

Research Article

Occurrence of White Sharks (*Carcharodon carcharias*) in Hawaiian Waters

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White sharks (*Carcharodon carcharias*) have been known in Hawaii (~158°W, 22°N) since the time of ancient Hawaiians. We compiled sightings and records from 1926 to the present (4 females, 2 males, and 8 unknown sex; 3.3–4.5 m total length) and compared them with satellite tracking records (7 females, 9 males, and 6 unknown; 3.7–5.3 m total length). White sharks have been sighted in Hawaii throughout the year, whereas satellite tracking studies show individuals near the North American coast during fall and offshore during spring for the eastern North Pacific population (northern fall/spring). The mismatch of these datasets could hypothetically be consistent with fall-sighted individuals being sourced from a different population or part of a resident population. However, recently documented multiyear movements of North American sharks revealed that the annual nearshore-offshore pattern does not hold for mature females, which ranged over larger areas and were offshore during the fall. We found that fall white shark sightings in Hawaii are predominantly of females, most likely visitors from the eastern North Pacific population. Misidentification of other species as white sharks frequently occurs by fishers and in the news media, and we suggest methods for discrimination of related species.

1. Introduction

White sharks (*Carcharodon carcharias*) are known to have occurred historically in Hawaii based on Hawaiian knowledge and artefacts predating European contact [1], and their presence continues to be documented by contemporary observations (this study) and electronic tracking [2–5]. This paper aims to provide a definitive record of the presence of white sharks in Hawaiian waters, based on confirmed incidents and satellite tracking data, while eliminating previously reported sightings that cannot be verified. We compared sightings data from Hawaii with satellite tracking data and consider life history hypotheses for the eastern North Pacific, in order to understand the likely origins of sharks that occur in Hawaii.

Observations of white sharks in Hawaii have been rare and brief, but have provided information on the seasonality of occurrence in the Archipelago and some information on sex

and size class. On the North American coast, the occurrence of white sharks has been studied via direct observation, photo cataloging, records of attacks on marine mammals and humans, fishery capture records, and satellite and acoustic telemetry. White sharks have been seen at aggregation sites (pinniped colonies) primarily during northern autumn [6], and satellite tracking studies record them moving west from the North American coast in the spring to offshore waters including Hawaii [2–5]. These data suggest that Hawaii white sharks are part of the same population that inhabits the North American west coast. However, sightings in Hawaii across nearly all months of the year conflict with the spring-offshore pattern, raising the possibility of either a resident population or an alternate source of visitors. New data for the seasonal movements of female sharks from North American aggregation sites [7, 8] allow a new interpretation of the Hawaii observation data.

A number of potential reasons for the migration to Hawaii have been suggested, focused on foraging and mating. Taylor [1] suggested that the winter aggregation of humpback whales (*Megaptera novaeangliae*) in Hawaii may provide a food source (via newborns or placentas), and that monk seals (*Monachus schauinslandi*) could provide a year-round food source. Coastal dolphin populations, notably spinner dolphins (*Stenella longirostris*) that aggregate during the day in shallow bays, are another potential food source. Jorgensen et al. [5] suggested foraging on deep scattering layer organisms. Weng et al. [3] and Jorgensen et al. [5] both speculated that since both males and females visit Hawaii, mating may occur in the Archipelago.

Reports of white sharks are frequently made by the news media, generally without adequate verification of species. Since there are a variety of sharks with similar sizes, and a number of species in the family Lamnidae that have similar features, verification based on morphology is important. We provide suggestions on verification and review a recent case that was widely reported, but based on a misidentification.

2. Materials and Methods

Information on the occurrence of white sharks in Hawaii was compiled from sighting and attack records, shark culling program data, remote cameras, submersibles, and published satellite tag records. Sex of sharks was recorded if the ventral surface was observed sufficiently to determine presence/absence of claspers. Length was taken from observer estimates, and in the case of some photographs was determined using laser spacers or stereovideo calculations [9].

We include published records of white sharks that were tracked with satellite tags to the Hawaii region. Three publications focusing on the northern California white shark aggregation reported on a total of 19 white sharks that moved from California to Hawaii [2, 3, 5]. One publication focusing on the Guadalupe, Mexico aggregation reported on three white sharks moving to Hawaii [4]. The months of occurrence of white sharks satellite tracked in Hawaii were determined from these published papers and combined with occurrence data from direct observations.

We considered sightings to be verified where specimens were in hand, photographs providing morphological information existed, evidence such as tooth pattern was analyzed from bites, or scientific observers recorded identifying characters. Where verification was not possible, records were not included in our analyses. Reports by the public of large sharks frequently do not include enough morphological information to make species identifications, even between major groups such as lamnids and carcharhinids.

Where limited information is available, it is important to distinguish between white sharks and other members of the family Lamnidae. In the eastern North Pacific, the salmon shark (*Lamna ditropis*) is commonly misidentified as a white shark, and while at least one specimen has been shown to occur in Hawaii [10], it exhibits a strong tropical submergence and this has not been directly observed or captured. In the Atlantic, the porbeagle shark (*Lamna nasus*) has a similar appearance to the white shark. In the Hawaii region, shortfin

mako sharks (*Isurus oxyrinchus*) occur regularly and have been misidentified as white sharks by the public and news media. We use a number of characters noted in the peer-reviewed literature to distinguish the two species. (1) Origin of first dorsal fin relative to the pectorals: in the white shark “first dorsal fin origin is usually over the pectoral inner margins” whereas in the mako “first dorsal fin origin is usually behind the pectoral fin free rear tips” [11]. (2) Snout shape: the mako shark snout is “acutely pointed” whereas the white shark snout is “bluntly conical” [11]. The acuteness of the point on the snout is commonly used by biologists and fishermen to distinguish the two species. Therefore, we propose a new metric to quantify this feature, the ratio of distance from tip to anterior edge of eye versus height at anterior edge of eye. The keys used to distinguish different lamnids utilize tooth morphology or other features typically unavailable from photographs. Since photos typically show the snout, our metric may be useful for identification in other cases.

In addition, the pattern on the flank of white sharks is typically an uneven line between the contrasting white ventral and grey dorsal surfaces (margin between dorsal dark and ventral white surfaces sharply delimited [11]), whereas mako sharks typically have a smooth transition from lighter to darker. The eye is larger relative to the body in the mako shark [11].

3. Results and Discussion

3.1. Records of White Sharks in Hawaii. Thirteen modern records for white shark sightings in Hawaii were verified (See Supplementary Material available online at <http://dx.doi.org/10.1155/2013/598745>) (Table 1, Figure 1), and 22 individuals were satellite tracked to Hawaii from the coast of North America, reported in published articles [2–5, 7]. White sharks occurred in both the Main and Northwestern Hawaiian Islands [5]. The presence of *Carcharodon carcharias* in Hawaiian waters has been known since the days of precontact Hawaiians, as evidenced by artifacts containing white shark teeth held in the various museums [1]. Contemporary records of white sharks date back to May 1926, when the remains of a man who apparently drowned in waters of Haleiwa, Oahu were recovered 16 days later in the stomach of a large shark landed off Kahuku, Oahu. Of five newspaper articles describing the incident, only one [12] identified the shark as *C. carcharias*. This appears to have been the first time a white shark was mentioned by name in any Hawaiian shark incident account in recent history.

Following the size classification of Bruce and Bradford [13], records of white sharks in Hawaiian waters have involved subadults and adults, ranging in size from 3.3 m (this study) to 5.3 m [5]. Where sex could be determined, males ranged from 3.5 m to 4.9 m and females from 3.3 m to 4.8 m. Juvenile (1.75–3 m) and young of the year (<1.75 m) size classes have not been reported, with the exception of shark 19690308, whose size was estimated from bite marks. Since it is not known what proportion of the shark’s jaws resulted in a 24 cm bite width, the length estimate may have a large margin of error. A length of 2.7 m would be at least 0.6 m less than any other reliably measured white shark in Hawaiian waters.

TABLE 1: White sharks observed in the Hawaiian Archipelago.

Date	Animal ID*	Location	TL (m)	Sex	Basis for identification	Source
May 18, 1926	19260603	Kahuku, Oahu	3.8	U	Captured specimen	[12]
Dec 7, 1959	19591207	Kahuku-Waialeale, Oahu	3.5	M	Original catch data	[14]
Mar 6, 1960	19600306	Windward Oahu	3.3	F	Original catch data	[14]
Mar 8, 1961	19610308	1 mile outside Honolulu Harbor	4.1	U	Captive specimen	[1, 15]
Jan 20, 1966	19660120a	Kawaihae Bay, Hawaii		U	Original catch data	[1, 16]
Jan 20, 1966	19660120b	Kawaihae Bay, Hawaii		U	Original catch data	[1, 16]
Mar 8, 1969	19690308	Makaha, Oahu		U	Tooth impressions in surfboard	[17]
May 3, 1969	19690503	Kawaihae Bay, Hawaii		M	Original catch data	[1, 16]
Oct 28, 2002	20021028	Penguin Bank, Molokai		U	Video footage	[18]
Oct 4, 2004	20041004	Makapuu, Oahu	3.9	F	Video footage	[18]
Jan 4, 2005	20050104	Molokini, Maui	Large	U	Photograph	[18], 1
Dec 28, 2005	20051228	Near Haleiwa, Oahu	4.5	F	Video footage	2
Jan 29, 2006	20060129	Mahukona, Hawaii	4.2	F	Photograph	3
May 1, 2011	20110501	Between Molokai and Maui	3.3	U	Video footage	4

* Animal ID is given as date in the format. Detailed descriptions of each individual are in the Supplementary Material available online at <http://dx.doi.org/10.1155/2013/598745>.

Sources: References ¹Photographs and descriptions by John Chakerain provided to K. Weng, 2012; ²Jimmy Hall photos provided to K. Weng; ³Todd Buczyzna photographs provided to K. Weng, 2012; ⁴Virginia Moriwake and Jeff Drazen, University of Hawaii.

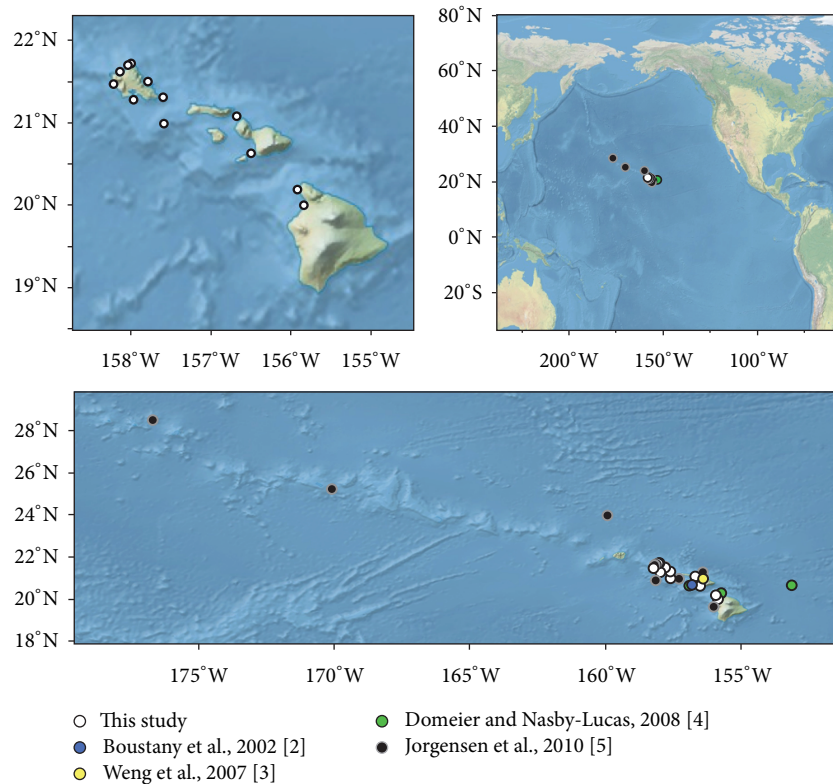


FIGURE 1: Location of white sharks sighted in Hawaii and reported in published satellite tracking studies.

Domeier [8] reported on a 3.15 m total length subadult male tagged off Guadalupe Island (GI) on December 6, 2007, which departed GI April 20, 2008 and migrated to a point 1100 km due north of Hawaii island. Although the shark did not enter the Hawaiian waters, it did travel through similar latitudes and longitudes.

Observations of white sharks in Hawaii included sightings from vessels and by divers as well as recordings on remote cameras and from submersibles. All records are from daytime periods and range from the surface to 446 m.

The relatively low abundance of white sharks in Hawaiian waters was evidenced by the results of large-scale shark

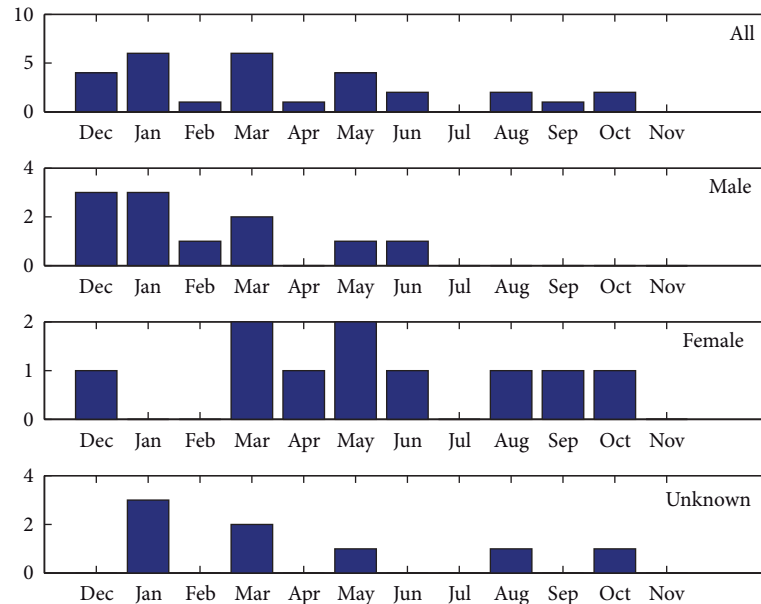


FIGURE 2: Distribution of white shark occurrences in Hawaii by month based on verified sightings (this study) and published records [2, 3, 5, 7].

culling operations conducted from 1959 to 1969. A total of 697 sharks were caught during the Billy Weaver Shark Research and Control Program (1959-60) [14]. Of those, only two were white sharks. Surprisingly, two white sharks were among 92 sharks caught during a 1966-67 abatement program at Kawaihae Bay, Hawaii island, and a third was caught in the same area in 1969 [1]. However, during the largest shark control effort in Hawaii's history, the 1967-69 Cooperative Shark Research and Control Program, 1,727 sharks were caught, but not a single white shark [19]. No white sharks were caught during three other shark control programs in the 1970s [20].

3.2. Origins of Hawaii White Sharks. White sharks in Hawaii may hypothetically be migrants from populations near North America, Japan, or Australia/New Zealand or a resident population. At present no evidence exists for connectivity between Hawaii and the Australia/New Zealand region, though tracking studies have occurred [13, 21, 22]. Insufficient research has occurred to evaluate connectivity with Asia. Large-scale tracking studies on the North American coast have revealed a high degree of connectivity with Hawaii and showed a seasonal pattern with sharks departing the coast during the northern autumn [2-4]. The lack of juvenile and young-of-the-year size classes and strong seasonal presence of subadult and adult males indicate that a resident Hawaii population is unlikely.

The seasonality of white shark occurrences in Hawaii based on both sightings, fishery records and published records, is shown in Figure 2. White shark occurrences are distributed through all months of the year except November, with a broad peak during northern winter-spring. Males are absent during northern summer-fall, while females occur all year round. The absence of males in the northern fall is consistent with those individuals leaving Hawaii and moving to North American aggregations in the fall-winter. In contrast, female sharks occur in Hawaii throughout the

year. The autumn occurrence of white sharks in Hawaii is not consistent with the seasonal pattern identified by early tracking studies [2-5]. However, this seasonal pattern is not the complete story and is part of a more complex migratory system in which females and males have different patterns [7]. Domeier and Nasby-Lucas [7] described migratory patterns of eight adult male and four adult female white sharks tagged with satellite-linked radio transmitters at their northeastern Pacific aggregation sites. Two of the males were tagged at the Southeastern Farallon Island (SEFI), and all other sharks were tagged at Guadalupe Island (GI). Males tagged at SEFI began their offshore migration with a mean departure of November 23, while males tagged at GI departed later, with a mean date of February 7. They all traveled to the same core region of the Shared Offshore Foraging Area (SOFA), then returned to their respective aggregation sites around the same time (mean returns July 30 to SEFI and August 7 to GI). Females began their offshore migration from GI about the same time as the males, with a mean departure date of February 5. However, they roamed a much larger expanse of ocean than the males, between GI and the SOFA's eastern edge. Three of the four females did not return to the adult aggregation area for at least a year after tagging, while one returned after 228 days. The biannual migrations of females described by Domeier [8] potentially put them far offshore of their North American coastal aggregation sites throughout the year, whereas annual migrations by males reflect a higher level of seasonality.

The seasonal differences in male and female white sharks visits to Hawaii are consistent with the life history hypotheses presented in a recent review [8]. Male visits are determined by the offshore migration from the North American coast [2, 3, 5], whereas female visits are poorly correlated with this migration [7]. The variability in seasonality of female visits is likely related to their two-year reproductive cycle in which they do not return to coastal aggregation sites off California

and Mexico on alternate years. During these periods, females occupy a large pelagic habitat. Our results suggest that this large pelagic habitat includes Hawaii. Hawaii may provide a good foraging area with warm water temperatures for female white sharks. Based on the girth of shark 2004I004, the observers speculated that it was pregnant [18]. Given the length estimate of 3.9 m, the shark would have been small for a reproductively mature female, assuming an average length at maturity of 4.5 m for females [23]. However, visual length estimates made without lasers, stereovideo, or clear scale references may have considerable error. Females may prefer warmer waters since fetal development would presumably occur faster [7].

3.3. Mating. Male and female white sharks in the Eastern Pacific may have very short periods of overlap during which mating could occur [7]. Male-female overlap at coastal seal colony aggregation sites occurs primarily during December and January, and Domeier [8] suggested that seal colony aggregations are the only locations where mature male and female sharks are in the same place at the same time [8]. Overlap in Hawaii is most likely during the northern spring (Figure 2), and Hawaii may provide clear landmarks that could facilitate interactions between male and female sharks. However, given that sightings have been of single sharks, there is no evidence for mating in the Archipelago. Hawaii receives visits from both Central California as well as Guadalupe Island sharks (more frequently from Central California) [8]; so interactions between these populations are possible in the Archipelago. Overlap offshore appears unlikely, due to the vast size of the SOFA, as well as the fact that it is used primarily by males, with females using a larger and more dispersed area [8].

3.4. Occurrence of Potential Prey in Hawaii. Taylor [1] noted the possibility of white sharks foraging on humpback whales or Hawaiian monk seals. The seasonality of white sharks in Hawaii overlaps with humpback whales, particularly for males (Figure 2), but the seasonal correlation is weak, suggesting that humpbacks are unlikely to be a driver of white shark visitation. The resurgence of the population of Hawaiian monk seals in the Main Hawaiian Islands may provide a slight increase in foraging opportunities for large sharks, though the population is far lower than the population of gray seals off the east coast of the US, where white sharks have returned [24]. The total population of monk seals in the Main Hawaiian Islands is likely to be between 150 and 200 [25], and given the low productivity of a long lived mammal such as this, monk seals represent a very small forage base for white sharks. Small cetaceans are present in Hawaii all year round and may be a food source for white sharks [8].

3.5. Depth Utilization and Foraging. Two papers have noted that white sharks engage in a diel vertical migration while in the Hawaii region; however, the nature of the migration differed, and each paper presented data from a single individual shark. Weng et al. [3] noted a reverse migration, being shallower during day and deeper during night, while

Jorgensen et al. [5] noted a normal vertical migration, being shallower at night. Sightings data presented in this paper are from daytime periods, ranging from the surface to 446 m, indicating that white sharks occupy a broad depth range, and are more consistent with the observations of Jorgensen et al. [5]. The reverse diel pattern presented by Weng et al. [3] is unlikely to be representative for white sharks in Hawaii.

The diel behaviors of white sharks are likely to be related to the behaviors of their prey, which may include midtrophic level fishes and squids as well as higher trophic level organisms that prey on them, such as marine mammals and large pelagic fishes. Jorgensen et al. [5] stated that the diel vertical migration of white sharks in Hawaii suggested foraging in the deep scattering layer (DSL) community. The Hawaiian slope environment is home to an assemblage of planktonic and micronektonic organisms that differ from the surrounding pelagic communities, termed the “mesopelagic boundary community” [26]. These organisms undertake a dramatic horizontal and vertical diel migration, moving from deep offshore daytime positions, to shallower nearshore nighttime positions [27]. Spinner dolphins closely follow the horizontal and vertical movements of these boundary community prey organisms [28]. The shallowest and most nearshore position of the boundary community, and associated spinner dolphins, is typically at midnight [29]. Both the Weng and Jorgensen papers provided figures detailing the transition from deep to shallow behavior occurring during crepuscular periods. These patterns are not consistent with a close association with the boundary community that exists near the Hawaiian Islands. The diel movements of the more distant pelagic DSL community are more strongly associated with light, thus making strong vertical movements during crepuscular periods [30]. As such, the patterns observed by Jorgensen et al. may represent white sharks that are further offshore.

3.6. Species Misidentification. In addition to the incidents and sightings listed in Table 1, we found eight other reports of white sharks in Hawaii from 1995 to 2012, but these reports did not contain information allowing species identification. Mako sharks are commonly mistaken for white sharks and there are numerous unverifiable reports of white sharks from Hawaii. A large shark videotaped near Kaena Point, Oahu was misidentified as a white shark by the news media [31] and erroneously re-reported as a white shark by many other news outlets. Our morphometric tests show that the individual was a mako shark, and other experts in shark biology who viewed the video and images agree that the individual was a mako (C. Meyer, G. Cailliet, and D. Ebert, personal communication). The base of the first dorsal fin is behind the trailing rear tip of the pectoral fin (not in line), a character of mako sharks. The ratio of distance tip to eye versus height at eye is approximately 0.6 for mako sharks and 0.8 for white sharks based on Compagno [11]. The Kaena shark had a ratio of 0.61.

4. Conclusions

Hawaiians utilized the teeth of white sharks before the time of European contact. Such individuals could have been migrants

from populations in North America, Asia, Australia/New Zealand, or hypothetically part of a resident population. We compiled sightings records during the past century, combined with analysis of published movement records. These data are consistent with recently published theories on North American white shark life history, with individuals occurring in Hawaii during the northern fall being female. The high variability in white shark behavior in the Archipelago indicates that they are unlikely to be focusing on a small number of prey species or foraging strategies. Since misidentification of putative white sharks is a common problem, we propose a simple method for distinguishing white sharks from closely related species in situations when traditional morphometric data are unavailable.

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