Latin American Journal of Aquatic Research, 50(1): 50-59, 2022
DOI: 10.3856/vol50-issue1-fulltext-2762

Research Article

Hematological and serum chemistry profile in wild Pacific mackerel (*Scomber japonicus*) from Todos Santos Bay, Baja California, Mexico

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ABSTRACT. The Pacific mackerel *Scomber japonicus* aquaculture is receiving growing attention, and further development of this industry is expected to protect wild stocks. Information on *S. japonicus* hematology is very limited. Therefore, the present study aimed to provide the hematological and serum chemistry profiles associated with sex and some seasonal variations in Pacific mackerel from Todos Santos Bay, Baja California, Mexico. Fish were sampled in April (spring) and August (summer). Results showed that the condition factor and all blood parameters analyzed in male and female mackerel were not affected by sex ($P > 0.05$). The seasonality effect on the mackerel was observed in some blood parameters such as mean corpuscular hemoglobin, total protein, globulin, and triglycerides that exhibited lower values in April compared to August ($P < 0.05$). While white blood cell count was higher in August ($P < 0.05$) compared with April. The fish sampled during the two sampling times were possibly a heterogeneous group of ages (1 to 3 years) with lengths ranging from 20 to 30 cm. Consequently, there is an urgent need to follow doing reference interval databases to assess Pacific mackerel health status under different conditions.

Keywords: *Scomber japonicus*; Pacific mackerel; hematology; serum chemistry; seasonal variations

INTRODUCTION

Small pelagic fish is one of the most important fishery resources around the world (FAO 2020). Over the last decades, the production of small pelagic fish in Mexico was from over 6000 t annual catch to 735,000 t between 1954 and 2018 (CONAPESCA 2018). Recently, Pacific mackerel (*Scomber japonicus* Houttuyn, 1782) has been highly popular in Baja California, México, as demonstrated by the historical series of fishing production, which increased from 8 to 12,487 t annual catch between 2009 and 2018 (CONAPESCA 2018). The Pacific mackerel is primarily fished by purse-seine vessels that harvest anchovy (*Engraulis mordax*), jack mackerel (*Trachurus symmetricus*), and sardine (*Sardinops sagax*). There is also a charter-boat sport fishery in Baja, California (Crone et al. 2009). The Pacific mackerel is a coastal pelagic species in the north-eastern Pacific ranging from south-eastern Alaska to Banderas Bay, Mexico, including California. They are common from Monterey Bay, California in USA, to Cabo San Lucas, Baja California Sur, Mexico (Lo et al. 2010, Weber & McClatchie 2012).

Great interest in the culture of new marine pelagic species has increased in response to reduced stocks from wild fisheries. Recently, *S. japonicus* aquaculture has received growing attention. Further development of this industry is expected to protect wild stocks and meet the demand of its use as food and bait by the tuna fishing industry (Mendiola et al. 2008). Consequently, the complete culture cycle of *S. japonicus* has been achieved in Japan (Murata et al. 2005). Some biological aspects of mackerel make it a candidate to be considered with potential in aquaculture activities. The

Corresponding editor: María Morales

S. japonicus temperature ranges allow faster growth through higher feed consumption rates (Mendiola et al. 2008). As in any other aquaculture, alterations of environmental factors and the presence of parasites can result in changes in physiological and behavioral responses of the fish due to stress and is one of the potential problems in the advancement of marine fish culture (Wedemeyer & McLeay 1981, Del Rio-Zaragoza et al. 2008, 2010, Vivanco-Aranda et al. 2018).

The physiological state and stress responses can be assessed by analyzing hematological parameters representing a useful tool for fish health status assessment. This routine should be used in clinical research in aquaculture (Fazio 2019, Ahmed et al. 2020, Del Rio-Zaragoza et al. 2021). The Pacific mackerel is an excellent candidate for mariculture in Mexico, but there is little information on its physiology. Therefore, the present study aimed was to provide the hematological and serum chemistry profiles associated with sex and some seasonal variations in *S. japonicus* from Todos Santos Bay, Baja California, Mexico.

MATERIALS AND METHODS

Study site

Wild Pacific mackerel *Scomber japonicus* (n = 160) were collected in 2017, the warmest year without an El Niño present in the tropical Pacific Ocean (NOAA 2017). Mackerel were collected during April (n = 58, one sample, spring 2017) and August (n = 102, one sample, summer 2017) with the help from a sportfishing business that collects them in Todos Santos Bay (31°40'-31°56'N, 116°36'-116°50'W; Fig. 1). At this time, the seawater temperature ranges from 16 to 18°C, before the highest temperatures were registered in early September (19 to 23°C; Del Rio-Zaragoza et al. 2021). The bay is affected by the California Current System. This current transports less saline and cool waters with high dissolved oxygen levels from the Polar Regions to the equator. The current speed is typically less than 25 cm s^{-1}. It flows towards the equator off California and the northern Baja California Peninsula (Mateos & Marinone 2017).

Seawater physical and chemical characteristics

Seawater samples were undertaken; at the same time that the fish were captured. In each season (spring and summer), four seawater samples were collected in the mackerel capture zone (in a middle point of the bay and near to the island of Todos Santos; Fig. 1) to evaluate the physical and chemical parameters of temperature, salinity, dissolved oxygen, pH, inorganic nutrients (nitrate, nitrite, phosphate, and silicate) and copper. A CTD profiler (conductivity, temperature, depth) model RBR Maestro was used to obtaining salinity, temperature, and depth. The data were treated according to international formulas (Mcdougall et al. 2010).

Dissolved oxygen was measured using the Winkler iodometric method described in Parsons et al. (1984). The pH was analyzed using a glass electrode based on solutions buffers prepared according to Dickson (1993). Nitrites and nitrates were determined using the spectrophotometric technique of the sulfanilamide (modified from Grasshoff et al. 2009). Phosphates were determined by the acid reduction technique ascorbic-ammonium molybdate and spectrophotometric determination of the complex formed, modified from Parsons et al. (1984). The measurement of silicates was done using the reduction technique with oxalic acid-ammonium molybdate, and the spectrophotometric determination of the complex formed, modified from Parsons et al. (1984) and the measurement of copper was made by the technique and method of differential pulse sweep anodic voltammetry, modified from Clesceri et al. (1998).

Fish transport

All mackerels collected in Todos Santos Bay during April and August were transported to the laboratory in our facilities at the Universidad Autónoma de Baja California (UABC) in plastic bags (10-15 fish per bag) with 50 L of seawater at 19.2 ± 1.4°C, and oxygen supply >7 mg L^{-1} (Del Rio-Zaragoza et al. 2018).

Fish collected were released in three 10 m^3 tanks (19 fish per tank in April and 34 fish per tank during August) with open flow and total water change twice per day. Fish survival was 81% in April and 84% in August, after 24 h of arrival to the laboratory and held for seven days to enable its recovery from the stress due to transport and then sampled for blood parameters. The wild pacific mackerel is a fish that readily accepts formulated food. The next day after arriving at the laboratory, a commercial diet (crude protein 46%, crude fat 16%, 3 mm granule size) was offered *ad libitum* (three times a day). During this time, tanks were supplemented with constant aeration and maintained under no controlled temperature conditions. Every day, leftover food and feces were removed from the tanks.

Samples collected

Injuries can occur during the capture and transport of fish. Mackerels with some injury were not considered for blood sampling because the blood parameters could be altered. Mackerels in April (n = 12) and August (n = 10) were carefully handled to reduce stress to a minimal level. Fish were not fed for 24 h before blood samples

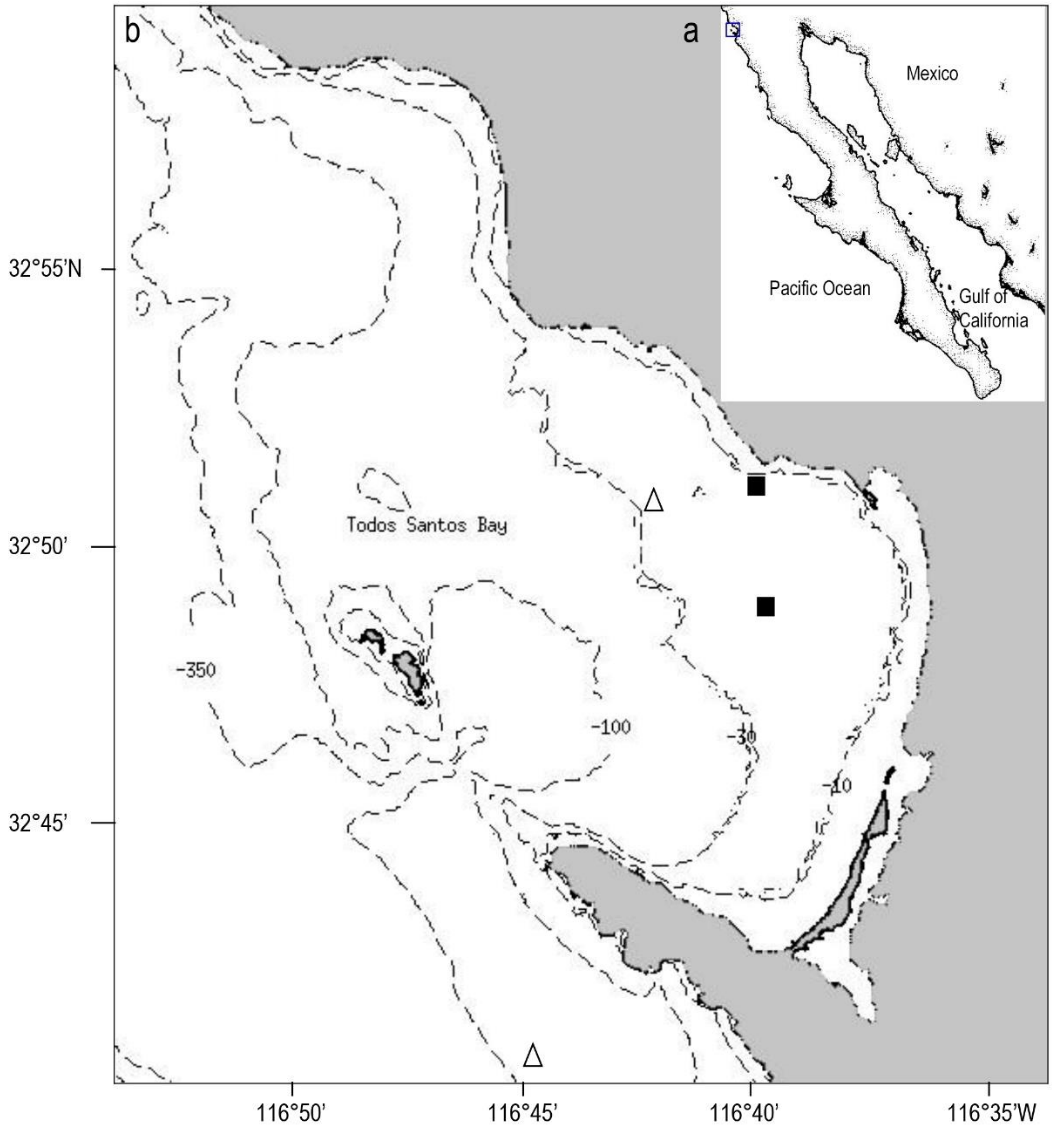

Figure 1. Study area. a) Baja California Peninsula, Mexico, and b) detailed view of the Todos Santos Bay and bathymetry. Sampling points near to Todos Santos Bay's island (Δ) and in the center of the Todos Santos Bay (■).

were taken. They were selected and anesthetized with MS-222 (150 mg L^{-1}), and after 3 min, blood samples were collected from the caudal vein using 1 mL non-anticoagulant syringes. The blood sample was immediately placed into two tubes: the first one had K_2EDTA (BD Microtainer, Franklin lakes, NJ, USA) to prevent coagulation. This tube was used for total red blood cell count (RBC) and total white blood cell count (WBC). The second tube without anticoagulant was used for the rest of the analysis, i.e. hematocrit (HCT). The leftover blood of the latter tube was centrifuged for 10 min at 600 g, and serum was stored in a -80°C ultra freezer for further analysis of serum chemistry.

After blood sampling, each specimen's weight and fork length were measured, and Fulton's condition factor (K) was calculated as $K = 100 \times W L^{-3}$. The fish sex was assessed using morphological criteria reported by Knaggs & Parrish (1973). The age was estimated according to the length-age data reported before for Pacific mackerel (Knaggs & Parrish 1973, Schaefer 1980).

Hematology and serum chemistry analyses

The hematocrit was estimated using a 2/3 filled capillary tube (Leex Equipment, Mexico). The tubes were sealed and placed in a micro-hematocrit centrifuge at 7000 rpm (Premiere® XC-3012, Mexico) for 10 min. The packed cells were measured using the hematocrit reader and reported as percentages (Del Rio-Zaragoza et al. 2008). According to the manufacturer's instructions, the hemoglobin (HGB) content in erythrocytes was determined using a HemoCue Hb 201 analyzer (HemoCue® AB, Angelholm, Sweden). The Natt & Herrick's (1952) method was used for total red blood cell (RBC) and white blood cells (WBC) plus thrombocyte count. The diluted sample was then placed in a Neubauer hemocytometer (Marienfeld-Superior, Lauda-Königshofen, Germany), and the cells were counted using an optical microscope (Karl Zeiss, Primo Star, México). The mean corpuscular volume (MCV), the mean corpuscular hemoglobin (MCH), and the mean corpuscular hemoglobin concentration (MCHC), were calculated using standard formulas with data of HCT, RBC, and HGB: MCV = (HCT / RBC) × 10; MCH = (HGB / RBC) × 10; MCHC = (HGB / HCT) × 100.

Following the manufacturer's instructions the total protein, albumin, glucose, and triglycerides were determined using a colorimetric kit assay (MexLab Group, Jalisco, Mexico). Total protein was analyzed with the Biuret method at 540 nm. In summary, the albumin was diagnosed with the bromo-cresol green method (BCG) at 620 nm. Glucose concentration with glucose oxidase method (God-Pad) at 505 nm. While triglycerides were analyzed using an enzymatic colorimetric method with glycerol phos-phate oxidase (GPO-PAP) at 520 nm. Readings of the absorbance were performed in a microplate reader (Multiskan GO, Thermo Scientific). Globulin was obtained by subtracting the value of albumin from the total protein. All blood parameters analyzed of each sample were performed in triplicate.

Statistical methods

All the data were first tested to confirm a normal distribution and homogeneity of variance. T-tests were used to analyze sex differences on biological index and blood parameters. T-tests were also used to analyze the sample period's effect (April and August) on biological index and blood parameters. All statistical analyses were performed using Sigma Stat 4.0 software (Systat Software, San Jose, CA, USA). The results are presented as the means ± standard deviation (SD), and data, given in percentage, were arcsine transformed before statistical comparisons. The results were considered significant at $P < 0.05$.

RESULTS

Seawater physical and chemical characteristics

Table 1 summarizes the seawater physical and chemical parameters assessed in this study, considered normal values for Todos Santos Bay. Seawater parameters like temperature show variation in different seasons and the same season among the different sample points. In addition, seawater physical and chemical parameters of the tanks (where fish were maintained until the blood samples were taken) during April and August. It was similar to the reported in the bay samples.

Biological index

Female mackerel during April resulted in a higher weight, length, and condition factor than males. However, no significant differences ($P > 0.05$) were found (Table 2).

Regarding the fish sampled during April and August, no significant differences ($P > 0.05$) in the weight, length, and factor condition were found. Nevertheless, fish during August showed a lower factor condition compared with April (Table 3). The fish lengths recorded during April and August range from 20 to 30 cm.

Hematology and serum chemistry analyses

Summaries of several blood parameters values in male and female mackerels are shown (Table 4). The results showed no significant differences ($P > 0.05$) in gender in fish sampled during the spring. Because there were no significant differences in all the blood parameters of male and female mackerels, the sex effect was not considered in August.

The seasonality effects on the mackerel were observed for some blood parameters such as mean corpuscular hemoglobin, total protein, globulin, and triglycerides that exhibited lower values in August compared to April ($P < 0.05$). Glucose concentration decreased in August, while white blood cell count was higher in August ($P < 0.05$) compared with April. The results are summarized in Table 5.

DISCUSSION

This study found that the condition factor analyzed in males and females of the Pacific mackerel (*Scomber japonicus*) was not affected by the sex effect. Fish condition factor exhibited a slowdown during August, but no statistical difference was found. This trend is possibly related to water temperature and food availability in Todos Santos Bay. The seawater temperature normally ranges from 16 to 18°C (0 to 10 m depth) during spring, and higher primary productivity. In the summer, the highest temperatures are normally registered in early September and range from 19 to 23°C (Espinosa-Carreón et al. 2001, Del Rio-Zaragoza et al. 2021).

Table 1. Physical and chemical characteristics of the seawater samples were analyzed at the Todos Santos Bay during April and August of 2017. Sampling points (CB: center of the Todos Santos Bay, NI: near Todos Santos Bay's island, see Fig. 1). T: temperature and DO: dissolved oxygen.

Collected point	T (°C)	Salinity	DO (mg L^{-1})	pH	Nitrate (µM)	Nitrite (µM)	Phosphate (µM)	Silicate (µM)	Copper (µg L^{-1})
April									
CB	11.4-18.3	33.4-33.5	8.2-8.4	7.8-8.1	0.0-0.1	0.0-0.0	0.0-0.1	21-36	--
NI	11.1-16.1	33.5-33.8	7.8-8.5	7.9-8.1	0.2-0.9	0.1-0.6	0.3-1.1	8-15	--
Tanks	16-18	33.5-33.6	7.6-8.2	7.5-7.7	--	--	--	--	--
August									
CB	18.7-25.0	33.3-33.5	8.1-8.7	7.7-8.1	0.1-0.5	0.1-0.5	0.2-1.5	0.1-3.2	0.96-1.06
NI	13.2-19.0	33.3-33.5	7.9-8.5	7.9-8.1	0.1-0.4	0.0-0.2	0.5-0.8	1.2-4.1	--
Tanks	20-23	33.5-33.9	7.2-7.7	7.5-7.6	--	--	--	--	--

Table 2. Biological index of male and female Pacific mackerel (*Scomber japonicus*) sampled during April for blood parameters. Values represent means ± standard deviation, and *P*-values from t-tests are also provided. Means with different superscripts letters are significantly different ($P < 0.05$) within the same parameter.

Parameter	Male (n = 6)	Female (n = 6)	*P*-value
Mean weight (g)	164.58 ± 20.93^a	164.56 ± 38.32^a	0.999
Mean length (cm)	26.78 ± 0.84^a	26.15 ± 1.28^a	0.336
Condition factor (K)	0.85 ± 0.05^a	0.90 ± 0.11^a	0.324

Table 3. Biological index of wild Pacific mackerel (*Scomber japonicus*) sampled during April and August for blood parameters. Values represent means ± standard deviation, and *P*-values from t-tests are also provided. Means with different superscripts letters are significantly different ($P < 0.05$) within the same parameter.

Parameter	April (n = 12)	August (n = 10)	*P*-value
Mean weight (g)	164.6 ± 29.44^a	123.4 ± 60.74^a	0.323
Mean length (cm)	26.46 ± 1.08^a	23.88 ± 3.13^a	0.053
Condition factor (K)	$0 .88 \pm 0.08^a$	0.84 ± 0.15^a	0.922

The mackerel's blood parameters showed similarities and differences between other fish species (Del Rio-Zaragoza et al. 2018, Fazio 2019). For example, high HCT and HGB values were found in mackerel and other healthy marine fishes such as the Pacific sardine (*Sardinops sagax*, Del Rio-Zaragoza et al. 2018) and the spotted rose snapper (*Lutjanus guttatus*, Del Rio-Zaragoza et al. 2011). The hematology of these fish species reflects the active nature of the fish and the habitat where they live. Generally, marine fish's hematological values are higher than freshwater fish (Del Rio-Zaragoza et al. 2011, Fazio 2019).

This study found that all blood parameters analyzed in males and females of the mackerels were not affected by the sex effect. Similar results to this study were found in spirlin (*Alburnoides eichwaldii*) concerning the sex effect on blood parameters (Kohanestani et al. 2013). Contrary to this study, variations in hematological parameters of Indian carp (*Catla catla*) were found about the sex, where the male fish may have higher values in almost all hematological parameters. Such variations were attributed to physiologically activeness in the male than the female fish (Pradhan et al. 2012). Another study performed in snow trout (*Schizothorax plagiostomusto*) attributed the differences in hematological parameters to higher metabolic rate and hormonal activity in males (Sheikh & Ahmed 2016).

The effects of seasonality during April and August on the mackerel were observed for blood parameters such as MCH, WBC count, total protein, globulin, glucose, and triglycerides. Seasonal variation in hematological parameters has been found in tench (*Tinca tinca*), sea bass (*Dicentrarchus labrax*), Indian carp, spirlin, pejerrey (*Odontesthes bonariensis*), snow trout (*Schizothorax plagiostomusto*), and Indian hill

Table 4. Hematology and serum chemistry parameters of male and female wild Pacific mackerel (*Scomber japonicus*) sampled during April. Values represent means ± standard deviation. The *P*-values from t-tests are also provided; means with different superscripts letters within the same group are significantly different ($P < 0.05$). Minimum and maximum values are displayed in parentheses. RBC: red blood cells, MCV: mean corpuscular volume, MCH: mean corpuscular hemoglobin, MCHC: mean corpuscular hemoglobin concentration, WBC: white blood cells.

Parameter	Male (n = 6)	Female (n = 6)	*P*-value
Hematocrit (%)	70 ± 7.09 (60 - 80)	64 ± 12.92 (46.6 - 86.3)	0.362
RBC ($\times10^6$ mm^3)	3.36 ± 0.607 (2.63 - 4.28)	2.68 ± 1.28 (1.03 - 4.04)	0.263
Hemoglobin (g dL^{-1})	14.81 ± 1.17 (13 - 16)	14.17 ± 1.19 (13 - 16)	0.376
MCV (fL)	199.83 ± 46.56 (140.18 - 26.6)	316.15 ± 211.03 (165.15 - 621.35)	0.217
MCH (pg)	45.14 ± 8.10 (31.77 - 53.69)	70.24 ± 44.05 (35.96 - 130.48)	0.200
MCHC (g dL^{-1})	22.91 ± 2.75 (20.13 - 28.25)	23.10 ± 5.86 (16.83 - 34.97)	0.818
WBC ($\times10^3$ mm^3)	13.30 ± 2.23 (10.20 - 15.80)	12.63 ± 2.97 (9.0 - 16.80)	0.670
Total protein (g dL^{-1})	5.43 ± 0.86 (4.14 - 6.48)	5.09 ± 0.86 (4.33 - 6.72)	0.504
Albumin (g dL^{-1})	2.14 ± 0.48 (1.52 - 2.91)	1.89 ± 0.21 (1.64 - 2.23)	0.282
Globulin (g dL^{-1})	3.29 ± 0.49 (2.62 - 3.89)	3.19 ± 0.66 (2.69 - 4.49)	0.773
Glucose (mg dL^{-1})	132.16 ± 49.20 (73.65 - 192.68)	123.13 ± 51.50 (68.27 - 201.79)	0.762
Triglycerides (mg dL^{-1})	257.41 ± 96.88 (96.03 - 378.41)	260.83 ± 112.56 (87.44 - 368.72)	0.956

trout (*Barilius bendelisis*) (Collazos et al. 1998, Pascoli et al. 2011, Pradhan et al. 2012, Kohanestani et al. 2013, Vigliano et al. 2014, Sheikh & Ahmed 2016, Sharma et al. 2017). Variations in hematologic parameters are due to seasonal water temperature and dissolved oxygen variations (Kohanestani et al. 2013). At higher temperatures, the oxygen concentration is lower compared to cold water. As a result, more erythrocytes are required to carry oxygen around the fish's body in warm water as the oxygen is less readily available. Under these conditions, values of blood parameters such as HCT, RBC, HGB, MCV, MCH, and MCHC may increase (Del Rio-Zaragoza et al. 2008). Nevertheless, our results do not agree with those observed in other species mentioned above. Because in April and August, no significant differences were found in HCT, RBC, HGB, MCV, and MCHC. These results can be attributed to the heterogeneous group of mackerel caught during these two months in the Todos Santos Bay with a length range of 21 to 30 cm and possibly with age groups (1 to 3 years) according to those reported by Knaggs & Parrish (1973) and Schaefer (1980). Nevertheless, smaller fish were captured in August compared to April. Consequently, low values of HCT, RBC, HGB, MCV, MCH, and MCHC were found in August, with only MCH being statistically significant. A general trend has been shown amongst hematological parameters and body length, suggesting that larger fish have a higher level of parameters such as HCT, HGB, and WBC (Del Rio-Zaragoza et al. 2021).

In this study, WBC counts of mackerels were lower in April than those measured during August. A similar response was found in tench, sea bass, spirlin, pejerrey and Indian hill trout (Collazos et al. 1998, Pascoli et al. 2011, Kohanestani et al. 2013, Vigliano et al. 2014, Sharma et al. 2017). It has been suggested that ambient changes along the year, such as photoperiod and temperature, may induce changes in the immune system. As winter approaches, lower WBC counts are found. On the other hand, higher WBC counts may be found during the summer and fall months (Pascoli et al.

Table 5. Hematology and serum chemistry parameters of Pacific mackerel (*Scomber japonicus*) were sampled during April and August. Values represent means ± standard deviation. *P*-values from t-tests are also provided; means with different superscripts letters within the same group are significantly different ($P < 0.05$). Minimum and maximum values are displayed in parentheses. RBC: red blood cells, MCV: mean corpuscular volume, MCH: mean corpuscular hemoglobin, MCHC: mean corpuscular hemoglobin concentration, WBC: white blood cells.

Parameter	April	August	*P*-value
Hematocrit (%)	66.42 ± 10.84^a	58.33 ± 13.51^a	0.189
	(46.6 - 86.3)	(36 - 73)	
RBC ($\times10^6$ mm^3)	3.02 ± 1.02^a	3.62 ± 1.39^a	0.052
	(1.0 - 4.2)	(0.2 - 5.1)	
Hemoglobin (g dL^{-1})	14.49 ± 1.17^a	12.74 ± 3.05^a	0.176
	(12.96 - 16.3)	(8.7 - 16.9)	
MCV (fL)	257.99 ± 157.8^a	162.00 ± 45.1^a	0.174
	(104.2 - 621.3)	(97.56 - 228.8)	
MCH (pg)	57.69 ± 32.92^a	34.12 ± 12.59^b	0.013
	(31.77 - 130.4)	(20.73 - 62.82)	
MCHC (g dL^{-1})	23.09 ± 4.58^a	20.89 ± 7.47^a	0.242
	(16.83 - 34.97)	(14.54 - 34.49)	
WBC ($\times10^3$ mm^3)	12.96 ± 2.53^a	19.08 ± 7.52^b	0.027
	(9 - 16.8)	(12 - 34.8)	
Total protein (g dL^{-1})	5.26 ± 0.84^a	3.12 ± 2.05^b	0.011
	(4.1 - 6.7)	(1.1 - 7.5)	
Albumin (g dL^{-1})	2.01 ± 0.37^a	1.85 ± 0.72^a	0.491
	(1.5 - 2.9)	(0.9 - 3.3)	
Globulin (g dL^{-1})	3.25 ± 0.56^a	1.37 ± 1.27^b	0.003
	(2.6 - 4.5)	(1.1 - 4.1)	
Glucose (mg dL^{-1})	127.6 ± 48.25^a	109.8 ± 88.6^a	0.121
	(68.2 - 201.7)	(33.1 - 289.3)	
Triglycerides (mg dL^{-1})	259.1 ± 100.1^a	129.5 ± 131.1^b	0.016
	(87.4 - 378.4)	(30.5 - 365.4)	

2011). WBC counts may increase in correlation with infection produced by several pathogens, indicating a protective response in the fish (Del Rio-Zaragoza et al. 2010, 2011, Vivanco-Aranda et al. 2018). Nevertheless, in this study, no sign of diseases was observed. Additionally, several stress conditions such as environmental quality, nutritional status, density, and age may influence this parameter (Del Rio-Zaragoza et al. 2008, 2021, Fazio 2019, Ahmed et al. 2020).

In addition, other blood parameters such as total protein, globulin, glucose, and triglycerides levels were significantly lower in mackerels during August than in April. Similar responses in the total protein and globulin levels were lower in Indian hill trout during summer and fall (Sharma et al. 2017). The decrease in protein concentration has been attributed to illness (liver damage), decreased nutrient absorption, nutritional deficiency, starvation, and infectious diseases (Wedemeyer & McLeay 1981, Del Rio-Zaragoza et al. 2011). The decrease in serum protein concentration in mackerel may be due to increased proteolysis and utilization of the product for metabolic purposes or utilization in the growth of gonads (Sharma et al. 2017). Our findings are in concordance with the reproductive behavior of Pacific mackerel in the northern Baja California, since spawning may occur from March through October, but the spawning of older mackerel peaks during spring (May), while for age-2 and age-1 fish, it peaks in summer (June and July; Schaefer 1980).

Contrary to reports in mackerel, glucose and triglycerides levels of Indian hill trout were higher in summer and fall whereas, lower levels were in winter and spring (Sharma et al. 2017). The increase in serum glucose levels is correlated with catecholamine production during thermal stress (Del Rio-Zaragoza et al. 2008). So, higher levels of glucose will be marked during summer. Moreover, processes related to environmental challenges appear more effective glycaemic inducers. Few processes result in glucose decreases, although it also occurs with food deprivation and hypoxia (Polakof et al. 2012). In Todos Santos Bay during summer, there is a decrease in salinity, an increase in the flow of warmer and surface water that is poor in nutrient concentrations and chlorophyll by the decrease in coastal upwelling (Espinosa-Carreón et al. 2001). So, food resources may be decreased. Consequently, serum total protein and glucose levels decrease in mackerels.

Seasonal variations in blood parameters are one of the key factors that affect fish hematology, with variations more pronounced as we move from the tropics to temperate regions, which also affect physicochemical parameters. Predominantly the effect of changes in ambient temperature and dissolved oxygen content associated with changing seasons leads to variability in fish blood parameters (Ahmed et al. 2020). Ahmed et al. (2020) appointed that season cannot be justified as the sole factor responsible for variations in hematological parameters, but other factors need to be considered.

The seawater physical and chemical parameters in the wild environment associated with the sampling point's show that the highest concentrations of nutrients are associated with upwelling (Lynn & Simpson 1987) and coincide with concentrations reported for nitrates (Segovia-Zavala et al. 1998). The maxims nutrient concentrations within Todos Santos Bay are associated with greater mixing processes (Cacho-López 1992) and upwelling stations outside the Todos Santos Bay, in Punta San Miguel and Punta Banda (Huyer 1983, Lynn & Simpson 1987). The maximum concentrations of phosphates reported in this work are comparable to those reported at the sampling points within the Todos Santos Bay (Delgadillo-Hinojosa et al. 2015). The cupper concentrations reported in this work are in the range of concentrations reported for Todos Santos Bay (Sañudo-Wilhelmy & Flegal 1996, Lares et al. 2009), and its distribution is associated with biological processes (Lares et al. 2009) and anthropogenic activity. The maxims copper concentrations reported in this study do not exceed the maximum permissible allowances established in NOM-001-SEMARNAT-1996 (DOF 2003). Thus, seasonality and physicochemical parameters of the seawater dominate the life cycle of fish. It coordinates their reproductive activity, affects body weight and condition, influences food intake, locomotor activity, coordinates their physiology, blood parameters, and immune response (Ahmed et al. 2020).

CONCLUSIONS

The present first study of hematological and serum chemistry profiles associated with the sex and some seasonal variations in wild Pacific mackerel might serve as a basis for future studies and diagnosis. Results showed that the condition factor and all blood parameters analyzed in the mackerel were not affected by sex. Some blood parameters (MCH, WBC count, total protein, globulin, glucose, and triglycerides) showed variations in April and August, probably related to water temperature, photoperiod, and other ambient factors. Our results in WBC count are in agreement with similar studies on different species. On the other hand, the fish sampled during the two sample times were possibly a heterogeneous group of ages (1 to 3 years) with lengths ranging from 20 to 30 cm. Consequently, there is an urgent need to follow doing reference interval databases to contribute aspects of its physiology in the Pacific mackerel.

ACKNOWLEDGMENTS

This research was financed by PRODEP-SEP (UABC-PTC-560) and Universidad Autónoma de Baja California (IIO-UABC 403/2358).

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Received: May 11, 2021; Accepted: September 27, 2021

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