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Caudal Spine Shedding Periodicity and Site Fidelity of Round Stingrays, *Urobatis halleri* (Cooper), at Seal Beach, California: Implications for Stingray-related Injury Management

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Abstract.—Natural caudal spine replacement rates, population size and site fidelity of round stingrays, *Urobatis halleri* (Cooper), at Seal Beach, California were determined to evaluate the efficacy of clipping of caudal spines of stingrays to reduce injury to human beachgoers. Of the 2,183 stingrays caught, clipped, tagged, and released at Seal Beach, only 13 (0.06%) were recaptured over a three-year period, indicating a large, mobile population. Natural spine replacement occurred between August–October, when a majority of rays were found with two spines. Monthly catch rates of rays were variable, but positively correlated with the number of injuries reported by beachgoers. There was no significant reduction in stingray-related injuries to beach goers at Seal Beach over the period when stingray caudal spine clipping was conducted.

Several families of rays (Chondrichthyes: Myliobatiformes) are equipped with one or more venomous caudal spines located along the dorsal edge of the tail. These spines are used in defense against predators and can also inflict painful and potentially dangerous wounds to humans who unwittingly step upon them (Kizer 1990; Ebert 2003; Johansson et al. 2004). In coastal areas where stingrays are abundant, stingray-related injuries are increasing as humans increasingly use the nearshore marine environment. This is particularly evident in southern California, where large numbers of stingray-related injuries are attributed to the round stingray, *Urobatis halleri* (Cooper), a common ray along nearshore sandy beaches and bays (Russel 1953; Babel 1967; Allen et al. 2002; Ebert 2003; Hoisington and Lowe 2005).

Round stingrays are particularly abundant at Seal Beach, California, a relatively small (1.6 km long), popular urban beach where 200–300 round stingray-related injuries are reported annually to lifeguards (Capt. R. Pounds, Seal Beach Lifeguards, pers. comm.). Most of these injuries are concentrated in the northernmost

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500-m portion of Seal Beach, where several electricity-generating stations along the lower San Gabriel River discharge warm seawater effluent. Large numbers of round stingrays are known to aggregate at Seal Beach due to this warmer water (Babel 1967; Hoisington and Lowe 2005; Vaudo and Lowe 2006). The large number of stingray-related injuries and resulting negative economic impacts at Seal Beach have led local officials to seek methods to control the stingray population. However, previous population-level control measures at Seal Beach, such as culling and ray-fishing derbies, were deemed ecologically unsound and met with little success in reducing human injury events (Capts. S. Cushman & R. Pounds, Seal Beach Lifeguards, pers. comm.).

One method used to reduce stingray-related injuries is clipping of the caudal spine, a method applied by public aquaria to allow the public to handle live stingrays without being injured. Because the caudal spine is a modified dermal denticle, lacking innervation, the spine can be easily clipped without causing pain or injury to the ray (Johansson et al. 2004). A large-scale spine-clipping program may have the potential to reduce injuries at public beaches; however, this approach has not been tested in the field. To test the efficacy of large-scale spine-clipping programs in reducing the incidence of stingray-related injuries, a systematic caudal spine-clipping program was initiated at Seal Beach.

The effectiveness of such a program, however, is dependent upon the natural rate of caudal spine replacement, which has been shown to be a periodic phenomenon in several species of stingrays (Teaf and Lewis 1987; Thorson et al. 1988; Amesbury and Snelson 1997), and the feasibility of clipping the spines of a large percentage of the population. Therefore, the goals of this study were to: 1) measure spine replacement rate and periodicity for the population of round stingray at Seal Beach, 2) estimate monthly ray abundance using catch per unit effort at a single location, and 3) evaluate changes in the number of stingray-related injury rates over the 2.5-year duration of the spine-clipping program.

Methods

Field Collection

Round stingrays (*Urobatis halleri*) were sampled monthly from inshore waters along Seal Beach, California (33° 44.3′ N, 118° 06.5′ W) from 7 April 2000 to 13 December 2002 (Fig. 1). Collections were made using a 100 m long × 4.0 m deep beach seine with 2.0 cm mesh, a central catch bag, and 100 m long towlines at each end. A personal watercraft (jet ski) was used to pull the seine parallel to shore at a distance of approximately 50 m and the free towline was then brought to shore approximately 50 m southeast of the deployment point and both ends were pulled evenly onto shore by hand until the seine was completely out of the water. All round stingrays caught during seines were placed into holding pools for subsequent measurements and tagging, after which the rays were immediately released at the site of capture. One to three tows of the beach seine were conducted on each seine date, depending on the number of rays captured.

Stingray Measurements

The sex, disc width (W_D; to the nearest mm), number of caudal spines, and length of each spine (to the nearest mm) was determined for each ray. Based on observations of captive rays, it was determined that the most dorsal spine was

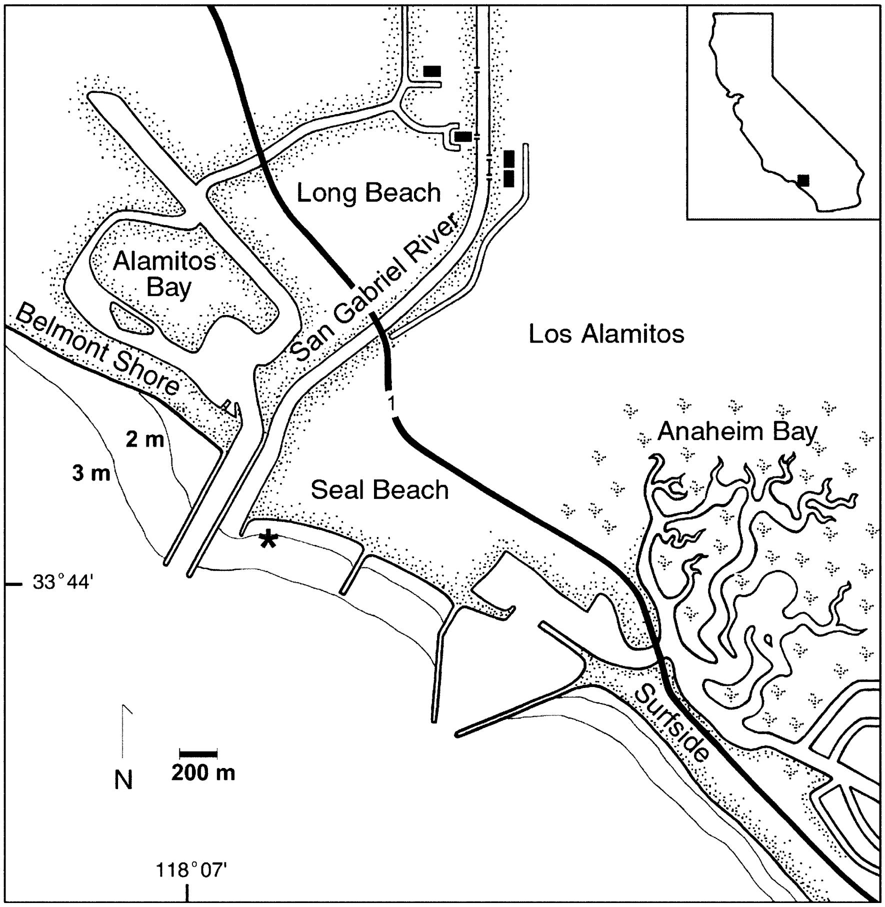

Fig. 1. Map of the Seal Beach, California study site. Asterisk indicates location of all beach seines conducted during this study. The black square in the inset shows the location of the Seal Beach area relative to California.

the primary (older spine), while secondary (replacement) spines erupted below the primary spine. Primary and secondary spine lengths were measured from the subcutaneous base of the spine shaft to its posterior point with calipers (accuracy ± 0.5 mm)(Johansson et al. 2004). After measurement, the erupted portions of all spines were clipped within 2–3 mm of the subcutaneous base using nail clippers. The relative growth rate of the secondary spine was determined using the ratio of secondary to primary spine length, and quantified using a linear regression. Analysis of covariance (ANCOVA) was used to test for a difference in caudal spine growth rates between field sampling years.

Tagging

All round stingray caught were tagged so we could track spine regeneration rates and spine growth from recaptured individuals in the field. From 7 April 2000 to 10 July 2002 all rays with a $W_D \geq 120$ mm, were fitted with a Peterson disc tag. Smaller rays (W_D 120–160 mm) were tagged in the pectoral fin, while larger rays ($W_D > 160$ mm) were tagged in the pelvic fin. Each tag carried a unique identification number and a contact phone number. These tags consisted of two 1.3 cm diameter × 1 mm thick plastic discs and a nickel pin. Tags were attached by placing a blank disc on the blunt end of the pin, pushing the pin through the fin of the ray, then placing the numbered disc on the pin, effectively sandwiching the fin between the discs. The pin was then folded down to hold the discs in place and any extra pin material was removed. Any subsequently recaptured rays were re-measured and released. To estimate tag retention, ten rays held in large tanks in the laboratory were fitted with Peterson disc tags using the same procedures described for field tagging. Growth rates of laboratory rays and the degree of fouling on the tag was assessed monthly for up to one year. Population estimates could not be made from tag-recapture data due to our failure to meet the assumptions of the Jolly-Seber open population model (Jolly 1965).

Injury Data and Catch per Unit Effort (CPUE)

Stingray-related injuries were tallied from Seal Beach Lifeguard injury reports from 1999 to 2002. Injuries were grouped by month and year and analyzed using a two-way ANOVA to examine temporal trends in injury frequency in relation to spine-clipping. Estimates of ray abundance were based on CPUE derived monthly from beach seines. Additionally, CPUE was analyzed by linear regression to examine the relationship between CPUE and number of injuries per month, and by ANOVA to examine temporal trends in catch rate.

Results

Spine Replacement

Spine-shedding and replacement exhibited a distinct seasonal cycle. Throughout most of the year, the majority of rays sampled at Seal Beach had only one (primary) spine. However, small secondary spines were first noted in many rays beginning in July (Fig. 2). The percentage of rays with secondary spines increased steadily and reached peak numbers in September and October. Thereafter, the percentage of rays with two spines decreased rapidly as primary spines fell off and were replaced. By December, almost no rays were caught that had two spines (Fig. 2).

During the spine replacement period (summer and fall), the ratio of secondary spine length to primary spine length increased significantly over time (linear regression, 2000: $df = 1{,}72$, $p < 0.001$; 2001: $df = 1{,}178$, $p < 0.001$; 2002: $df = 1{,}435$, $p < 0.001$) (Fig. 3). Primary spines were shed and replaced by secondary spines as this ratio approached 0.8 to 1.0. In some cases, the secondary spine was larger than the primary spine (Fig. 3). Although secondary spine growth rate was somewhat variable between years, there was no significant difference in the rate of growth of the secondary spine among the three sampling years (ANCOVA: $df = 2{,}685$, $p = 0.11$) and no difference in the growth periodicity ($df = 2{,}685$, $p = 0.08$).

Tag and Recapture

We tagged 2,183 juvenile and adult round stingrays at Seal Beach, California and recaptured 13 (0.6%) during the course of the study. All rays were recaptured

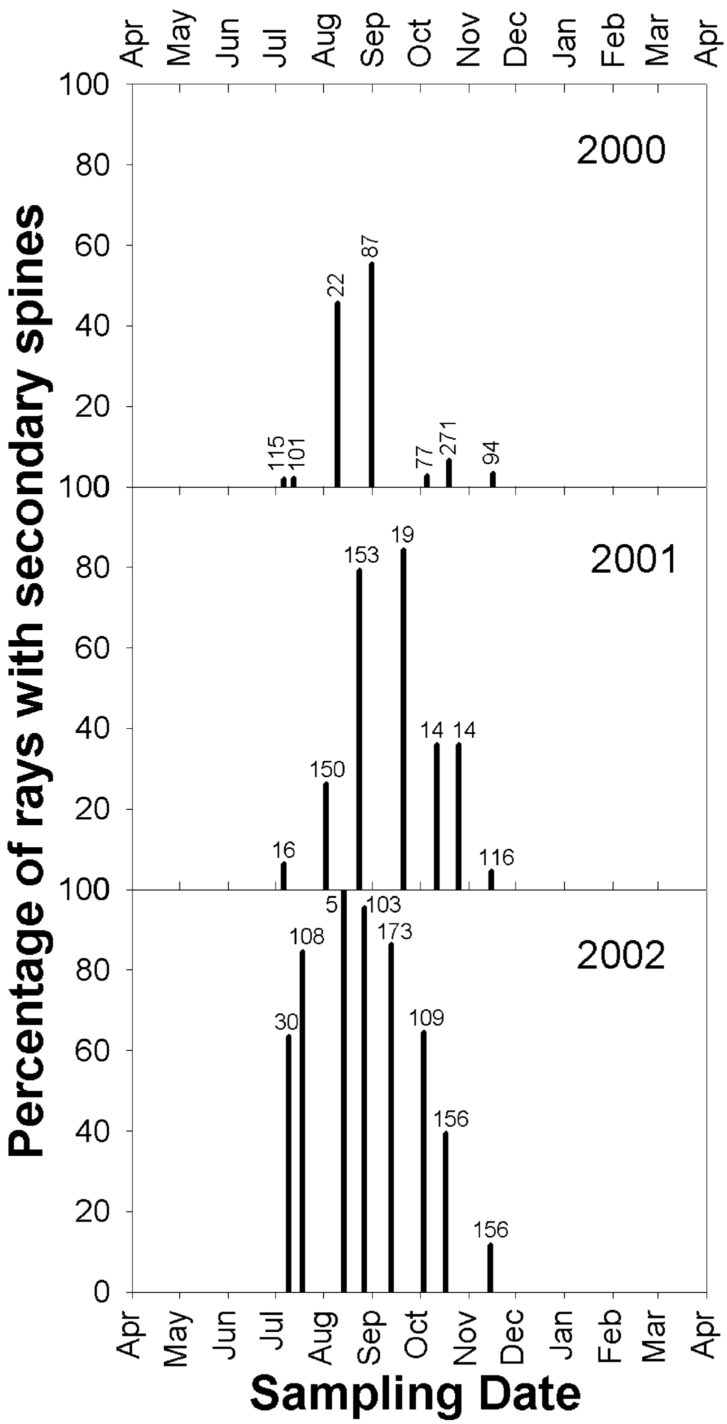

Fig. 2. Percentage of rays with secondary spines during discrete sampling dates, 2000 through 2002. Numbers above each bar represent the sample size on that date. No rays were found with secondary spines from December through July.

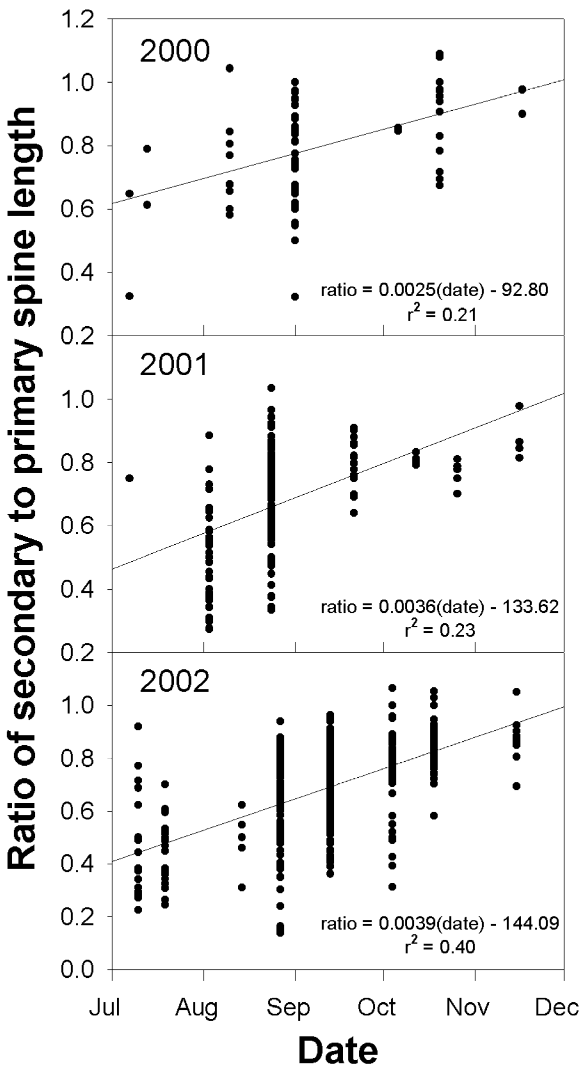

Fig. 3. Ratio of secondary to primary spine length for individual rays during the spine replacement period (July through December) for 2000 through 2002. Linear regression equations and r^2 values are shown for each data set ($p < 0.001$ for all).

within 1.6 km of the initial capture site and nine of the 13 rays were recaptured within a few hundred meters of the initial capture site. The time at liberty of these rays ranged from six to 259 d, with a mean of 79 ± 68 d ($\bar{x}$ ± SD). Minimal growth of clipped spines (< 2 mm) was observed from recaptured rays examined. Observations of captive tagged rays indicated high survivorship (100%) and tag retention (100%) out to a period of 9 months.

Reported Injuries

From 1998, when the Seal Beach lifeguards began keeping records of stingray-related injuries, through 2002, an average of 279 ± 77 (± SD) stingray-related

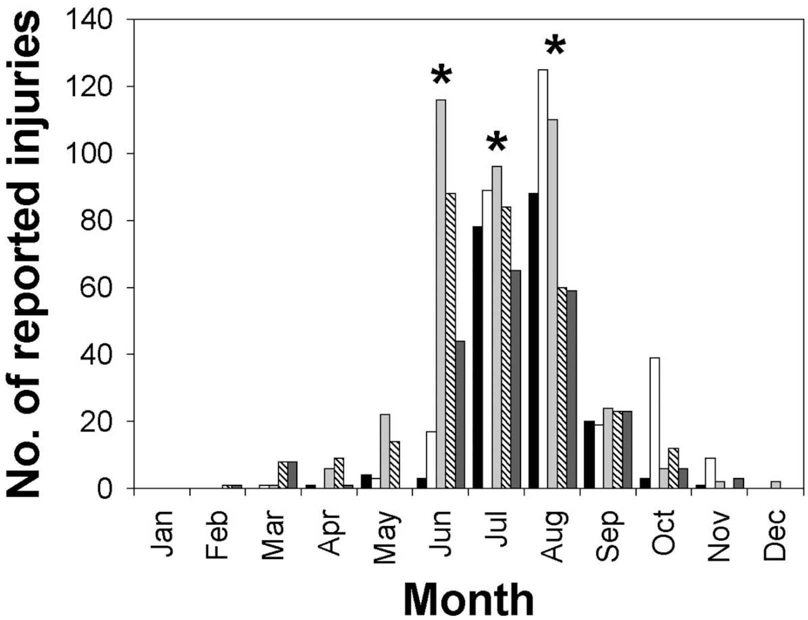

Fig. 4. Monthly number of reported stingray-related injuries at Seal Beach, CA for the years 1998 (black bars), 1999 (white bars), 2000 (light gray bars), 2001 (hatched bars), and 2002 (dark gray bars). Spine-clipping was initiated in 2000. Asterisks denote months with significantly higher numbers of injuries over all years pooled.

injuries have been reported each year, with significantly higher numbers of injuries occurring during the months of June, July, and August (Two-way ANOVA: df = 11,44, $p < 0.001$) (Fig. 4). However, there was no significant difference in the monthly occurrence of reported injuries before and after the inception of the spine-clipping program (Two-way ANOVA: df = 4,44, $p = 0.16$).

Catch per Unit Effort (CPUE)

The number of round stingrays caught per seine tow (CPUE) was highly variable during the project, but did not vary significantly by month (ANOVA, df = 11,30, $p = 0.49$) (Fig. 5). Mean daily CPUE was 56 ± 82 rays per tow. When years were pooled there was a significant positive relationship between mean CPUE and mean number of injuries reported per month (linear regression, df = 1,10, $r^2 = 0.33$, $p = 0.052$).

Discussion

The round stingray, *Urobatis halleri,* exhibits annual caudal spine replacement, with secondary spine growth occurring during the summer through fall. The percentage of captured round stingrays with two spines peaked in August and September, exceeding 80% in 2001 and reaching 100% in 2002 (Fig. 2). The high percentage of round stingrays possessing secondary spines in these years suggests that most, if not all, of the population undergoes an annual molt. However, fewer than 60% of the round stingrays caught in 2000 possessed secondary spines, which is likely attributable to insufficient sampling during the expected peak time

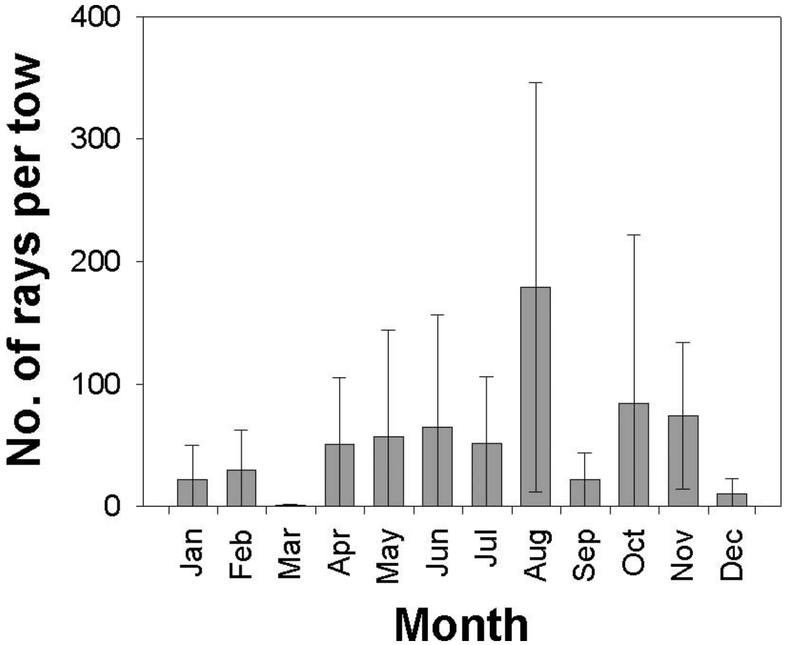

Fig. 5. Mean number of rays per beach seine tow (± SD) pooled by month over the three-year sampling period (2000–2002).

of secondary spine occurrence. The greatest sampling effort and sample sizes generally occurred in 2002, which may represent the best estimate of peak secondary spine occurrence during this study. It is also possible that the exact timing of peak spine replacement may vary slightly from year to year, perhaps due to environmental factors such as food availability or water temperature.

The Atlantic stingray, *Dasyatis sabina* (Lesueur), exhibits an annual spine replacement cycle very similar to round stingrays at Seal Beach; with secondary caudal spines first appearing in June, and all primary spines being shed by November (Teaf and Lewis 1987; Amesbury and Snelson 1997). However, not all stingrays follow an annual spine replacement cycle, with several stingray species within the family Potamotrygonidae shedding their spines every six months and replacement spines alternating between the dorsal and ventral position, relative to the primary spine (Thorson et al. 1988). In contrast, we observed all secondary spines ventral and slightly posterior to the primary spine in round stingrays. These species specific differences in spine shedding periodicities may be related to differing predation pressures or somatic growth rates.

One individual round stingray possessed two fully developed spines in February when all other round stingrays possessed one. A similar exception was reported by Amesbury and Snelson (1997), who observed one anomalous Atlantic stingray with two spines in February, which they attributed to retarded spine growth, and another with two spines in May, which was attributed to improper molting. Although we are not certain why one round stingray possessed two spines in February, it may be that a ray with supernumerary spines underwent spine-shedding at a different time than the majority of the population. We observed six round stingrays with three spines and Russel (1955) likewise reported up to 4 spines in round stingrays, suggesting a small degree of variation in spine numbers within the population. It is unknown, however, when and how many spines are shed in round stingrays with multiple supernumerary spines. Alternatively, two fully developed spines in February could be the result of trauma to the spine, which may have caused the individual to be out of phase with the remainder of the population (Johansson et al. 2004).

A qualitative examination of tag-recapture data suggests that a large, mobile population of round stingrays exists at Seal Beach, California. In addition, recaptured rays showed minimal growth of clipped spines during the periods they were recaptured. This is largely attributed to most recaptures occurring during fall months when rays would have already shed primary spines and their secondary spines would be of maximum size. Although the low recapture rates could be due to high mortality of stingrays caused by catch and release tagging trauma, this is unlikely based on the high survivorship and tag retention of rays captured in beach seines and maintained in captivity for periods up to two years. Low recapture rates may be attributed to the relatively small sampling area compared to the total available habitat; however, the possibility of this is reduced due to the large number of seines conducted. Therefore, the implications of a low recapture rate despite large seine catches are most likely attributable to large population size and that rays are leaving the area within several days to weeks after catch and release (Vaudo and Lowe 2006).

Because there is minimal fishing effort for stingrays outside of the Seal Beach sampling area (e.g., local fishing piers), recapture rates at locations other than Seal Beach were low. Rays recaptured in this study showed a maximum distance traveled of 1.6 km with a mean time at liberty of 79 $\pm$ 68 d. However, other studies have indicated that round stingrays are capable of traveling greater distances. Of 482 round stingrays tagged at multiple locations from Santa Monica, CA to Oceanside, CA, 61 were recaptured over a period of 4–14 months (Russel 1955). Thirty-two of the 61 rays were recaptured in the same place as original capture, but 10 were recaptured more than 15 km from the original capture site. Babel (1967) found one tagged round stingray 4.75 km from the initial point of capture after 208 d at liberty. In a more detailed study of movement patterns, Vaudo and Lowe (2006) used a combination of acoustic telemetry techniques to quantify short-term fine-scale movements and site fidelity of round stingrays to Seal Beach. Rays caught and tagged at Seal Beach remained within the area for up to several days and then moved up to several kilometers along the coast. Some rays were also found to leave Seal Beach in the fall and returned the following summer. Although it is not known how far rays disperse from Seal Beach, one ray was found to move from Seal Beach to Newport Bay and back within a period of three months, covering a linear distance of 60 km.

Catch data (CPUE) indicates that some rays are present at Seal Beach year round, although there was a large seasonal variation in ray numbers. When CPUE data were pooled for the three years no significant monthly differences were found. However, when monthly CPUE values were examined over individual years, higher numbers of round stingrays were caught during the summer and fall, with numbers decreasing during the winter months. This is supported by findings of Hoisington and Lowe (2005) who used a combination of beach seining and diver surveys to quantify abundances and densities of round stingrays at Seal Beach. Rays were more abundant and occurred in higher densities at Seal Beach than at neighboring beaches and were most often found within 30 m of the shoreline, where the water was warmest. Ray abundance was found to decrease following periods of high wave activity. Therefore, the high inter-annual variability in ray CPUE may be related to annual weather patterns and periods of high surf activity (Hoisington and Lowe 2005; Vaudo and Lowe 2006).

CPUE data taken in conjunction with tag-recapture data suggest that a large population of round stingrays inhabit Seal Beach. Monthly beach seines revealed high CPUE values during summer and fall months, but yielded very few recaptures, indicating a very high turn over of rays at Seal Beach. Large populations of round stingrays have been noted in other locations in southern California. In a comprehensive fish survey of San Diego Bay, Allen *et al.* (2002) found round stingrays comprise up to 25% (687 kg) of the total fish biomass sampled, although seasonal abundance varied, rays were consistently more abundant throughout the year in San Diego Bay than at Seal Beach. This suggests that round stingrays form aggregations at Seal Beach, but leave the area after periods of several weeks.

Stingray-inflicted injuries to beachgoers primarily occurred during the summer months with few injuries reported during the winter months. Periodic beach counts by Seal Beach lifeguards indicate dramatically higher beach attendance during summer months (June–August) (Capt. R. Pounds, Seal Beach Lifeguards, pers. comm). Analysis of shark attack data by Baldridge (1974) also indicated that most shark attacks occurred during the summer months, which was attributed to the increase in the number of recreational water-users during these months, which would increase the probability of interaction. Some of the variability in the reported number of stingray-inflicted injuries at Seal Beach versus ray CPUE may be better explained by the increasing numbers of beach users at Seal Beach during the summer months.

The primary focus of this study was to determine whether caudal spine clipping of round stingrays at Seal Beach could be used as a management alternative to culling to reduce injuries to beach goers. However, round stingrays were found to aggregate in high numbers at Seal Beach during summer and fall months during the same periods when the beach is most frequently used by beachgoers (Hoisington and Lowe 2005). While rays aggregate in large numbers at Seal Beach, they also exhibit high turn over, making it difficult to capture and treat a large enough percentage of the population to significantly reduce the number of rays with functional caudal spines. In addition, round stingrays naturally undergo caudal spine-shedding in early fall, during periods of their peak abundance at Seal Beach and because they exhibit seasonal fidelity to Seal Beach (Vaudo and Lowe 2006), spine-clipping would have to be done annually. Even though 2,183 rays were caught and spine-clipped over a 2.5-year period, no significant effect on the number of reported injuries at Seal Beach was observed since the program's initiation. Thus, it can be concluded that the rapid regeneration and annual shedding of caudal spines, along with the suspected large population size of round stingrays at Seal Beach, makes caudal spine-clipping, at the level used in this study, an ineffective technique for reducing stingray induced injuries.

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