

# CALIFORNIA FISH AND GAME

## “Conservation of Wildlife Through Education”

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Volume 105

Winter 2019

Number 1

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## California Fish and Game

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## Notes from the Editor

This winter issue of the 105<sup>th</sup> volume, the first issue of 2019, will delight those who enjoy reading about marine fish, as all three articles in this issue focus on that subject. The first is an interesting note about an exceptionally long-term recovery tag of a California scorpionfish which was at liberty for significantly longer than ever recorded for the species. The second article is also a note that describes a method to use dorsal fin spines to estimate the age of roosterfish. The third article, again a note, describes primary and secondary nursery habitats for two species of sharks in the San Francisco Bay: leopard sharks and brown southhound sharks. All three provide interesting commentary to further our knowledge of marine fish off the coast of California.

The *Journal* was pleased to have a guest Associate Editor for this issue, Jean Win. Dr. Win received her PhD in Marine Science from Griffith University in Australia. Her background is in fish ecology and biology and coastal food webs. She has been working for CDFW as an Environmental Scientist for the Southern California Fisheries Research and Management Project since 2015. In her position, she collects fishery independent data and assesses the stock status of state managed finfish. We are grateful to Dr. Win for her participation as an editor for this issue.

We also have a new permanent Associate Editor that has joined our team, Felipe La Luz. Mr. La Luz completed his B.S. in Wildlife, Fish, and Conservation Biology at the University of California-Davis with an emphasis on fisheries biology. After graduating, he continued to work closely with researchers at the University on projects examining fish physiology and behavior, and later utilized otolith structure and microchemistry to elucidate growth and migration patterns of native fishes. During this time, he also participated in multiple field studies that monitored aquatic communities in throughout the Sacramento-San Joaquin Delta as well as large scale salt marsh restoration projects in South San Francisco Bay. He was also an active member in the Sacramento-Davis Student Subunit of the American Fisheries Society and later served on the Executive Committee of California Nevada Chapter of the American Fisheries Society. Mr. La Luz joined CDFW in 2015 as lead biologist for the Region 3's Summer Townet Survey, a long-term trawl program implemented in 1959 to monitor juvenile pelagic fishes in the Sacramento-San Joaquin Delta. He also participated in collaborative multi-agency groups such as the Interagency Ecological Program Science Management Team and Smelt Working Group, which informs real time operations of large water diversions. Throughout his education and career, Felipe's research interests have focused on the ecology of California's native fish fauna with an emphasis on threatened smelts (Osmeridae) as well as large minnows (Cyprinidae) native to the Central Valley. Felipe is currently an Environmental Scientist in the Operations unit at the Water Branch where he applies his knowledge of native fishes and estuarine ecology to real time operations and long-term water management in the Sacramento-San Joaquin Delta. We are excited for Mr. La Luz to join our team of wonderful Associate Editors that put so much time into maintaining the high standards for this journal.

As I mentioned in the previous issue, changes are coming to the *Journal*. One of those changes in the introduction of special issues. We will be working on three special issue

this year with the hope to do a similar number next year as well. The topics of these special issues are highly relevant to California currently: cannabis, fire, and human recreation and their impacts on fish and wildlife resources in the state. If you would like to find out more about our Special Issues, please see our webpage: <https://www.wildlife.ca.gov/Publications/Journal/Special-Issues>.

Ange Darnell Baker, PhD  
Editor-in-Chief  
*California Fish and Game*

## A very long term tag recovery of a California Scorpionfish (*Scorpaena guttata*)

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Key words: California scorpionfish, days at liberty, Floy FD-94, *Scorpaena guttata*, tag return

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During the four-year period from 21 November 2002 to 24 July 2006, we performed a mark-recapture study on nearshore groundfish off southern and central California (Hanan and Curry 2012). For the study, volunteer fishermen aboard chartered commercial passenger fishing vessels (CPFV) caught by hook and line, 32 species of groundfish (32,366 total fish), including 2,751 California Scorpionfish, *Scorpaena guttata*; these fish were marked with Floy FD-94 tags and released. As of the date of the Hanan and Curry paper, 257 scorpionfish were reported as recaptured with an average days at liberty (DAL) of 408.8 days (431.6 SD; range 2 - 2,126 days). A total of 76 (33%) of these recaptured scorpionfish were recaptured within 1 km of their original tagging site, 155 (67%) were within 5 km, and 17 (1%) were recaptured at distances of 50 km or more from the original tagging site with a range of 68 to 1,788 DAL.

On 21 November 2017, a tagged California scorpionfish was reported caught by Mr. Robert Rosenberg, a recreational angler, on a one-day trip aboard the CPFV *New Del Mar* out of Marina Del Rey, California. He had previously caught three other of our tagged scorpionfish during 2003 and 2004, which likely aided in his recognition of the bryozoan-encrusted tag. He removed the tag (#14769, which he sent to the authors) and released the fish “unharmd and looking very healthy” (R. Rosenberg, personal communication).

This scorpionfish was tagged on 26 January 2004 aboard the CPFV *Redondo Special*. The fish was at liberty for nearly 14 years (5,048 days), which is substantially longer than the maximum days at liberty (DAL) reported for this species. In previous studies, Hanan and Curry (2012) reported tagged-recaptured scorpionfish remaining at liberty for 2,126 days. Love et al. (1987) reported a maximum DAL of 915 days for this species. Hartmann (1987) documented a scorpionfish at liberty for 670 days, and Turner et al. (1969) recovered a tagged scorpionfish that had been at liberty for 507 days.

The fish was recaptured in about 30 m (100 ft) of water approximately 3 km off El Segundo (R. Rosenberg, personal communication). The fish was originally captured and tagged at 33°52'5"N, 118°27'4"W in 34 m (112 ft) of water, approximately 3.2 km south-



west of El Segundo. Based on the description of the recapture site, we surmise that the fish was certainly recaptured within 50 km and probably within 5 km of the original capture-tag-and-release site. While this species has been documented to move distances as great as 200 km (Hanan and Curry 2012), mark-recapture studies have also shown that this species demonstrates strong site fidelity (Turner et al. 1969, Hartmann 1987, Love et al. 1987, Hanan and Curry 2012), especially to known spawning grounds during the spawning season (May–September) (Love et al. 1987). However, as this fish was originally tagged in January, during the non-spawning season and recovered in November, also the non-spawning season, in generally the same location, this may indicate some site fidelity for non-spawning sites.

At the time of recapture the fish was at least 20 inches in length, and weighed at least 2 pounds (R. Rosenberg, personal communication). At the time of tagging in 2004 this fish was measured at 265 mm (~10.5 inches) fork length. Sex was not determined. Using the von Bertalanffy equations completed by Love et al. (1987), we estimate that this fish was 5 to 6 years of age at the time of tagging. Given the DAL, we estimate the fish to be 19 to 20 years old at the time of recapture. This is close to the maximum reported age for females (21 years) and exceeds the maximum reported age for males (15 years) (Love 2011).

### ACKNOWLEDGMENTS

The authors would like to thank R. Rosenberg for his assistance during the original study period 2002–2006, and for his taking the time to report multiple recaptures since then, and K. Thiesfeld with Humboldt State University for comments that helped improve this paper.

### LITERATURE CITED

- HANAN, D. A., AND B. E. CURRY. 2012. Long-term movement patterns and habitat use of nearshore groundfish: tag-recapture in central and southern California waters. *Open Fish Science Journal* 5:30–43.
- HARTMANN, A. R. 1987. Movement of scorpionfishes (Scorpaenidae: *Sebastes* and *Scorpaena*) in the southern California Bight. California Department of Fish and Game Fishery Bulletin 73:68–79.
- LOVE, M. S., B. AXELL, P. MORRIS, R. COLLINS, AND A. BROOKS. 1987. Life history and fishery of the California scorpionfish, *Scorpaena guttata*, within the southern California Bight. *Fishery Bulletin* 85:99–116.
- LOVE, M. S. 2011. Certainly more than you want to know about the fishes of the Pacific coast: a postmodern experience. Really Big Press, Santa Barbara, California, USA.
- TURNER, C. H., E. EBERT, AND R. R. GIVEN. 1969. Man-made reef ecology. California Department of Fish and Game, Fishery Bulletin 146. California Department of Fish and Game, Sacramento, California, USA.

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## Potential use of dorsal fin spines of the roosterfish for age estimation

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Key words: age, fin spines, individual growth, *Nematistius pectoralis*, sport fishing

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The roosterfish (*Nematistius pectoralis* Gill, 1862) is the only species in the genus *Nematistius* (family Nematistiidae). The most distinguishable external feature of this species is the presence of 7 elongated (comb-shaped) dorsal spines, which give rise to its common name (Rosenblatt and Bell 1976) and allow it to be easily identified from other species (Niem 1995). This species does not present sexual dimorphism.

The roosterfish is distributed in the Pacific Ocean, from San Clemente in southern California to San Lorenzo Island in Peru, including the Gulf of California and the Galapagos Islands (Love et al. 2005). It is a coastal pelagic species that plays a dominant role as a nearshore predator in the waters of Mexico and Central America (Love et al. 2005, Sepulveda et al. 2015). It inhabits mainly coastal areas, with juveniles often found along the shoreline and larger individuals commonly distributed in areas close to reefs and subsurface features (Niem 1995, Sepulveda et al. 2015).

Roosterfish can reach up to 191 cm in total length and weight over 50 kg (Robertson and Allen 2015). In terms of feeding habits, it is considered a specialist predator that commonly feeds at depths of 3 to 4 meters, mainly on coastal pelagic species such as mojarras (e.g., *Eucinostomus gracilis* and *E. dowii*) and anchovies (e.g., *Anchoa ischana* y *A. spp.*) (Rodríguez-Romero et al. 2009).

In Mexico, the roosterfish is reserved for recreational fishing activities, with commercial protection offered within a coastal strip of 50 nautical miles from shore, and daily retention limits set at two organisms per day per fisher (NOM-017-PESC-1994, DOF 1995<sup>1</sup>,

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1 DOF. 1995. Diario Oficial de la Federación (DOF). Norma Oficial Mexicana NOM-017-PESC-1994, para regular las actividades de pesca deportiva en las aguas de la jurisdicción federal de los Estados Unidos Mexicanos, Tomo 15-19, México, D.F.

2013<sup>2</sup>). The roosterfish is considered a prized species by the sport fishing community, which provides direct and indirect economic benefit to the tourism commerce along the coast of the Baja California peninsula and the Sea of Cortez. In 2007 these activities generated income of over 633.6 million dollars in the region of Los Cabos alone (Ditton et al. 1996, Sosa-Nishizaki 1998, Southwick et al. 2010). The roosterfish is also caught incidentally by artisanal fleets that operate along the coast, but this species is not directly targeted due to its relatively dark myotomal musculature and low food-value compared to other inshore species (Sepulveda et al., 2015).

Despite the ecological and economic importance of the roosterfish, there are few studies on its biology, ecology, and movement patterns (Sepulveda et al. 2015, Ortega-Garcia et al. 2017). Parameters such as age and individual growth are essential for fisheries management and are the basis of most stock assessment models (Goldman 2005). Age and growth can be determined by various methods including: growing fish in confinement, examining hard parts, which encode age information, and through biochemical testing. The feasibility and use of different methods depends on accessibility, habitat and life history. In most instances, it is necessary to determine the age of wild fish through the examination of calcified structures, from which age can be estimated. The structures, which have been shown to encode age information include bones (fin rays, vertebrae, cleithra, opercular bones), scales and otoliths (Stevenson and Campana 1992). These structures tend to sequentially accumulate calcified growth material as they age, thus producing concentric areas that often have characteristics reflecting the time of year (season) in which the material is being deposited (Calliet et al. 2006). Fin spines and soft rays have been used to estimate the age structure and growth rate of a wide variety of freshwater and marine fishes (Kopf et al. 2010). These calcified structures can be removed and processed easily and quickly (Beamish and Fournier 1981), often provide good legibility (Hill et al. 1989) and may exhibit growth bands that reflect the different seasons of the year (Kopf et al. 2011).

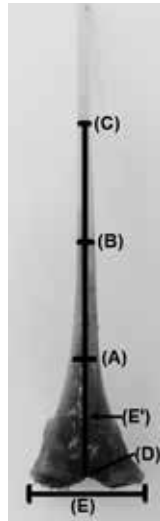
To date, there is a single study focused on age and individual growth of roosterfish by Ortega-Garcia et al. (2017). These authors analyzed daily growth increments in sagittal otoliths from individuals caught in El Golfo Dulce, Costa Rica, and the southern Baja California Sur peninsula, Mexico and concluded that daily growth increments in sagittal otoliths can only be used to estimate age in individuals measuring up to 66 cm fork length (~1 year of age). Aging efforts from otoliths of larger specimens were largely unsuccessful because daily incremental marks were difficult to differentiate, and annuli were not readily visible. Thus, sagittal otoliths were not considered a suitable structure for age estimates of individuals greater than one year. The current study focused on identifying alternative hard structures that may be used to estimate age and individual growth of larger individuals (>1 yr). The primary objective of this study was to assess which sections of roosterfish dorsal fin spines have the most legible indicators of growth for use in future aging studies.

From January 2010 to December 2012, roosterfish were sampled from the sport fishing fleet in Cabo San Lucas, Baja California Sur, Mexico. Fork length (FL) to the nearest 0.1 cm and weight to the nearest 0.01 kg were recorded from each roosterfish sampled. The dorsal fin was removed from the base with a knife and stored for further laboratory preparation.

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2 DOF. 2013. Diario Oficial de la Federación (DOF). Modificación a la norma oficial mexicana NOM-017-PESC-1994, para regular las actividades de pesca deportivo-recreativa en las aguas de jurisdicción federal de los Estados Unidos Mexicanos, publicada en el diario oficial de la federación el 9 de mayo de 1995, Tomo 15-19, México, D.F.

The first five spines of each dorsal fin were cleaned; and the distance between the inferior apophyses of the base of each spine was measured with a caliper (Helios Vernier) to the nearest 0.05 mm (Figure 1). This measurement was used as a reference unit to ensure uniform sampling for the transverse sections. The spines were marked, orientation was noted, and the sections were labelled from the base and along the primary axis, at 100%, 200% and 300% of the reference unit (Figure 1). This was done to provide a consistent transverse section location across samples.



**FIGURE 1.**— Front view of the fourth spine of the dorsal fin of roosterfish (*Nematistius pectoralis*) showing the section levels (A): 100%, (B): 200% and (C): 300%. E is the distance between lower apophysis and corresponds to the same distance as E' measured from the base (D) of the spine.

To select the most appropriate spine and section level for observing and counting growth marks in the roosterfish, the linear relationship between each of the diameters measured in each spine and fork length was analyzed using the following equation:

$$FL = a + b(D)$$

where: *FL* is fork length (cm), *a* is the intercept with the *Y* axis, *b* is the slope of the regression line, and *D* is spine diameter (cm).

This relationship was determined for each spine and section level, resulting in 15 linear relationships (5 spines x 3 section levels). The spine and section level selected through this procedure corresponded to the relationship that yielded the highest linear trend (proportional growth) between fish length (*FL*) and spine diameter (*D*), denoted by the highest coefficient of determination ( $r^2$ ) (Daniel 2012).

Cross-sections of different thicknesses (0.25 mm, 0.45 mm and 0.5 mm) were sliced from each section level (Figure 1) in each spine using a low-speed saw (Buehler brand, model 11-1280-160) with a Diamond Wafering Blade (15HC series). Digital images of the cross-sections were obtained with a camera (Carl Zeiss brand, model AxioCam MRc 5) adapted to a stereoscope (Carl Zeiss brand, model Stemi SV11).

Digital images of the spine cross-sections were evaluated to determine the thickness at which growth marks were observed with greatest clarity, and consequently could be readily enumerated by two independent readers. Each growth mark consisted of an opaque band followed by a translucent band. Readings were made directly on the digital images of sections to avoid the direct manipulation of the spine sections due to their fragility.

To evaluate the precision between counts made by each reader, the coefficient of variation (Chang 1982) was calculated:

$$CV_j = 100\% * \sqrt{\frac{\sum_{i=1}^R (X_{ij} - X_j)^2}{R-1}} \frac{1}{X_j}$$

where:  $CV_j$  is the estimated coefficient of variation for the  $j$ th fish,  $X_{ij}$  is the  $i$ th age estimation of the  $j$ th fish,  $X_j$  is the mean age estimation for the  $j$ th fish, and  $R$  is the number of times each fish is aged. The relationship between number of growth marks and fork length was analyzed through a linear regression.

Given that organisms were not sampled in all months of the year, the validation of whether the marks observed in cross-sections have an annual formation period was beyond the scope of this study.

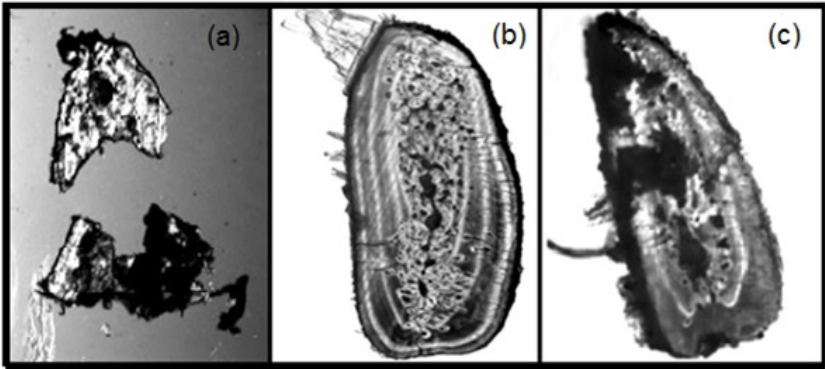
All organisms sampled ( $n=93$ ) were obtained from the retained catch from sport fishing activities based off the southern portion of Baja California Sur. Samples sizes ranged from 14 to 133 cm FL, with most individuals (76% of the total organisms sampled) falling between 50 and 90 cm FL. Because exceptionally small and large individuals are typically released by the recreational fleet, samples < 40 cm and above 100 cm FL were scarce.

Putative growth marks were identifiable within the dorsal spine cross-sections of all roosterfish examined, with opaque-translucent bands most clearly legible in the 0.45-mm-thick cross-sections of the dorsal spines. The 0.25 mm sections were extremely fragile and brittle and determined to be unsuitable for consistent quantification of growth marks, while it was difficult to distinguish between opaque-translucent bands in 0.5 mm sections (Figure 2).

The fourth dorsal fin spine yielded the highest  $r^2$  values (Table 1) during linear regression analysis between spine diameter at different section levels and fork length. Although the 300% section level of the fourth dorsal fin spine had a slightly higher  $r^2$  ( $r^2=0.947$ , Table 1), when compared to the 200% section level ( $r^2=0.932$ , Figure 2b, Table 1), the latter provided increased growth mark legibility. Given the importance of growth mark differentiation, the 200% section was chosen for the cross-sections analysis and the counting of putative growth marks.

Most cross-sections (93%) at the 200% section level of the fourth dorsal fin spine of the roosterfish, allowed observing and counting growth marks, which were clearly visible. The precision in growth-mark counts performed by two independent readers was high, as indicated by the low coefficient of variation ( $CV=9.67\%$ ); therefore, there was consistency between the counts by both readers. The count of growth marks on cross-sections ranged from 0 to 4 opaque-translucent bands. Individuals with one growth mark were the most abundant, followed by individuals with 0 and 2 marks, whereas individuals with 3 and 4 marks were scarce (Figure 3).

The number of growth marks (GM) increased with fork length and there was a significant relationship between the number of growth marks and roosterfish fork length ( $FL=47.33 + 20.95 * GM$ ,  $r^2=0.569$ ,  $P < 0.05$ ). Roosterfish with a single growth mark ranged



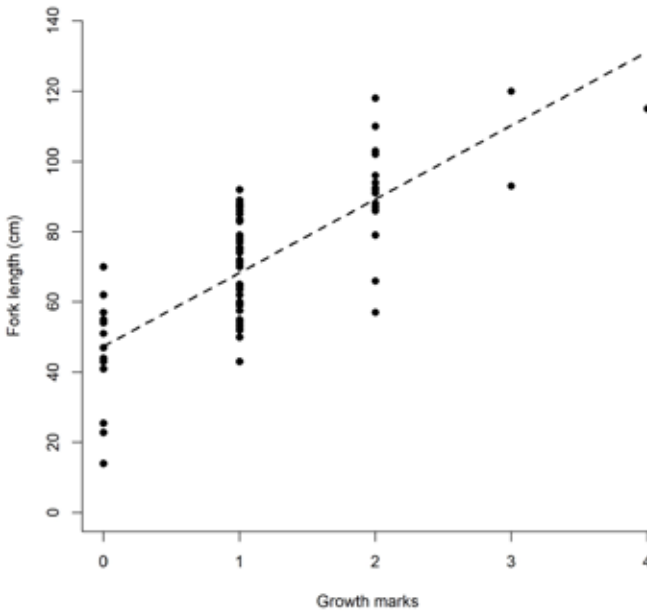
**FIGURE 2.**— Photographs of cross-sections of different thicknesses a) 0.25 mm, b) 0.45 mm and c) 0.5 mm of spines of the dorsal fin of roosterfish (*Nematistius pectoralis*) landed by the sport fleet of Cabo San Lucas, B.C.S. in the period 2010-2012.

**TABLE 1.**— Coefficients of the linear regressions for each spine in each section level for roosterfish (*Nematistius pectoralis*) caught by the sport fishing fleet of Cabo San Lucas, B.C.S. between 2010-2012.

Spine #	Section level	<i>a</i>	<i>b</i>	<i>r</i> <sup>2</sup>	<i>P</i>
1	100%	9.55	24.78	0.913	< 0.05
	200%	15.53	29.59	0.908	< 0.05
	300%	20.79	35.21	0.691	< 0.05
2	100%	4.83	21.93	0.917	< 0.05
	200%	13.93	24.28	0.913	< 0.05
	300%	14.85	31.22	0.911	< 0.05
3	100%	5.05	24.25	0.871	< 0.05
	200%	12.89	33.44	0.902	< 0.05
	300%	10.43	42.95	0.902	< 0.05
4	100%	4.16	24.82	0.897	< 0.05
	200%	14.71	34.26	0.932	< 0.05
	300%	8.31	48.21	0.947	< 0.05
5	100%	12.34	24.77	0.751	< 0.05
	200%	10.31	44.38	0.864	< 0.05
	300%	6.27	55.81	0.875	< 0.05

in size from 43 to 92 cm FL and fish with two growth marks varied from 57 to 118 cm FL (Figure 3).

This study provides information on potential use of dorsal spines in determining age and growth parameters for the roosterfish, a valuable coastal resource of the eastern Pacific. Because previous work identified difficulties in aging roosterfish beyond 1yr (66 cm FL) using otoliths, this study examined the first five dorsal spines to assess the presence



**FIGURE 3.**— Linear regression (straight line) between the fork length and the number of growth marks derived from counting in cross-sections at the section level of 200% of the fourth dorsal fin spine of the roosterfish (*Nematistius pectoralis*) landed by the sport fleet of Cabo San Lucas, B.C.S in the period 2010-2012.

of putative growth marks and their potential in future aging efforts. From the specimens examined, it was determined that the fourth dorsal spine provides clearly legible growth marks that align with previous growth hypotheses (Ortega-Garcia et al. 2017). Although additional field validation is needed to determine whether dorsal fin growth marks can be used to accurately estimate roosterfish age and growth parameters, this work provides the initial basis from which future ageing studies can be conducted.

Although it was not possible to obtain samples from individuals outside of the typical range of fish landed in sport fishing operations that occur along Southern Baja California, the size range did encompass and surpass the sizes of individuals for which ageing was not possible ( $> 66$  cm FL) for previous roosterfish growth estimates (Ortega-Garcia et al. 2017). Most of fish sampled ranged from 50-90 cm FL because roosterfish under 40cm are rarely landed in the sport fishery and individuals in excess of 100cm FL are considered “trophy fish” and typically released following capture. Despite the limited size range of individuals sampled in this work, it was possible to identify consistent readings from potentially valuable hard structures for use in future ageing work.

In this study, the thickness of the roosterfish dorsal spine section that yielded the optimal platform for observing putative growth marks was 0.45 mm. Similarly, optimal thickness for ageing blue marlin (*Makaira nigricans*) was identified to be 0.45 mm (Jakes-Cota 2008) and 0.6 mm for sailfish (*Istiophorus platypterus*, Ramírez-Pérez 2005). Optimal section

thickness has been shown to vary from one species to another, as dorsal spine morphology varies greatly between various groups of fishes. In the yellowfin tuna (*Thunnus albacares*) and little thunny (*Euthynnus alletteratus*), the most suitable thickness proposed for counting growth marks ranges from 0.75 mm to 1 mm (Lessa and Duarte-Neto 2004; Alcaraz-García 2012), while swordfish (*Xiphias gladius*) has been shown to have an optimal thickness that ranges between 1 mm to 1.5 mm (Chong and Aguayo 2009).

For several species of large pelagic fish, fin spines have been shown to be the most suitable structure for determining age (Kopf et al. 2010). Spines are more suitable for non-lethal examination and processing relative to other hard structures, such as otoliths and vertebrae (Sun et al. 2002; Kopf et al. 2010). One of the basic assumptions in age determination is the growth proportionality between the hard structure used and fish size (Bagenal 1974). This study found the strongest linear relationship between fish FL and the diameter of the fourth dorsal fin spine, relative to other dorsal spines.

The spines used for counting growth marks by species, since the growth of bones shows specific sensitivity to internal (e.g., physiological and pathological) and external (e.g., climatic) factors (Panfili et al. 2002). In several species, such as tuna (yellowfin tuna and little thunny), aging analyses have focused on the use of the first dorsal fin spine (Lessa and Duarte-Neto 2004; Alcaraz-García 2012); while for swordfish, the second dorsal fin spine (Chong and Aguayo 2009); and in blue marlin and sailfish, the fourth spine (Ramírez-Pérez 2005; Jakes-Cota 2008).

The 200% section location was found to be the most suitable for the observation and counting of putative growth marks. At this location the marks are clearly visible, in contrast with other section levels, hence increasing the possibility of counting and measuring them. The selection of the fourth dorsal fin spine and the 200% section level are consistent with the criteria of greatest legibility of growth marks (Panfili et al. 2002) and growth proportionality with fish length (Hill et al. 1989).

Few previous studies have evaluated which spine and section level are most suitable for the observation and counting of growth marks. The importance of standardizing age determination methods when using fin spines has been emphasized by Kopf et al. (2010), who recommend that after selecting the most appropriate spine to estimate age, at least some form of standardization should be applied, so cross-sections are obtained from the same level using consistent criteria. This type of analysis can be used to develop a standardized methodology for the estimation of age in roosterfish, so that future studies on this species can be comparable.

When using the fourth spine, the putative growth marks examined in this study were clearly visible and legible in nearly all cases (93%), with good agreement between individual readers ( $CV=9.67\%$ ). There is no *a-priori*  $CV$  value that can be used for reference because it can be influenced by factors other than the reader, including the fish species and the nature of the hard structure (Campana 2001). In studies of shark age determination, which were based on counting growth marks in the vertebrae, it is common to find  $CV$  values higher than 10% (Campana 2001). In large pelagic fish,  $CV$  values between 10 and 15% are common (DeMartini et al. 2007), while for fish species of moderate longevity some authors suggest that a 5%  $CV$  may serve as a reference point (Campana 2001). The  $CV$  calculated in this study suggests relatively high precision in the counts performed independently by the readers and confirms that the fourth dorsal fin spine may offer future studies an opportunity to accurately determine roosterfish age.



Although field validation is necessary for accurately determining the age of roosterfish, this work was compared to previous aging hypotheses for reference (Ortega-Garcia et al. 2017). Ortega-Garcia et al. (2017) found that otoliths were not useful for accurately ageing fish over 66 cm FL or ~1-year-old, as daily ring differentiation decreased with increasing size. Roosterfish with one growth mark on dorsal spines ranged in size from 43-92 cm FL, a size range spanning the mean size (66 cm FL) of age-1 roosterfish estimated from daily otolith ring counts (Ortega-Garcia et al. 2017). The wide size range of fish with one dorsal fin growth mark was likely due to the potential inclusion of individuals that may be slightly older than one year and also the intermittent sampling protocol used in this work. Although we acknowledge the need for future validation and the inclusion of a larger size range of individuals, these data support the use of the fourth dorsal spine in future aging work for this species.

In general, opaque bands are wider than translucent bands, and as the number of marks in a section increases, the width of each band decreases (Jakes-Cota 2008). A complete growth mark consists of a broad opaque band (rapid growth) followed by a narrow translucent band (slow growth) when viewed under transmitting light (Fablet 2006); the presence and characteristics of such marks (opaque and translucent) were observed in all sections of rooster fish spines. The size, shape and clarity of marks can vary between individual fish, populations, and species, as well as between different methods of preparation of the hard structures (Fablet 2006).

The interpretation of growth marks to determine age is not straightforward, since it can be misled by the presence of false marks and the vascularization of the nucleus of fin spines (Kopf et al. 2010). False growth marks have the potential to be an important source of error in age determination studies. False growth marks have been described as partial segments that do not extend around the sections of fin spines (Speare 2003). False growth marks are sometimes, but not always, thinner and less clear than true marks. Although false growth marks were occasionally found in cross-sections of fourth dorsal fin spine in the roosterfish, these were easily detected because they were very diffuse and did not form a complete ring around the focus of the cross-sections of the spine.

The vascularization of the nucleus of fin spines is known as bone remodeling, a process that has been reported for different fish species (Panfili et al. 2002). Vascularization can lead to underestimating age and overestimating growth because it tends to obscure the first growth marks. Vascularization occurs to some extent in all fin spines, and the vascularized proportion increases directly with fish length (Franks et al. 2000; Drew et al. 2006). In the roosterfish, it was found that the vascularized area is small and does not obscure the first growth marks; therefore, it is not a factor that likely influenced the counting of said marks in this study.

The correlation between the number of growth marks and fork length for roosterfish in this study was high and supports the findings presented in previous studies on this species (Ortega-Garcia et al. 2017). The number of growth marks increased with length for all individuals examined, further suggesting its potential use as an age estimation tool in future studies. The accurate estimation of age and growth in the roosterfish will largely depend on the successful validation of the periodicity of formation of growth marks on cross-sections of dorsal fin spines or other hard structures. The mark-recapture of chemically-tagged (i.e., oxytetracycline) wild fish is one of the best methods that can be used for such validation studies. Nonetheless, this work provides the necessary foundation for future testing of age and growth hypotheses for the roosterfish.

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## LITERATURE CITED

- ALCARAZ-GARCÍA, T. 2012. Edad, crecimiento y mortalidad natural del bonito *Euthynnus alletteratus* (Rafinesque, 1810) en el suroeste del Golfo de México. M. S. Thesis, Universidad Veracruzana, Boca del Río, Veracruz, México.
- BAGENAL, T. B. 1974. Ageing of fish: Proceedings of an international symposium on the ageing of fish held at University of Reading, 9-20 July 1973. Unwin Brothers, Old Woking, England.
- BEAMISH, R. J., AND D. A. FOURNIER. 1981. A method for comparing the precision of a set of age determinations. Canadian Journal of Fisheries and Aquatic Sciences 38:982-983.
- CAILLIET, G. M., W. D. SMITH, H. F. MOLLET, AND K. J. GOLDMAN. 2006. Age and growth studies of chondrichthyan fishes: the need for consistency in terminology, verification, validation, and growth function fitting. Environmental Biology of Fishes 77:211-228.
- CAMPANA, S. E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. Journal of Fish Biology 59:197-243.
- CHANG, W. Y. B. 1982. A statistical method for evaluating the reproducibility of age determination. Canadian Journal of Fisheries and Aquatic Sciences 39:1208-1210.
- CHONG, J., AND M. AGUAYO. 2009. Edad y crecimiento del pez espada (*Xiphias gladius* Linnaeus, 1758) en el Pacífico suroriental (Diciembre 1994 - Septiembre 1996). Latin American Journal of Aquatic Research 37:1-15.
- DANIEL, W. W. 2012. Bioestadística: Base para el análisis de las ciencias de la salud. Limusa Wiley, México.
- DEMARTINI, E. E., J. H. UCHIYAMA, R. L. HUMPHREYS, J. D. SAMPAGA AND H. A. WILLIAMS. 2007. Age and growth of swordfish (*Xiphias gladius*) caught by the Hawaii-based pelagic longline fishery. Fishery Bulletin 105:356-367.
- DITTON, R. B., S. R. GRIMES, AND L. D. FINKELSTEIN. 1996. A social and economic study of the recreational billfish fishery in the southern Baja Area of Mexico. Texas A&M University, Fort Lauderdale, USA.
- DREW, K., D. J. DIE, AND F. AROCHA. 2006. Understanding vascularization in fin spines of white marlin (*Tetrapturus albidus*). Bulletin of Marine Science 79:847-852.
- FABLET, R. 2006. Semi-local extraction of ring structures in images of biological hard tissues: Application to the Bayesian interpretation of fish otoliths for age and growth estimation. Canadian Journal of Fisheries and Aquatic Sciences 63:1414-1428.
- FRANKS, J. S., N. J. BROWN-PETERSON, M. S. GRIGGS, N. M. GARBER, J. R. WARREN, AND K. M. LARSEN. 2000. Potential of the first dorsal fin spine for estimating the age of wahoo, *Acanthocybium solandri*, from the Northern Gulf of Mexico, with com-

- ments on specimens from Bimini, Bahamas. Proceedings of the Gulf and Caribbean Fisheries Institute 51:428-440.
- GOLDMAN, K. J. 2005. Age and growth of elasmobranch fishes. Pages 76-102 in J. A. Musick and R. Bonfil, editors. Management techniques for elasmobranch fisheries. FAO Fisheries Technical Paper 474, Rome, Italy.
- HILL, K. T., G. M. CAILLIET, AND R. L. RADTKE. 1989. A comparative analysis of growth zones in four calcified structures of Pacific blue marlin, *Makaira nigricans*. Fishery Bulletin 87:829-843.
- JAKES-COTA, U. 2008. Edad y crecimiento del marlin azul *Makaira nigricans*, desembarcado en Cabo San Lucas, B.C.S., México. M. S. Thesis, Centro Interdisciplinario de Ciencias Marinas – Instituto Politécnico Nacional, La Paz, Baja California Sur, México.
- KOPF, R. K., K. DREW, AND R. L. HUMPHREYS JR. 2010. Age estimation of billfishes (*Kajikia* spp.) using fin spine cross-sections: the need for an international code of practice. Aquatic Living Resources 23:13-23.
- KOPF, R. K., P. S. DAVIE, D. BROMHEAD, AND J. G. PEPPERELL. 2011. Age and growth of striped marlin (*Kajikia audax*) in the southwest Pacific Ocean. ICES Journal of Marine Science 68: 1884–1895.
- LESSA, R., AND P. DUARTE-NETO. 2004. Age and growth of yellowfin tuna (*Thunnus albacares*) in the western equatorial Atlantic, using dorsal fin spines. Fisheries Research 69:157-170.
- LOVE, M. S., C. W. MECKLENBURG, T. A. MECKLENBURG, AND L. K. THORSTEINSON. 2005. Resource inventory of marine and estuarine fishes of the West Coast and Alaska: A checklist of North Pacific and Arctic Ocean species from Baja California to the Alaska-Yukon Border. U.S. Department of the Interior, U.S. Geological Survey, Biological Resources Division, Seattle, USA.
- NIEM, V. H. 1995. Nematistiidae. Page 1322 in W. Fischer, F. Krupp, W. Schneider, C. Sommer, K. E. Carpenter and V. H. Niem, editors. Guía FAO para la identificación de especies para los fines de la pesca. Pacífico centro-oriental. Volumen III. Vertebrados-Parte 2. FAO, Rome, Italy.
- ORTEGA-GARCIA, S., C. SEPULVEDA, S. AALBERS, U. JAKES-COTA, AND R. RODRIGUEZ-SÁNCHEZ. 2017. Age, growth, and length-weight relationship of roosterfish (*Nematistius pectoralis*) in the eastern Pacific Ocean. Fishery Bulletin 115:117-124.
- PANFILI, J., H. PONTUAL, H. TROADER, AND P. J. WRIGHT. 2002. Manual of fish sclerochronology. Ifremer-IRD coedition, Brest, France.
- RAMÍREZ-PÉREZ, J. S. 2005. Edad, crecimiento y mortalidad del pez vela *Istiophorus platypterus* (Shaw y Nodder, 1791) de la costa sur de Sinaloa, México. M. S. Thesis, Centro Interdisciplinario de Ciencias Marinas – Instituto Politécnico Nacional, La Paz, Baja California Sur, México.
- ROBERTSON, R., AND G. ALLEN. 2002. Shorefishes of the Tropical Eastern Pacific: An Information System. CD-ROM. Smithsonian Tropical Research Institute, Balboa, Panama.
- RODRÍGUEZ-ROMERO, J., G. MORENO-SÁNCHEZ, A. ABITIA-CÁRDENAS AND D. PALACIOS-SALGADO. 2009. Trophic spectrum of the juvenile roosterfish, *Nematistius pectoralis* Gill, 1862 (Perciformes: Nematistiidae), in Almejas Bay, Baja California Sur, México. Revista de Biología Marina y Oceanografía 44:803-807.

- ROSENBLATT, R. H. AND M. A. BELL. 1976. Osteology and relationships of the roosterfish, *Nematistius pectoralis* Gill. Natural History Museum of Los Angeles County Contributions in Science 279:1-23.
- SEPULVEDA, C., S. AALBERS, AND D. BERNAL. 2015. Post-release survival and movements patterns of roosterfish (*Nematistius pectoralis*) off the Central American coastline. Latin American Journal of Aquatic Research 43:162-175.
- SOSA-NISHIZAKI, O. 1998. Historical review of the billfish management in the Mexican Pacific. Ciencias Marinas 24:95-111.
- SPEARE, P. 2003. Age and growth of black marlin, *Makaira indica*, in east coast Australian waters. Marine and Freshwater Research 54(4): 307-14.
- SOUTHWICK, R., R. NELSON, AND J. A. AREAN. 2010. The economic contributions of anglers to the Los Cabos economy: quantifying value in a sustainable fishery. Interdisciplinary Environmental Review 11:69-89.
- STEVENSON, D. K., AND S. E. CAMPANA. 1992. Otolith microstructure examination and analysis. Canadian Special Publication of Fisheries and Aquatic Sciences 117:126.
- SUN, C. L., S. P. WANG, AND S. Z. YEH. 2002. Age and growth of the swordfish (*Xiphias gladius* L.) in the waters around Taiwan determined from anal-fin rays. Fishery Bulletin 100:822-835.

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## Primary and secondary nursery areas for leopard and brown smoothhound sharks in San Francisco Bay, California

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Both leopard (*Triakis semifasciata*) and brown smoothhound sharks (*Mustelus henlei*) are inshore species endemic to the eastern Pacific ranging from the Gulf of California to Oregon, with brown smoothhound sharks also found off Ecuador and Peru. Leopard sharks are viviparous without a yolk sac placenta, while brown smoothhound sharks are viviparous with a yolk sac placenta. Both species give birth in the spring to early summer with leopard sharks producing 7 to 36 young about 20 centimeters total length (cm TL), while brown smoothhound sharks give birth to up to 10 young from 19 to 30 cm TL in the spring (Ebert 2003).

In U. S. waters, parturition for both species takes place in several California bays including Humboldt, Tomales, San Francisco and several locations south (Smith and Abramson 1990, Ebert 2003, Ebert and Ebert 2005, Smith 2005, Carlisle et al. 2007, Lewallen et al. 2007, Carlisle and Starr 2009, Russo 2015). These bays are generally composed of a variety of habitats including deepwater channels, shallow mudflats, eelgrass meadows and shoreline marsh sloughs and channels. Elkhorn Slough (Monterey Bay) is a long, winding channel surrounded by marsh and smaller drainages where leopard sharks, but not brown smoothhound sharks, are known to give birth (Ackerman 1971).

Primary nurseries have been defined as places where parturition occurs and neonates in the range of length-at-birth for that species are found and spend the earliest parts of their lives (Bass 1978, Merson and Pratt Jr. 2007). Similarly, secondary nurseries are larger areas where slightly older, but not yet mature, sharks forage and grow, following departure from primary nursery grounds. These definitions and concepts were applied to the determination of physical boundaries of nurseries in this study. Though it varies by species and locale, individual sharks may remain in their primary nurseries from one to three years or return to their natal nurseries seasonally up to nine years after parturition (Springer 1967, Talent 1985, Ebert 1989, Rechisky and Wetherbee 2003, Ebert and Ebert 2005, Heithaus 2007, Heupel et al. 2007, McCandless et al. 2007a, b, Nosal et al. 2014).

Identification of specific nursery habitat for elasmobranchs has been defined as a key component for overall species management (McCandless et al. 2007a, Hussey et al. 2009, Hughes et al. 2014). Generally, San Francisco Bay has long been known among scientists as a “nursery” for leopard sharks, brown smoothhound sharks, broadnose sevengill sharks (*Notorhynchus cepedianus*), and bat rays (*Myliobatis californicus*) (Ebert 1989, Ebert 2003, Russo 2015).

Given the variety and extent of habitats within the bay, however, details of specific parturition sites are lacking for most species. The purpose of this phase of the overall study (1970 to 2001) was to determine primary and secondary nursery habitats for leopard and brown smoothhound sharks within South San Francisco Bay, adding new knowledge to the biology of both species.

Fishing trips were conducted monthly, year-round, weather and equipment availability permitting, at pre-chosen locations to spread coverage and to answer specific data gaps, primarily between coordinates 37° 48' N, 122° 22' W (San Francisco Bay Bridge) and 37° 27' N, 122° 01' W at the entrance of Alviso Slough at the south end of San Francisco Bay (Figures 1, 2). Long-lines, rod and reel, and otter trawls were employed from 1970 to 1996; thereafter rod and reel was used exclusively until 2001. On several occasions, catch events (one date, location, and gear type) occurred in the approximate locations as previously fished as determined by detailed nautical charts, depth, and triangulation. Sampling methods for the overall study included 146 catch events using two 6 mm thick, 152 m long nylon long-lines; 36 catch events using rod and reel (3-5 h, 3-4 rods); and 42 events using a 1.3 cm mesh, 4.8 m otter trawl (7-15 min tow time).

Rod and reel and trawl catch events produced neonates and young-of-the-year (YOY) that were not captured by long-lines due to hook and mesh size selectivity. While long-line efforts were scattered throughout the central part of the South Bay as well as south of the Dumbarton Bridge, otter trawl events were generally restricted to the shallows (<5 m) of the East Bay shoreline and the larger Coyote Creek, the Guadalupe and Alviso Sloughs and near the entrances to Newark and Mowry Slough (Figure 2). Eelgrass meadow locations were largely unknown at the time and were discovered only as a result of initial trawling. Trawling in the narrow channels of Newark, Mowry and Mud Sloughs was determined to be too destructive and dangerous and thus avoided. Although some specimens were sacrificed for diet and reproductive data (Russo 1975, Russo 2018), the over-arching paradigm was “catch and release.”

Neonate leopard sharks were defined as specimens presumably within a month or so of parturition, as evidenced by unhealed and visible natal scars located ventrally between the pectoral fins and measuring about 4 mm long (Brewster-Geisz and Miller 2000, Lucifora et al. 2005, Duncan and Holland 2006, Hussey et al. 2010, Aca and Schmidt 2011) and measuring 16 to <25 cm TL. Neonates born within ten days of capture appeared gaunt with slightly concave bellies, as they fed on residual yolk and energy reserves stored in their livers (Francis and Stevens 2000, Mollet et al. 2000) prior to feeding on wild prey. YOY leopard sharks measured >25 to 50 cm TL, while juveniles measured from >50 to 80 cm TL and adult males were >86 cm TL with females >105 cm TL in this overall study (R. Russo unpublished data). Neonate brown smoothhound sharks were defined as specimens born within a month or so and showing unhealed natal scars and measuring 17 to <30.4 cm TL (in this study), while YOY were generally <40 cm TL and adults were >51 cm TL (Yudin and Cailliet 1990, Ebert 2003, Perez-Jimenez and Sosa-Nishizaki 2008). As a means

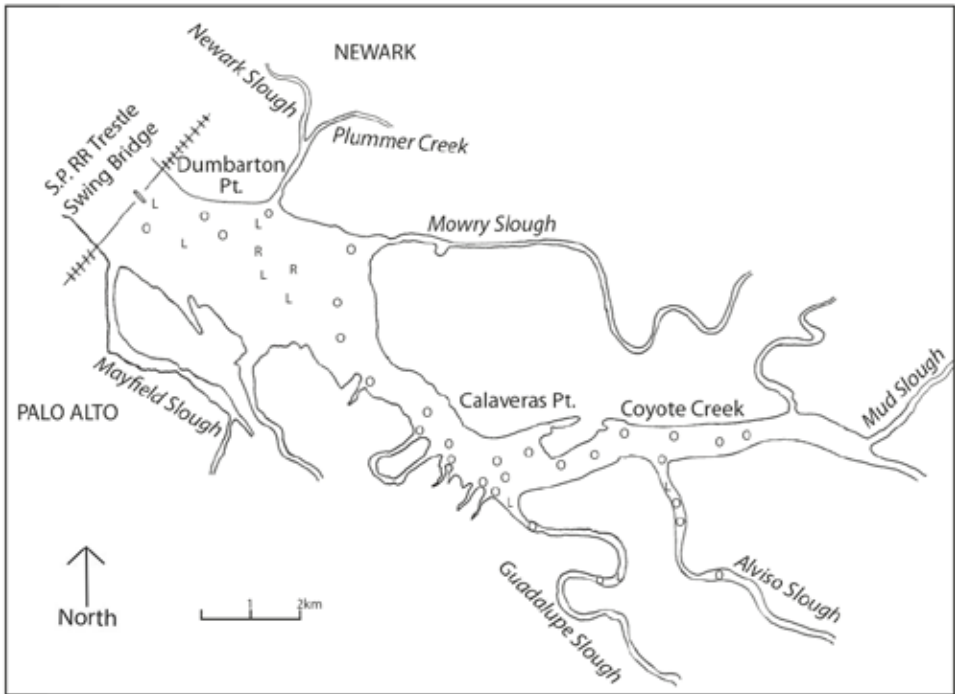


**FIGURE 1.**—Map of San Francisco Bay study area showing the locations of 224 sampling events (1970-2001) by gear type with long-lines (L), otter trawl (O), and rod and reel (R). While all otter trawl ( $n=42$ ) locations are indicated here and in Figure 2, long-line and rod and reel symbols represent one or more catch events of that gear type in that immediate vicinity in many instances. Map courtesy of the East Bay Regional Park District (EBRPD)

of assigning size/life stage categories, size ranges are relative and not finite in that actual individual growth can be influenced by metabolism, food availability, competition, health parasites, and other factors, as we see with most animals.

The mean total length (MTL) was calculated only for the 328 specimens captured in a commercial shrimp trawl. For all specimens captured in this study, careful attention was paid to the size and the condition of each neonate and its natal scar, and YOY such that capture locations could be characterized with regard to their degree of utilization as primary and secondary nursery grounds (Adams and Paperno 2007).

Across the period of the study, 4,121 elasmobranchs were captured, including 2,478 (60.1%) leopard sharks, of which 696 were neonate and YOY specimens from South San Francisco Bay. Additionally, there were 842 (20.4%) brown smoothhound sharks including



**FIGURE 2.**—An expanded view as existed in 1985 of the southern end of South San Francisco Bay, south of the Dumbarton Bridge and the Railroad Trestle where leopard shark neonates and YOY were captured mostly by trawl. Map courtesy of the EBRPD.

234 neonates and YOY; 316 (7.7%) spiny dogfish (*Squalus suckleyi*) adults and juveniles; 107 (2.6%) juvenile tope sharks (*Galeorhinus galeus*); 126 (3.1%) broadnose sevengill sharks of all age classes; 239 (5.8%) bat rays of all age classes; and 13 (0.3%) adult big skate (*Raja binoculata*). On 23 May 1979 while on board a commercial shrimp trawler in the Alviso Slough area (Russo 2015), an additional 328 recently born leopard shark neonates ranging from 17 to 21 cm (19.4 cm MTL) were superficially examined (length, sex, general condition) as bycatch.

Overall, leopard shark neonates ranged in size from 16.5 to 25 cm TL with the 16.5 cm neonate caught by otter trawl on 21 May 1982 being the smallest reported thus far in the literature. Brown smoothhound shark neonates ranged in size from 17.5 to 30.4 cm TL, in contrast to the literature.

The use of otter trawl and rod and reel throughout the South Bay (Table 1) resulted in captures of neonate ( $n = 378$ ) and YOY ( $n = 318$ ) leopard sharks at the entrances to Mowry and Newark Sloughs (Figure 2), within Coyote Creek and Guadalupe and Alviso Sloughs and around the edges of Arrowhead Marsh in the East Bay (Figure 3) and, to a lesser extent, in near-shore eelgrass meadows.

Results of the sampling (Table 1) indicate that brown smoothhound neonates and YOY strongly preferred eelgrass habitat, while leopard shark neonates and YOY primarily utilized marsh sloughs and channels, and to a lesser extent eelgrass meadows. Both tended to move



**TABLE 1.**—Catch locations (1970–2001) for 3,320 sharks including 2,478 leopard sharks and 842 brown smoothhound sharks by approximate age classes as related to habitat of capture with the number of sharks (N) and the percentage (%) for that growth phase. Each growth phase per species is also calculated for Total percentage (%) compared to other growth phases. Size/life stage categories are as found in this study and from the literature.

Life Stage	Open Bay >5m to <11 m N / %	Eel Grass Meadows <3m N / %	Marsh Sloughs N / %	Total N / %
<u>Leopard Shark</u>				
Neonate	-	81 (21.4)	297 (78.6)	378 (15.2)
YOY*	18 (5.6)	94 (29.6)	206 (64.8)	318 (12.8)
Juvenile	983 (94.6)	21 (2.0)	35 (3.4)	1,039 (41.9)
Adult	634 (85.3)	36 (4.9)	73 (9.8)	743 (30.0)
<u>Brown Smoothhound Shark</u>				
Neonate	1 (0.7)	132 (99.3)	-	133 (15.8)
YOY*	14 (13.9)	87 (86.1)	-	101 (12.0)
Juvenile	188 (87.8)	26 (12.2)	-	214 (25.4)
Adult	367 (93.2)	27 (6.8)	-	394 (46.8)

\*YOY = young-of-the-year

out into open Bay as older juveniles. Of the 378 neonates captured by trawl and rod and reel, 297 (78.6%) were captured in sloughs and channels, while 81 (21.4%) were captured in eelgrass (Table 1). Similarly, of the 318 YOY leopard sharks captured, 206 (64.8%) were captured in sloughs and channels, while 94 (29.6%) were captured in eelgrass. A small, size-related aggregation of YOY ( $n = 18$ , 5.6%) leopard sharks all within 15.2 cm of each other (R. Russo, unpublished data) were captured by long-line in open water between 5 to 7 m deep. While most of the juvenile leopard sharks ( $n = 983$ , 94.6%) were captured in deep water <10 m by long-line, a relatively small number were captured in eelgrass ( $n = 21$ , 2.0%) or in marsh sloughs and channels ( $n = 35$ , 3.4%) by other methods. Similarly, most adult leopard sharks ( $n = 634$ , 85.3%) were captured by long-line in deep water >7 m, while 36 (4.9%) were caught by trawl and rod and reel in eelgrass and 73 (9.8%) were captured by all methods in marsh sloughs and channels primarily south of the Dumbarton Bridge.

The captures of juvenile and adult leopard sharks in eelgrass and marsh sloughs and channels usually coincided with parturition and mating period of April through June. Leopard shark neonates were captured along the East Bay shoreline north of the San Mateo Bridge in April and May, but were not captured south of the Dumbarton Bridge until the first week of June. Sexually mature leopard shark females ( $n = 19$ ) captured by long-line at the entrance to Mowry Slough were examined 21 June 1971 with 13 (68.4%) recently impregnated having uterine embryos. The remaining six (31.6%) had experienced parturition, but had empty uterine canals and had not yet been re-impregnated by this date.

Over 99% of brown smoothhound shark neonates ( $n = 132$ ) were captured in near-shore eelgrass meadows (Table 1), with one rare exception of a 30.4 cm TL neonate being



**FIGURE 3.**—Aerial view of Arrowhead Marsh (foreground) in 1990, which is part of the Martin Luther King Jr. Memorial Shoreline Regional Park in San Leandro Bay and east of the Oakland Airport with Bay Farm Island at the water's edge, the outer Bay and San Francisco in the background. Photo courtesy of Steve Bobzien.

captured in water 10.7 m deep, which was likely the result of an accidental, premature birth. Of the 101 YOY captured, 87 (86.1%) were found in eelgrass meadows with only 14 (13.9%) found in deeper water (<7 m deep) immediately adjoining eelgrass meadows. All neonate and YOY brown smoothhound sharks were captured by trawl or rod and reel with most neonates captured in May. The majority of juvenile brown smoothhounds ( $n = 188$ , 87.8%) and adults ( $n = 367$ , 93.2%) were captured by long-line in deep water <11 m, while nearly an equal number of juveniles ( $n = 26$ , 12.2%) and adults ( $n = 27$ , 6.8%) were captured by trawl or rod and reel in eelgrass meadows generally in May and June. No brown smoothhound sharks were captured south of the Dumbarton Bridge nor in marsh sloughs or channels. Thus eelgrass meadows north of the bridge were found to be the most important primary nursery habitat for neonate and YOY brown smoothhounds.

Trawling helped define eelgrass meadows along the East Bay shoreline that occupy a relatively narrow zone usually within a few hundred meters of shore, ranging from 10 m to 30 m in width given slope, depth, and light penetration sufficient to sustain the eelgrass, but generally in 2.5 to 3.5 m of water. In South San Francisco Bay, the eelgrass meadows along the eastern shoreline are rarely if ever exposed at low tide, making these meadows suitable for brown smoothhound shark and some leopard shark parturition, but at the same time exposing them to avian predators at low tide (Russo 2015).

Non-eelgrass meadows or open Bay secondary nursery habitat was more difficult to quantify as the topography of the South Bay from the East Bay shoreline to the San Francisco Peninsula is a gently tapering mud-covered slope that gradually becomes deeper to about 20 m near the Peninsula shoreline. Therefore, no clear demarcation lines or shear drop-offs

help define a secondary nursery boundary. Evidence of secondary nursery site activity can be deduced only from species composition and size combined with catch-event locations.

Based on analysis of trawl and rod and reel data collected in this study, past observations of avian predators capturing neonate and YOY leopard sharks in marsh sloughs and channels (Russo 2015), eyewitness reports of leopard sharks mating in marsh sloughs and channels (T. Laine, personal communication, Mowry Slough, 23 June 1978; L. Fancher, personal communication, Newark Slough, 29 June 1981) and a report of a kayaker in Newark Slough seeing “baby” leopard sharks (L. Jones, personal communication, 18 June 1986; R. Russo unpublished data), the primary nursery sites for leopard sharks are salt marsh sloughs and channels in the East Bay and extreme southern end of the Bay, especially those that retain water at low tide, as well as adjoining eelgrass meadows. Evidence also indicates a large number of neonates concentrated near Coyote Creek and Alviso and Guadalupe Sloughs south of the Dumbarton Bridge (Figures 1, 2).

Collection data also indicate that the primary nursery sites for brown smoothhound sharks are limited to near-shore eelgrass meadows of the East Bay, largely between the Oakland Airport and the San Mateo Bridge, but possible elsewhere along the western shoreline where eelgrass may grow. Because brown smoothhound shark neonates were not captured south of the Dumbarton Bridge or observed among the commercial shrimp trawls of May 1979 (Russo 2015) in the Alviso Slough area, the neonates of this species appear to have a more restricted primary nursery area than leopard sharks, at least in the East Bay.

The 20-hectare Arrowhead Marsh (Figure 3) in San Leandro Bay along the northeastern shoreline of South San Francisco Bay under the management of the East Bay Regional Park District is a significant primary nursery for leopard sharks north of the Dumbarton Bridge, as evidenced by two May trawl events capturing 47 neonates estimated to be <10 d old given their physical condition.

The secondary nursery sites for YOY of both species appear to be a large portion of the South Bay in water <8 m deep with some overlap. Leopard shark YOY appear to wander more from primary nursery sites than do brown smoothhound shark YOY who appear to stay within a few km of eelgrass meadows based on where they were captured (Table 1). The deep-water channel is from 15 to 20 m deep and generally within 1 km of the West Bay shoreline. This deep-water habitat is dangerous for smaller sharks as sevengill sharks 2 to 3 m long patrol the area and have been known to attack sharks caught on long-lines (Russo 2015). Only juveniles and adults of both species were caught in this environment.

Since tag studies indicate leopard sharks are largely residential in San Francisco Bay (Smith et al. 2003) and considering San Francisco Bay is the largest estuarine environment in the range of this species (Conomos et al. 1985), this Bay may well represent the largest primary and secondary nurseries for leopard sharks and perhaps brown smoothhound sharks throughout their range. There are an estimated 20,234 hectares of salt marsh habitat in San Francisco Bay (M. Salomon, San Francisco Estuary Institute, personal communication 13 March 2018). While not all marshland sloughs and channels and eelgrass meadows may function in this manner, there are some that are worthy of evaluation. The western shoreline areas adjoining Palo Alto, Redwood City, and San Mateo may also serve as primary nursery sites for these two species, but must be studied to confirm this usage (Heupel et al. 2007). Similarly, the marshland and eelgrass meadows of the North Bay near Tiburon and the Napa and Petaluma Rivers along with the vast marshlands west of Mare Island may have similar value.

Finally, 17 years have passed since this research, and physical changes in the available marshes and eelgrass meadows, especially in the southern extreme of South San Francisco Bay, may have occurred due to human impacts or environmental changes, compromising their value. The potential for primary nursery grounds for both shark species may have degraded or may be far more extensive than described herein and should be explored to develop a much more comprehensive understanding. The marsh sloughs and channels and shallow-water eelgrass meadows of San Francisco Bay should be considered ever more important in light of these findings in the overall management of these sharks.

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### LITERATURE CITED

- ACA, E. Q., AND J. V. SCHMIDT. 2011. Revised size limit for viability in the wild: neonatal and young of the year whale sharks identified in the Philippines. *Asia Life Sciences* 20(2):361-367.
- ACKERMAN, L. T. 1971. Contributions to the biology of leopard sharks, *Triakis semifasciata* (Girard) in Elkhorn Slough, Monterey, California. M.A. Thesis, Sacramento State College, Sacramento, California. USA.
- ADAMS, D. H., AND R. PAPERNO. 2007. Preliminary assessment of a near-shore nursery ground for the scalloped hammerhead off the Atlantic Coast of Florida. *American Fisheries Society Symposium* 50:165-174.
- BASS, A. J. 1978. Problems in the studies of sharks in the southwest Indian Ocean. Pages 545-594 in E. S. Hodgson and R. F. Mathewson, editors. *Sensory biology of sharks, skates, and rays*. Department of the Navy, Office of Naval Research, Arlington, Virginia. USA.
- BREWSTER-GEISZ, K. K., AND T. J. MILLER. 2000. Management of the sandbar shark, *Carcharhinus plumbeus*: implications of a stage-based model. *Fishery Bulletin* 98:236-249.
- CARLISLE, A., A. KING, G. M. CAILLIET, AND J. S. BRENNAN. 2007. Long-term trends in catch composition from elasmobranch derbies in Elkhorn Slough, California. *Marine Fisheries Review*, NOAA 69:25-45.
- CARLISLE, A. B., AND R. M. STARR. 2009. Habitat use, residency, and seasonal distribution of female leopard sharks *Triakis semifasciata* in Elkhorn Slough, California. *Marine Ecology Progress Series* 380:213-228.
- CONOMOS, T. J., R. E. SMITH, AND J. W. GARTNER. 1985. Environmental setting of San Francisco Bay. *Hydrobiologia* 129:1-12.
- DUNCAN, K. M., AND K. N. HOLLAND. 2006. Habitat use, growth rates and dispersal patterns of juvenile scalloped hammerhead sharks *Sphyrna lewini* in a nursery habitat. *Marine Ecology Progress Series* 312:211-221.

- EBERT, D. A. 1989. Life history of the Sevengill shark, *Notorynchus cepedianus* Peron 1807, in two northern California bays. *California Fish and Game* 75:102-112.
- EBERT, D. A. 2003. Sharks, rays, and chimaeras of California. *California Natural History Guide* 71. University of California Press. Berkeley, California. USA.
- EBERT, D. A., AND T. B. EBERT. 2005. Reproduction, diet, and habitat use of leopard sharks, *Triakis semifasciata* (Girard), in Humboldt Bay, California, USA. *Marine and Freshwater Research* 56:1089-1098.
- FRANCIS, M. P., AND J. D. STEVENS. 2000. Reproduction, embryonic development, and growth of the porbeagle shark, *Lamna nasus*, in the southwest Pacific Ocean. *Fishery Bulletin* 98:41-63.
- HEITHAUS, M. R. 2007. Nursery areas as essential shark habitats: a theoretical perspective. Pages 3-13 in McCandless, C. T., N. E. Kohler, and H. L. Pratt Jr. editors. *Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States*. American Fisheries Society Symposium 50:35-43.
- HEUPEL, M. R., J. K. CARLSON, AND C. A. SIMPFENDORFER. 2007. Shark nursery areas: concepts, definition, characterization and assumptions. *Marine Ecology Progress Series* 337:287-297.
- HUGHES, B. B., M. D. LEVEY, J. A. BROWN, M. C. FOUNTAIN, A. B. CARLISLE, S. Y. LITVIN, C. M. GREENE, W. N. HEADY, AND M. G. GLEASON. 2014. Nursery functions of U. S. west coast estuaries: the state of knowledge for juveniles of focal invertebrates and fish species. The Nature Conservancy, Arlington, Virginia. USA.
- HUSSEY, N. E., J. D. MCCARTHY, S. F. J. DUDLEY, AND B. Q. MANN. 2009. Nursery grounds, movement patterns and growth rates of dusky sharks *Carcharhinus obscurus*: a long-term tag and release study in South African waters. *Marine and Freshwater Research* 60:571-583.
- HUSSEY, N. E., S. P. WINTNER, S. F. DUDLEY, G. CLIFF, D. T. COCKS, AND M. A. MACNEIL. 2010. Maternal investment and size-specific reproductive output in carcharhinid sharks. *Journal of Animal Ecology* 79:184-193.
- LEWALLEN, E. A., T. W. ANDERSON, AND A. J. BOHONAK. 2007. Genetic structure of leopard shark (*Triakis semifasciata*) populations in California waters. *Marine Biology* 152:599-609.
- LUCIFORA, L. O., R. C. MENNI, AND A. H. ESCALANTE. 2005. Reproduction, abundance and feeding habits of broadnose sevengill shark *Notorynchus cepedianus* in north Patagonia, Argentina. *Marine Ecology Progress Series* 289:237-244.
- MCCANDLESS, C. T., N. E. KOHLER, AND H. L. PRATT, JR. 2007a. Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States. American Fisheries Society, Bethesda, Maryland, USA.
- MCCANDLESS, C. T., H. L. PRATT, JR., N. E. KOHLER, R. R. MERSON, AND C. W. RECKSIEK. 2007b. Distribution, localized abundance, movements, and migrations of juvenile sandbar sharks tagged in Delaware Bay. Pages 45-62 in C. T. McCandless, N. E. Kohler, and H. L. Pratt, Jr., editors. *Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States*. American Fisheries Society, Bethesda, Maryland, USA.
- MERSON, R. R., AND H. L. PRATT, JR. 2007. Sandbar shark nurseries in New Jersey and New York: evidence of northern pupping grounds along the United States East Coast. Pages 35-43 in McCandless, C. T., N. E. Kohler, and H. L. Pratt, Jr., edi-

- tors. Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States. American Fisheries Society, Bethesda, Maryland, USA.
- MOLLET, H. F., G. CLIFF, H. L. PRATT, JR., AND J. D. STEVENS. 2000. Reproductive biology of the female shortfin mako, *Isurus oxyrinchus*, Rafinesque 1810, with comments on the embryonic development of lamnoids. Fishery Bulletin 98:299-318.
- NOSAL, A. P., A. CAILLAT, E. K. KISFALUDY, M. A. ROYER, AND N. C. WEGNER. 2014. Aggregation behavior and seasonal philopatry in male and female leopard sharks *Triakis semifasciata* along the open coast of southern California, USA. Marine Ecology Progress Series 499:157-175.
- PEREZ-JIMENEZ, J. C., AND O. SOSA-NISHIZAKI. 2008. Reproductive biology of the brown smoothhound shark *Mustelus henlei*, in the northern Gulf of California, Mexico. Journal of Fish Biology 73:782-792.
- RECHISKY, E. L., AND B. M. WETHERBEE. 2003. Short-term movements of juvenile and neonate sandbar sharks, *Carcharhinus plumbeus*, on their nursery grounds in Delaware Bay. Environmental Biology of Fishes 68:113-128.
- RUSSO, R. A. 1975. Observations on the food habits of leopard sharks, *Triakis semifasciata* and brown smoothhounds, *Mustelus henlei*. California Fish and Game 61:68-81.
- RUSSO, R. A. 2015. Observations of predation and loss among leopard sharks and brown smoothhounds in San Francisco Bay, California. California Fish and Game 101:149-157.
- RUSSO, R. A. 2018. Prey of neonate leopard sharks in San Francisco Bay, California. California Fish and Game 104:173-179.
- SMITH, S. E., AND N. J. ABRAMSON. 1990. Leopard shark *Triakis semifasciata* distribution, mortality rate, yield, and stock replenishment estimates based on a tagging study in San Francisco Bay. Fishery Bulletin 88:371-381.
- SMITH, S. E., R. A. MITCHELL, AND D. FULLER. 2003. Age-validation of a leopard shark, *Triakis semifasciata*, recaptured after 20 years. Fishery Bulletin 101:194-198.
- SMITH, S. E. 2005. Leopard shark mating observed off La Jolla, California. California Fish and Game 91:128-135.
- SPRINGER, S. 1967. Social organization of shark populations. Pages 149-174 in P. Gilbert, R. F. Mathewson, and D. P. Rall, editors. Sharks, Skates, and Rays. Johns Hopkins Press: Baltimore, Maryland. USA.
- TALENT, L. G. 1985. The occurrence, seasonal distribution, and reproductive condition of elasmobranch fishes in Elkhorn Slough, California. California Fish and Game 71:210-219.
- YUDIN, K. G., AND G. M. CAILLIET. 1990. Age and growth of the gray smoothhound, *Mustelus californicus*, and the brown smoothhound, *Mustelus henlei*, sharks from Central California. Copeia 1:191-204.

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## LITERATURE CITED

- BLEICH, V. C., N. J. KOGUT, AND D. HAMILTON. 2011. Information for contributors to California Fish and Game. *California Fish and Game* 97:47-57.
- CSE (COUNCIL OF SCIENCE EDITORS). 2006. Scientific style and format: the CSE manual for authors, editors, and publishers. 7th edition. The Rockefeller University Press, New York, USA.

**Front.**—California Scorpionfish (*Scorpaena guttata*). Photo by Derek Stein, CDFW.


**Back.**—Leopard shark (*Triakis semifasciata*).  Brian Gratwicke.





Photo by Brian Gratwicke. 



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