California Fish and Game 104(4): 173-179; 2018

Prey of neonate leopard sharks in San Francisco Bay, California

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Key words: bay shrimp, elasmobranchs, jointworms, lugworms, marine pill bug, neonate, polychaete

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The leopard shark (*Triakis semifasciata*) is one of the most recognizable inshore elasmobranchs along the Pacific Coast from Oregon to the Gulf of Mexico. While several studies have focused on the diet of leopard sharks (Ackerman 1971, Russo 1975, Talent 1976, Webber and Cech Jr. 1998, Kao 2000, Webber 2003), most have examined juvenile to adult stage animals. Although fish eggs have been found in the stomachs of neonates from Humboldt Bay (Ebert and Ebert 2005), detailed information on the specific diet of neonate leopard sharks has been fragmentary at best, and not previously reported for San Francisco Bay.

A study designed to collect general biological data from elasmobranchs in San Francisco Bay, California was conducted from 1970 to 2001 on a monthly basis between the San Francisco Bay Bridge (37° 48' N, 122° 22' W) and the entrance to Alviso Slough in the south end of San Francisco Bay (37° 27' N, 122° 01' W). Methods included long-line (1.5 h sets), otter trawl (7-15 min runs), and rod and reel (3-5 h) at over 130 locations with many stations repeated. While each catch event had a data collection purpose, priorities changed over time as data gaps developed. In advance of gastric evacuation techniques (Webber and Cech Jr. 1998), data collection on dietary habits and reproductive condition involved internal examination of specimens. Although "catch and release" was the dominant paradigm, early stomach contents analysis of adults and juveniles (Russo 1975) reduced the need for further euthanization for that purpose in this study.

Otter trawl and rod and reel were used to capture 378 neonates and 318 young-of-the-year (YOY) for the primary purposes of identifying sex, size, location and condition. Trawl runs were restricted to shallow, near-shore eelgrass beds along the East Bay shoreline and the entrances to marsh channels such as Newark and Mowry Sloughs or inside major sloughs like Guadalupe and Alviso. Despite efforts to minimize impacts with short run times and avoidance of sensitive habitats, the volume of oyster shell or other materials in the trawl net was thought to have been responsible for neonate mortality of a cluster of specimens during two such trawls in May of 1982 (Arrowhead Marsh, San Leandro) and 1985 (Guadalupe Slough, Alviso), presenting an opportunity for a combined diet analysis of 19 neonates (Figure 1). This diet anaylsis was simply a snapshot in time and represented only that month. Identification of prey items was determined by using the keys in Light's Manual (Smith and Carlton 1975). The Index of Relative Importance (IRI) (Pinkas et al. 1971) along with the percentage IRI (%IRI) (Cortés 1997) could not be calculated due to the absence of weight measurements. Specimens were measured in centimeters total length (cm TL) with a mean total length (cm MTL) calculated along with the standard deviation (± SD). Prey items were calculated between male and female neonates as percentage frequency of occurrence (%FO) followed by the percentage frequency total (%FT) for both sexes.

The stomach contents of deceased neonates, ranging in size from 17.7 - 24.5 cm (20.1 cm MTL ±1.8 SD), were examined in the laboratory. Two neonates (10.5%) had empty stomachs. Seventeen neonates (89.5%) had been feeding on three species of crustaceans and three species of polychaete worms with 88.2% (*n*=15) of the stomachs examined containing identifiable prey items (Table 1). Two or more prey species occurred in five neonate stomachs (29.4%). Ten neonates (58.8%) contained single prey species.

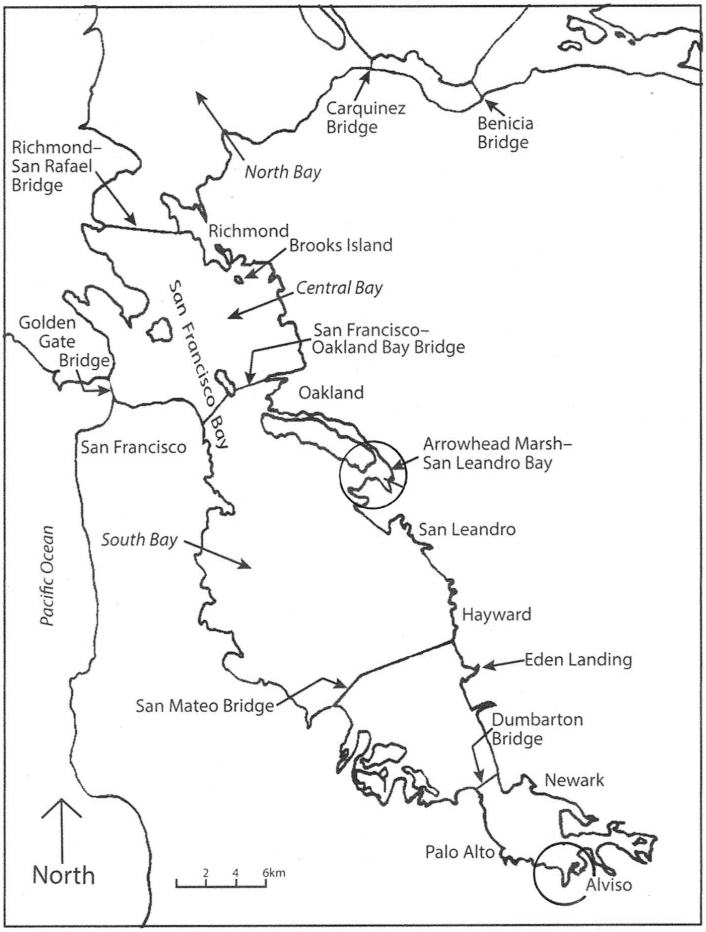

Figure 1.— Map of overall study area of San Francisco Bay with circles marking the trawl areas related to this study including Arrowhead Marsh and Guadalupe Slough at the southern end of the Bay. Map courtesy of the East Bay Regional Park District.

Table 1.— The analysis of 19 leopard shark neonates with regard to the sex, type of prey or condition of the stomach, and number of prey items removed, using common names for table simplicity.

Neonate #	Neonate Sex	Prey Item(s)(whole or pieces)	Number
		Trawl 1 Arrowhead Marsh 21 May 1982	
1	M	Unidentified	–
2	F	shrimp/crab	6/2
3	M	polychaete pieces	5
4	M	Unidentified	–
5	M	shrimp	7
6	M	jointworm	3
7	F	jointworm/lugworm	2/3
8	M	shrimp/jointworm	3/3
9	F	shrimp	9
10	F	pileworm	4
11	M	pill bug	3
12	M	crab/pileworm	1/4
		Trawl 2 Guadalupe Slough 15 May 1985	
13	F	shrimp	8
14	F	shrimp	9
15	F	shrimp	7
16	F	empty	–
17	F	empty	–
18	F	shrimp	7
19	M	shrimp/pileworm	6/2

Eleven (64.7%) of the neonates contained crustaceans. Bay shrimp, *Crangon franciscorum*, especially small, young specimens 1.5 - 2 cm long, appeared to be the single most significant prey species found in 52.9%FT (*n*=9) (Table 2.) of the stomachs with 35.3% (*n*=6) of the neonates containing bay shrimp only. Of the seven neonates collected from the Guadalupe Slough, five (71.4%) of the neonates were full of bay shrimp, while the remaining two (28.5%) had empty stomachs. In comparison, of the 12 neonates from Arrowhead Marsh (San Leandro), only four neonates (33.3%) contained shrimp and of those only two were full to apparent capacity. This suggests that bay shrimp are more readily available in the southern end of the Bay, which likely correlates with the extensiveness of leopard shark nurseries in the area (Russo 2015). Other crustaceans, including small shore crabs, *Hemigrapsus oregonensis*, 11.8%FT (*n*=2) and marine pill bugs, *Gnorimosphaeroma luteum*, 5.9%FT (*n*=1), both of which tend to be found under rock and gravel or among eelgrass roots and therefore less exposed (Ricketts et al. 1985), were found in three of the stomachs examined. In the case of the ten neonates (58.8%) mentioned earlier with single prey species, the stomachs were packed to near capacity with >7 specimens of small shrimp (*n*=6) or polychaete worms (*n*=4) suggesting "gorge" feeding, which has been observed in aquarium-raised neonates (R. Russo, East Bay Regional Park District, unpublished data).

Table 2.— The analysis of prey items from 17 neonate leopard sharks including nine males and eight females measured by the number of shark stomachs with a prey item (N), the frequency of occurrence (%FO), and the combined frequency of occurrence for males and females per prey item (%FT).

Neonate Stomach Contents (*n*=17)						
	Males (*n*=9)		Females (*n*=8)		Combined	
Food Items	N	%FO	N	%FO	NT	%FT
Crustaceans						
Crangon franciscorum	3	33.3	6	75.0	9	52.9
Hemigrapsus oregonensis	1	11.1	1	12.5	2	11.8
Gnorimosphaeroma luteum	1	11.1	–	–	1	5.9
Worms						
Axiothella rubrocincta	2	22.2	1	12.5	3	17.6
Neanthes cf. brandti	2	22.2	1	12.5	3	17.6
Arenicola brasiliensis	–	–	1	12.5	1	5.9
Unidentifiable polychaete pieces	1	11.1	–	–	1	5.9
Unidentified material	1	11.1	1	12.5	2	11.8

The second most important prey were various species of polychaete worms (whole or identifiable pieces) in neonates (*n*=7, 41.2%) with 35.3% (*n*=6) of these neonates (Table 1) containing one or more of the following: the pile worm, *Neanthes cf. brandti*, jointworms, *Axiothella rubrocincta*, and lugworms, *Arenicola brasiliensis*. *N. cf. brandti* worms appeared in four (17.6%FT) of the neonates with a fourth neonate containing pieces likely *Neanthes* but too damaged to be precisely determined. *A. rubrocincta* occurred in three (17.6%FT) of the neonates. *A. brasiliensis* was found only once (5.9%FT). Additionally, 23.6% (*n*=4) of the stomachs contained polychaete worms only, while 11.8% (*n*=2) contained unidentified material. Finally, 10.5% (*n*=2) of the stomachs were empty.

In mixed prey stomachs (29.4%, *n*=5) crustaceans and various polychaetes were found together without any indication of a preference of one species over another. Instead, the mixture of prey contents, either crustaceans and polychaetes or mixed species of polychaetes, seemed random and suggested that the neonates in this sample simply consumed what was available at the moment of feeding encounter. Based on shrimp trawl observations (Russo 2015), the southern end of the South San Francisco Bay south of the Dumbarton Bridge has historically been a shrimp nursery area where the likelihood of a neonate predator encountering large masses of shrimp is common as reflected in the contents of five of the seven neonate's stomachs from the Guadalupe Slough area.

Missing from these prey samples were other mudflat worms including specimens of peanut worms, *Siphonosoma ingens*, burrowing polychaetes, *Glycera robusta*, and gallery worms, *Capitella capitata*, identified as abundant members of the intertidal mudflat community in invertebrate surveys conducted in 1980 (R. Russo, East Bay Regional Park District, unpublished data). Although neonates are expected to feed on these worms as well as others, their absence in this analysis may be explained by the small sample size of the sharks examined.

Furthermore, no fish eggs were found in stomachs of these specimens at this time even though herring, *Clupea pallasii*, and smelt, *Atherinopsis californiensis*, eggs are an important seasonal component for leopard sharks, which are known to also gorge themselves when this food is available (Russo 1975, Ebert and Ebert 2005). The absence of fish eggs in the specimens examined in contrast to Ebert and Ebert (2005) is most likely an issue of timing and availability in the area of capture given the sheer seasonal abundance of herring and smelt eggs in several areas of the South Bay.

Leopard sharks are opportunistic feeders, taking anything that is available at the point of contact (Ackerman 1971, Russo 1975, Talent 1976). The frequency of bay shrimps and polychaete worms in individual stomachs in this sample can be explained by suspected behavior of neonates simply taking all they could at the point of encounter as mentioned earlier.

The diversity of benthic prey, including many other species of worms and invertebrates not mentioned here, but known to occur in the mudflat, eelgrass, and marsh slough environments (MacGinitie and MacGinitie 1968, Morris et al. 1980, Ricketts et al. 1985) provides for ample feeding opportunities. Bay shrimp tend to live either partially buried or on the surface of sandy or muddy bottom and are therefore exposed. The polychaete worms mentioned here are periodically active at the surface of their exposed tubes or burrows making them vulnerable to the quick-acting, suction and burrowing habits of leopard sharks (Ackerman 1971, Russo 1975, Talent 1976). This behavior has been observed in aquarium feeding studies where pieces of clam necks, squid, and polychaete worms were buried into the sediments. Tank neonates responded quickly by locating the potential prey and thrusting their faces deep into the sediments to reach the food. As observed, leopard shark neonate's feeding schedule consists of short periods of hunting and consumption followed by long periods of resting on the bottom with intermittent slow cruising during digestion (R. Russo, East Bay Regional Park District, unpublished data).

In South San Francisco Bay, many of the larger sloughs and channels (Mowry, Newark, Guadalupe, and Alviso) retain water during low tide, which allows neonate leopard sharks to stay in place but exposes them to greater danger from avian predators (Russo 2015). In some cases and theoretically in response to tidal or temperature conditions, neonate leopard sharks are suspected to move out of the smaller channels to feed in nearby eelgrass beds where they have been captured along with neonate brown smoothhound sharks, *Mustelus henlei*, and neonate sevengill sharks, *Notorynchus cepedianus* (Russo 2015). Since neonate brown smoothhounds were not captured south of the Dumbarton Bridge or inside marsh sloughs and channels, it appears that neonate leopard sharks have nearly exclusive access as elasmobranchs to an abundant food supply in an area that has long been known as a bay shrimp nursery habitat (Russo 2015).

While a larger sampling of neonates' stomach contents during other months would expand our understanding of the diversity of invertebrate prey items, this study indicates the importance of small, easily accessible and generally ignored prey during the earliest growth phases of leopard sharks. These prey species, and others yet to be determined, apparently serve as "starter foods" that help facilitate rapid growth of 20 cm or more during the first year of life (R. Russo, East Bay Regional Park District, unpublished data).

Inshore, shallow water areas have been studied as nursery feeding grounds for various elasmobranchs (Medved and Marshall 1981, Cortés and Gruber 1990, Wetherbee et al. 1990, Heupel and Hueter 2002, Rechisky and Wetherbee 2003, McCandless et al. 2007, Carlisle and Starr 2010). While there is a growing body of data on the variety of prey items consumed in some species' nursery areas, data on the dietary needs of smaller, coastal elasmobranch neonates remain incomplete. Such in-depth studies must be conducted in order to develop effective management decisions and conserve essential early-stage neonate habitat.

Acknowledgments

I wish to thank the many colleagues, friends, and family who assisted in gathering field data over a 31-year period, but most especially K. Burger, P. Alexander for trawl assistance and my three sons: B. Russo, R. Russo, and K. Russo for rod and reel assistance. Additionally, I extend gratitude to G. M. Cailliet for early suggestions and K. Morgan for providing the Webber thesis.

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Received 28 April 2018
Approved 11 July 2018
Associate Editor was P. Reilly