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

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

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3 The state of *Seriola spp.* other than yellowtail (*S. quinqueradiata*) farming
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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) .

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3 Recently, *S. lalandi* has been targeted as potential new species for aquaculture in South Africa
4 and Namibia (O'Neill et al., 2015). Limited production of other *Seriola spp.* species is reported,
5 with *S. rivoliana* at 400 – 500 tonnes/year in southern US and Hawaii (Fig. 2), (Sims, 2013) and
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7 possibly similar volumes for greater amberjack in the Mediterranean (De la Gándara, 2006;
8
9 Ottolenghi et al., 2004) and Taiwan (Lu et al., 2012) (Fig. 3). Greater amberjack is an epipelagic
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11 fish species diffused in the circumglobal temperate area, showing high growth rate (reaching 6
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13 kg within 2.5 years of culture), excellent flesh quality and high economic value (Mazzola et al.,
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15 2000). Greater amberjack has the second longest history as a farmed *Seriola* species; its culture
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17 started in 1978 in Japan where it is still considered an important species (Miwa et al., 2011;
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19 Matsunari et al., 2013a), with a production volume of 38770 tons in 2013. Greater amberjack
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21 farming further developed in the Mediterranean region in the second half of the 1980's, and
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23 more recently in Vietnam (Ottolenghi et al., 2004), Korea, some coastal areas of China (Wu
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25 and Pan, 1997; Rongxing et al., 2008; Yokoyama et al., 2013; Ouqin et al., 2014) and in Taiwan
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27 (Lu et al., 2012). Major producers of greater amberjack in the Mediterranean have been Spain
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29 (in Balearic Islands, Murcia and Tarragona) (Grau 1999) and Italy (Giovanardi et al., 1984;
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31 Pipitone and Andaloro 1995; Lazzari et al., 2000), followed by Malta
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33 (http://www.fao.org/fishery/countrysector/naso_malta/en), Croatia (Benovic, 1980), Turkey
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35 (Yilmaz and Şereflişan, 2011) and Saudi Arabia. Longfin yellowtail (*S. rivoliana*) can be found
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37 in the East Atlantic coasts from Portugal to Azores and Madeira (Smith-Vaniz, 1986) and, less
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39 frequently, in Galicia (Spain) (Bañón and Garazo, 2006), the British Isles (Wheeler, 1986) and
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41 Mediterranean Sea (Castriota et al., 2004). This species is commercially cultured in Hawaii
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43 (Verner- Jeffreys et al. 2006) and it shows good potential for aquaculture diversification.
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45 Longfin yellowtail (*Seriola rivoliana*) in fact adapts well to rearing conditions and to dry
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47 commercial feeds. This species also responds positively to hormonal treatments to induce
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49 reproduction, although broodstock are reported to give poor spawns and low larval survival
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51 (Roo et al., 2012; Roo et al., 2014; Roo et al 2015). A further amberjack species, the Pacific
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53 yellowtail (*Seriola mazatlanana*) has been reported to spawn in Ecuador (Benetti 2000; Venizelos
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55 and Benetti, 1996), USA and Latin America (Tucker 2012). Recently, Florida Pompano
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3 (*Trachinotus carolinus*) has been introduced in commercial farm in Florida, thus confirming
4 the high commercial interest in Carangid fish (Schrandt and Powers, 2015).
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7 The aim of this review is to provide an update of *Seriola spp.* farming in the world, excluding
8 yellowtail, and to identify strengths and weaknesses of these species as candidates for
9 aquaculture diversification in different areas of the world.
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13 **Feeding**

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15 In the early years of amberjack farming, farmed amberjack were fed raw frozen fish. Today
16 extruded pellets are successfully used to grow this species (Garcia-Gomez, 2000), while trash
17 fish is still occasionally used for broodstock feeding (Tab. 1). The higher efficiency of
18 formulated feeds versus trash fish for amberjack feeding is reflected in the improved feed
19 conversion rate (FCR), reported to decrease from 5 to 1,22 (Mazzola et al., 2000). This is
20 similar to data reported for yellowtail, where FCR ranges from 0.9-2.6 with extruded pellets,
21 compared to figures ranging up to 17.5 in the case of raw fish, depending on fish size (Talbot et
22 al., 2000; Nakada, 2008). In terms of nutrient levels in amberjack feeds, research efforts have
23 been devoted to quantify macronutrient (Garcia-Gomez, 2000; Jover et al. 1999; Talbot et al.
24 2000, Ottolenghi et al., 2004), amino acid (Limin et al. 2006) and gross energy requirements
25 (Vidal et al., 2008) (Tab. 1). With respect to *S. lalandi*, optimal crude protein and fat levels
26 (Jirsa et al., 2011; Jirsa et al., 2014) and gross energy requirements (Aguilera et al. 2013) have
27 been quantified (Tab. 1), while nitrogen loading from cage operations has also been investigated
28 (Fernandez and Tanner 2008). Being the most recent candidate for aquaculture, little
29 information is available on *S. rivoliana* artificial feeding; Fernández-Palacios et al (2015) used
30 mackerel at 2% of body weight for broodstock feeding, while requirements for growout should
31 be presumably comparable with those reported for other *Seriola spp.* species. In order to reduce
32 production costs and improve sustainability of the *Seriola spp.* aquaculture industry, extensive
33 research has been carried out to quantify optimal inclusion levels of vegetable proteins
34 (Ottolenghi et al., 2004). Following the experiences on several piscivorous fish species,
35 different fish meal substitutes have successfully been tested, such as soybean meal at 10%
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3 inclusion level in feeds for *S. lalandi* (Bowyer et al., 2013a) and at 20-30% for *S. dumerili*
4 (Tomas et al., 2005). A novel non-GM soybean cultivar with reduced levels of heat-resistant
5 oligosaccharides (raffinose and stachyose) and protease inhibitors has been tested at levels up
6
7 to 40 – 48% inclusion in feeds for *S. lalandi* (Buentello et al., 2014; Jirsa et al., 2011) and soy
8
9 protein concentrate (SPC) up to 20% inclusion again in feed for *S. lalandi* (Bowyer et al.,
10
11 2013b). Recently, 80% replacement of fish meal with squid meal, defatted *Haematococcus*
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13 *pluvialis* and *Schizochytrium limacinum* meals has also been successfully achieved in *S.*
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15 *rivoliana*, thus showing potential application for single-cell protein (SCP) utilization (Kissinger
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17 et al 2016). Animal by-products such as poultry meal have also been successfully tested in
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19 Japanese amberjack (Nakada, 2008) and yellowtail (Bowyer et al 2012a). Less information is
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21 available on the substitution of fish oil with alternative lipid sources: in *S. lalandi* the use of
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23 canola oil and poultry oil, alone or in combination, to replace fish oil led to reduced activity of
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25 digestive enzymes (Bowyer et al 2012a; Bowyer et al 2012b). Among micronutrients, only
26
27 selenium has been investigated in *S. lalandi* for possible toxic effects (Le and Fotedar, 2014).
28
29 Feeding is known to significantly impact product quality of farmed fish and in this respect,
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31 O’Neil et al (2014) stated that nutritional characteristics of farmed *S. lalandi* can be potentially
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33 better respect to their wild counterpart. Broodstock nutrition impacts reproductive success and
34
35 juvenile quality (Talbot et al., 2001; Fernández-Palacios et al., 2013). Rodríguez-Barreto et al
36
37 (2014) found that gonad maturation of female broodstock is improved by increasing dietary
38
39 eicosapentaenoic to arachidonic acid ratio up to 9. Inclusion of krill meal and astaxantin in *S.*
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41 *lalandi* broodstock feeds improved egg quality (Kolkovski and Sakura, 2004), while feeding *S.*
42
43 *lalandi* broodstock feeds improved egg quality (Kolkovski and Sakura, 2004), while feeding *S.*
44
45 *dumerili* and *S. rivoliana* broodstock with raw fish such as mackerel and squid are reported to
46
47 have positive effect on artificial spawn induction and fecundity (Roo et al 2015; Fernández-
48
49 Palacios et al., 2015b). Larval rearing has been successfully achieved by feeding *Artemia* and
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51 rotifers appropriately enriched or by mesocosm technology (Papandroulakis et al., 2005;
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53 Hamasaki et al 2009; Matsunari et al., 2013; Yamamoto et al., 2013). *Artemia* replacement will
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55 certainly be a further step to improve sustainability of *Seriola spp.* farming. Supplemental
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57 inclusion of Vitamin E and C (Kolkovski and Sakakura 2004), increase of temperature of larval
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3 culture water for *S. lalandi* (Cobcroft et al., 2013) and supplemental inclusion of
4 docosahexaenoic acid (DHA) in feeds for *S. rivoliana* (Mesa-Rodríguez A, Hernández et al.,
5 2013) are reported to decrease the incidence of skeletal deformities during larval rearing. The
6 natural predatory behavior of these fish sometimes causes cannibalism, particularly at larval
7 stages, which has even been observed at low density for *S. lalandi* and *S. quinquerediata* (Stuart
8 and Drawbridge, 2012; Kolkovski and Sakakura 2004). Light intensity, water temperature and
9 turbidity are all reported to affect larval predatory behavior (Carton 2005; Ma, 2014; Stuart and
10 Drawbridge 2012). Feeding management also needs optimization in order to ensure full
11 utilization of feed and reduce competition in rearing cages (De la Gandara et al., 2004; Talbot et
12 al., 1999).

23 24 25 26 27 **Feed additives**

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

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3 taurine supplementation. In fact, supplemental taurine has been reported to be needed for
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5 Japanese amberjack fed soybean-based diets (Takagi et al., 2008), while a recent study suggests
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7 that somewhere between 0.20% and 0.32% dietary taurine is required for *S. lalandi* fed a diet
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9 containing soybean protein concentrate as the major protein raw material (Jirsa et al., 2014).
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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;
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15 Aguilera, 2013) and *S. lalandi* (Aguilera et al., 2013).
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20 21 Pathology

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23 Many pathogens are reported to affect *Seriola spp.* under farm conditions (Tab. 2). In Japan
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25 amberjack farming has been hardly constrained by disease diffusion since its beginning and
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27 yellowtail culture industry periodically experiences epidemic diseases and mass mortalities,
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29 caused by encephalomyelitis (Yokoyama et al., 2010), pseudotuberculosis from *Photobacterium*
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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
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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 seriolae*
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49 (Heteraxinidae) or *Cryptocaryon irritans* (Ciliophora) (De la Gandara 2006). Gill fluke
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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
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55 *Caligus curtus* and the isopod *Gnathia vorax* have also been reported to cause mass mortalities
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57 (Grau et al., 1999). Transfer of juveniles between countries has been reported to spread
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3 pathologies to native areas, for example the spread of encephalomyelitis into Japan when *S.*
4 *dumerili* juveniles were imported from China or tropical areas (Yokoyama et al., 2013; Nakada
5 2008; Yoshinaga et al., 2006). Also in China diseases outbreak is a major constraint to the
6 potential of greater amberjack farming, in particular vibriosis (Rongxing et al., 2008). The main
7 diseases of *S. lalandi* in Australia and New Zealand include flatworm parasites (*Benedenia*
8 *seriolae*) and *Zeuxapta seriolae*, which inhabit the gills and the skin, respectively (Kolkovski
9 and Sakakura 2004), facilitating secondary microbial infections. These infestations are typically
10 treated with hydrogen peroxide disinfection baths but an anthelmintic orally administered,
11 praziquantel, has also been tested (Williams et al., 2007). Metazoan parasite infestations in *S.*
12 *lalandi* in southern Australia are a major threat to sea-cage aquaculture, in particular
13 *Paradeontacylix spp.*(*Digenae*), *Kudoa sp.* and *Unicapsula seriolae* (*Myxozoa*) (Hutson et al
14 2007). In California, the presence of *Anisakis sp.* and the first case of cutaneous myxoma in fish
15 has been reported in *S. lalandi* (Keller et al. 2011). In *S. rivoliana*, disease caused by a
16 monogenean (*Neobenedia sp.*) is reported as the main cause of broodstock mortality (Roo et al.,
17 2014). In Ecuador, epitheliocystis was found in *S. mazatlana* when first farming attempts started
18 at the end of 1990's (Venizelos and Benetti, 1996). Vaccination has proven effective in modern
19 *Seriola sp.* farming, since its early application in Japan with the use of oral vaccine against
20 *Listonella garvieae* in 1997 (Ooyama et al., 1999). In the following years, monovalent, divalent
21 and trivalent vaccines, water-based injection vaccines containing iridovirus, *L. anguillarum* and
22 *L. garvieae* or *L. garvieae*, *L. anguillarum* and *Streptococcus dysgalactiae*, were introduced
23 (Brudeseth et al., 2013). Yellowtail vaccination against pasteurellosis (Gravningen et al., 2008)
24 and lactococcicosis (Nakaima et al., 2014) has been very effective, leading to decreased
25 antibiotic use. Vaccination has been suggested as the best strategy to prevent vibriosis in
26 Chinese greater amberjack farming (Rongxing et al., 2008). Most of the vaccines currently
27 available are based on classical fermentation, cultivation or recombinant technologies, while it
28 is likely that future vaccines will be inactivated vaccines, live-attenuated vaccines and DNA
29 vaccines (Brudeseth et al., 2013). Environmental factors such as water temperature influence
30 fish health, and in fact water temperature below 10 °C can lead to inflammation of distal
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3 intestine that can cause in turn mortality in *S. quinqueradiata* and *S. lalandi* (Miegel et al.,
4 2010), while the decrease of water temperature from 22 °C to 18 °C is related with increase of
5 sub-acute enteritis in *S. lalandi* (Bansemer et al., 2015). *S. lalandi* reared at 18 °C reduced
6 growth, feed efficiency and nutrient retention respect those held at 22 °C of water temperature
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11 (Bowyer et al., 2012a; Bowyer et al., 2012b).
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13 14 **Artificial reproduction**

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17 In Japan the artificial reproduction of *S. dumerili* was first obtained in the Aquaculture Research
18 Laboratory of Nagasaki Prefectural Institute of Fisheries in the early 1990's (Tachihara et al.,
19 1993, Garcia and Diaz, 1995) and several years later it was accomplished in other regions, such
20 as Mediterranean (Mazzola et al., 2000; Muraccioli et al., 2000) and Australia (Poortenaar et al.,
21 2001). The first reports of spontaneous reproduction of greater amberjack came from fish held
22 in large tanks (500 mc) (Jerez et al., 2006). In following trials tank volumes were reduced, still
23 obtaining high quality spawns as long as good broodstock nutrition and health were maintained
24 (Fernández-Palacios et al., 2013). *S. dumerili* females reared in captivity reach sexual maturity
25 later compared to wild fish and inappropriate rearing conditions may negatively affect spawning
26 activities and reproductive physiology (Kozul et al 2001; Micale et al., 1999). For these reasons
27 hormonal treatments are used, initially based on human chorionic gonadotropin (Kozul et al
28 2001). Roo et al (2013) obtained gonadal maturation induction with intramuscular injections of
29 GnRHa (20 µg/kg-1 of body weight) in broodfish of *S. dumerili* under controlled conditions.
30 Mylonas et al (2004) then demonstrated the existence of a reproductive dysfunction of greater
31 amberjack in captivity and proved that releasing-hormone agonist (GnRHa) implants can be
32 successfully used for the induction of multiple spawns of viable eggs. Fernández-Palacios et al
33 (2015b) recently developed a protocol based on intramuscular injections of GnRHa (20 µg/kg-1
34 of body weight) administered every 10 days to *Seriola dumerili* fluent males and 500 µm
35 oocyte-bearing females. In other amberjack species, the control of artificial reproduction has
36 been achieved only recently. The first studies on *S. lalandi* artificial reproduction aimed to
37 understand the spawning behavior of wild caught broodstock and early larval development
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3 (Moran et al 2007). Temperature-induced spawning was demonstrated in California in 2010
4 (Stuart and Drawbridge 2013). Muncaster et al (2013) showed that GnRHa (500 µg/kg-1 of
5 body weight) implants did not stimulate reproduction or spawning of this species, while
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9 Nocillado et al. (2013) showed that kisspeptin treatment stimulate gonadal development in pre-
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11 pubertal male *S. lalandi*. As with other *Seriola* species, skeletal deformities are also described in
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13 hatchery-reared *S. lalandi* (Martinez-Montano et al 2014). First successful attempt of artificial
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15 reproduction of *S. rivoliana* was obtained in Hawaii in 2003 (Laidley et al., 2004), while more
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17 recently protocols for artificial spawning of this species have been described by Roo et al (2014)
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19 and Fernández-Palacios et al (2015a).

20 21 22 23 24 25 **Bottlenecks and needs**

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28 In the light of the literature consulted, the main bottlenecks for further expansion of *Seriola* spp.
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30 farming appear to be disease impact, lack of genetic improvement programs and incomplete
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32 knowledge of nutrient requirements for these species. The availability of modern vaccines, as
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34 the one used against Lactococciosis (Nakaima et al 2014) represents a potential tool for
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36 reducing disease impact in *Seriola* spp. farming. From the technological point of view, some
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38 best practices have also been suggested for *S. dumerili* rearing, such as deeper cage submersion.
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40 In fact Shirakashi et al (2013) obtained a reduction up to 80% and 95% in the incidence of skin
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42 fluke infection when *S. dumerili* cages were submerged at a depth of 2 and 4 m, respectively.
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44 These results can be explained by positive phototactic behavior of parasite larvae, more
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46 concentrated in the superficial water layers and more active during the central part of the day.
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48 The most innovative and promising research on different *Seriola* spp. species are focused on
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50 modern genetic techniques, such as parentage allocation and pedigree reconstruction, focused
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52 on disease resistance and better growth (Whatmore et al., 2013; Kolkovski and Sakakura 2004).
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54 Genomic techniques are also considered a promising perspective for yellowtail farming. In
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56 Japan a whole genome radiation hybrid panel for *Seriola quinqueradiata* gene mapping has
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58 been recently obtained (Aoki et al., 2014), which is considered as an important step for the
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3 identification of genes related to important farming traits. Selective breeding and genome
4 selection approaches are used in New Zealand at the National Institute of Water and
5 Atmospheric Research (NIWA), in order to provide the industry high-performance *S. lalandi*
6 offspring (Camara and Symonds, 2015). A better understanding of the nutrient requirements
7 and of the nutritional value of different raw materials for *Seriola* spp. is also needed, in order to
8 allow sustainable farming of these species. Application of experimental models already used for
9 other species may allow rapid development in the area of nutrition of *Seriola* spp.
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20 21 **Conclusions**

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23 It is very well known that world aquaculture production is dominated by species on the lower
24 end of the food chain, but from a realistic point of view, production of piscivorous, high value
25 fish species for international markets, like amberjacks, will presumably continue (Subasinghe
26 and Hishamunda 2012). Developed and developing countries can benefit from aquaculture of
27 high value species since it has been estimated that fishery and aquaculture trade in some cases
28 can reach more than half of the total of traded commodities (FAO 2014). The investments
29 needed to resolve the current bottlenecks to increased *Seriola* production are far below the
30 capacity of single commercial operators, and may benefit from cooperative organizational
31 systems that align the priorities of fish producers, research associations and regulatory bodies.
32 Such policies have successfully been implemented in Japan, where the aquaculture industry is
33 an integrated and efficient system based on such cooperation between stakeholders, combined
34 with a central government that has been supporting Japanese amberjack farming since its
35 beginning (Nakada 2008). Similarly, governmental may facilitate development of *Seriola* spp.
36 farming in other countries. In New Zealand for instance, significant investments from the
37 Foundation for Research Science and Technology and the Ministry of Business, Innovation and
38 Employment have highlighted the potential for *S. lalandi* farming (Martinez-Montano et al.,
39 2014; McKenzie 2014; Symonds et al., 2014). In the Canary Islands (Spain), during the last
40 decade the Autonomic Government of Canary Islands has started an intensive program aiming
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3 at development of farming techniques for *S. rivoliana* and *S. dumerili*. New Zealand and the
4 Canary Islands are, in fact, areas where further development of *Seriola spp.* farming is expected.
5 Looking at world production figures (Fig. 1), a further obvious candidate for *Seriola spp.*
6 farming development is China, due to its geographical proximity to Japan and being first
7 country in the world for aquaculture production, although the lack of published production
8 statistics make it difficult to derive a clear perspective of the progress to date. Considering that
9 most of modern high-value farmed fish species need significant technological development, the
10 case of amberjack farming can be used as an example for further emerging piscivorous species.
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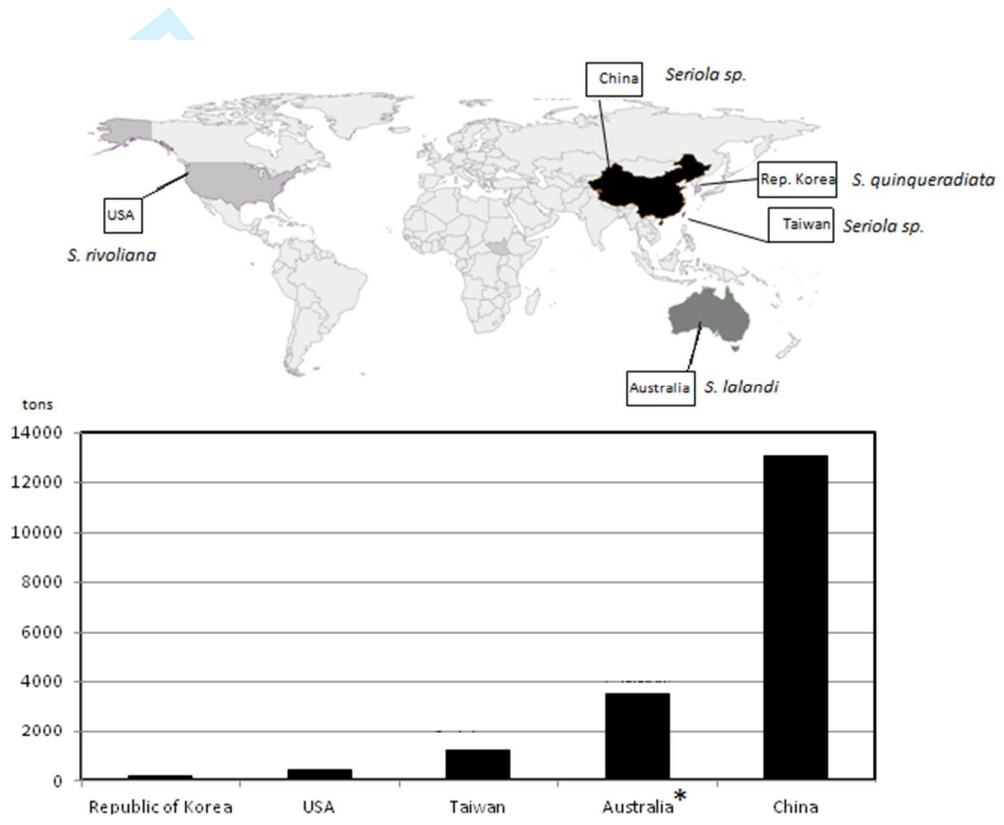
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Fig. 1



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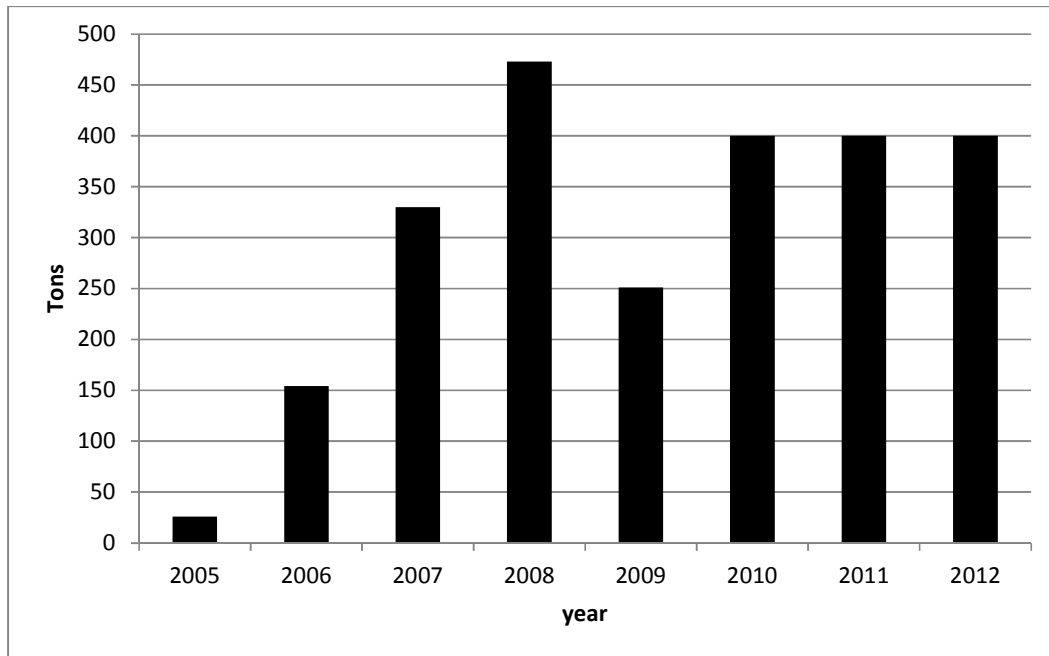


Fig. 2

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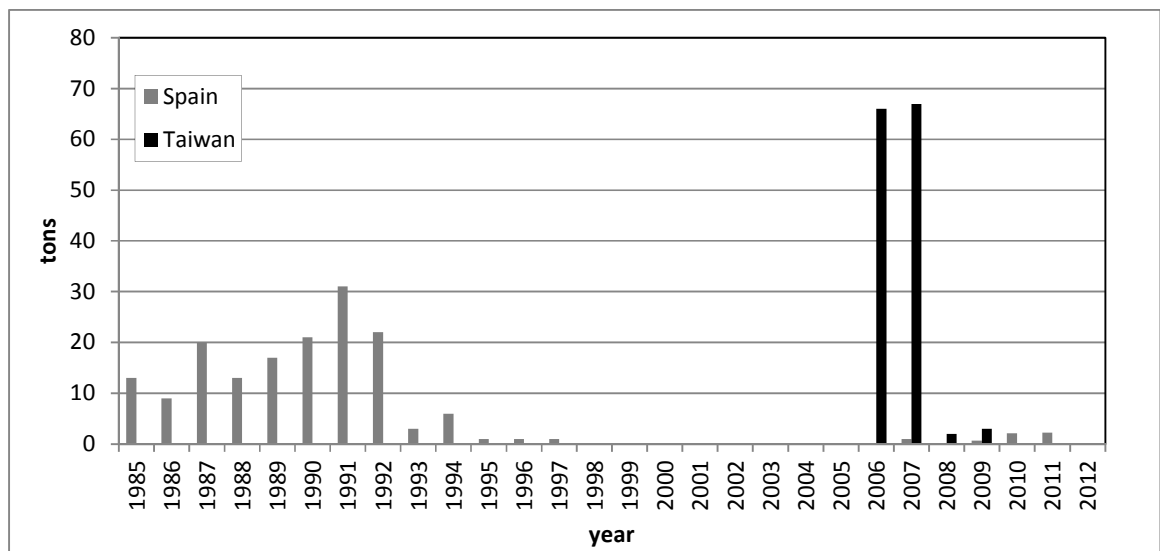


Fig. 3

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 juveniles	and 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; 10.6% - 18.8% CL	Growth out	Jirsa et al., 2011
<i>S. lalandi</i>	48.2% - 50.6% CP; 12.8% - 14.7% CL	Growth out	Jirsa et al., 2014
<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

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2				
3	<i>S. dumerili</i>	<i>Neobenedenia girellae</i>	Japan	Shirakashi et al.,
4				
5				2013
6				
7				
8	<i>S. dumerili</i>	<i>Anisakid</i>	Japan	Yoshinaga et al.,
9				
10				2006
11				
12				
13	<i>S. dumerili</i>	<i>Vibrio hollisae</i>	China	Rongxing et al.,
14				
15				2008
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17				
18	<i>S. dumerili</i>	<i>Vibrio harveyi</i>	China	Wu and Pan,
19				
20				1997
21				
22				
23	<i>S. lalandi</i>	<i>Paradeontacylix</i> sp., <i>Kudoa</i> sp.,	Southern	Hutson et al.,
24		<i>Unicapsula seriolae</i> , <i>Benedenia seriolae</i> ,	Australia	
25		<i>Zeuxapta seriolae</i>		2007
26				
27				
28				
29				
30	<i>S. lalandi</i>	<i>Benedenia seriolae</i> , <i>Zeuxapta seriolae</i>	Australia and	Kolkovski and
31				
32			New Zealand	Sakakura, 2004;
33				
34				Lackenby et al.,
35				
36				2007
37				
38				
39	<i>S. lalandi</i>	<i>Zeuxapta seriolae</i> , <i>Benedenia seriolae</i>	South Australia	Williams et al.,
40				
41				2007; Mooney
42				
43				et al., 2006
44				
45				
46	<i>S. lalandi</i>	" <i>Candidatus Parilichlamydia</i>	South Australia	Stride et al.,
47		<i>carangidicola</i> "		
48				2013
49				
50				
51	<i>S. lalandi</i>	<i>Viral nervous necrosis</i>	Japan	Arimoto et al.,
52				
53				1993
54				
55				
56	<i>S. lalandi</i>	<i>Vibrio harveyi</i>	Western Australia	Stephens and
57				
58				
59				
60				

			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>	Epitheliocystis	Ecuador	Venizelos and Benetti, 1996

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