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Re: 2024 Final Report

Dear Elakha Alliance,

Proposal Summary: We proposed to conduct a preliminary study on the presence and spatial distribution of predatory sharks (white shark, *Carcharodon carcharias*, and broadnose sevengill shark, *Notorynchus cepedianus*) in relation to potential sea otter reintroduction sites in Oregon using electronic tagging to inform potential risk of shark-induced mortality during reintroduction. Here we provide a final report on project milestones achieved with funding from the Elakha Alliance and Oregon Conservation and Recreation Fund (OCRF) over the period January 2022 to Dec 31, 2023 and the ongoing research leveraged on this support.

Summary: To date in ~200 hours of baiting and exploration at multiple sites in Oregon, we have yet to encounter local white or sevengill sharks that could indicate consistent aggregations. However, records from tagged white sharks migrating up from California and sevengill sharks down from Washington are steadily accumulating over time. A small but consistent portion of the white sharks that we have tagged in California are showing up on acoustic receivers placed at various sites throughout Oregon. These sharks span sizes from juvenile to adult, and have occurred primarily in winter, but sporadically in all seasons. Otter strandings at their range periphery in California are driven by the novel presence of juvenile white sharks that have shifted north in response to ocean warming. At least one of our tagged juveniles was detected in Oregon. To further assess environmental drivers of northward shifting in juvenile white sharks we implemented intensive drone surveys in Monterey Bay in relation to environment, primarily ocean temperature. Similarly, a small portion of the sevengill sharks we tagged in Washington (Willapa Bay and Puget Sound) have been detected in Oregon and as far as southern California.

Together the data generated to date show us promising approaches and challenges in elucidating Oregon's regional and seasonal shark hotspots and the potential for future increases in the suitability of Oregon's coastal water for (juvenile) white sharks. Continued efforts to target sharks in Oregon and other regions in combination with the 5 to 10-year longevity of tags will continue to generate useful data on shark movements, focal areas and overlap with sea otters, while our emerging habitat suitability study will inform future white shark distribution.

Field effort: This report covers the full period January 2022 to Dec. 31, 2023 during which time, we spent 24 field days from November 2022-Nov. 2023 (5 days in 2022 and 19 days in 2023; total ~200 hours) baiting/attracting white and sevengill sharks in Oregon. Locations in Oregon visited for field work include near-shore sites we identified as being

likely places for white shark presence (Newport, Seal Rock, Yaquina Head, Otter Rock, Tillamook Head & Cape Arago) and offshore spots where white sharks were reported. We spent 39 days from March 2022 – December 2023 (19 days 2022 and 20 in 2023; total ~400 hours) catching and sampling Sevengill sharks in Willapa Bay and Puget Sound, Washington. We also spent 46 days (25 days 2022 and 21 days 2023) with collaborators surveying and tagging white sharks in central California. In total we performed 120 drone flights on 50 survey days totaling 70 flight hours and recorded 160 white sharks in central California. Coupled with each drone overflight, we recorded *in situ* sea surface temperature (SST) to validate against satellite derived temperature data.

Acoustic Receivers: The US Coast Guard denied our request to use navigational buoys to affix acoustic receivers due to concerns the units would affect their ability to service the moorings. However, we partnered with the Oregon Coast Aquarium to deploy moored receivers in sheltered but key locations and the Ocean Observatory Initiative (OOI) to install receivers on oceanographic buoys. We deployed 9 permanent (semi/annual servicing) acoustic receiver stations along the Pacific Northwest outer coast (Table 1; Figure 1) to increase our probability of detecting acoustically tagged sharks. Receivers include acoustically released units, diver-serviced units and those integrated into OOI buoys. To our knowledge these represent the only long-term acoustic network in coastal Oregon. We also deployed eight additional acoustic receivers in California and six in the Puget Sound, Washington. Eight of the 9 Pacific Northwest outer coast receivers have been downloaded at least once and are currently deployed and collecting data. Only the Rogue Reef receiver has yet to be downloaded given its recent deployment. One receiver (Cape Arago) was lost during anomalous winter storms in January 2023. Data from the receiver over this period were lost, but the unit was replaced in February 2023.

Acoustic Tagging: We have yet to encounter white or sevengill sharks during our field efforts in Oregon. This is not completely surprising given no one has ever studied these species in Oregon so determining seasons, location, effective fishing methods, etc. are difficult. As per our proposed contingency plan, we also targeted animals in California and Washington where we have established tagging programs. We tagged 39 white sharks in California (n=22 in 2022 and n=17 in 2023; Table 2) and n=34 Broadnose Sevengill sharks in Washington (n=15 in 2022 and n=19 in 2023; Table 3). Though tagged outside of Oregon, we expected white and sevengill sharks tagged in adjacent regions to move through and be detected in the study areas in Oregon.

Acoustic Detections: We detected 22 sharks on our receiver array in Oregon and Washington (Figure 1) over the course of the study. Overall white shark presence was highest in late fall and early winter months with 2 animals detected in 2021, 4 in 2022 and 1 in 2023. No white sharks were detected at Tillamook Head (Figure 2) near a potential re-introduction site. This is likely because the receiver has only been deployed through the summer 2023, not a period of expected white shark presence. One white shark was detected in Newport (Figure 3) and three were detected in Cape Arago (Figure 4), though the receiver was lost during expected the peak detection period in fall 2022. None of the white sharks showed a significant period of residency at the receivers, with typically only a few detections- indicative of transiting behavior.

We assessed acoustic detections of juvenile white sharks in relation to SST to determine cold threshold, and a possible thermal barrier limiting northerly movement. Although we detected juveniles in temperatures as low as 14 °C, a clear preference for temperature > 17.5 °C was evident (Fig 5).

Sevengill sharks showed coastal transits in early spring and early fall, typically avoiding periods where white sharks were present. Sevengill sharks appeared to travel from south to north in the spring and north to south in the fall. We likely missed the early spring movements in 2023 at Cape Arago when we lost the receiver. But sharks showed up in late March at Newport and then early April in Tillamook Bay. We have not downloaded the summer data from 2023 yet in Willapa Bay, but we can conjecture that these animals returned to Willapa throughout the summer. While most of the coastal detections represented transiting movements, sevengill sharks showed significant residency in Willapa Bay. This suggests limited risk in other coastal areas (i.e., Oregon), but has significant implications for proposed re-introductions into bays (see below).

In addition to the sharks detected, our receiver array recorded movements of other important species including green sturgeon (*Acipenser medirostris*), salmon (*Oncorhynchus tshawytscha*.) and soupfin sharks (*Galeorhinus galeus*). While not in the scope of this project, this provides evidence of added value of the work and infrastructure supported by the Elakha Alliance, USFWS, and the OCRF.

White shark drone survey results: During the course of this work we developed new methodologies to measure white sharks' total body lengths (TBL) with reasonable accuracy and precision to identify approximate life stages, which will be the topic of a student led methodology manuscript. We found the mean TBL of white sharks surveyed in juvenile shark aggregating sites at the northern end of the sea otter range to be 2.7m (sd = 0.67m, n = 113). We found that juvenile white sharks in north Monterey Bay tended to aggregate in higher numbers when SST is above 17 °C (Figure 6). This result confirmed acoustic detection results in this area where we saw a cold threshold near 17.5 °C. Furthermore, when ocean temperatures cooled below 17.5 °C, only larger juveniles were detected (Figure 7). Together this supports the hypothesis that juveniles are temperature limited (white sharks are endothermic) and will likely be limited to areas where temperatures are above a threshold corresponding to their size.

Foraging Ecology: Though not within the scope of our original proposal, with support from Elakha Alliance, USFW and OCRF we also collected stomach contents from sevengill sharks to look for evidence they were eating marine mammals and sea otters. We collected stomach contents from 44 sevengill sharks with contents in 29 (66%). Seven sharks had marine mammal in their stomach, which was verified by the USFWS genetics lab to be Harbor seal (*Phoca vitulina*; Figure 8)- but one animal had what seemed to be hair from a different species. We are currently analyzing the hair follicles to determine its origin. Preliminary data from stomach content analysis of sevengill sharks sampled in Willapa Washington suggest that even small (<2m) sevengill sharks do at least occasionally target marine mammals when foraging.

Discussion: We collected preliminary data on the presence of sevengill and white sharks in Oregon. These species have never been studied in Oregon, and outside of opportunistic sightings or acoustic detections, very little was known about their presence to effectively target efforts. As we expected because of this, catching and attracting white and sevengill sharks in this region was difficult; in over ~200 hours of baiting and exploration at multiple sites in Oregon, we did not encounter local white or sevengill sharks. However, we planned for this potential difficulty by tagging sharks in surrounding regions at established field sites. Tagged white sharks migrated up from California and sevengill sharks down from Washington, providing seasonal movement information. The detected white sharks span sizes from juvenile to adult, with primary occurrence in winter, but evidence of sporadic presence in all seasons. These detections fit well with the seasonal timing of human-shark interactions in Oregon (Figure 9), a topic of future work. Similarly, 11 sevengill sharks we tagged in Washington were detected in Oregon and as far as southern California. Similar to white sharks, these animals seemed to move through without spending a significant amount of time at any receiver location. Additionally, sevengill sharks tend to move through in the late fall months and into early winter and again in spring. We can infer directionality of movements, north in the spring and south in the fall, based on residency evidence in Willapa through the summer. However, additional units along the coast will provide more robust evidence into directionality. None of the white or sevengill sharks tended to remain near a receiver for an extended period of time (with the exception of Willapa Bay, WA)- animals seemed to simply move through a region. This could be evidence that animals do not seasonally aggregate as they do in other regions. Alternatively, this may just indicate that our receivers are not ideally placed to detect their residency and additional receivers are necessary. Increasing the number of receivers in the water would increase our odds of detecting aggregations. Additionally, increasing the array would provide more evidence of directionality and given the 5 to 10-year longevity of tags, would increase the value of each tag deployed to generate useful data on shark movements, focal areas and overlap with sea otters. Sevengill sharks in Willapa Bay showed significant presence of marine mammal in their stomachs, evidence of recent interactions. This suggests that they are actively and effectively hunting mammals. This is a highly significant finding, as current feasibility modeling only includes white shark mortality risks, but not sevengill shark-induced rates (T. Tinker *pers comm*). This could indicate a significant consequence for re-introduced sea otters, especially in bays (e.g. Coos Bay) are proposed re-introduction sites, and necessitates further investigation.

Given almost nothing was previously known about white shark and sevengill shark presence in Oregon, our study provides critical preliminary information for specific risk for sea otter re-introductions in Oregon and the surrounding regions. We also established the preliminary foundational infrastructure to build on this preliminary knowledge and continue to inform the overlap between shark species and sea otters.

Project communications: Chapple presented preliminary findings to the OCRF Fund Advisory Committee on October 2, 2023. Additionally, on September 20th, 2023, we met with Tim Tinker (Hydra), Mike Harris (CDFW) and representatives from the Monterey Bay Aquarium to share findings and next-steps for feasibility models of sea otter re-

introduction. We shared information about coastal overlap of sea otters/sharks, but more importantly introduced findings about overlap in estuaries as well. For example, sea otters may be proposed to be re-introduced into Coos Bay, but current modeling scenarios have no parameter of shark overlap/mortality risk in these areas because white sharks in California do not inhabit estuaries. However, our sevengill shark work shows significant potential for spatial and temporal overlap and mammal/shark interactions. Additional data from bays in Oregon will be critical to appropriate parameterization of the models.

Future Directions: The next phase of our project will take a 3-pronged approach. First, we will invest additional effort into acoustic tagging white sharks in California to increase the number of possible migrants to Oregon and continue to maintain and expand the acoustic array to maximize the value of these tags. During our initial phase, we have shown this is an effective, however indirect, means to generate data in Oregon. Second, we will collect and analyze preliminary environmental DNA (eDNA) seawater samples from various locations using established techniques to detect concentrations of white shark DNA, which may provide additional resolution in white shark distribution. Lastly, we will synthesize all available data streams to produce a predictive model on Oregon white shark distribution – this will include merging data generated from this project with historical tagging data, marine mammal distributions, sea otter strandings, habitat types, shark sighting data and shark interactions with humans (see preliminary data in Figure 8). We will then analyze occurrences (geographically, seasonally) against environmental data (i.e., sea surface temperature, dissolved oxygen, primary productivity, etc.) to develop a map of predicted shark hotspots across the historic sea otter distribution gap between Washington and California.

Table 1. Initial deployment information for 9 receivers placed in coastal OR and 2 in Washington.

State	Receiver Location	First Deployment date
Oregon	Newport (nearshore)	July 2020
Washington	Grays Harbor (nearshore)	July 2020
Washington	Grays Harbor (midshelf)	July 2020
Oregon	Cape Arago	May 2021 (Lost 12/22-2/23)
Oregon	Otter Rock	February 2022
Oregon	Seal Rock	February 2022
Oregon	Orford Reef	June 2022
Oregon	Tillamook Head	March 2023
Oregon	Rogue Reef	June 2023

Table 2. Metadata of acoustic tags deployed on white sharks.

Common Name	Date	Location	Sex	TL (cm)
White shark	1/17/22	Central California	U	290
White shark	1/17/22	Central California	F	305
White shark	11/4/22	Central California	M	396
White shark	11/4/22	Central California	M	351
White shark	11/4/22	Central California	M	335
White shark	11/5/22	Central California	F	381
White shark	11/5/22	Central California	F	U
White shark	11/5/22	Central California	M	366
White shark	11/5/22	Central California	M	366
White shark	11/5/22	Central California	M	396
White shark	11/6/22	Central California	M	335
White shark	11/7/22	Central California	U	U
White shark	11/7/22	Central California	U	361
White shark	11/7/22	Central California	M	381
White shark	11/7/22	Central California	U	427
White shark	11/15/22	Central California	F	335
White shark	11/15/22	Central California	F	351
White shark	11/12/22	Central California	M	335
White shark	11/20/22	Central California	U	367
White shark	11/21/22	Central California	F	366
White shark	11/21/22	Central California	F	320
White shark	12/15/22	Central California	F	305
White shark	7/20/23	Central California	U	259
White shark	7/25/23	Central California	F	213
White shark	9/23/23	Central California	F	228
White shark	9/23/23	Central California	F	289
White shark	10/7/23	Central California	M	351
White shark	10/9/23	Central California	F	335
White shark	10/30/23	Central California	M	411
White shark	11/1/23	Central California	F	335
White shark	11/5/23	Central California	F	381
White shark	11/5/23	Central California	F	300
White shark	11/10/23	Central California	F	335
White shark	11/13/23	Central California	F	351
White shark	11/26/23	Central California	F	381
White shark	11/26/23	Central California	F	381
White shark	11/1/23	Central California	F	274
White shark	11/28/23	Central California	F	427
White shark	12/10/23	Central California	F	290

Table 3. Metadata of acoustic tags deployed for sevengill sharks.

Common Name	Date	Location	Sex	TL (cm)
Sevengill	4/15/22	Willapa Bay, WA	F	191
Sevengill	4/15/22	Willapa Bay, WA	F	196
Sevengill	4/16/22	Willapa Bay, WA	M	252
Sevengill	5/16/22	Willapa Bay, WA	M	232
Sevengill	5/17/22	Willapa Bay, WA	F	244
Sevengill	5/23/22	Puget Sound, WA	F	138
Sevengill	5/23/22	Puget Sound, WA	M	212
Sevengill	6/13/22	Willapa Bay, WA	M	222
Sevengill	6/14/22	Willapa Bay, WA	F	183
Sevengill	7/21/22	Willapa Bay, WA	F	176
Sevengill	8/23/22	Willapa Bay, WA	F	257
Sevengill	8/23/22	Willapa Bay, WA	M	U
Sevengill	8/25/22	Willapa Bay, WA	F	248
Sevengill	9/26/22	Willapa Bay, WA	F	170
Sevengill	9/27/22	Willapa Bay, WA	M	228
Sevengill	5/7/23	Willapa Bay, WA	M	170
Sevengill	5/7/23	Willapa Bay, WA	F	166
Sevengill	6/2/23	Willapa Bay, WA	M	151
Sevengill	6/2/23	Willapa Bay, WA	M	205
Sevengill	6/2/23	Willapa Bay, WA	M	171
Sevengill	6/2/23	Willapa Bay, WA	M	234
Sevengill	6/3/23	Willapa Bay, WA	M	199
Sevengill	6/8/23	Puget Sound, WA	M	165
Sevengill	6/14/23	Puget Sound, WA	M	151
Sevengill	6/14/23	Puget Sound, WA	M	145
Sevengill	7/17/23	Willapa Bay, WA	M	131
Sevengill	7/25/23	Willapa Bay, WA	M	228
Sevengill	7/27/23	Willapa Bay, WA	M	167
Sevengill	8/11/23	Puget Sound, WA	M	139
Sevengill	8/15/23	Puget Sound, WA	M	136
Sevengill	8/16/23	Willapa Bay, WA	M	178.5
Sevengill	8/16/23	Willapa Bay, WA	F	151
Sevengill	9/10/23	Willapa Bay, WA	M	244
Sevengill	9/13/23	Willapa Bay, WA	F	178

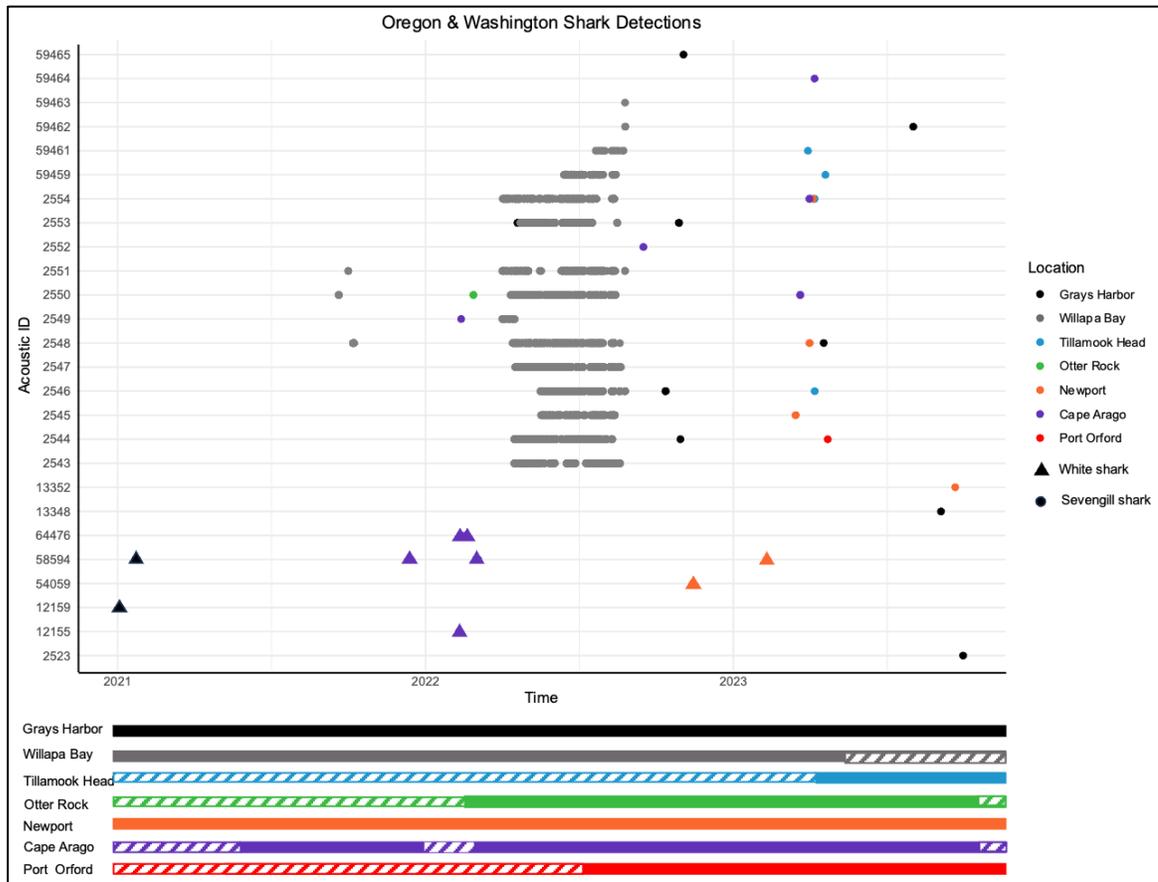


Figure 1. All acoustic tag and receiver data (from north to south) including tagged Sevengill (●) and white sharks (▲) supported through this funding. The acoustic receivers include units in Oregon and the outer coast of Washington and Willapa Bay. The solid color bars indicate when each receiver was active and recording. Hashed colors indicate when receivers were not deployed or if data have not yet been retrieved.

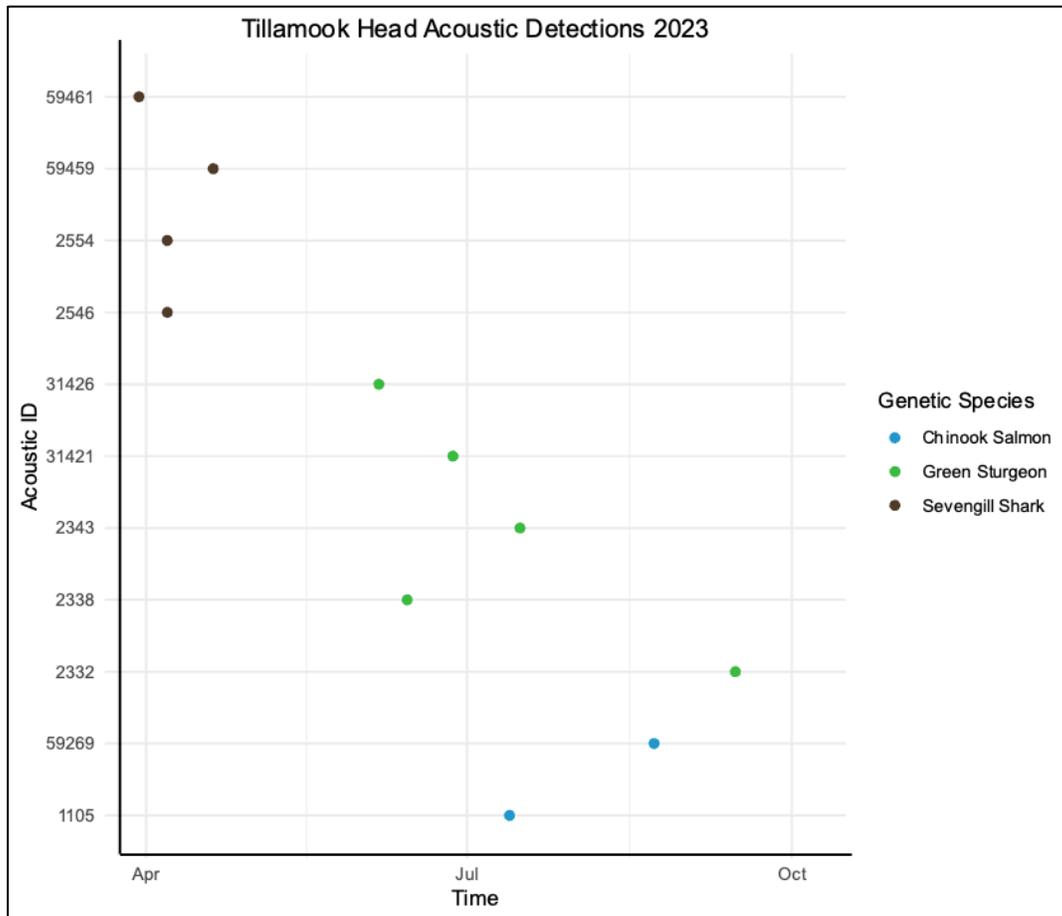


Figure 2. Detections of tagged animals at Tillamook Head. The x-axis represents the entire duration of deployment of the receiver.

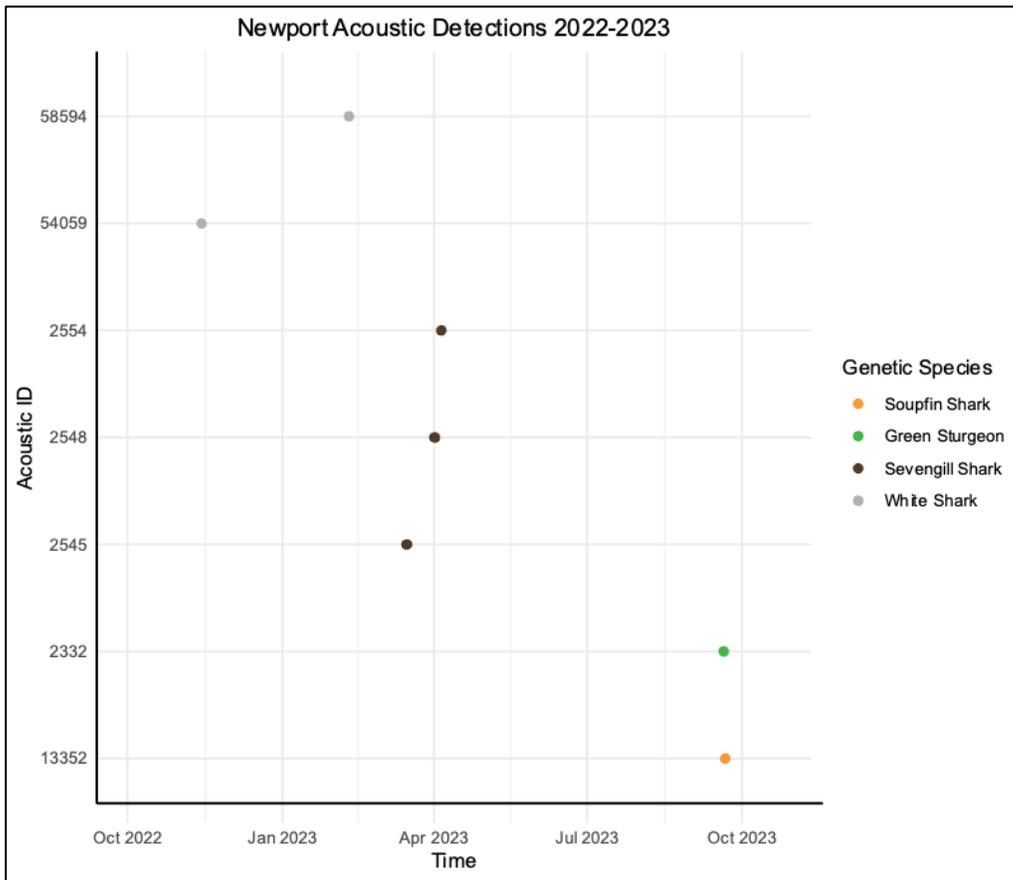


Figure 3. Detections of tagged animals off Newport, OR. The x-axis represents the entire duration of deployment of the receiver.

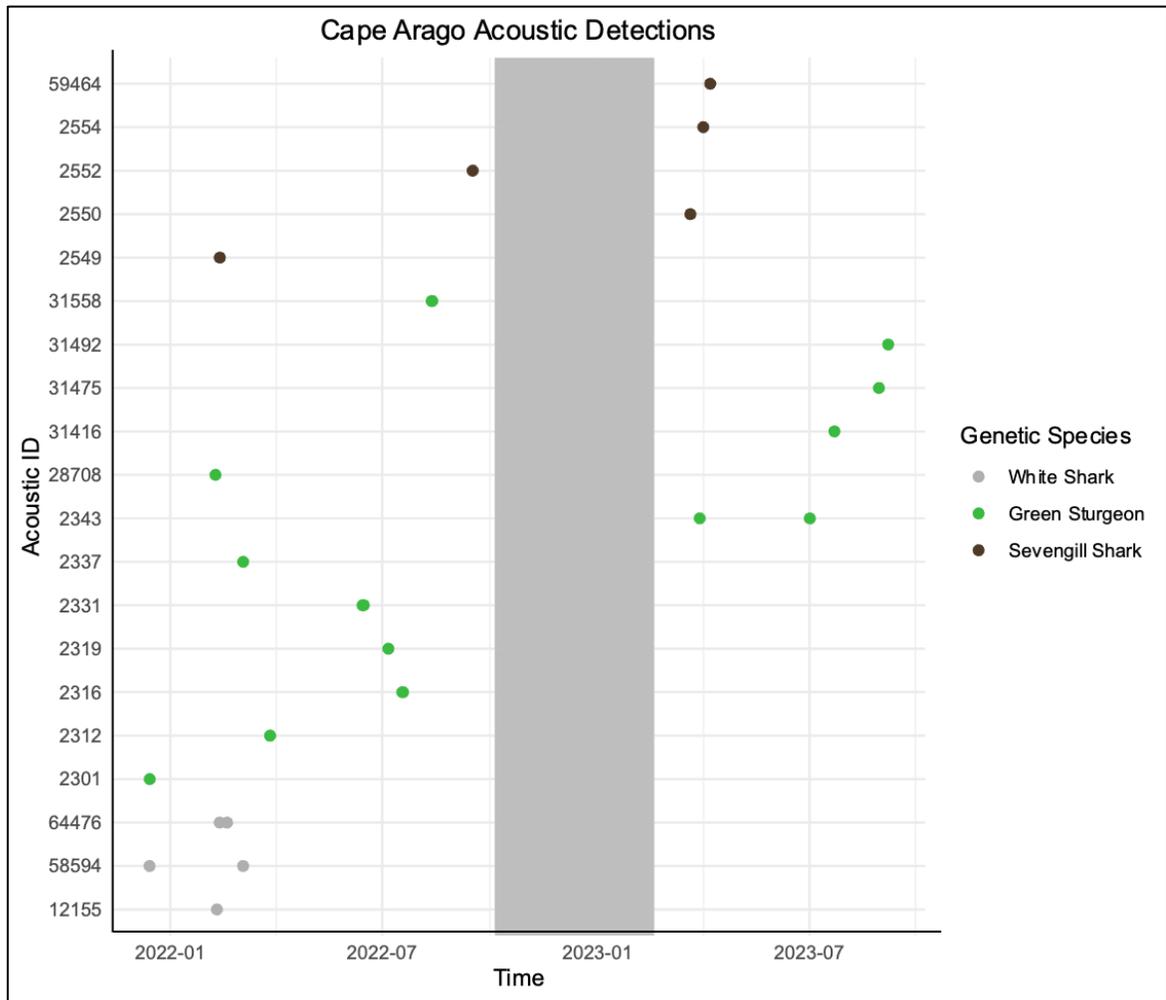


Figure 4. Detections of tagged animals at Cape Arago. The x-axis represents the entire duration of deployment of the receiver with the gray area representing the period where the receiver was lost.

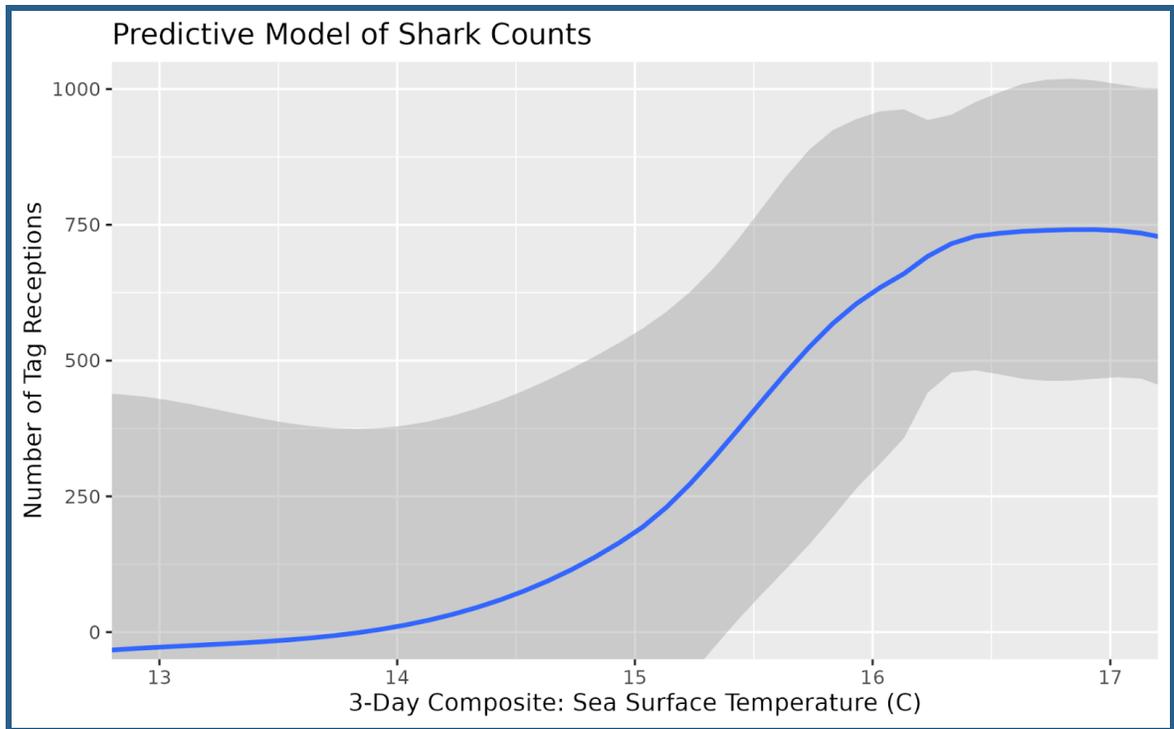


Figure 5. Acoustic detections of white sharks increased above 17.5 deg C, suggesting the lower limit to temperature preference.

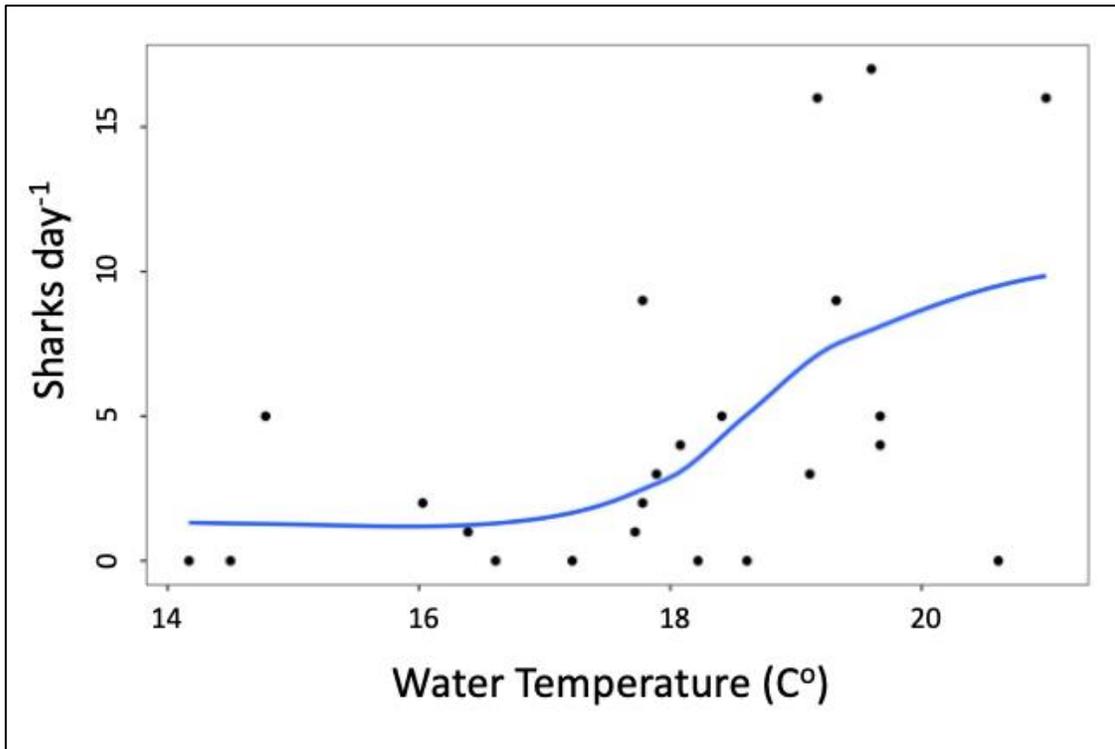


Figure 6. Juvenile white shark abundance assessed from drone surveys in relation to Sea Surface Temperature.

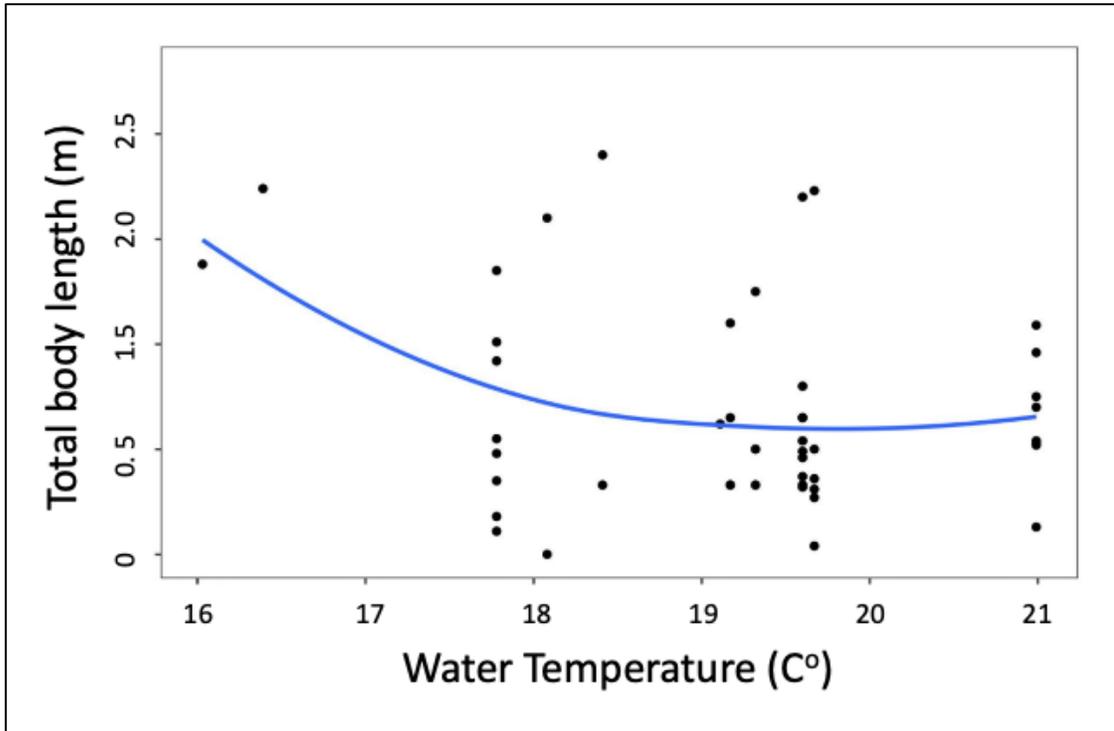




Figure 8. Harbor seal (*Phoca vitulina*) blubber taken from the stomach of a Sevengill shark in Willapa Bay.

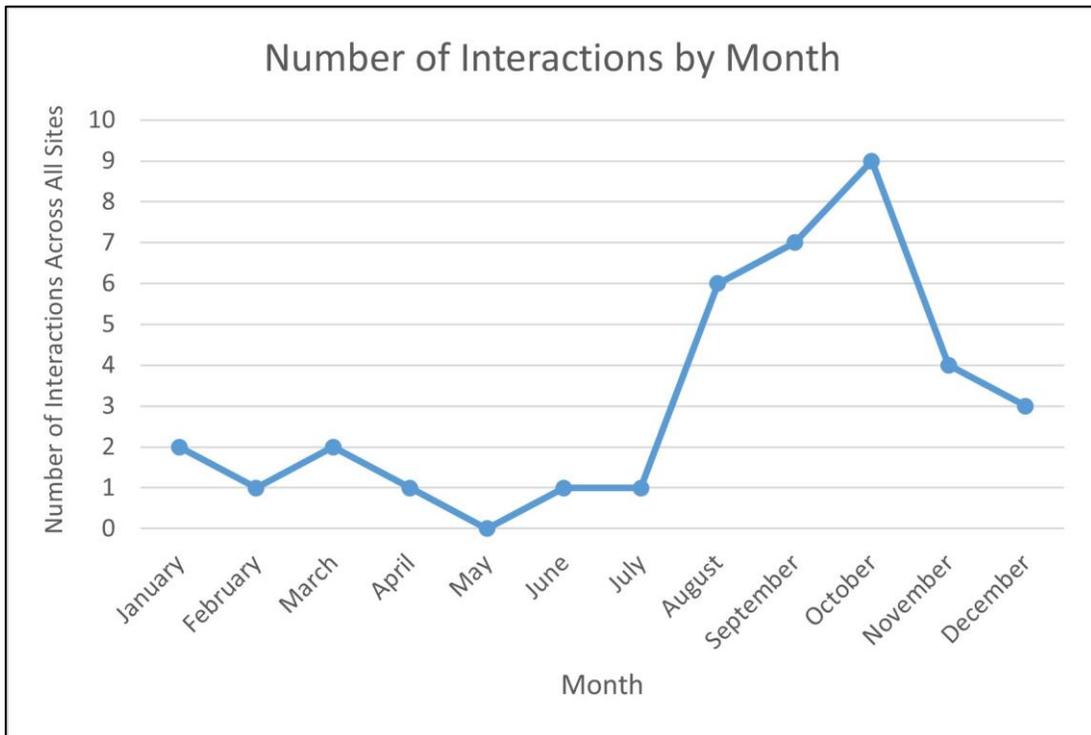


Figure 9. Seasonal distribution of human-shark interactions, which can be an indicator of seasonality of shark presence.

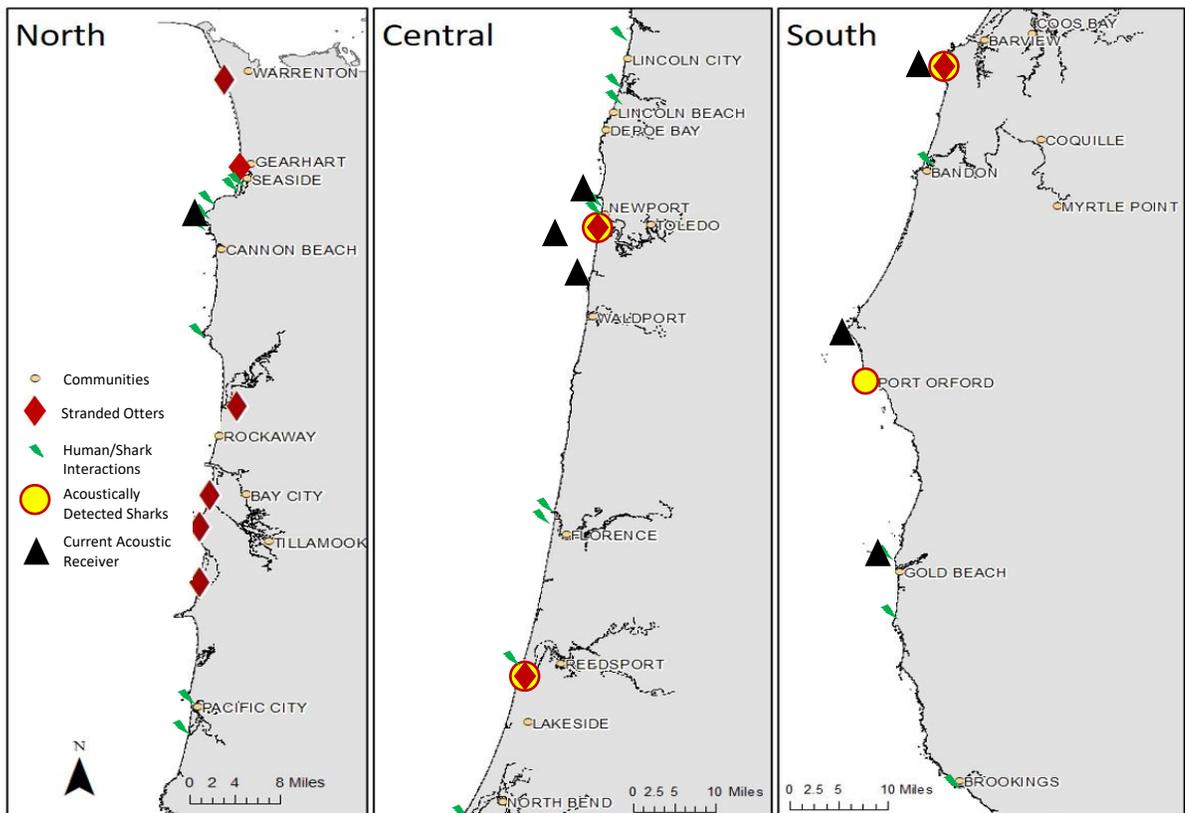


Figure 8. Combined preliminary data of acoustic receivers, detections, otter strandings and human shark interactions for future analysis.