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Observations of predation and loss among leopard sharks and brown smoothhounds in San Francisco Bay, California

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The San Francisco Bay is the largest along the Pacific coast of the United States (Conomos et al 1985). With deepwater channels, shallow mudflats, and marsh sloughs and channels, it supports a variety of elasmobranchs including leopard shark (*Triakis semifasciata*), brown smoothhound (*Mustelus henlei*), spiny dogfish (*Squalus suckleyi*), soupfin shark (*Galeorhinus galeus*), sevengill shark (*Notorynchus cepedianus*), bat ray (*Myliobatis californicus*) and big skate (*Raja binoculata*).

Little detailed information has been published on the predation or mortality of leopard sharks, especially newborn and young-of-the-year (YOY) in San Francisco Bay (Russo and Herald 1968, Ebert 1986, 1991). Preliminary surveys indicate that marsh sloughs and channels are primary nursery grounds for leopard sharks, while brown smoothhounds generally use near-shore eelgrass beds (R. Russo, East Bay Regional Park District, unpublished data). As observations made incidentally during these surveys, predation on leopard sharks and brown smoothhounds by other sharks and piscivorous birds in the area is first reported here. Bycatch of leopard sharks in the commercial shrimp fishery and other observations of leopard shark kills are also reported as potential impacts to the leopard shark population.

Between 1970 and 2001, fishing trips were conducted monthly at various locations, primarily between coordinates 37° 48' N, 122° 22' W, the 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 (Figure 1). All specimens captured were identified, sexed, and measured in centimeters total length (cm TL) in a natural position. Newborn leopard sharks were defined as specimens showing unhealed and visible natal scars between the pectoral fins and measuring from 17 to <25 cm TL; YOY up to 50 cm TL with healed or absent natal scars; juveniles as 51–<100 cm TL; and sexually mature adults as >105 cm TL (Ebert 2005).

Sampling methods included rod-and-reel (3–5 h), long-lining (45–90 min), and otter trawl (7–15 min). Long-lines were two 6-mm thick, 152-m long nylon lines rigged with 5/0 hooks baited with squid every meter and capturing juvenile and adult sizes. Smaller size specimens were captured with a 1.3 cm mesh, 4.8-m otter trawl.

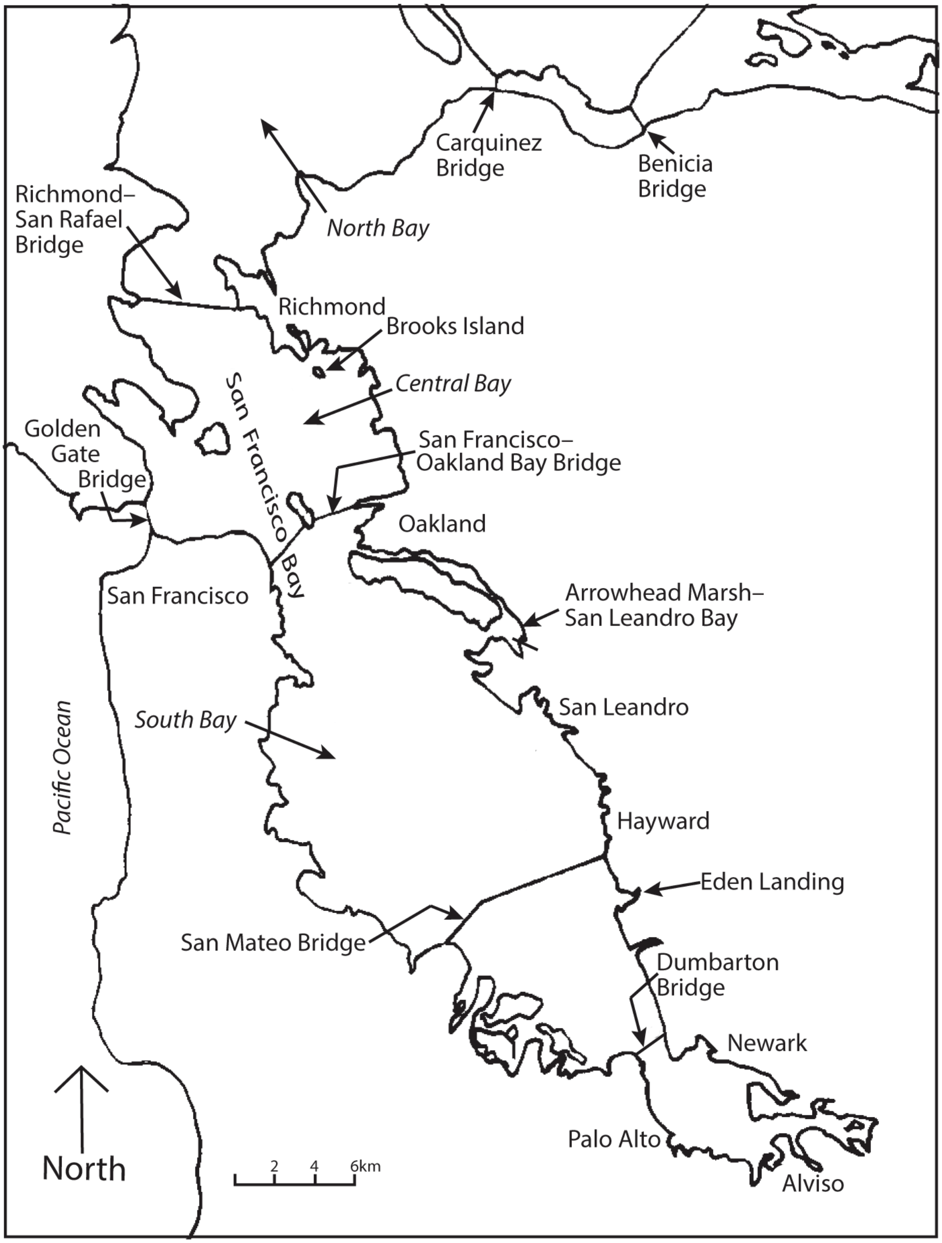

Figure 1.—Map of San Francisco Bay, California, indicating key locations mentioned in the text. Map courtesy of East Bay Regional Park District, Oakland, California.

Between 1970 and 1996 all of the methods described above were used to capture 3,790 elasmobranchs (Russo 2013). From 1997 to 2001 rod-and-reel was used to catch an additional 331 elasmobranchs for a combined total of 4,121 specimens. Of this total 2,478 (60.1%) were leopard sharks and 842 (20.4%) were brown smoothhounds ranging from newborns to sexually mature adults. Long-lines captured 1,782 YOY, juvenile, and adult leopard sharks, but no newborns. Otter trawls captured 245 newborn and YOY leopard sharks, but often resulted in the fatality of the newborns. Rod-and-reel captured 451 newborn and YOY leopard sharks. Narrow, shallow Mowry and Newark sloughs and similar habitats were avoided by choice, and use of otter trawl and rod-and-reel methods was restricted to the larger Guadalupe and Alviso sloughs, as well as open water.

Leopard sharks and other elasmobranchs were attacked while caught on long-lines during 12.8% of the sets. Since no sixgill shark (*Hexanchus griseus*) were caught south of the San Francisco Bay Bridge and none on long-lines, the observed sevengill sharks were assumed to be the predators. Predation on long-line sets was limited to a few sharks per line, and occasionally the attacking sharks became hooked. On 16 June 1975, for example, a male sevengill shark 190.5 cm TL was caught on a long-line <1.8 km southeast of Hunter's Point with the caudal fin and posterior 1/3 of the body of a male leopard shark hanging out of its mouth.

On other occasions, however, retrieved long-lines contained mostly bodiless heads. On 12 October 1975, a long-line was retrieved following a 1.5-h set approximately 4 km west of the San Leandro Marina in South San Francisco Bay in 6.7 m of water with leopard sharks on 34 consecutive hooks and only four whole bodies remaining, similar to Ebert (1991). The rest of the hooks had the heads of leopard sharks severed over the gill slits or just caudal of the first dorsal fin (Figure 2). Two juvenile sevengill sharks measuring 113

Figure 2.—Severed heads of three sharks, as removed from a long-line in South San Francisco Bay, California. The head at the left is that of a spiny dogfish shark, while the two heads at right are those of leopard sharks. Photo by author.

and 128 cm TL were caught on this same line with large portions of leopard sharks in their stomachs. On 28 June 1976, another long-line set 2 km off Hunter's Point was retrieved with 28 leopard sharks, 26 of which had been severed behind the head. A sevengill shark measuring 185.4 cm TL became entangled in the line and hooks as it attempted to swallow and an entire leopard shark measuring 71.1 cm TL subsequently was removed from the sevengill shark's mouth and stomach.

On several occasions newborn and juvenile sevengill sharks were either captured in inshore nursery areas or observed preying on newborn or YOY leopard sharks. On 15 May 1980, for example, a female sevengill shark measuring 101.6 cm TL was caught inshore by rod-and-reel in 2.2 m of water among eelgrass, where we had been catching newborn and YOY leopard sharks, just west of the San Leandro Marina. This sevengill shark contained three newborn brown smoothhounds and a newborn leopard shark its stomach. On 18 August 1996, five young sevengill sharks (49–61 cm TL) were caught by rod-and-reel in 1.8 m of water approximately 0.5 km west of the entrance to the San Leandro Marina within a span of 35 minutes, suggesting that a loose group of those predators was patrolling the mudflats and eelgrass beds. On 30 July 2000, a YOY leopard shark (40 cm TL) was caught by rod-and-reel in less than 2 m of water 0.75 km west of the San Leandro Marina. As the leopard shark was brought to the surface, I noticed a churning action in the water within 10 cm of its tail, which continued all the way to the side of the boat. Once the leopard shark was within reach, I observed multiple bite attempts by a young sevengill shark that I had watched pursue the leopard shark for at least 5 m at the surface. Once alongside the boat, the sevengill shark was netted and brought aboard for examination, along with the small leopard shark. The sevengill shark measured 46 cm TL and still showed the natal scar between its pectoral fins which, combined with its length, indicated it was a newborn (Ebert 1989).

On 4 July 2001, a 112 cm TL sevengill shark was caught by rod-and-reel in 1.6 m of water at the entrance to San Leandro Bay (Arrowhead Marsh and Airport Channel, just east of the Oakland Airport) that had swallowed a juvenile male leopard shark (51 cm TL) whole. Similar observations were made involving both leopard sharks and brown smoothhounds (newborns, YOY, and juveniles) in inshore eelgrass beds or near the entrances to salt marshes along the eastern shoreline of South San Francisco Bay.

On 20 April 2000, I visited a Caspian tern (*Hydroprogne caspia*) nesting colony on Brooks Island Shoreline Preserve near the Richmond Harbor and observed a tern returning to the colony with a newborn leopard shark estimated to be 19 cm TL in its beak (Figure 3). Keith Larsen (Department of Fisheries and Wildlife, Oregon State University) and other researchers were conducting a study of the nesting and food habits of Caspian terns at Brooks Island and Eden Landing, just south of the east end of the San Mateo Bridge. Based on time away from the colony, researchers thought that terns were utilizing local mudflat and marsh environments for food (Roby et al. 2009). Larsen reported that on several occasions he witnessed Caspian terns returning to the breeding grounds of the island with what he thought were young leopard sharks. Based on 35 mm slides he showed me of terns with prey items in their beaks, I confirmed the identifications of both newborn leopard sharks and brown smoothhounds.

On 3 February 2009, Gail West (G. West, photographer, 6 April 2009, personal communication) observed a great blue heron (*Ardea herodias*) attacking a young leopard shark (Figure 4) at the shoreline near Damon Slough, San Leandro Bay. The attack occurred over a period of 18 minutes, with the heron jabbing the shark with its beak multiple times about the head and gill areas before swallowing it. The leopard shark appeared to be approximately 53 cm TL, as estimated by using the beak-length formula for herons (Bayer 1985) and several of West's photographs.

Figure 3.—A Caspian tern with a deceased newborn leopard shark in its beak. Photo courtesy of Bird Research Northwest.

Figure 4.—Frontal view of a great blue heron with a young-of-the-year leopard shark in its beak. Photo courtesy of G. West.

On 23 May 1979 while aboard a commercial shrimp trawler operated by Captain Tom Laine in the lower reaches of Alviso Slough, as well as the open waters just north of the entrance to the slough and south of Calaveras Point in the southernmost end of San Francisco Bay, I observed six consecutive trawls. Each trawl set caught 136–181 kg of bay shrimp (*Crangon* spp.) along with 40–60 newborn leopard sharks (17–21 cm TL), resulting in 328 newborns for the day's total bycatch; neither YOY leopard sharks nor newborns of other elasmobranch species were caught. The mass and weight of shrimps captured in each trawl likely contributed to the near 100% mortality of these newborns upon dumping the net. The few newborns still showing signs of life were relocated to laboratory aquaria the same day in aerated buckets of seawater, but all died within 24–36 h after capture.

Following the initial report of dead and dying sharks along the East Bay shoreline (Russo and Herald 1968) and the preliminary chemical findings of leopard sharks (Russo 1975), I continued to collect data on the annual kill of elasmobranchs until the mid-1980s. While the numbers of dead or distressed sharks on East Bay beaches never approached those observed in 1967 (1,000 specimens in one month at Alameda), a few to several dozen dead sharks and rays were often discovered on intertidal mudflats at low tide. For example, between 28 May and 5 September 1982, 80 sharks and rays were collected from a 1-km stretch of shoreline at Alameda's Robert Crown Memorial State Beach. Affected elasmobranchs included 33 (41.2%) brown smoothhounds, 29 (36.2%) leopard sharks, 11 (13.8%) bat rays, five (6.3%) spiny dogfish, and two (2.5%) sevengill sharks. Most of these sharks and rays were already dead when found on the beach, but five (6.3%) were still alive. These individuals were taken out into 1 m of water and released, but all returned to the beach within 15 minutes after release. Additionally, on 2 August 1982, I found 29 leopard sharks ranging in size from 50 to 119.4 cm TL ($\bar{x}$=104.3 cm) that had been shot or stabbed multiple times. All were found close together at low tide on the shoreline of Hayward.

While these results confirm earlier work identifying sevengill sharks as apex predators (Ebert 1986), new information is provided that shows sevengill sharks preying on leopard sharks and brown smoothhounds in their nursery areas. Although the predation of long-line caught sharks was generally limited to just a few individuals on some lines, the loss of 88–93% (30/34, 26/28) of long-line caught specimens during two sets suggests that aggregations of sevengill sharks, or "packs" as described by Ebert (1991), were involved in such predation events. Further research is needed to determine the extent to which newborn and YOY sevengill sharks enter smaller sloughs and channels to hunt for leopard sharks.

Quantitative results of research at Eden Landing near Hayward revealed that leopard shark newborns comprised 11.9% (*n*=72) of the total number of fish (*n*=604) brought in to the Caspian tern nesting colony there, but comprised 92.3% of the 78 sharks identified at this site; brown smoothhound newborns comprised 7.7% (Roby et al. 2003). In 2009, the number of leopard shark newborns taken by Caspian terns at this breeding colony comprised only 4.6% (*n*=81) of the totals number of fish taken (*n*=1,770), but accounted for 56.3% (*n*=81) of the total number of sharks taken (*n*=144) with brown smoothhound newborns comprising 34.0% (*n*=49) and unidentified shark newborns comprising 9.7% (*n*=14); I suspect these unidentified individuals were brown smoothhounds because, aside from leopard sharks, no other newborn elasmobranchs were ever captured during our study (Roby et al. 2009, Collis et al. 2012). It is possible that leopard shark newborns, being in shallow marsh channels and sloughs near nesting colonies, especially at low tide, are more vulnerable to Caspian tern predation than brown smoothhound newborns that tend to occupy eelgrass beds where smoothhounds possibly benefit from their coloration and the protective cover of eelgrass blades and may be more difficult for terns to see.

The observation of a great blue heron capturing and eating a leopard shark YOY presents two new biological elements in the life history of leopard sharks: (1) great blue herons are predators of leopard shark newborn and YOY in their marsh shallows, the extent of which is unknown at this time; and (2) given the estimated size of the leopard shark (53 cm TL) captured at this event, newborn and YOY leopard sharks can remain in, or at least re-visit, the shallow sloughs and channels of salt marshes for several months following parturition, feeding on small invertebrates including worms, small shrimps and crabs, and marine pill bugs (Russo 1975). This observation raises questions concerning the extent of newborn and YOY loss to this predator, and whether or not other avian marsh predators such as great egrets (*Ardea alba*) or snowy egrets (*Egretta thula*) engage in similar predation.

Given a single day event involving 328 newborn leopard sharks caught in a commercial trawl, the overall impact of this kind of bycatch loss to recruitment for this species in the South Bay is largely unknown, as no attempts were made to analyze the annual catch loss due to the unknown number of commercial operators and the length of time this fishery has existed. While the South Bay commercial shrimp fishery appears to have ceased in recent years, a North Bay shrimp fishery near marshlands still exists (R. Bartling, California Department of Fish and Wildlife, personal communication, 1 February 2012); I suggest this fishery should be monitored carefully for impacts to leopard sharks.

The cause of dead, disabled, or disoriented sharks along the beaches and shorelines areas of San Francisco Bay remains a mystery and has resulted in considerable public concern with numerous articles continuing to appear in local newspapers. While some research on this problem involving domoic acid has been done (Schaffer et al. 2006), the cause remains unknown. Future investigations should consider the possible role of heavy metals, chlorinated hydrocarbons (Russo 1975), and rodenticides, as well as meningoencephalitis associated with *Carnobacterium* sp., which is known to cause similar symptoms (Schaffer et al. 2013; M. Okihiro, California Department of Fish and Wildlife, personal communication, 19 January 2015) in the stranding deaths of San Francisco Bay elasmobranchs and the disorientation and beaching of live leopard sharks and brown smoothhounds (Russo and Herald 1968).

Previous suggestions that nursery areas in shallow coastal waters provide critically important habitat, food, shelter, and opportunities to evade predators for several species of elasmobranchs (Springer 1967, Medved and Marshall 1981, Snelson et al. 1984, Talent 1985, Branstetter 1990) may be applicable to certain regions of the United States, but not to the West Coast. Newborns <55 cm TL may indeed escape predation in Gulf of Mexico and East Coast shark nurseries (McCandless et al. 2007), but leopard sharks and brown smoothhounds <55 cm TL in San Francisco Bay nurseries clearly are vulnerable to attack as evidenced by events described here.

The abundance of small prey items for newborn leopard sharks inhabiting marsh sloughs and channels, as well as near-shore eelgrass beds, may simply outweigh the risk of predation for this species. In view of the documented predation on newborn and YOY leopard sharks by avian predators in salt marshes, and by sevengill sharks in near-shore eelgrass beds, neither environment is predation-free as once presumed. The use of leopard shark and brown smoothhound nursery areas by sevengill sharks, Caspian terns, and great blue herons in capturing newborns, combined with take from the commercial shrimp fishery, as well as annual shark kills add several elements to the overall complex biology of all species mentioned and the ecology of marsh sloughs and channels. As reported here for the first time, newborn and YOY leopard sharks are key elements in the diets of several predators, as well as being vulnerable to exploitation, and these factors must be considered in any management plan developed for this species.

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