Main pathologies reported in farmed *Seriola spp.* (except Japanese amberjack)

Species	Pathology or pathogen	Region or country	Reference
<i>S. dumerili</i>	<i>Photobacterium damsella</i> subsp. <i>piscicida</i>	Mediterranean	Crespo et al., 1994
<i>S. dumerili</i>	<i>Vibrio harveyi</i>	Mediterranean	Rigos and Katharios, 2010
<i>S. dumerili</i>	<i>Paradeontacylix</i> sp., <i>Zeuxapta seriolae</i> , <i>Cryptocaryon irritans</i> , <i>Ichthyophonus hoferi</i>	Mediterranean (Spain)	De la Gandara, 2006
<i>S. dumerili</i>	<i>Heteraxine heterocerca</i> , <i>Caligus curtu</i> ,; <i>Gnathia vorax</i>	Mediterranean (Balearic Sea)	Grau et al., 1999
<i>S. dumerili</i>	Epitheliocystis,; Sanguinicoliasis, Pseudotuberculosis	Mediterranean	García and Díaz, 1995
<i>S. dumerili</i>	Epitheliocystis, Microsporidiasis, <i>Nocardia kampachi</i> , <i>Benedernia seriolae</i>	Japan	García and Díaz, 1995
<i>S. dumerili</i>	Meningitis	Japan	Iida et al., 1998
<i>S. dumerili</i>	Microsporidians	Japan	Miwa et al., 2011
<i>S. dumerili</i>	<i>Enterococcus seriolicida</i> , Myxosporean parasite, Iridovirus	Japan	Nakada, 2008
<i>S. dumerili</i>	<i>Lactococcus garvieae</i>	Japan	Nakajima et al., 2014

<i>S. dumerili</i>	<i>Neobenedenia girellae</i>	Japan	Shirakashi et al., 2013
<i>S. dumerili</i>	<i>Anisakid</i>	Japan	Yoshinaga et al., 2006
<i>S. dumerili</i>	<i>Vibrio hollisae</i>	China	Rongxing et al., 2008
<i>S. dumerili</i>	<i>Vibrio harveyi</i>	China	Wu and Pan, 1997
<i>S. lalandi</i>	<i>Paradeontacylix</i> sp., <i>Unicapsula seriolae</i> , <i>Benedenia seriolae</i> , <i>Zeuxapta seriolae</i>	<i>Kudoa</i> sp., Southern Australia	Hutson et al., 2007
<i>S. lalandi</i>	<i>Benedenia seriolae</i> , <i>Zeuxapta seriolae</i>	Australia and New Zealand	Kolkovski and Sakakura, 2004; Lackenby et al., 2007
<i>S. lalandi</i>	<i>Zeuxapta seriolae</i> , <i>Benedenia seriolae</i>	South Australia	Williams et al., 2007; Mooney et al., 2006
<i>S. lalandi</i>	" <i>Candidatus</i> <i>carangidicola</i> "	<i>Parilichlamydia</i> South Australia	Stride et al., 2013
<i>S. lalandi</i>	<i>Viral nervous necrosis</i>	Japan	Arimoto et al., 1993
<i>S. lalandi</i>	<i>Vibrio harveyi</i>	Western Australia	Stephens and

				Savage, 2010
<i>S. lalandi</i>	<i>Anisakiasis sp., cutaneous myxoma</i>	California	Keller et al., 2011	
<i>S. rivoliana</i>	<i>Vibrio ssp., Pseudoalteromonas sp., Photobacterium damsella</i>	Hawaii	Verner-Jeffreys et al., 2006	
<i>S. mazatlana</i>	<i>Epitheliocystis</i>	Ecuador	Venizelos and Benetti, 1996	