BIBLIOGRAPHY REVIEW ON REPRODUCTION OF THE MOST IMPORTANT FISH SPECIES OF THE GENUS *SERIOLA*

Final Degree Work of Degree in Marine Sciences

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The title of the work is: BIBLIOGRAPHY REVIEW ON REPRODUCTION OF THE MOST IMPORTANT FISH SPECIES OF THE GENUS *SERIOLA*

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1. Introduction

This work consists of a bibliographic review on the reproduction of the species of the Genus *Seriola*, that have a great value for the aquaculture; *Seriola dumerili*, *S. rivoliana*, *S. lalandi* and *S. quinqueradiata* also known as greater amberjack, longfin yellowtail, yellowtail amberjack, and japanese yellowtail, respectively. These species have been chosen because of their rapid growth, their good adaptation to captivity, their high survival rate, their global distribution and their good acceptance in the market due to their excellent flesh quality (Mazzola *et al.*, 2000; Skaramuca *et al.*, 2000; Mylonas *et al.*, 2004; Jerez *et al.*, 2006; Sawada *et al.*, 2006; Hamasaki *et al.*, 2009; Lloret *et al.*, 2012; Rodríguez-Barreto *et al.*, 2012; Blanco *et al.*, 2015; Fernández-Palacios *et al.*, 2015a; O'Neill *et al.*, 2015; Roo *et al.*, 2015; Hossain *et al.*, 2016; Sanchís-Benlloch *et al.*, 2017; Zupa *et al.*, 2017).

According to Hossain *et al.* (2016), the aquaculture has become an important sector of food production at global level. Aquaculture has acquired an important role in the last decades in its function of supplying a population that is growing. According to the Food and Agriculture Organization of the United Nations (FAO, 2014), the world-wide population exceeds the 7 billion people and the consumption of fish products per capita is estimated at approximately 20 kilograms. For the first time, the products consumed from aquaculture, have exceeded those from catch (FAO, 2014).

The world's population increases each year, and the limitation of the land resources promotes the search for solutions that can address this serious problem. The planet is covered by more than 70 % of water, so the first solution is found in the sea: fishing. The fish are found in areas where the abundance of food resources makes these thrive. There are many zones in the oceans that are deserted. Fishermen know these places where species abound and capture them indiscriminately on a massive scale. Overfishing is a current problem because it is destroying populations and leading to a lot of species on the brink of extinction. Aquaculture is an alternative to traditional fishing which allows to control the production of species and safeguard those who live in the natural environment, as well as offer some resources that supply the world's growing population (FAO, 2014).

One of the greatest challenges facing the aquaculture is to complete the life cycle of a species. This requires controlling from the hatching of the eggs until they reach the adult phase and reproduce. The most difficult part of the aquaculture is to ensure that species are able to reproduce in captivity. Reproduction in the genus *Seriola* has been a major bottleneck for researchers by their difficulty to reproduce in captivity (Micale *et al.*, 1999;

Mylonas *et al.*, 2004; Jerez *et al.*, 2006; Sawada *et al.*, 2006; Moran *et al.*, 2007; Rodríguez-Barreto *et al.*, 2012; Rodríguez-Barreto *et al.*, 2014; Roo *et al.*, 2014; Fernández-Palacios *et al.*, 2015b; Rodríguez-Barreto *et al.*, 2017; Zupa *et al.*, 2017).

For the aquaculture is important to achieve that the species reproduce in captivity and produce a large amount of quality fingerlings. This ensures the production of the company. If the species cannot be reproduced in captivity, would have to import fingerlings of other farms or capture them of their habitat. This is a costly and risky solution since they can suffer stress in transport or be contaminated by parasites, viruses or bacteria (Sawada *et al.*, 2006; Miki *et al.*, 2011).

This work focuses on collecting information from different articles about the reproduction of these species in aquaculture, treating not only the issue of the reproduction in captivity but also the distinct factors that affect it.

2. Characteristics of the Genus *Seriola*

The genus *Seriola* (Cuvier, 1816) is the biggest of the Carangidae family, included in the order Perciformes, and is distributed in all the oceans of the world (Saito, 2012).

According to Bauchot & Pras (1987), the Carangidae family comprise pelagic fish with a good swimming, carnivores, voracious, mostly gregarious, and migrant. They can be found in the Atlantic Ocean, Indian and Pacific Ocean. The fish of this family are quite variable in the shape of the body, have ranges that vary from elongate and fusiform to deep and compressed. It has 25 genera with about 140 species (Whitehead *et al.*, 1989).

The genus *Seriola* is constituted by species from epipelagic until epibenthic that are found both in neritic and coastal waters, from the surface of the sea up to the 360 meters of depth. There are species that can form small to moderate shoals and feed, mainly, of other smaller fish. To feed, they are guided by their sense of sight, so they depend on the lighting (Whitehead *et al.*, 1989; Stuart & Drawbridge, 2013). They are species gonochoristic with synchronous ovarian development and a spawning multiple patterns (Sanchís-Benlloch *et al.*, 2017; Zupa *et al.*, 2017).

As already it mentioned before, it is a genus that has a great ecological and economic importance in the global market (Swart *et al.*, 2015). The genus *Seriola* includes nine species, which have been chosen the most known and that greater value in the world's market (Stuart-Smith *et al.*, 2016).

Greater amberjack, longfin yellowtail, yellowtail amberjack and japanese yellowtail are carnivorous and migratory species. Juveniles of these species form groups, which are called schools because younger individuals learn from the greatest. These groups are often associated with floating objects, but they could find under the jellyfish or shoals of salpa (*Boops salpa*). Adults are generally solitary and usually inhabit fields of kelp, rocky areas, cliffs, reefs, shipwrecks and islands (Lythgoe & Lythgoe, 1994; Corbera *et al.*, 1996; Manooch & Potts, 1997; Micale *et al.*, 1999; Mazzola *et al.*, 2000; Harris *et al.*, 2007; Moran *et al.*, 2007; Pinheiro *et al.*, 2013; Froese & Pauly, 2017; Zupa *et al.*, 2017).

2.1. Description of *Seriola dumerili*

Seriola dumerili (Risso, 1810) is a species with a circumglobally distribution. It is present from Nova Scotia through the Caribbean to Brazil, in the Gulf of Mexico, in Bermuda, from England to South Africa, China, Japan, Australia, the Hawaiian Islands, in the United States and in the Mediterranean except in the Black Sea and in the Adriatic Sea (Manooch & Potts, 1997; Kozul *et al.*, 2001; Harris *et al.*, 2007). In Figure 1, the distribution of the species around the world.

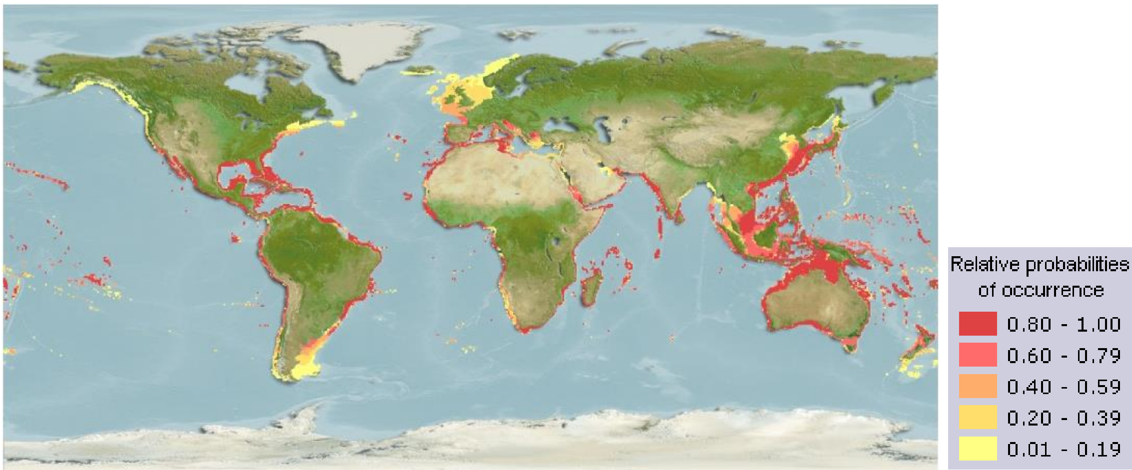

Figure 1: Distribution of greater amberjack (AquaMaps, 2016).

They live in between 18 and 72 meters deep and can reach 360 meters of depth (Corbera *et al.*, 1996; Micale *et al.*, 1999; Mazzola *et al.*, 2000; Harris *et al.*, 2007). This species measures 110 centimeters as maximum and it comes to weigh between 25 and 40 kilograms (Debelius, 1997; Sley *et al.*, 2016). In Figure 2, shows a photo of this species.

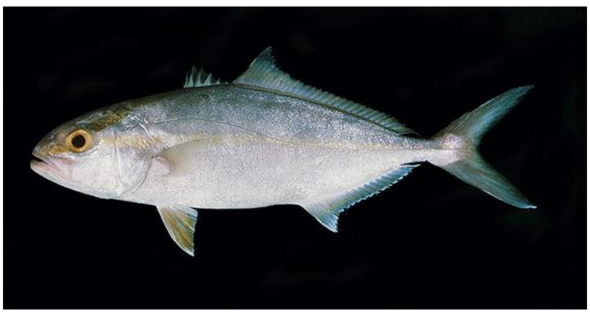

Figure 2: Picture of greater amberjack (Randall, J.P., 1983)

Seriola dumerili is considered a predatory and opportunist species that feeds on crustaceans, fingerlings, squids, some invertebrates and small fish, such as *Trachurus trachurus* and *Boops boops*. The diet varies according to the individual size (Terofal & Wendler, 1993; Corbera *et al.*, 1996; Debelius, 1997, Mazzola *et al.*, 2000; Rodríguez-Barreto *et al.*, 2012; Sley *et al.*, 2016).

According to its distribution area, the spawning period is different, although it usually takes place in spring and summer (Terofal & Wendler, 1993). In the Mediterranean region, the spawning is between late spring and early summer. As Corbera *et al.* (1996), during the spawning period, it is close to the coast while when it finishes this period, in winter, it is located at greater depth.

2.2. Description of *Seriola lalandi*

Seriola lalandi (Valenciennes, 1833) is a species that is distributed in all subtropical seas of the world. We can find it in Japan, Southern Australia, New Zealand, Canada, United States of America, New Caledonia, on the South African coast and Chile, among others (FAO, 2005; Hutson *et al.*, 2007; Shiraishi *et al.*, 2010; Blanco *et al.*, 2015; O'Neill *et al.*, 2015). In Figure 3, shows the distribution of this species around the world.

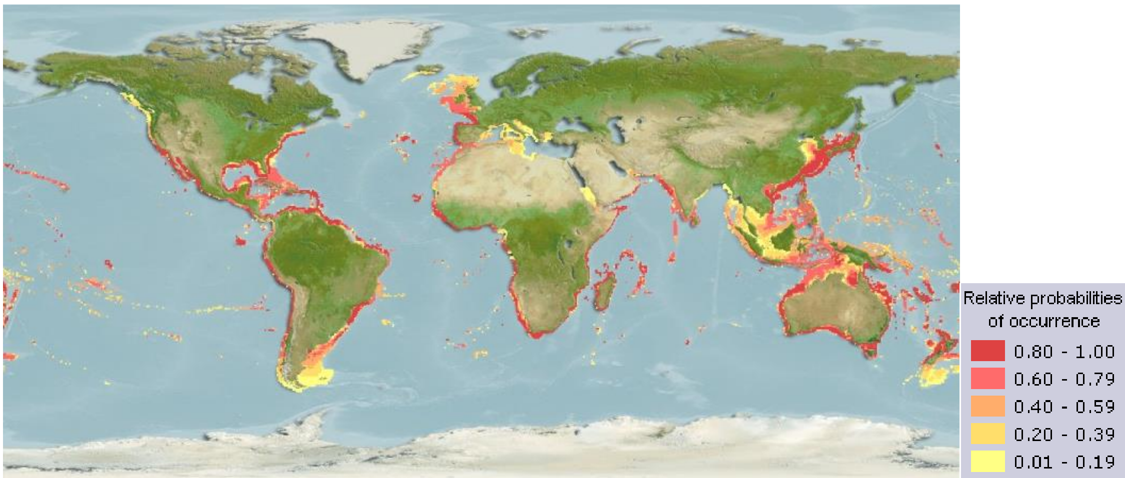

Figure 3: Distribution of yellowtail amberjack (AquaMaps, 2016).

There are in depths varying from 3 up to 825 meters. It prefers warm waters, but it can also be in colder waters. It is a predatory species that feeds on, mainly, small fish, although we also find in its diet squids and crustaceans (Moran *et al.*, 2007; Froese & Pauly, 2017).

This species usually measures approximately 100 centimeters, being able to come, occasionally, to the 190 centimeters. It can reach a weight of 60 kilograms, although its maximum recorded weight has been 96.8 kilograms. Often live an average of 8 years, although its maximum reported age has been 12 years (Debelius, 1997; FAO, 2005; Shiraishi *et al.*, 2010). In Figure 4, shows a photo of this species.

Figure 4: Image of yellowtail amberjack (Robertson, DR, 2010)

The spawning period is different in each region. Shiraishi *et al.* (2010), reported that the spawning of this species to the East China Sea was between April and June. Meanwhile, Stuart & Drawbridge (2013) points out that in California the spawning was between early May and early August.

2.3. Description of *Seriola quinqueradiata*

Seriola quinqueradiata (Temminck & Schlegel, 1845) is a pelagic fish that is endemic to Japan and other adjacent regions. It is possible to locate in the Northeast of Pacific, specifically, from the east of the Korean Peninsula to the Hawaiian Islands (FAO, 2005; Froese & Pauly, 2017). In Figure 5, it is possible to observe the distribution of this species.

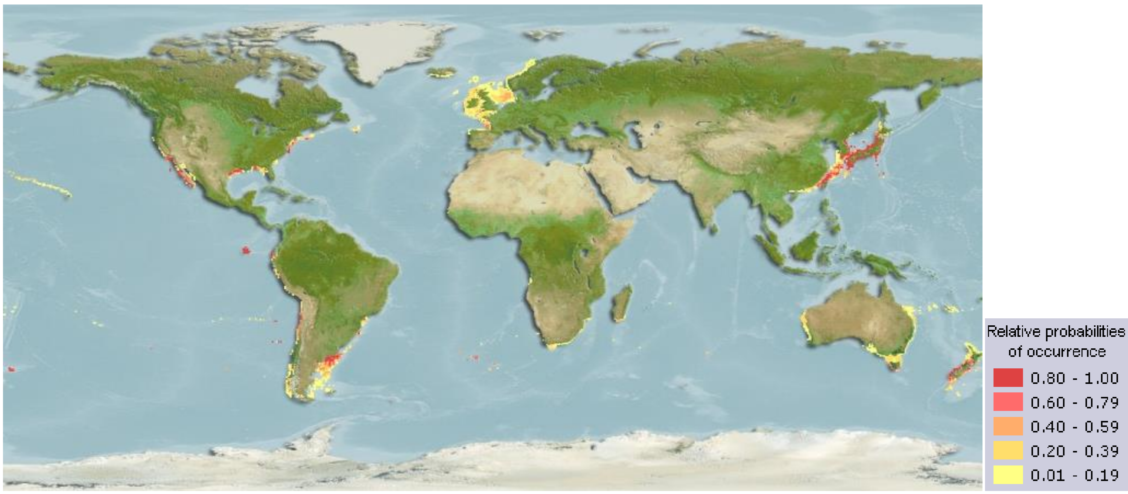

Figure 5: Distribution of japanese yellowtail (AquaMaps, 2016).

It is a carnivorous species that eats especially fish, but its diet also includes squids and some invertebrates. Some fish that comprise its diet include mackerel, chub mackerel and sardines (FAO, 2005).

It can reach a maximum of 150 centimeters and a maximum weight of 40 kilograms (FAO, 2005). In Figure 6, shows a photo of this species.

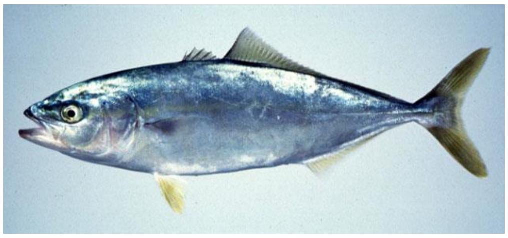

Figure 6: Image of japanese yellowtail (Suzuki, T., 1992)

It spawns at about 200 meters along the coast of the East China Sea, during the months of February and March. Juveniles migrate toward the north, it feeds for about three or five years and returns to the south to reproduce. This species in captivity begins to mature and spawn two months later, from late April to early May (FAO, 2005).

2.4. Description of *Seriola rivoliana*

Seriola rivoliana (Valenciennes, 1833), is a species with circumglobal distribution. It is located in Portugal, Azores and Madeira, Canary Islands, from New Jersey to Argentina, South Africa, the Gulf of Mexico, Florida, Caribbean and Brazil (Lythgoe & Lythgoe, 1994; Debelius, 1997; Pinheiro *et al.*, 2013; Froese & Pauly, 2017). In Figure 7, we can observe the distribution of this species around the world.

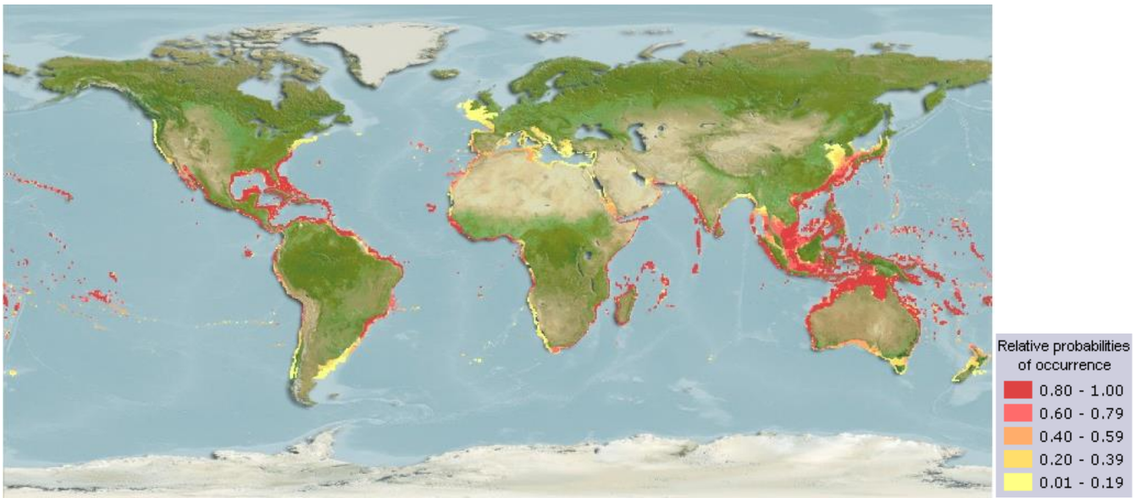

Figure 7: Distribution longfin yellowtail (AquaMaps, 2016).

Its supply is mainly based on other small fish which include chub mackerel (*Scomber japonicus*) and blue jack mackerel (*Trauchurus picturatus*), although also some invertebrates are included in its diet (Roo *et al.*, 2015; Froese & Pauly, 2017).

In accordance with Roo *et al.* (2014), *S. rivoliana* is known by its rapid growth, being able to come to a length of a maximum of 160 centimeters and to a maximum of 59 kilograms. According to Fernández-Palacios *et al.* (2015a), this species in captivity can reach a growth of 2 kilograms in a year. In Figure 8, shows a photo of this species.

Figure 8: Image of longfin yellowtail (Wirtz, P., 2014)

As it is a species that is distributed throughout the world, the reproductive period depends on the region in which it inhabits. Roo *et al.* (2015), pointed out that the spawning period of this species in the Canary Islands was between June and October.

3. Reproduction in captivity

The chosen species are candidates for the aquaculture development because they have a high value in the market, a rapid growth in high densities of cultivation, high performances of biomass and a good adaptation to the culture conditions (Skaramuca *et al.*, 2000; Sawada *et al.*, 2006; Rodríguez-Barreto *et al.*, 2012).

Despite all the advantages that it present, the production of these species is based, mainly, on the capture of wild specimens, since the reproduction in captivity of these species keeps on being a big problem (Rodríguez-Barreto *et al.*, 2012; Zupa *et al.*, 2017).

Mylonas *et al.* (2004) argue that the difficulty of the species greater amberjack (*S. dumerili*) for reproductive maturation and spontaneous spawning in culture conditions, is quite recognized. In addition, they claim that the reproductive dysfunction observed in females is common in famed fish. In aquaculture, the final oocyte maturation does not occur in females. For this reason, they comment that most of the studies of reproduction about this species are based on wild juveniles or eggs produced from mature broodstock induced with hormones.

In 2002, Jerez *et al.* (2006) managed to get some specimens of greater amberjack spawning in the Canary Islands after 6 years in captivity in raceways of 500 m^3, under natural conditions of temperature and photoperiod and fed low-value fish. As reported in his study, spawning occurred from April to October, coinciding with the increase in temperature of 19º C to 24º C. A total of 14 million eggs were collected on 38 spawns, with a fertilization percentage of 61.75 %.

According to Sawada *et al.* (2006), the unstable supply of fingerlings of greater amberjack in aquaculture from Japan promotes the capture of young specimens in the wild in foreign waters. Imported fingerlings can bring diseases to Japanese waters that had not existed before and this could be a problem. The challenge of producing this species focuses on the maturation and spawning in captivity.

Stuart & Drawbridge (2013) report in their study that a population of yellowtail amberjack (*Seriola lalandi*) of California obtained natural spawning in a tank of 140 m^3 when the water temperature reached 16° C and ended when the temperature exceeded 22° C. The highest annual value of the fertility of the population was 226,000 eggs/kg of the total biomass of females and was observed in 2009.

Roo *et al.* (2014) comment that the bottleneck for mass production of longfin yellowtail (*Seriola rivoliana*) is unreliable juvenile supply, resulting in poor reproduction and low survival.

According to Fernandez-Palacios *et al.* (2015b), some authors have achieved gonadal maturation and spontaneous spawning of greater amberjack while, generally, the final oocyte maturation is inhibited in captivity. They describe that the normal development of oocytes is interrupted by follicular atresia and this prevents spawning. They also add that these circumstances are often reported in the Mediterranean area. To solve this problem, proposed therapies of induction with hormone.

In cultures of Rancheros del Mar in La Paz, Baja California, Mexico, Quiñones-Arreola *et al.* (2015) have managed natural spawning of domesticated broodstock of longfin yellowtail (*Seriola rivoliana*). The fertilization rate was 75.3 ± 2.8%, the total number of spawns was 28 ± 1% and the total number of eggs was 163790.

Zupa *et al.* (2017) have also observed reproductive dysfunction in the greater amberjack and claim that it is because they are migratory fish that do not adapt well to captivity. They commented that, in their study, males reared in captivity during the spawning had ceased their spermatogenic activity, still showing a moderate amount of sperm in the light of the seminiferous lobules. They propose the use of hormones to induce spawning.

As has been observed, most reproduction studies are realized on the species greater amberjack. This may be due to its importance in aquaculture and global distribution. Also, it should be noted that, generally, studies focus on the inability of females to complete its reproductive cycle.

4. Factors that affect to the reproduction in captivity

Reproduction is a very complex process that can be affected by several factors such as nutrition, genetic background, environmental conditions, water quality, infectious diseases, transport damage or stress of broodstock due to captivity (Mylonas *et al.*, 2004; Matsunari *et al.*, 2006; Rodríguez-Barrero *et al.*, 2012; Stuart & Drawbridge Stuart, 2013; Jirapongpairoj *et al.*, 2015; Rodríguez-Barreto *et al.*, 2017). Below, some of these factors that exert an effect on reproduction.

4.1. Physical factors that modulate/affect reproduction

4.1.1. Temperature and photoperiod

In the cultivation of species, the temperature is a very important parameter to be considered because it affects both the growth, survival, reproduction of fish and egg development (Nakada, 2002; Matsunari *et al.*, 2006; Moran *et al.*, 2007; Rodriguez-Barreto *et al.*, 2017).

Manooch & Potts (1997) have demonstrated the importance of proper temperature for spawning of greater amberjack and they provide that this temperature must be stable to start regular periods of spawning.

Skaramuca *et al.* (2000) have observed that the best temperature range for spawning of species *Seriola quinqueradiata* and *Seriola dumerili* is between 18 and 20° C. They also suggest that with a temperature of 12º C, decreases the food intake and with temperatures below 9º C and above 31° C find high mortality rate.

Kozul *et al.* (2001) have indicated that greater amberjack starts spawning when the temperature is above 18° C.

Chuda *et al.* (2002) have been noticed in their study of japanese yellowtail (*Seriola quinqueradiata*), that the gonadal growth increased before maintaining high water temperatures (19° C) and a long photoperiod (16 hours of light) during the months from December to February. The mean diameter of oocytes increased from 120 µm presenting in November to 712 µm in January.

Poortenaar *et al.* (2003) described that *Seriola* species are very sensitive to temperature changes with small fluctuations, affecting reproduction and food consumption. They add in their study that the optimum temperatures for spawning of japanese yellowtail, greater amberjack, and yellowtail amberjack are 19º C, 21 ± 0.5° C and 21° C respectively.

Jerez *et al.* (2006) proved that there is a relationship between temperature and food intake; when the temperature increases, the ingestion rate increases. They observed that greater amberjack continues to feed during the start and end of the spawning period when temperatures drop, the ingestion rate decreases.

According to Benetti (2008) the temperature control is the key to natural spawning and differs among species; 26º C for longfin yellowtail and 17ºC for yellowtail amberjack.

Stuart & Drawbridge (2013) have documented that *S. lalandi* starts spawning when the water temperature is above 16° C and ends when the temperature exceeds 22º C.

Fernandez-Palacios *et al.* (2015a) have observed in their study of longfin yellowtail species (*S. rivoliana*) that temperature intervenes in the increase of fertility, inducing maturation of gametes and ovulation. Accordingly, the inhibition of reproduction can be caused by inadequate water temperature. Furthermore, they noted that for spawning, the suitable temperature to initiate it is 26º C. They also pointed out that in other studies, it has been obtained natural spawning with temperatures between 21.4 and 28.1° C, and have estimated an optimum range of temperatures between the 24.1 to 27° C. In the Canary Islands, this temperature is not reached, but at about 20º C, females have sufficient size of oocytes, more than 500 µm, for hormonal induction.

According to Jerez *et al.* (2006), the gonadal development of greater amberjack is controlled by various hormones and modulated and accelerated by photoperiod and temperature.

Fernandez-Palacios *et al.* (2015a) observed in his study in the Canary Islands that the effect of photoperiod on the spawning of *Seriola rivoliana* in captivity during the months of October and November was lower.

Higuchi *et al.* (2017) note that in fish that show a marked seasonal reproductive activity, photoperiod is considered as an environmental factor, key to the initiation and completion of sexual maturation. They have observed in their study of japanese yellowtail, that changes in day length, from 8 to 18 hours of light, encourage the initiation of reproductive development.

Sanchis-Benlloch *et al.* (2017) found that the photoperiod modulates pubertal development in yellowtail amberjack.

Optimal temperatures range for spawning of these species differ between them and it is also different according to the location of these as you can see in each study.

It has also been able to perceive that the photoperiod is a factor that modulates reproduction and could be an important help for their initiation.

4.1.2. Salinity

Blanco *et al.* (2015) observed that salinity can affect fish. According to their study, a salinity less than the sea salinity (30 g/L), favorably influences the growth of the genus *Seriola* and it positively affects the physiology of fish.

Sanchis-Benlloch *et al.*, (2017) have demonstrated that the salinity is one of the parameters that modulate the maturation of species, so in culture is important to have the appropriate salinity range.

Although there are few studies that discuss the effect of salinity on reproduction, it has been seen that it has a role in the maturation of fish.

4.1.3. Culture conditions

Micale *et al.* (1999) noted that captivity influences the physiology of greater amberjack, especially females, affecting the spontaneous spawning. They discussed, that many females are unable to reach the final stages of vitellogenesis and oocyte maturation.

According to Jerez *et al.* (2006), the absence of spawning of amberjack greater may be related to insufficient stimulation of the gonads due to stress caused by confinement, which inhibited vitellogenesis and oocyte maturation.

Some factors that can cause stress on cultivation of greater amberjack are: high density, inadequate nutrition and unequal size of the fish, which encourages aggressive behavior. These factors may cause cannibalism and asphyxia in juvenile stages (Miki *et al.*, 2011).

Fernandez-Palacios *et al.* (2015a) have shown in their study of longfin yellowtail the ability to succeed in the reproduction of this species in tanks of a small volume of 10 m^3. This could be a breakthrough for reproduction in captivity.

Quinones-Arreola *et al.* (2015) have conducted a study on longfin yellowtail species, which indicates a difference between the captured from the wild and specimens under culture conditions. Their results reveal that the captured specimens had better physiological, such as body weight, fertilization rate, the total number of spawning, spawning frequency and the total number of eggs condition.

According to Rodríguez-Barreto *et al.* (2017), tank size, flow rate or depth of the water column can affect the success of reproduction in the species greater amberjack. They noted that the spontaneous spawning needs moderate and high volumes and low population densities, to avoid stress to the broodstock. The culture conditions that cause stress to fish directly, influence the pattern of use and mobilization of energy reserves. The population density produces chronic stress that can affect the metabolism and growth, mobilizing energy reserves, including lipids, to meet the demands caused by stress and this can affect reproduction.

Stress due to confinement, transport, and handling of spawning fish is a big problem that must be minimized to avoid interrupting the reproduction.

4.2. Biological factors that modulate/affect reproduction

4.2.1. Feed

One of the factors influencing the reproduction of these species is related to the broodstock's nutrition. One problem is the inadequate formulation of diets for these species during the spawning season, which does not meet their nutritional requirements (Rodríguez-Barreto *et al.*, 2012; Stuart & Drawbridge, 2013; Zupa *et al.*, 2017).

Verakunpiriya *et al.* (1997) studied the benefits of astaxanthin supplementation in diets for broodstock population of *Seriola quinqueradiata* injected with the hormone HCG (600 IU/kg fish). The dry feed was supplemented with 30 ppm astaxanthin and gave higher results to total production for the quality of the eggs and the final number of normal larvae.

According to Poortenaar *et al.* (2003), the genus *Seriola* broodstock in captivity are often fed with high-quality diets, fresh or frozen, and it is recommended that supplements of vitamins and minerals are added. In their study of japanese yellowtail, they obtained better results in the quality of eggs and larvae with a diet of dried pellets; the rate of fertilization of eggs from broodstock fed with dry pellets was 57% compared to 3% of fed fish.

Matsunari *et al.* (2006) have discovered that including taurine in feed supplied to the japanese yellowtail broodstock has a positive effect on reproduction because it can accelerate ovarian maturation.

Vassallo-Agius *et al.* (2002) have described the benefits of including squid meal in the diet of broodstock, arguing that improved performance on the japanese yellowtail spawning due to its high content of cholesterol and phospholipids.

Also, Watanabe & Vassallo-Agius (2003) in their study of the reproduction of japanese yellowtail, noted that including astaxanthin in the diet, improved performance spawning of this species. Furthermore, they contributed to include vitamin E, positively help the broodstock for their important role in the quality of eggs due to its ability to capture free radicals. In addition, they concluded that the combination of astaxanthin with paprika as dry feed ingredients produced a performance in the spawning of this species, which was similar to the performance of them fed with raw fish.

As been well observed De La Gándara *et al.* (2004) in their study of broodstock of great amberjack, food has a hierarchical social behavior in farmed fish. This hierarchy regulates food intake, dominant individuals eat first and eat to satiety while the dominated have to wait, often cannot eat to its fill. This could result in non-dominant do not have enough nutritional requirements that promote reproductive development. A solution to this problem would minimize the densities of broodstock in tanks.

According to Rodríguez-Barreto *et al.* (2012) in their study of the great amberjack, lipids, fatty acids and highly unsaturated fatty acids (HUFA) play an important role in reproductive processes, the ontogeny of the embryo and early stages of larval development of the fish. Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are the main HUFA. In addition, they observed that the EPA is catabolized selectively with respect to DHA to provide energy during ovarian maturation before spawning. Arachidonic acid is another HUFA with multiple functions related to reproduction, including attracting pheromones. EPA and ARA compete for the same enzyme complex and imbalances between the proportions of these two acids can lead to deregulation of different mediators involved in reproduction. High levels of EPA inhibit the conversion of ARA in PGF2α and PGE2 which are two prostaglandins involved in maturation and ovulation processes oocyte. If the EPA level is much higher than ARA, it can adversely affect the reproductive process. They also have observed that high levels of EPA affect DHA, this relationship (DHA/EPA) is important in the maintenance of the structure and function of the cell membrane. So, it could affect fish physiology.

Rodríguez-Barreto *et al.*, (2012) observed that reserves of body lipids are an important energy reserve that is used during reproduction, and also its transferred to ovaries during vitellogenesis to help with eggs reserves. For this reason, the lipid content of the ovaries increases during the spawning season, falling in the liver and muscle.

Miura *et al.* (2014) confirm that diet restriction suppresses gonadal development during the spawning season of *Seriola quinqueradiata*.

Roo *et al.* (2015) have studied the importance of the proteins in diets for broodstock of longfin yellowtail, because of it is the most abundant in eggs nutrient and used as a main source of energy during embryonic development also play an important role in fertilization processes. In addition, protein is essential in the diets of broodstock because it is essential to complete oogenesis and clearly affects fertility. They add that some studies report that artificial feeds are harmful to broodstock while claiming that fresh food is better for them. However, they say that the feed with raw fish has several disadvantages, such as large variations in their nutritional value, nutrient degradation, low stability of water and the risks of transmission diseases and parasites. Because of this, they aim to improve the quality of dry feed. Notably, they have reported that ingredients derived from squid, krill oil and tuna are good for improving the quality of the eggs.

Hossain *et al.*, (2017) state that adequate food for great amberjack, can also help increase the resistance of fish against some diseases, including some functional nutrients to diets, such as some nucleotides.

Rodríguez-Barreto *et al.* (2017) have noted in their study of great amberjack that fatty acids have proven to be very important for the broodstock because they determine the composition of the gonads, thereby affecting the quality of sperm and egg. In the formulation of diets for broodstock, it is important to get the necessary elements for the compositions of ovarian lipids of cultured fish approaching that of wild fish.

Zupa *et al.* (2017) have proposed the investigation of the formulation of a specific diet that will help overcome the decreases of phospholipids (DHA and ARA) in the gonads, found in great amberjack.

Adequate food is essential to provide the nutrients needed to start their reproductive performance. During the spawning season, there are a redistribution of nutrients to provide more energy to the reproductive organs to form the gametes. Formulating a diet for broodstock, considering their requirements at the spawning season, can stimulate the maturation of gametes and subsequently help with the weight loss that suffered in this period and could be recovered in a short time.

4.2.2. Diseases caused by bacteria, viruses, and parasites

Aquaculture development of the genus *Seriola* is limited by infectious diseases caused by bacteria, viruses and parasites that cause high mortality in cultures (Ji *et al.*, 2008; Fernández-Palacios *et al.*, 2015a.). Broodstocks are often affected by various diseases that cause high mortality among the population.

According to Alcaide *et al.* (2000), bacterial diseases are a serious problem in the cultivation of japanese yellowtail species in Japan, where streptococcossis caused by *Lactococcus garvieae*, is the largest bacterial disease. The species of *Photobacterium damselae* subs *piscicide* has also been reported as an important pathogen for cultivation of Japanese yellowtail and greater amberjack in Japan, that cause high mortality among these species.

Poortenaar *et al.* (2003) assert that streptococcosis cause mass mortality in japaneses yellowtail in Japan. Other common bacterial diseases of this species in culture are pseudotuberculosis and vibriosis. Also, some monogeneans parasites are often a problem in the cultivation of the genus *Seriola*.

According to Ernst *et al.* (2005) monogeneans parasites are a major problem management for cultivation of the genus *Seriola*. Monogeneans skin, *Benedenia Seriolae* and *Neobenedenia melleni*, and monogeneans gill, *Heteraxine heterocercal* and *Zeuxarpa Seriolae*, can infect fish and affect their growth and survival.

Hutson *et al.* (2007) note that the parasites that infect *Seriola* species are ecologically and economically important since they cause high mortality in their populations.

Ji *et al.* (2008) set out that one of the causes of the limited cultivation of greater amberjack is disease outbreaks. These diseases are caused by parasites, viruses and/or bacteria. Among bacterial diseases are pasteurellosis, vibriosis, and streptococcosis, which are the most serious. Vibriosis caused by *Vibrio spp.*, is the most important bacterial disease for greater amberjack, resulting in great economic losses.

Lloret *et al.* (2012) manifest that parasites can reduce growth, fecundity, and survival, and change behavior and sexual characteristics of infected hosts. They say that these changes can affect not only at the individual level but also at the population, community and ecosystem levels.

According to Roo *et al.* (2014), one of the causes of mortality among *Seriola rivoliana* broodstocks is monogenean parasite outbreaks, *Neobenedenia spp.* It has identified monogeneans infections as a major concern for the industry of *Seriola* in Japan and Australia, since they cause loss of fish growth, reducing its market value, and mortality.

Jirapongpairoj *et al.* (2015) also exposed problems that cause infectious diseases in the culture of genus *Seriola*. These diseases include: nocardiosis, iridoviral disease, viral ascites and pasteurellosis.

Quiñones-Arreola *et al.* (2015) report that the maintenance of broodstock populations of *Seriola rivoliana* is difficult because of its susceptibility to a number of pathogens, parasites, and bacteria.

As we have seen, most pathogens do not directly affect the reproduction of the species of the genus *Seriola*, but they affect both younger population, influencing their growth, and the broodstock, causing high mortality.

5. Hormonal induction

Reproduction in captivity for the genus *Seriola* is a major obstacle to overcome for promoting aquaculture development. Rarely natural and spontaneous spawning of these species is achieved and in most cases, the spawning is limited so is necessary to propose differents solutions. One solution that has been tried to be implemented to solve this problem is the induction with hormones (Micale *et al.*, 1999; Fernández-Palacios *et al.*, 2015a; Zupa *et al.*, 2017).

According to Micale *et al.* (1999), the development of the oocytes occurs in two phases: primary growth phase independent gonadotropin (PGP) and secondary growth phase dependent gonadotropin (SGP), also called vitellogenesis. In their study, they have found that the great amberjack not developed over early vitellogenesis. This may be due to insufficient gonadotrophin stimulation, which they describe as a possible follicular atresia of oocytes because of the effects of stress of captivity. They propose the stimulation of oocyte maturation by inducing hormone.

On the other hand, the sustained release systems of GnRHa (implants) induce the stimulation long-term of the release of the hormone luteinizing (Lh) with a single treatment and have proven to be effective to induce final oocyte maturation, ovulation, and spawning in many fish.

Chuda *et al.* (2002) have reported that a single injection of 500 IU HCG / kg is the most simple and efficient method to induce oocyte maturation and ovulation for good quantity and quality of eggs in *Seriola quinqueradiata*.

According to the study by Mylonas *et al.* (2004), artificial induction with hormones is offered as a proposal to gonadotrophin stimulation. Some artificial hormones are human chorionic gonadotropin (HCG) and gonadotropin-releasing hormone agonists (GnRHa). The most commonly used hormone is GnRHa, injection produces a short stimulation of hormone luteinizing (Lh), responsible for the final maturation of the oocyte. This hormone has a very short half-life, so more doses to broodstock are necessary to induce the spawning. They have observed that captive reproductive maturation and spawning has been achieved both naturally as induced with hormones in other species of the genus *Seriola*, as japanese yellowtail (*S. quinqueradiata*), longfin yellowtail (*S. rivoliana*) and yellowtail amberjack (*S. lalandi*).

Matsunari *et al.* (2006) observed that they could achieve successful spawning for the species *Seriola quinqueradiata*, injecting 20 µg of the hormone GnRHa / kg body weight, every ten days during the spawning season.

Roo *et al.* (2010) induced spawning to a broodstock population of *Seriola rivoliana* through repeated hormone injections (20 µg LHRH / kg body weight) during the months of July to October at 2009. These injections resulted in 10 successful spawning with an eggs average of 275,000 per spawning, 72% of floating eggs and fertilization rate of 92.5%.

Fernandez-Palacios *et al.* (2015a) discovered that they could induce the spawning in the species *Seriola rivoliana* obtaining high-quality fingerlings by injecting 20 µg of hormone GnRHa / kg body weight, every ten days during the spawning season. In their study, they injected the fish three times a month between June and November. They obtained 33 spawns and a total of 20189700 eggs with 15 injections. The fertilization rate was 99.1 ± 1.2% and viable eggs were 77.2 ± 9.8%.

Fernández-Palacios *et al.*, (2015b) have commented that in numerous studies on the reproduction of greater amberjack have been reported poor quality of fingerlings in the first spawning of these species. The quality of the spawn is related to several factors including the size of the fish, the maturation of the injected fish, feeding and handling of broodstock, the sex-ratio in tanks, the number of injections and environmental conditions.

According to Sanchis-Benlloch *et al.* (2017), the gonadal development of yellowtail amberjack is controlled mainly by two pituitary gonadotropins: follicle stimulating hormone (FSH), which plays a crucial role in the onset of ripening; and luteinizing hormone (LH), which has an important role in the early stages of reproductive development and final oocyte maturation.

In the species of this study, generally, reproduction is interrupted by an insufficient stimulation of gonadotropic. This causes that there is no sufficient release of luteinizing hormone, so it fails to produce the final maturation of oocytes. The studies are about, mainly, how it affects this stimulation in females, but there are few studies on males.

Many authors have described the efficiency of induction with different hormones and different doses, and have reported different results. It should be taken into account that the results depend not only on those factors but also on the species and factors both related to the size, age and physiological conditions of the fish, as with environmental factors.

6. Conclusion

In this study, the importance of the genus *Seriola* in aquaculture lies on its global distribution, its rapid growth, good adaptation to captivity and its high quality of meat. However, reproduction in captivity of these species is a complicated process involving many factors. There are many parameters that must be considered to achieve the implementation and accomplish quality fingerlings.

So far, the most reliable method to get the spawning of these species has been induction with hormone. As already seen in some articles, however, it is possible to get the natural and spontaneous spawning of species in captivity improving the quality of life of the broodstock.

Articles that exist about reproduction in these species, do not control all the factors that may affect it, so there is a detailed study of the most optimal conditions for its cultivation, as the concentration of oxygen for example. Therefore, it would be interesting to conduct a study which consider a series of factors that modulate or influence the reproduction: formulate a diet that contains specific nutritional requirements for the reproduction season, keep them in tanks with low fish density, minimize the stress to which they may be subtjected and provide environmental conditions similar to which they would have in the wild.

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