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REVIEW OF RESEARCH AT THE ACHOTINES LABORATORY

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1. INTRODUCTION

The egg, larval, and juvenile stages of marine fishes are characterized by high rates of mortality and growth. Most marine fishes, particularly pelagic species, are highly fecund, produce small eggs and larvae, and feed and grow in complex aquatic ecosystems. The identification of environmental or biological factors that are most important in controlling survival during the early life stages of marine fishes is a potentially powerful tool in stock assessment.

Because vital rates (mortality and growth) during the early life stages of marine fishes are high and variable, small changes in those rates can have profound effects on the properties of survivors and recruitment potential (Houde 1989). Understanding and predicting the factors that most strongly influence pre-recruit survival are key goals of fisheries research programs.

2. RESEARCH ON THE EARLY LIFE HISTORY OF TUNAS

The Antigua Convention states that the Commission shall perform the following functions, giving priority to tunas and tuna-like species:

> *Promote, carry out and coordinate scientific research concerning the abundance, biology and biometry in the Convention Area of fish stocks covered by this Convention and, as necessary, of associated or dependent species, and the effects of natural factors and human activities on the populations of these stocks and species.*

Although decades of research have provided considerable information on the populations of adult tunas, relatively little is known about the early life history stages and the factors that affect pre-recruit survival. Tunas are among the most commercially valuable marine fish stocks in the world (FAO 2014), and

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[1] Postponed until a later date to be determined

recruitment variability is one of the most important factors affecting their population fluctuations (IATTCCIAT 2004).

Tuna stocks are characterized by order-of-magnitude recruitment fluctuations, but the underlying mechanisms controlling the variability in recruitment remain poorly understood. Yellowfin tuna (*Thunnus albacares*) are recruited to the surface fishery in the eastern Pacific Ocean (EPO) at approximately 30 cm in length and 6 months of age (Aires-da-Silva and Maunder 2012). Yellowfin recruitment in the EPO has fluctuated by a factor of 3.2 over the past 30 years (Minte-Vera *et al*. 2014). Yellowfin are highly fecund (batch fecundities > 1,000,000 oocytes per female) and spawn almost daily during their reproductively active periods (Schaefer 2001). Yellowfin early life stages are characterized by high mortality rates, high metabolic rates, and exponential growth (Margulies *et al* 2007a, Wexler *et al*. 2007). This pattern of reproduction and early life history has strong potential for regulation of recruitment during larval or early juvenile stages, when initial numbers in a cohort are large and vital rates (mortality and growth) are high (Houde 1987, Margulies *et al*. 2001). Most tunas exhibit similar patterns of high reproductive potential and pre-recruit life stages that are characterized by fast growth and high mortality (Davis *et al.* 1991, Tanaka *et al*. 1996, Margulies *et al*. 2007a).

Prior to the 1980s, few studies had been undertaken to examine the mechanisms that control pre-recruit survival of tunas or to estimate their vital rates during their early life stages. These considerations motivated the IATTC to establish a research facility at Achotines Bay in the Republic of Panama for the purpose of studying the early life histories of tropical tunas and tuna-like fishes (scombrids).

3. THE ACHOTINES LABORATORY AND THE IATTC EARLY LIFE HISTORY PROGRAM

The Achotines Laboratory is located on the southern coast of the Azuero Peninsula in the Los Santos province of the Republic of Panama (Figure 1). This region is in the northwestern portion of the Panama Bight. The continental shelf is quite narrow at this location; the 200-m depth contour occurs only 6 to 10 km (3 to 5 nm) from shore. This provides the scientists working at the Achotines Laboratory with ready access to oceanic waters where spawning of tunas occurs during every month of the year. The annual range of sea-surface temperature in these waters is approximately 21º to 29º C.

The early life history research program involves laboratory and field studies of tropical scombrids aimed at gaining insight into the recruitment process and the factors that affect it. Previous research on recruitment of non-scombrid fishes suggests that abiotic factors, such as temperature, light, current patterns, and wind conditions, and biological factors, such as feeding, growth, and predation, can affect recruitment (Houde 1997). As the survival of pre-recruit fishes is probably controlled by a combination of these factors, the IATTC research program addresses the interaction between the biological system and the physical environment (Lauth and Olson 1996, Owen 1997).

Research on tropical scombrids at the Achotines Laboratory has involved two distinct phases. The first phase of research was directed predominantly at coastal, tropical scombrids, mainly black skipjack (*Euthynnus lineatus*), bullet and/or frigate tunas (*Auxis* spp.), sierra (*Scomberomorus sierra*), and striped bonito (*Sarda orientalis*), during the period from 1984 to 1995. From 1996 to present, the focus of research shifted to the reproductive biology and early life history of yellowfin tuna, utilizing eggs spawned by captive yellowfin broodstock.

An additional project is underway during 2020 to develop a long-term plan to strengthen research at the Achotines Laboratory. The objectives of the plan are to diversify and strengthen the research conducted at the Laboratory as support for a wide array of research activities under the Strategic Science Plan (see Staff Activities Report, Project U.1.a.).

The Achotines Laboratory also periodically supports research by other IATTC scientists for studies of bycatch reduction methods as well as behavioral, feeding, and tagging studies of tunas. For example, during 2019-2020, the Achotines Laboratory is supporting a study by scientists of the International Seafood Sustainability Foundation (ISSF) to acoustically discriminate yellowfin tuna among yellowfin, bigeye and skipjack prior to purse-seine sets on FADs. The study will provide new technology for minimizing the catch of undersized yellowfin in purse-seine catches around FADs (see Staff Activities Report, Project M.1.c.).

In this report, we review the research conducted on reproductive biology and the early life history of yellowfin at the Achotines Laboratory. We also summarize the key research findings from the studies and present brief summaries of 4 areas of research that hold great promise for linkage with stock assessment research.

4. RESEARCH ON YELLOWFIN TUNA

4.1. Research on reproductive biology and early life history of yellowfin

From 1996 to present, the IATTC has conducted research on the reproductive biology in captivity and early life history of yellowfin (Margulies *et al*. 2016). The objective of the research is to develop a more complete understanding of daily mortality processes occurring during pre-recruit life stages (larval and early-juvenile stages) and how mortality is influenced by key environmental and biological factors. The ultimate goal of our experimental program on yellowfin early life history is the contribution of new insights into recruitment variability. The ability to forecast yellowfin recruitment, prior to the age at entry to the fishery (6 months), would be a powerful stock assessment tool.

Yellowfin research at the Achotines Laboratory has focused on important aspects of adult growth, spawning dynamics, genetics of spawning fish, early life stage development, growth dynamics of larvae and early-juveniles (in the laboratory and *in situ*), and the effects of important physical factors on pre-recruit survival and growth. The results of this research are summarized in a series of publications listed on the IATTC website. Funding to support the research and infrastructure improvements required to conduct yellowfin research at the Achotines Laboratory has been provided by the IATTC, the Overseas Fishery Cooperation Foundation (OFCF) of Japan, the Japan International Cooperation Agency (JICA), the Japan Science and Technology Agency (JST), the European Union, the International Seafood Sustainability Foundation (ISSF), and the U.S. National Oceanic and Atmospheric Administration (NOAA).

4.2. Key research findings from studies of yellowfin tuna

The studies of the reproductive biology and early life history of yellowfin tuna conducted since 1996 at the Achotines Laboratory have contributed significantly to our understanding of yellowfin biology and the factors that influence pre-recruit survival. The key findings to date of the yellowfin research program are as follows.

1. A spawning population of yellowfin was established, which represents the first occurrence worldwide of sustained spawning by yellowfin in land-based facilities. The spawning dynamics, growth, genetics, physiology, and early life history of yellowfin were studied over multiple years.
2. Methods for the successful capture, transfer, and husbandry of yellowfin were developed. A diet of 50% squid and 50% fish, such as thread herring or anchoveta, seems to provide adequate nutrition for broodstock yellowfin and fuels almost continuous spawning. Estimates of growth in length of captive fish decreased with increasing lengths of the fish, ranging from 18 to 37 cm year^{-1} during 1996-2001 and from 11 to 62 cm year^{-1} during 1999-2014. Growth in weight was estimated at 11 to 26 kg year^{-1} during 1996-2001 and 4 to 36 kg year^{-1} during 1999-2014, and these estimates also decreased with

increasing weights of the fish. The stable environment of onshore tanks seems to promote good health and sustained spawning of yellowfin (Wexler *et al.* 2003).

3. The spawning patterns of yellowfin in relation to physical and biological factors have been described. The broodstock fish spawned as long as they received adequate daily food rations and water temperature was >23.3º C. Water temperature appears to be the main exogenous factor controlling the occurrence and timing of spawning for yellowfin. Courtship and spawning behaviors are ritualized, and yellowfin appear to have the ability to adjust the timing and final maturation processes of spawning based on minute changes in water temperature (Margulies *et al*. 2007b).
4. The age at first spawning for female yellowfin in captivity was estimated at 1.3 to 2.8 years, averaging slightly less than 2.0 years. Over short periods (<1 month), spawning females increased their egg production by 30 to 234% in response to short-term increases in daily ration of 9 to 33%. The ability to increase egg production in response to greater food abundance has adaptive significance and would allow yellowfin to exploit patchy food resources and periodic increased production in the ocean (Margulies *et al*. 2007b).
5. Genetic monitoring of the spawning yellowfin was conducted by comparing mitochondrial DNA variation of spawning females with those of their eggs and larvae. The analysis provided the identification of individual spawning females and estimates of their spawning periodicity. Individual females are capable of spawning daily for extended periods of time as long as they remain in the appropriate range of water temperatures (>23.3º C) and have sufficient food.
6. Water temperature is significantly, inversely related to egg size, egg stage duration, larval size at hatch, and yolk-sac larval duration of yellowfin. Fertilized yellowfin eggs average 1.0 mm in diameter and 43 µg in dry weight. Hatched larvae average 2.5 mm SL and 30 µg in weight, while larvae at first feeding average 3.3 mm SL and 22 µg in weight. The growth potential from early-stage larva to size at recruitment (30 cm, 6 months of age) is very high, approaching 10^6 to 10^7 times (Margulies *et al*. 2007b).
7. Trials have been conducted at the Achotines Laboratory to investigate the feasibility of developing bycatch-reduction devices, such as sorting grids and bubble curtains, which will allow smaller fish to escape from tuna purse seines while retaining larger fish. Results from the trials have indicated that yellowfin swim through sorting grids and are reluctant to pass through bubble curtains. Other projects related to bycatch reduction studies of the IATTC have been supported by the Achotines Laboratory. One project was funded by the European Union and involved a feasibility study of the use of biodegradable and non-entangling materials to construct FADs. Preliminary data were gathered on durability of biodegradable materials for FAD construction. The other project was funded by the International Seafood Sustainability Foundation (ISSF) and involved studies by Drs. Gala Moreno and Guillermo Boyra on the acoustic properties of yellowfin as a means to discriminate among species in the purse seine fishery. Preliminary data were encouraging for determining target strength-fish length relationships and frequency responses of yellowfin. A second phase of acoustic research, described previously, is being conducted by the ISSF during 2019-2020.

5. PROMISING LINKS BETWEEN YELLOWFIN EARLY LIFE RESEARCH AND STOCK ASSESSMENT

5.1. Laboratory and *in situ* growth of larval and juvenile yellowfin

Variability in either the instantaneous rate of mortality or specific growth rates can generate major changes in stock abundance at defined stages. Growth variability alone has the potential to influence stage durations and cumulative mortality during the larval and juvenile life stages of marine fishes (Houde 1989).

The Early Life History group has focused most of its experimental efforts with yellowfin on investigations of growth dynamics during the larval and early-juvenile stages.

Since 1997, we have studied growth in the laboratory of yellowfin larvae and juveniles reared from eggs from the captive yellowfin broodstock. We have investigated the effects of food availability, water temperature, and other physical factors on the survival and growth of yellowfin larvae and juveniles up to 118 days after hatching. Early-larval growth (the first 2 weeks) is exponential in length and weight (<0.35 mm day^{-1} in length and 20 to 35% body weight day^{-1}), but growth increases significantly during the late-larval and early-juvenile stages (>0.6 mm day^{-1} and ca. 20-50% body weight day^{-1}) (Figures 2 and 3). Yellowfin larvae become piscivorous at around 6.5 mm SL, and the timing of the onset of piscivory probably determines, in part, an individual's growth potential. Laboratory cohorts that are early piscivores (ca. 6.0-7.0 mm SL) grow more rapidly, and individuals that remain zooplanktivorous lag in growth and/or are cannibalized. Early juvenile growth from 18 to 118 days after hatching is rapid and non-linear, ranging from 1.0 to 3.8 mm/day in length (Figure 3). This growth is characterized by at least two stanzas of exponential growth (Figure 4); from 0.5 to 2 months of age, the daily specific growth rate in length is 3.5 times faster than from 2 to 4 months of age. The analysis of early-juvenile growth from 0.5 to 6 months of age is ongoing and is being expanded during 2020 with the addition of more early-juvenile growth data. In 2015, for the first time worldwide, early-juvenile yellowfin were transferred to and reared in a sea cage just offshore from the Achotines Laboratory. This successful rearing of juvenile yellowfin now provides an opportunity to experimentally study, for the first time, the growth and feeding dynamics of all pre-recruit life stages (0-6 months of age) of yellowfin.

Density-dependent regulation of growth has been identified as a significant potential factor in the control of pre-recruit survival (Shepherd and Cushing 1980, Rothschild 1986). For yellowfin, density-dependent mortality may weaken any relationship between egg production and recruitment consistent with the IATTC stock assessment of yellowfin (Minte-Vera *et al*. 2014). It is possible that relative growth rate or density-dependence in feeding success and growth during the larval stage could contribute to variations in pre-recruit survival of yellowfin. Faster growth shortens the period of greatest vulnerability to daily mortality by predation. A larval or juvenile growth index, perhaps estimated quarterly in the Panama Bight, may prove useful as an index of recruitment strength (Margulies *et al*. 2007a). This type of sampling program to estimate *in situ* juvenile growth could be developed at the Achotines Laboratory via quarterly or seasonal sampling and aging of juveniles collected by nightlighting. We have conducted similar analyses of *in situ* growth during selected years in the Panama Bight, and we found some localized correspondence between high growth rates of larvae and recruitment estimates (Wexler *et al.* 2007). Our experimental results have indicated an early onset of substantial density-dependent growth of yellowfin during the first 2.5 weeks after hatching. Increases of 2-4 times in larval density have resulted in growth deficits up to 56% during larval stages. We have also noted strong indirect evidence of density-dependent growth in larval cohorts during certain years in the Panama Bight (Wexler *et al.* 2007). Our experimental evidence suggests that density-dependence in growth persists into the early-juvenile stages of yellowfin. Even subtle density effects on growth during the relatively long pre-recruit juvenile stage (5 months) could have a "fine-tuning" effect on recruitment and the mean biomass of a cohort (Margulies *et al*. 2016). This association will be studied experimentally at the Achotines Laboratory during 2020-2021.

5.2. Effects of wind-induced turbulence on yellowfin larval survival

Feeding success of marine fish larvae can be influenced by the levels of wind-induced microscale turbulence in the feeding environment (Rothschild and Osborn 1988, Cury and Roy 1989). The probability of prey encounters and feeding success of larvae may increase with increases in wind-induced microscale turbulence up to an asymptotic wind and turbulence level and then decrease at higher levels of turbulence

(MacKenzie *et al*. 1994). Our studies of feeding of yellowfin larvae in Japan in 1992 indicated a strong potential for the influence of microscale turbulence on the feeding success of yellowfin larvae. We expanded these investigations during 1997-2000 in a series of laboratory experiments at the Achotines Laboratory which examined the survival of yellowfin larvae during the first week of feeding under conditions of variable microturbulence. Turbulence in the experimental tanks was measured as the mean horizontal velocity of a neutrally buoyant surface drogue; in 1999 and 2000 these velocities were calibrated against velocities measured at depth with a microacoustic Doppler current meter. Patterns of survival in response to experimental microturbulence were summarized in Margulies *et al.* (2016), and preliminary results were reported by Kimura *et al.* (2004).

Our analysis of the 1997-2000 data indicates that survival during the first week of feeding is up to 2.7 times higher at intermediate levels of microturbulence (ca. $7.4 \times 10^{-9} m^2 s^{-3}$ to $2.25 \times 10^{-8} m^2 s^{-3}$ as an energy dissipation rate) than at lower or higher levels of turbulence (Figure 5). Using a boundary layer model that equates microturbulence levels in the mixed layer of the ocean with wind speed, we have made estimates of optimal wind speeds for larval yellowfin survival, based on depths of 5-20 m for the maximum concentration of the larvae (estimated from larval field survey data in the literature). The optimal wind speed estimates range from 2.0 to 4.5 m sec^{-1}. These are the first such estimates reported for yellowfin tuna early life stages, and among the first estimates of microturbulence effects on survival of marine larvae based on extended experimental trials.

The estimated optimal wind speeds for larval survival were examined for correlations with historical yellowfin recruitment estimates in the EPO for select 2°x2° areas. Wind speed data for the 1987-2007 period were obtained from the Blended Sea Winds Database, National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite, Data, and Information Service (NESDIS), National Climatic Data Center (NCDC) (Zhang *et al.* 2006). The percentage of days with optimal wind speeds within a given 2°x2° area was estimated and correlations were calculated with IATTC quarterly estimates of yellowfin recruitment (time-lagged 6 months to account for pre-recruit development). A spatial pattern was observed both latitudinally and longitudinally for the areas selected (Figure 6). The areas closer to shore, east of 100°W, showed positive correlation values, while the correlation coefficients became negative further offshore and west of 100°W. All areas south of the equator exhibited positive correlations. The correlation analysis was also conducted for quarter-year combinations (*e.g*. quarters 1 and 2, quarters 1 and 3, *etc*.). For the six positively correlated areas in the southeast region of the study area, quarters 1 and 2 contributed most strongly to the positive correlation between optimal wind speed and recruitment. In nearly all of these regions, the correlations became significantly positive when only the first two quarters of each year were considered (Area 11 off Peru was marginally non-significant). The areas west of 100°W showed negative correlations regardless of quarter-year combination.

The wind speed-recruitment analysis can be refined and expanded, but this analysis is promising for assessing yellowfin recruitment patterns. The wind speed-recruitment analysis is summarized in a nearly-completed draft manuscript. The correlation analysis reported here involves different spatial scales of variables (EPO-wide recruitment estimates versus 2°x2° estimates of wind speed). More geographical coverage would improve the analysis and ongoing development of spatial components to the IATTC's recruitment estimates would allow the examination of wind speed data and recruitment on the same spatial scale.

5.3. Comparative studies of the early life histories of yellowfin and Pacific bluefin

In 2011, the IATTC, Kindai University (KU) of Japan, and the *Autoridad de los Recursos Acuáticos de Panamá* (ARAP) began a 5-year comparative study of the reproductive biology and early life history of yellowfin and Pacific bluefin tunas (Science and Technology Research Partnership for Sustainable Development, SATREPS). The joint research project was funded through March 2016 by the Japan International Cooperation Agency (JICA) and Japan Science and Technology Agency (JST) and has been conducted mostly at the Achotines Laboratory and the Fisheries Laboratories of Kindai University in Wakayama Prefecture, Japan. Comparative studies have been continued during 2017-2020 using existing program funding from Kindai University and the IATTC. The studies are the first in the world to investigate important comparative aspects of the reproductive biology, genetics, and early life histories of Pacific bluefin tuna and yellowfin tuna. Although Pacific bluefin are temperate to subtropical and yellowfin are tropical to subtropical in their adult life histories, the early life stages of both species require warm-water (> 24°C) ecosystems as nursery grounds, thus providing a common background for comparative studies. Experimental results are being used to comparatively model mortality processes occurring during the pre-recruit life stages of both species. An additional objective of the project is to develop technologies for the rearing and study of juvenile yellowfin, including sea-cage culture. As noted above (Section 5.1), in 2015 early-juvenile yellowfin were transferred to and reared in a sea cage just offshore from the Achotines Laboratory. Juveniles from this rearing series survived up to 158 days after hatch. Experimental research on yellowfin juveniles at the Achotines Laboratory will be emphasized during 2020-2021.

Comparative experiments of larval stages of both species are ongoing during 2020, but preliminary results indicate that Pacific bluefin larvae hatch and initiate feeding at slightly larger sizes than yellowfin. Bluefin larvae, given their larger size and greater endogenous energy reserves, exhibit greater resistance to starvation at first-feeding (9-26 hrs longer, depending on temperature) compared to yellowfin. However, larger size confers no apparent advantage to Pacific bluefin larvae in growth or survival when small microzooplankton prey are the prevalent forage (Figure 7). Yellowfin larvae exhibit greater growth potential and higher survival when foraging on small microzooplankton prey, particularly at lower food concentrations (< 500 microzooplankton/L). However, greater size of Pacific bluefin larvae may confer feeding and growth advantages when foraging on large zooplankton prey, and this hypothesis continues to be experimentally investigated in 2019-2020. Comparative experimental results indicate that yellowfin larval stages may be characterized by a “bet-hedging” pattern of feeding with enhanced abilities to utilize low or unpredictable levels of microzooplankton prey occurring in nursery habitats in the tropical and subtropical Pacific. Pacific bluefin larval stages may be characterized by a “match-mismatch” pattern of feeding with a match to higher food concentrations necessary to support larval survival. These higher food requirements may be met in Pacific bluefin larval nursery areas of the western Pacific by eddies and convergent fronts that serve to concentrate and retain larval prey. It is unclear, however, how predation pressure may interact with larval feeding success to influence the larval mortality dynamics of the two species.

5.4. The effects of climate change and anthropogenic impacts on yellowfin eggs and larvae

The 5th Intergovernmental Panel on Climate Change (IPCC) assessment (Stocker *et al*. 2013) estimates a global average decline in ocean surface pH of 0.30-0.32 by 2100 due to increasing concentrations of dissolved carbon dioxide (pCO_2) from anthropogenic activities. Across regions of the Pacific Ocean where yellowfin tuna spawn and develop, mean surface water pH is predicted to decrease by 0.26-0.49 pH units by 2100 (Ilyina *et al*. 2013). Ocean acidification is a concern for its potential effects on the growth, development, and survival of early life stages of tunas in oceanic habitats and on the spatial extent of suitable nursery habitat for tunas.

To investigate the potential effects of ocean acidification on yellowfin early life stages, a laboratory study was conducted by multiple collaborating organizations at the Achotines Laboratory in 2011. Two separate trials were conducted to test the impact of increased pCO_2 on eggs, yolk sac larvae, and first-feeding larvae.

Acidification levels tested ranged from present day to levels predicted to occur in some areas of the Pacific within the next 100 years (near future) to 300 years (long term). The study results were variable between trials but did indicate the potential for significantly reduced survival (Figure 8) and size of larvae and prolonged egg hatch times at acidification levels that are similar to near future predicted levels (Bromhead *et al*. 2015). Histological analysis of organ development in larvae indicated significant lethal and sub-lethal effects on larval organs at pH levels even higher than those at which significant impacts were detected on survival and growth (Frommel *et al*. 2016). A third manuscript describing the effects of acidification on otolith development in yellowfin larvae is nearly completed.

The potential impacts of climate change on early life stages are an important consideration in future assessments of tunas in the EPO. The Bromhead *et al*. project group held a workshop in Sydney, Australia, in January 2016, to review the current status of information on the effects of ocean acidification on pelagic fisheries in the Pacific Ocean and to examine options for assessing the impact on tuna resources. The workshop results have been incorporated into modeling studies of the effects of acidification on larval yellowfin abundance in the tropical Pacific (Senina *et al*. 2018). If acidification does progress to predicted levels for the Pacific Ocean, it is unclear whether tunas possess the capacity to adapt to acidification through selection for more resistant individuals (Bromhead *et al*. 2015). It is also unclear whether resistant individual traits are heritable (Munday *et al*. 2012). To date, there is evidence that near future levels of ocean acidification can have significant negative effects on organ development, survival and growth of yellowfin eggs and larvae. These results can allow models such as SEAPODYM (Lehodey *et al*. 2008) to be parameterised to include acidification effects and other climate change variables in the development of spawning-habitat indices. In addition, new studies of pollutant effects on yellowfin early life stages have been proposed at the Achotines Laboratory with collaborating scientists from Scripps Institution of Oceanography.

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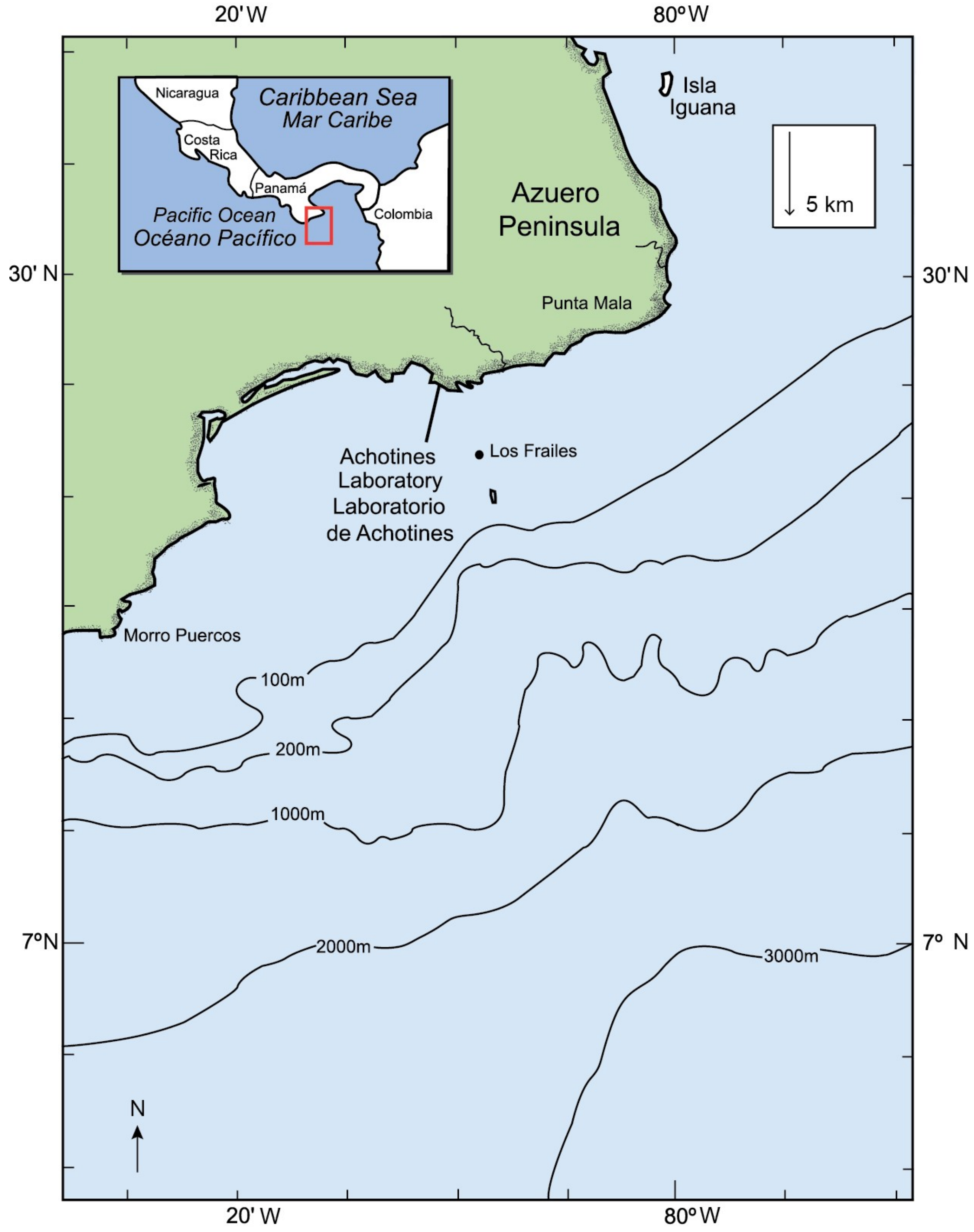
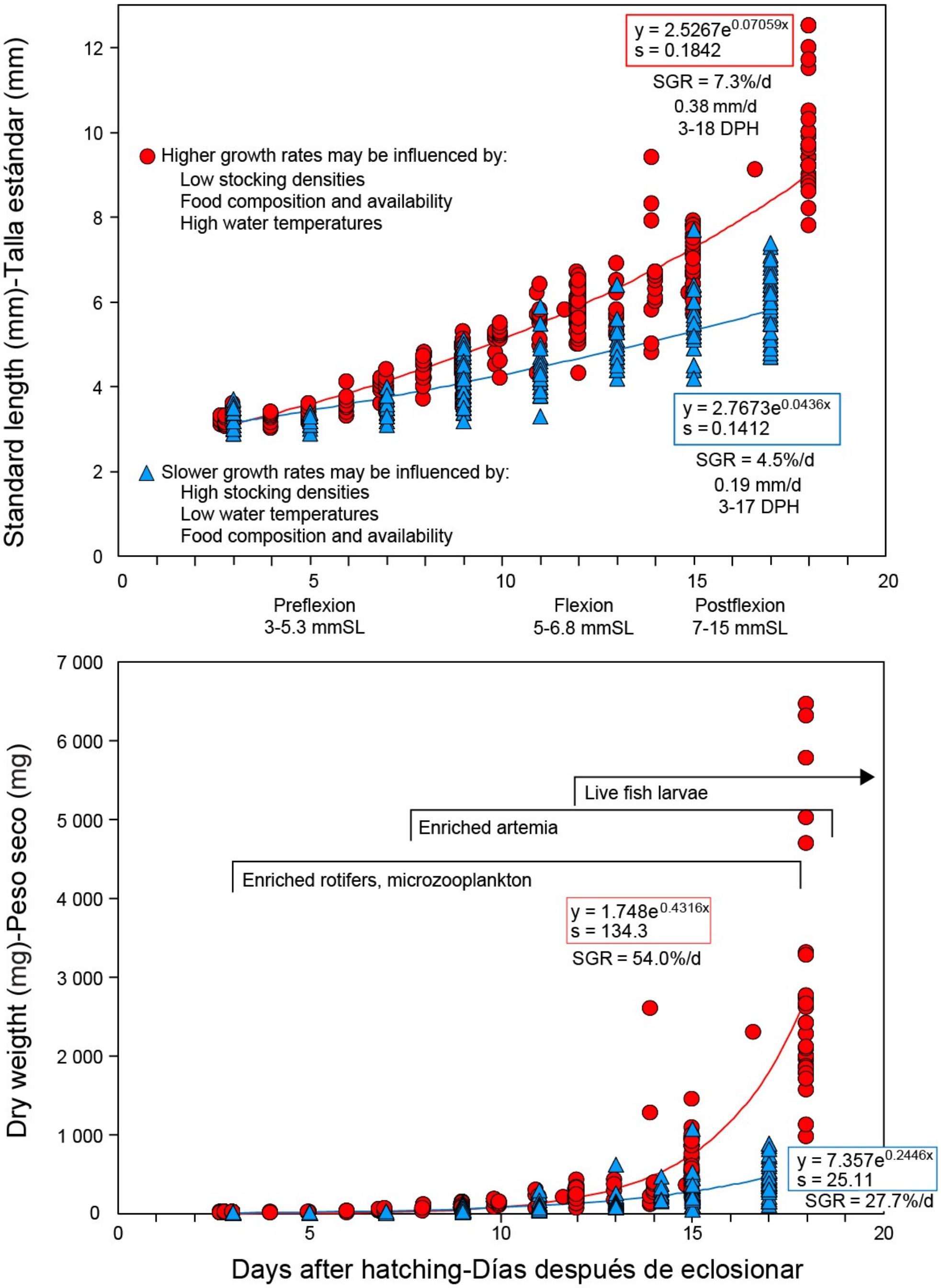


FIGURE 1. Location of the Achotines Laboratory, Republic of Panama.

FIGURA 1. Ubicación del Laboratorio de Achotines, República de Panamá.



(Stage terminology follows Kendall, et al. (1984))

FIGURE 2. Relationships between standard length (top panel) and dry weight (bottom panel) and age in days after hatching of yellowfin reared in the laboratory for the fastest- (red line) and slowest-growing (blue line) cohorts. Prey type at age routinely offered in the laboratory and stage terminology at standard length are also shown.

FIGURA 2. Relaciones entre talla estándar (panel superior) y peso seco (panel inferior) y edad en días desde eclosión de aletas amarillas criados en el laboratorio correspondientes a las cohortes de crecimiento más rápido (línea roja) y más lento (línea azul). Se indican también el tipo de presa por edad ofrecido rutinariamente en el laboratorio y la terminología estándar de etapas por talla estándar.

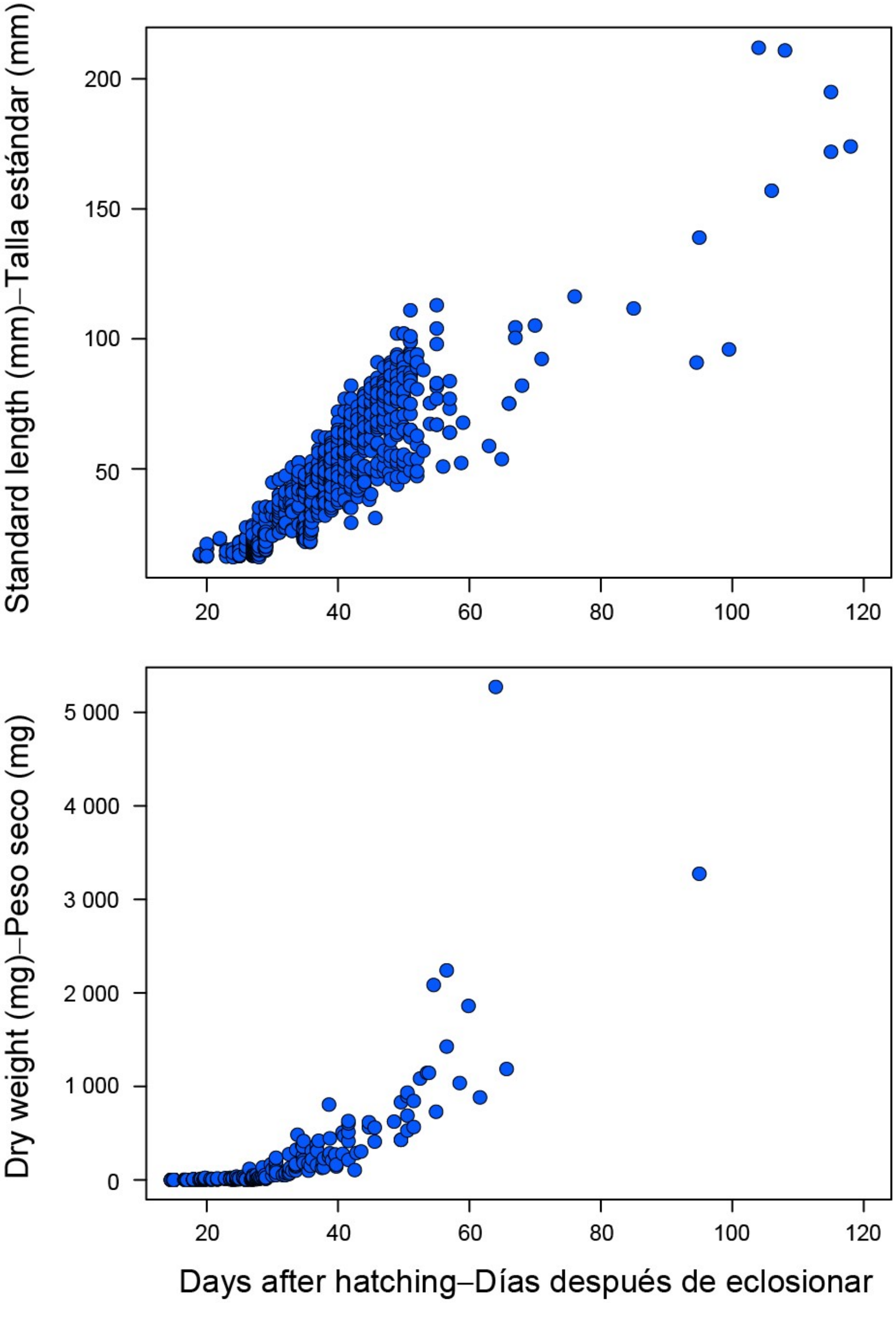


FIGURE 3. Growth in length (top panel) and dry weight (bottom panel) of yellowfin early-juveniles from 15 to 118 days after hatching in the laboratory.

FIGURA 3. Crecimiento en talla (recuadro superior) y peso seco (recuadro inferior) de aletas amarillas juveniles tempranos entre 15 y 118 días después de eclosionar en el laboratorio.

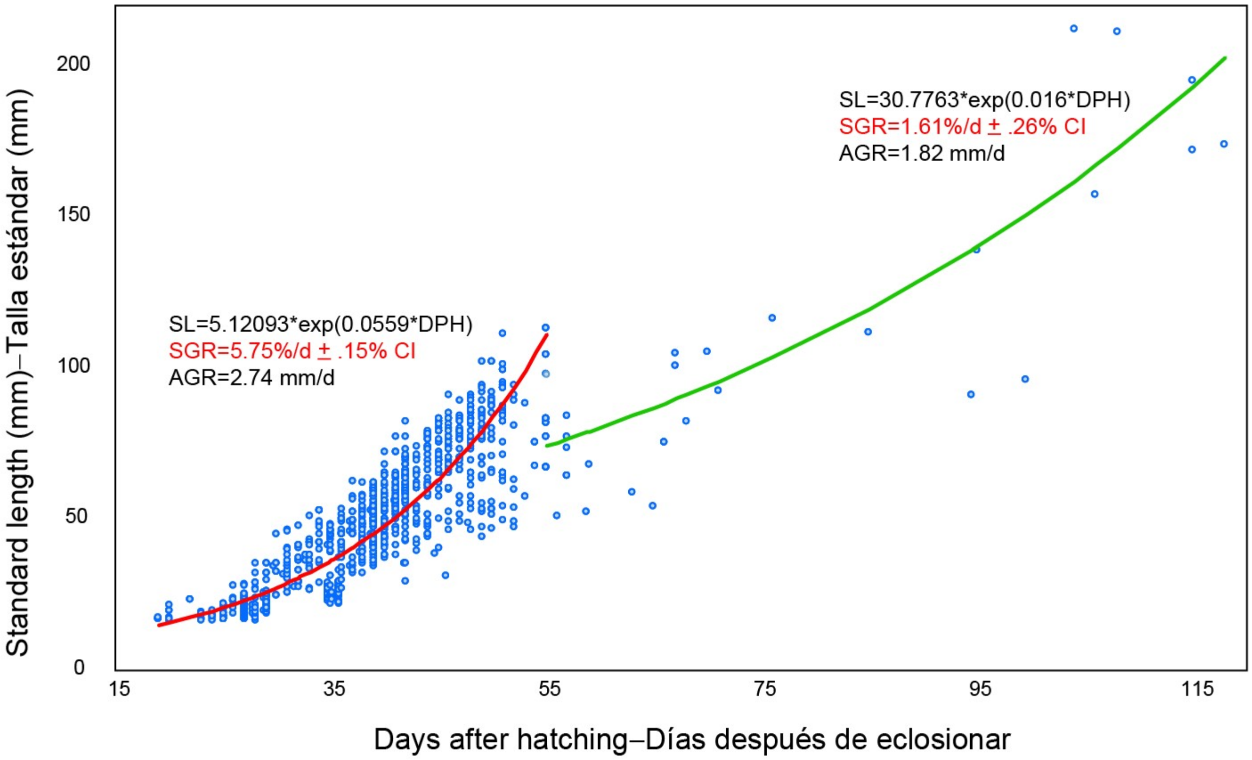


FIGURE 4. Standard length of early-juvenile yellowfin in two different growth stanzas.

FIGURA 4. Talla estándar de aletas amarillas juveniles tempranos en dos escalones de crecimiento diferentes.

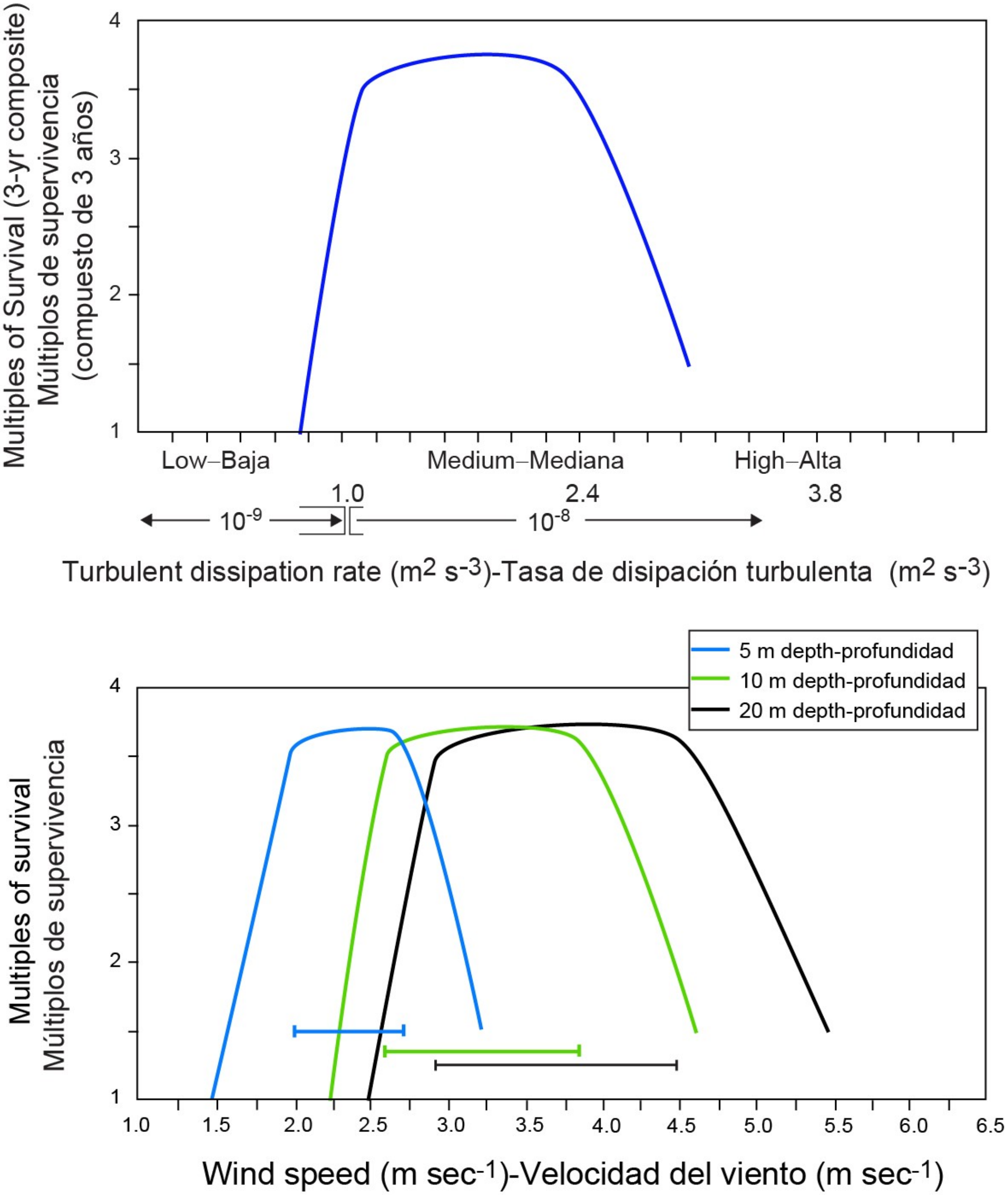
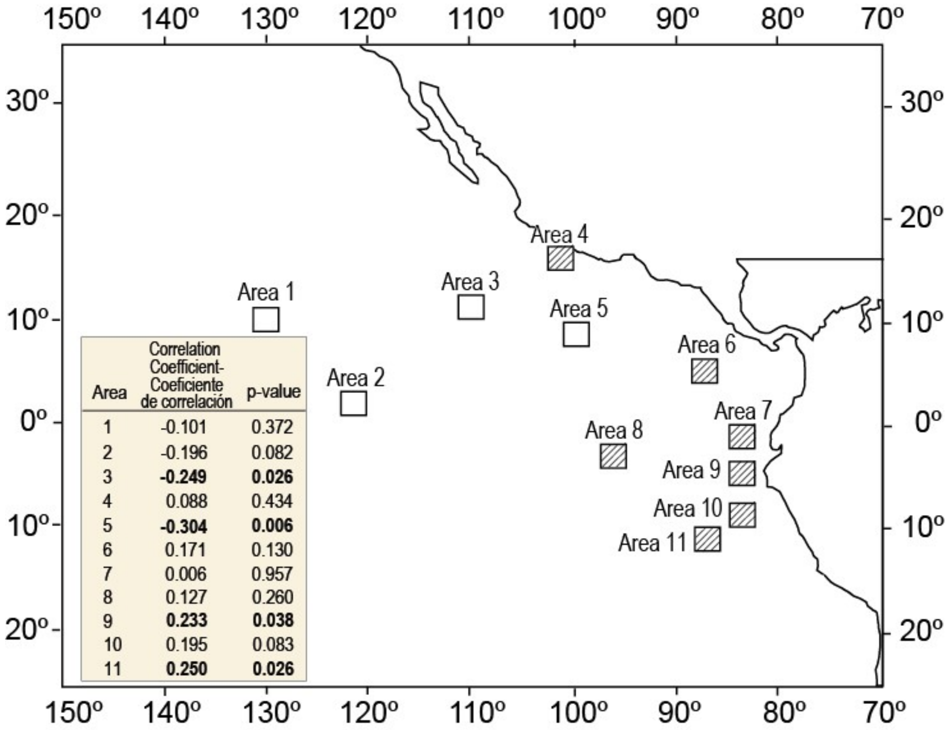


FIGURE 5. Relationship between microturbulence (estimated in the top panel as the turbulent dissipation rate and converted in the bottom panel to wind speed) and survival of yellowfin larvae during the first week of feeding. The survival curve is a smoothed, composite curve representing the mean survival estimated during 4 trials over 3 years.

FIGURA 5. Relación entre microturbulencia (estimada como tasa de disipación turbulenta y convertida en velocidad del viento en el panel inferior) y supervivencia de larvas de aleta amarilla durante la primera semana de alimentación. La curva de supervivencia es una curva compuesta suavizada que representa la supervivencia media estimada durante 4 pruebas en 3 años.



Area	Correlation Coefficient- Coeficiente de correlación	p-value
1	-0.101	0.372
2	-0.196	0.082
3	**-0.249**	**0.026**
4	0.088	0.434
5	**-0.304**	**0.006**
6	0.171	0.130
7	0.006	0.957
8	0.127	0.260
9	**0.233**	**0.038**
10	0.195	0.083
11	**0.250**	**0.026**

FIGURE 6. Correlation analysis results of recruitment (R) of yellowfin and the percentage of days with optimal wind speeds for selected 2°x2° areas of the eastern Pacific Ocean. Shaded boxes signify areas of positive correlation and open boxes negative correlation (bold values are statistically significant at an alpha level of 0.05).

FIGURA 6. Resultados del análisis de correlación del reclutamiento (R) de aleta amarilla y el porcentaje de días con vientos de velocidad óptima en áreas seleccionadas de 2°x2° en el Océano Pacífico oriental. Los cuadros sombreados señalan áreas de correlación positiva, y los blancos una correlación negativa (los valores en negritas son estadísticamente significativos en un nivel alfa de 0.05).

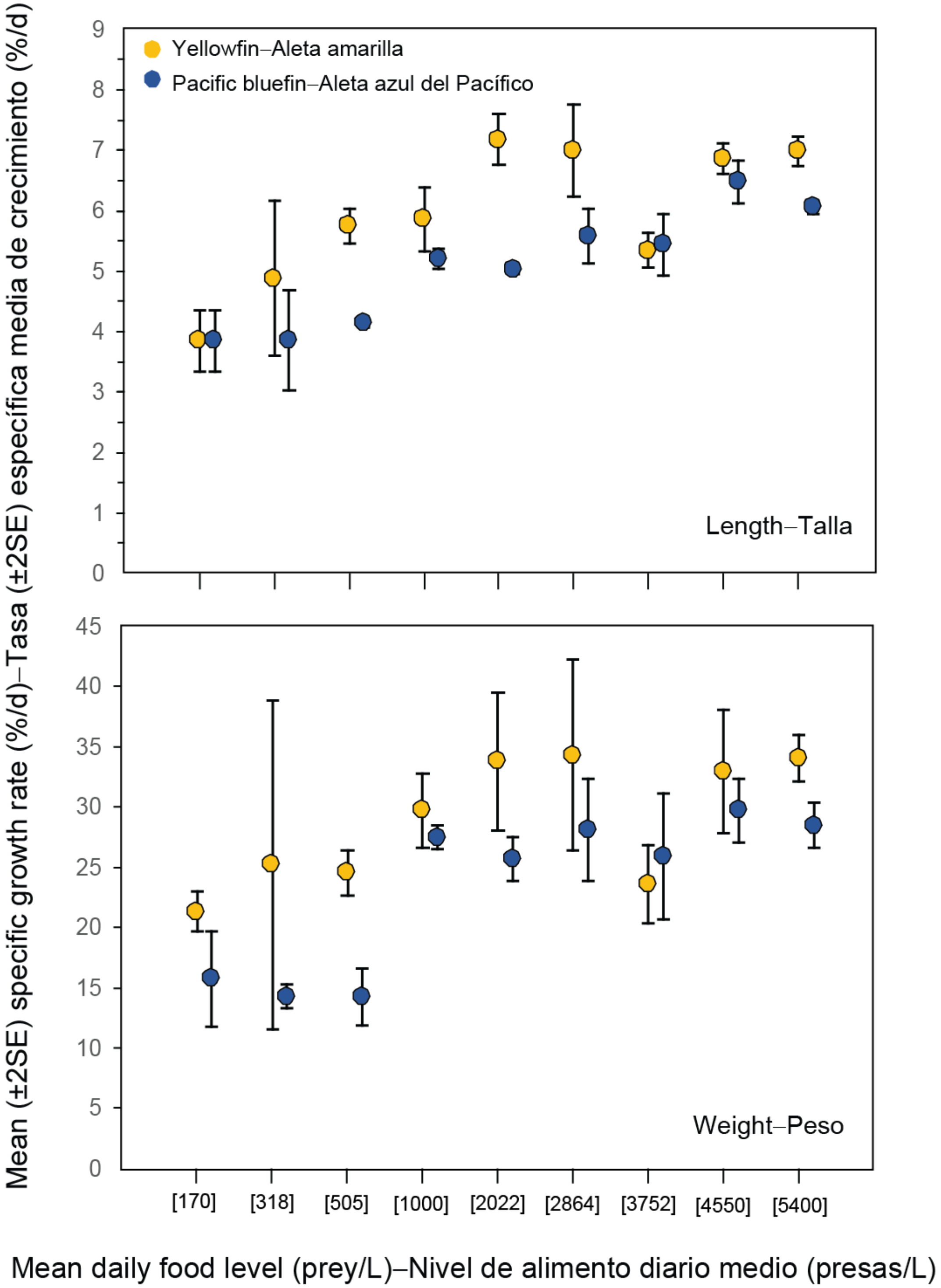


FIGURE 7. Mean specific growth rates in standard length (top panel) and dry weight (bottom panel) for yellowfin and Pacific bluefin larvae over a range of mean daily food levels during the first 10 days of feeding.

FIGURA 7. Tasas específicas medias de crecimiento en talla estándar (panel superior) y peso seco (panel inferior) de larvas de aleta amarilla y aleta azul del Pacífico correspondientes a una gama de niveles medios de alimento diario durante los 10 primeros días de alimentación.

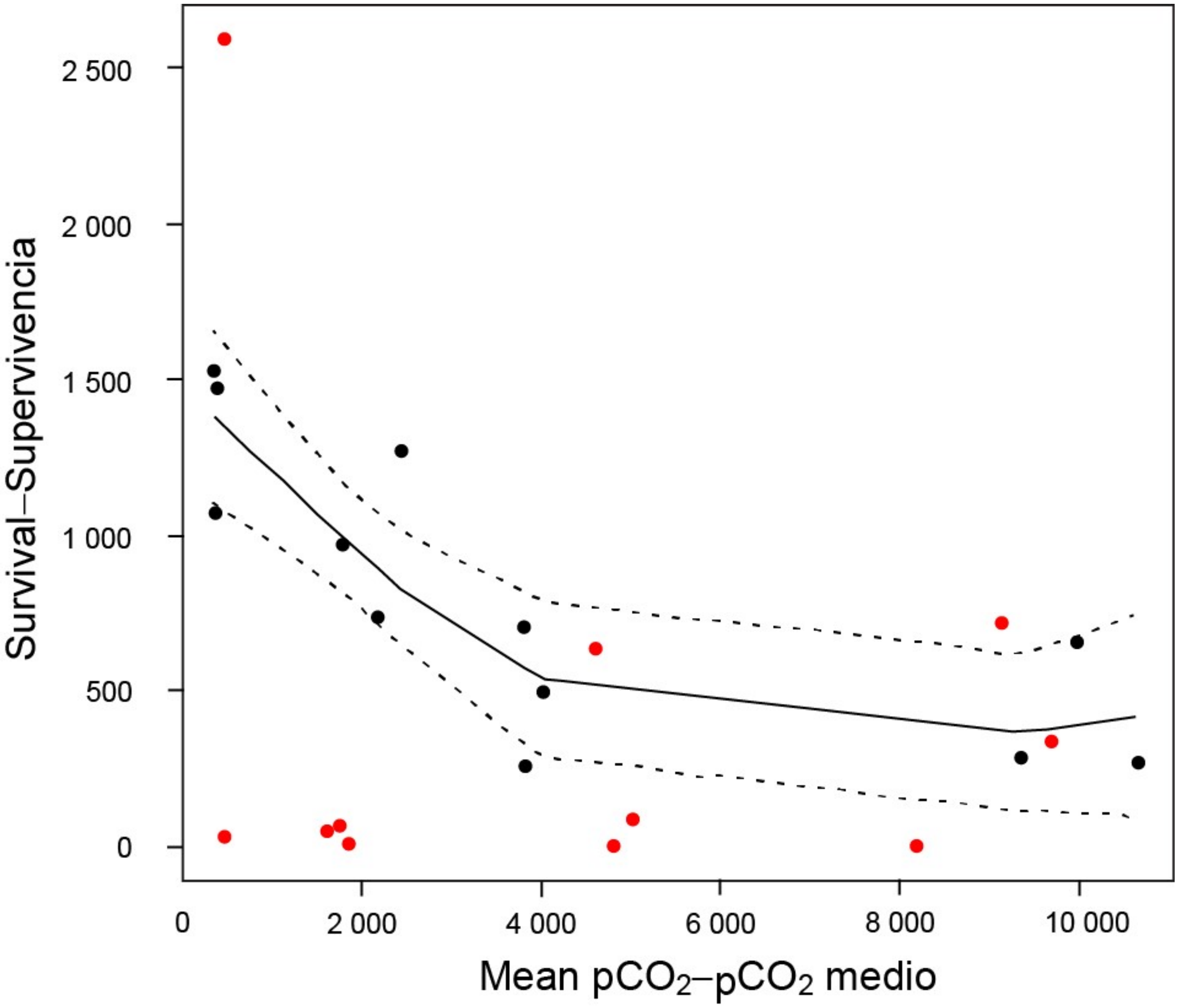


FIGURE 8. Predicted relationship between mean pCO_2 and yellowfin larval survival after 7 days of growth (Trial 1, black line) (Trial 2, red dots). Dashed lines for Trial 1 represent 95% confidence intervals; points indicate the data used to fit the models (Bromhead *et al.* 2015).

FIGURA 8. Relación entre pCO_2 medio y supervivencia de aletas amarillas larvales al cabo de 7 días de crecimiento (Prueba 1, línea negra) (Prueba 2, puntos rojos). Las líneas de trazos en la Prueba 1 representan los intervalos de confianza de 95%; los puntos indican los datos usados para ajustar los modelos (Bromhead *et al.* 2015).