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Phase II- Chinook Occurrence and Stock Origin along coastal WA relative to SRKW (Update Report)

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14. ABSTRACT
The U.S. Navy conducts military training and testing in Pacific Northwest range areas to prepare combat-ready military forces, whereas NOAA Fisheries is responsible for managing threatened and endangered species in marine waters and providing permits to the U.S. Navy. NOAA Fisheries and the U.S. Navy share the common goals of minimizing the impact of military training and testing activities on endangered species without compromising training and testing efforts and reducing adverse environmental effects. This work provides vital geographic and distributional data within the Navy's range areas, allowing the Navy the flexibility to proceed with training and testing while providing protective measures for both salmonids and killer whales.

This research jointly studied Chinook salmon and Southern Resident killer whales (SRKW) in the Northwest Training and Testing (NWTT study area) Range. The authors used acoustic telemetry to map salmon behavior and overlap with SRKW occurrence. By tracking Chinook salmon, SRKW's primary prey, the project aims to guide actions to conserve both species. The data will help adjust activities to minimize harm to these protected species. From May to September 2023, 101 Chinook salmon were caught, tagged, and released north of the Columbia River near the Washington Coast. Acoustic transmitters were surgically implanted into the fish, allowing them to be detected by stationary receivers deployed in the ocean, estuaries, and nearby rivers. The fish's locations and movements were recorded and used to

assess their spatial distribution and behavior. SRKW detections were also collected from March to October 2023 at 15 passive acoustic moorings on the Washington coast. These acoustic moorings, in combination with the 69 kHz receivers, are currently in operation. All but one of the salmon tagged so far were Snake River spring/summer Chinook ESU and the remaining Chinook origin is yet to be determined. Tasks the are still to be completed include tagging an estimated 60 Chinook salmon and analyzing concurrently collected SRKW data. Spring-run Chinook salmon that are returning to the Columbia River are being targeted for this portion of the study, but there is uncertainty regarding the origin of fish captured at sea.

Another aspect of this project is centered around the integration and deployment of Vemco VR2c-cabled receivers on NSF-funded Ocean Observatories Initiative (OOI) buoys, located in Federal waters off the coast of Washington State. These acoustic receivers are designed to detect Vemco-coded 69kHz tags implanted in marine species for passive acoustic monitoring. The OOI buoys, equipped with a comprehensive suite of sensors, are well-suited for this application and a near real-time data communication capability. These buoys collect in situ oceanographic data, including temperature, salinity, pressure, dissolved oxygen, chlorophyll and CDOM fluorescence, light backscatter, and depth-average water velocity. This array of sensors provides a rich contextual backdrop against which animal movements can be better understood and interpreted. Phase I of a three phase process for full integration has been completed. In phase I we completed hardware attachment and deployment durability. Phase II, software integration and near real-time data communication, is currently underway and progressing satisfactorily. Phase III, serving the data via the NANOOS portal, will follow successful accomplishment of Phase II.

15. SUBJECT TERMS
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Executive Summary

The U.S. Navy conducts military training and testing in Pacific Northwest range areas to prepare combat-ready military forces, whereas NOAA Fisheries is responsible for managing threatened and endangered species in marine waters and providing permits to the U.S. Navy. NOAA Fisheries and the U.S. Navy share the common goals of minimizing the impact of military training and testing activities on endangered species without compromising training and testing efforts and reducing adverse environmental effects. This work provides vital geographic and distributional data within the Navy's range areas, allowing the Navy the flexibility to proceed with training and testing while providing protective measures for both salmonids and killer whales.

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Background

The U.S. Navy engages in military training and testing within Pacific Northwest ranges to ensure their forces are combat-ready, while NOAA Fisheries oversees the protection of threatened and endangered marine species, issuing permits to the Navy under the Endangered Species Act (ESA) and Marine Mammal Protection Act (MMPA). The Navy's Marine Species Monitoring (MSM) Program, which is linked to these permits, seeks to understand how the Southern Resident Killer Whale (SRKW) and certain Evolutionarily Significant Units (ESUs) of Chinook salmon, both ESA-listed, share their habitats. Since 2014, the Navy has supported the Northwest Fisheries Science Center's (NWFSC) research to map the SRKW's offshore distribution and identify essential habitats. Beginning in 2018, the Navy has also sponsored the NWFSC to track the offshore distribution of Chinook salmon. NOAA Fisheries and the U.S. Navy share the common goals of minimizing the impact of military training and testing activities on protected species without compromising training and testing efforts and reducing adverse environmental effects. This work provides vital geographic and distributional data for protected species within the Navy's range areas, allowing the Navy to proceed with training and testing while providing protective measures for salmonids and resident killer whales. This report provides an update on the ongoing research activities, summarizing the latest findings on salmon distribution, SRKW vocalizations, and the implementation and use of 69 kHz (VR2c-cabled) receivers on Ocean Observatories Initiative (OOI) buoys to collect these data.

Research efforts to bolster Southern Resident Killer Whale (SRKW) recovery have delved into the ramifications of noise and disturbance, pollutants and contaminants, the availability of prey, and more recently, the implications of genetic inbreeding (Kardos et al., 2023, NMFS, 2008). SRKWs demonstrate a preference for Chinook salmon as their primary prey (Ford et al. 2006, Krahn et al. 2007, Krahn et al. 2009, Hanson et al. 2010, Wasser et al. 2017, Hanson et al., 2021), and the general decline in Chinook salmon numbers could potentially hinder SRKW recovery by leading to decreased birth rates and increased mortality rates among juveniles. Spring-run Chinook salmon utilize coastal habitats along the west coast of Vancouver Island and Washington State during their migration and marine residency. The task of mitigating harvest impacts on these diminished populations is further complicated by variations in habitat use among the populations, such as differences in their migratory patterns and residency on the continental shelf. Moreover, region-wide ecosystem-based management necessitates consideration of the interactions between Chinook salmon and resident killer whales. However, information on the dynamics of predator-prey relations in marine shelf habitats is not yet comprehensive. Hence, management strategies designed to revive at-risk Chinook salmon stocks and ensure sufficient prey for all resident killer whales could benefit from a deeper understanding of the temporal and spatial distribution of salmon.

Animal biotelemetry has been instrumental in developing our current understanding of the movements, migration patterns and trophic interactions of marine, avian, and terrestrial species (Eriksen et al., 2011; Fischer et al., 2009; Sulikowski et al., 2010). Acoustic telemetry has emerged as a widely employed technique in this context, effective due to the ability of acoustic signals to travel over long distances through water. This study utilizes both passive acoustic monitoring; listening for SRKW vocalizations, and acoustic ultrasonic transmitting tags. Both are described in the following text.

SoundTraps, also known as passive acoustic monitoring (PAM) devices, are being used to monitor Southern Resident Killer Whales (SRKW). PAM are essential tools for monitoring the presence of vocalizing marine mammals, including SRKW. These devices enable researchers to detect and analyze the vocalizations of marine mammals over extended periods, which is crucial for understanding their behavior, distribution, and how they are affected by environmental changes and human activities (Baumgartner et al. 2017). For instance, PAM has been used to assess the effects of noise exposure on the vocal behavior of free-ranging killer whales. Studies have demonstrated that SRKWs, in particular, may increase the amplitude of their calls in response to vessel noise, suggesting a potential strategy to overcome background noise interference (Holt et al., 2009). Additionally, the use of PAM has enabled the detection of these whales in areas congested with anthropogenic underwater noise sources, such as commercial ships and whale-watching boats, highlighting the significance of sound for their biosonar, communication, and passive listening (Holt et al., 2008). Furthermore, PAM devices are instrumental in the ongoing research to monitor and interpret different soundscapes within SRKW critical habitats, which can vary significantly from open ocean areas to those dominated by anthropogenic noise-sources. These soundscapes can have implications on the orcas' ability to communicate and find prey (Vagle et al., 2018). Overall, PAM provide invaluable insights into marine mammal monitoring and are key to implementing effective conservation measures for species like the SRKW (Verfuss et al. 2018).

The movement patterns of SRKW are complex and seasonally driven; some pods engage in extensive travel along the North American west coast, extending from the southern reaches of California to the northern waters of British Columbia, while others may stay relatively close to specific areas like the Salish Sea, particularly during the salmon runs on which they heavily rely. Passive acoustic monitoring has been pivotal in providing insights into the SRKWs' distribution and behavior, particularly within critical habitats. This acoustic data, collected through an array of hydrophones, is crucial for understanding the SRKWs' use of the NWTT study area and surrounding areas. Such monitoring has revealed patterns in their vocalizations that correlate with foraging and social interactions, helping to shed light on their presence and movements in relation to prey availability and human activities along Washington State's coastline (Hanson et al., 2013). This ongoing study integrates these detections with broader research efforts, contributing to a more comprehensive understanding of SRKW ecology and assisting in the development of effective conservation strategies.

This study also utilizes acoustic telemetry to track the movement and timing of individual Chinook salmon as they traverse the oceanic shelf. This method of animal biotelemetry utilizes acoustic ultrasonic transmitting tags, which are attached or implanted in marine species. These tags are designed to emit a specific acoustic sequence, unique to the transmitting tag, allowing for the individual identification of tagged marine animals (Block, 2011). These underwater acoustic signals are detected, decoded and stored by hydrophones equipped with acoustic receivers, which are anchored at pre-established 'listening stations' (Klimley et al., 1998). These listening stations can be deployed in extensive arrays to effectively track the migratory movements of tagged marine species, with a range of up to 800 meters. However, this range can vary depending on environmental conditions and equipment configuration (Heupel et al., 2006). The migratory patterns of Chinook salmon are diverse; some undertake extensive journeys, such as those originating from the Columbia River and traveling to the Gulf of Alaska, while others undertake shorter voyages, remaining in marine waters proximate to their birth rivers, like those from the Columbia River that migrate to Washington State's coast. In this investigation, acoustic tags are being implanted in Chinook salmon to monitor their spatial distribution and behavioral patterns within the vicinity of the NWTT study area along Washington State's shoreline. These findings are being integrated with SRKW location data, acquired by colleagues at the Northwest Fisheries Science Center and Oregon State University, to evaluate the concurrence of both species' movements over time and across regions.

Operating over prolonged deployment periods, these acoustic listening stations consistently monitor and record the presence of tagged and vocalizing marine animals within their range while also contributing to regional collaborative acoustic networks. These collaborative networks enhance research by expanding the geographic scope of detection data and fostering partnerships that aim to advance marine research and management (Ellis et al., 2019). To demonstrate the effectiveness of more permanent listening stations, we are establishing an acoustic ultrasonic transmitting tag receiver on the NSF-funded Ocean Observatories Initiative (OOI) Coastal Endurance Array. This mooring was selected as the primary platform for the deployment of this acoustic receiver because of its proximity to the Navy's NWTT study area and the ability of OOI buoys to collect oceanographic data relevant to the movement patterns of managed marine species. Equipped with a suite of sensors, these buoys collect a range of oceanographic data that can significantly enhance the understanding of environmental contexts influencing species movement patterns. The parameters measured include temperature, salinity, pressure, dissolved oxygen, chlorophyll and CDOM fluorescence, light backscatter, and depth-average water velocity. These variables are crucial in movement studies as they provide insights into the conditions that marine species experience and respond to in their natural habitats. Furthermore, the cabled design of the (Vemco VR2c) receivers enables the OOI mooring electronics to facilitate the rapid relay of detection data to shore-based facilities, with information becoming available through OOI's raw data server within hours of collection. By integrating environmental data with passive acoustic monitoring of tagged marine species, we can gain a more comprehensive understanding of how different oceanographic conditions affect marine species and their movement patterns in the NWTT study area and broader Northeast Pacific. The near real-time availability of acoustic detection data will enhance our ability to mitigate and avoid negative interactions between these populations of vulnerable marine species and anthropogenic activities (e.g., commercial fishing, military operations, and maritime traffic).

Methods

Fish tagging and detection- Chinook salmon were caught with hook and line or were collected in the Snake River and were tagged from May to September 2023 and were detected by stationary acoustic receivers deployed in the coastal Pacific Ocean, estuaries, and nearby rivers. Fish that were tagged in previous years and as a part of other projects were detected on our array and are reported here if we had the tag metadata available. Chinook salmon that we tagged were surgically implanted with InnovaSea 69 kHz transmitter tags (random ping rate between 1 ping per 60 and 120 s). Each individual was immediately put into anesthetic (25 mg/L; AQUI-S® 20E) until the fish reached level III anesthesia (i.e., total loss of equilibrium and no reaction to touch stimuli, ~4 min.). The use of AQUI-S® 20E was used under INAD permit #11-47. Once anesthetized, the fork length (nearest cm) was measured, scales were taken from the preferred area for aging, and a fin clip was taken from the anal fin for genetic analysis. To implant the transmitter, a 10-15 mm incision was made with a sterile scalpel, the transmitter and a passive integrated transponder (PIT; for detection at freshwater points such as dams) were inserted into the body cavity, and the incision was sutured with two or three simple interrupted surgeon's knots using an Ethicon Y513 4-0 Monocryl suture with a 19 mm reverse cutting needle. After surgery, the fish was placed in a recovery tank of fresh seawater with an aerator until the fish was vigorously swimming and recovered (~5-10 min.). After recovery, the fish was released near the capture location. The latitude, longitude, and time of fish release were recorded for each individual. We tagged 101 Chinook salmon from May to September 2023 from the Columbia River (Figure 1). We deployed InnovaSea 69 kHz VR2AR acoustic receivers along the coast of Washington State to detect acoustically tagged Chinook salmon (Figure 1).

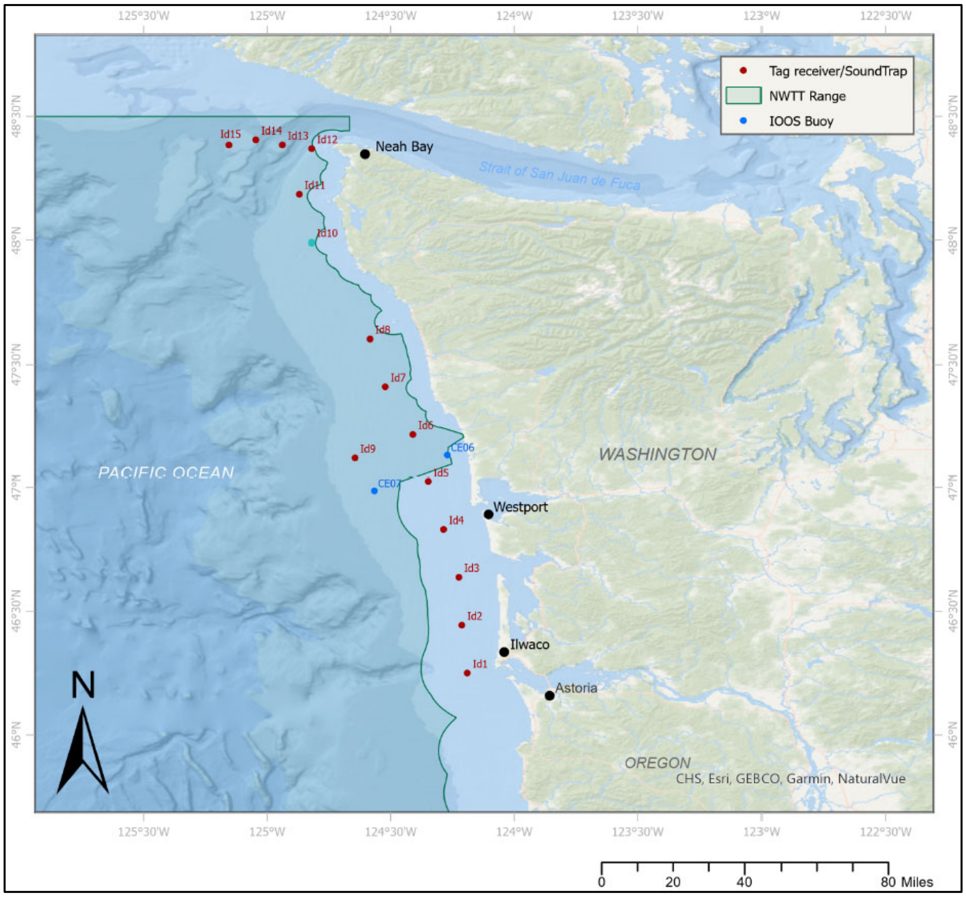

***Figure 1**. Map of acoustic receiver/Sound Trap and IOOS buoy locations along the Washington Coast. Each mooring has a 69 kHz receiver and a Sound Trap that records animal vocalizations.*

Killer Whale Vocalizations- In 2023, 15 SoundTraps were deployed in March and May. Six of them were recovered between September and October, and three remain installed on the northern margin of the Olympic Coast National Marine Sanctuary (OCNMS). In a second deployment in November, four SoundTraps and four corresponding acoustic receivers for stations 1-4 (ID#) on the map in Figure 1 were deployed. In total, fifteen moorings, each comprising a SoundTrap and an acoustic receiver, were deployed along the coast of the state of Washington near the 50-meter isobath. Each instrument was spaced approximately 20 km apart, except for four of them, which are located on the northern margin of the OCNMS with a separation of approximately 10 km each (Figure 1).

The SoundTraps deployed in March 2023 were programmed to continuously record at a sampling rate of 192 kHz, while those deployed in November 2023 were programmed to record at the same frequency but with a recording period of 12 minutes and 8 minutes of inactivity. This was done to extend the battery life, especially during the winter months when maintaining the SoundTraps can be challenging due to weather conditions.

IOOS Buoy Integrated acoustic tag detection- A stepwise approach structures this project into three distinct phases, starting with a proof-of-concept trial for the physical hardware attachment and durability in Phase I. Integration of non-cabled Vemco VR2W acoustic receivers occurred within the OOI Coastal Endurance Array. These receivers share characteristics with the cabled VR2c units, such as size, durability, longevity, housing material, and acoustic range, but do not require software integration. Unlike the VR2c-cabled receivers, VR2W units do not offer near real-time transmission; physical retrieval is necessary for data access, requiring manual download of the detection log. To facilitate successful deployments of future acoustic receivers, a specific mounting bracket was designed and constructed to attach VR2c-cabled receivers to the existing OOI Endurance Near Surface Instrument Frame (NSIF) platform. This bracket secures the acoustic receivers during deployment and underwent field testing with the deployment of VR2W non-cabled receivers at stations CE06 ISSM and CE07 SHSM in spring/summer 2023 (Figure 1). Selection of the OOI Coastal Endurance Array buoys, particularly CE06 Inshore Surface Mooring (CE06 ISSM) and CE07 Shelf Surface Mooring (CE07 SHSM), for this project was strategic due to their proximity to the Navy's Study Area. Situated near Grays Harbor, Washington State, CE06 ISSM is located at 47.1347°N, -124.271°W in a bathymetric depth of 29 meters, and CE07 SHSM at 46.9859°N, -124.566°W in a depth of 87 meters, offering monitoring capabilities in varying marine environments.

Simultaneous with Phase I, work on Phase II began, focusing on the integration of the software components of the VR2c units with the OOI data transmission system. Unlike the VR2W non-cabled receivers, which require physical recovery to access detection data, VR2C-cabled receivers need integration with OOI electronics. This system queries the receivers, copies their acoustic detection data, and then telemeters the data to shore within hours of collection, making it available through OOI's raw data server. Since phase II was initiated, the availability of ports on the OOI Coastal Endurance Array mooring electronics compatible with the RS232/RS485 external connectors on VR2c receivers has been confirmed. Successful data transfer between the VR2c receivers and OOI controllers was achieved in land-based trials. The forthcoming part of this phase includes incorporating these data packets into the telemetered data stream. Phase III, serving the data via the NANOOS portal, will follow the completion of Phase II.

Results and Discussion

Salmon detections (preliminary results)- In May of 2023, of the 100 smolts and one sub-adult of Chinook salmon were tagged and released off the coast of Washington, 56 individuals were detected during the months of May and June with 640 detections. 635 detections occurred in May and 35 occurred in June. Chinook salmon smolts detected during 2023 were mostly detected between 11:00 a.m. and 6:00 p.m. (Figure 2) with reduced activity at night.

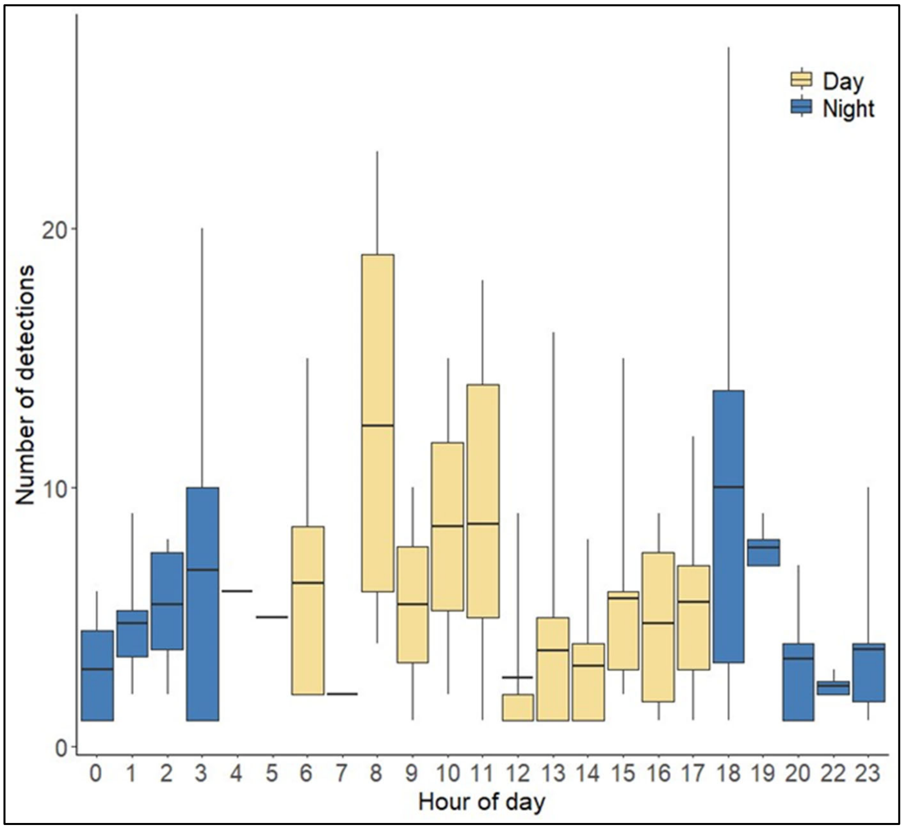

Figure 2. *Number of detections for smolts of Chinook salmon for each in 2023. The yellow color represents daylight hours, and dark blue color depicts night hours. Horizontal black lines show the mean of number of detections, and vertical lines show the 95% confidence intervals.*

The highest spatial activity was located south of the Washington state coast. Smolts moved along the Washington coast, but the highest activity remained south of the state, between the mouth of the Columbia River and the receivers located at Long Beach, WA (Figure 3). Most tagged individuals made north-south trips along the entire Washington coast and vice versa during the detectability period (Figure 4), with the last detection generally near the mouth of the Columbia River.

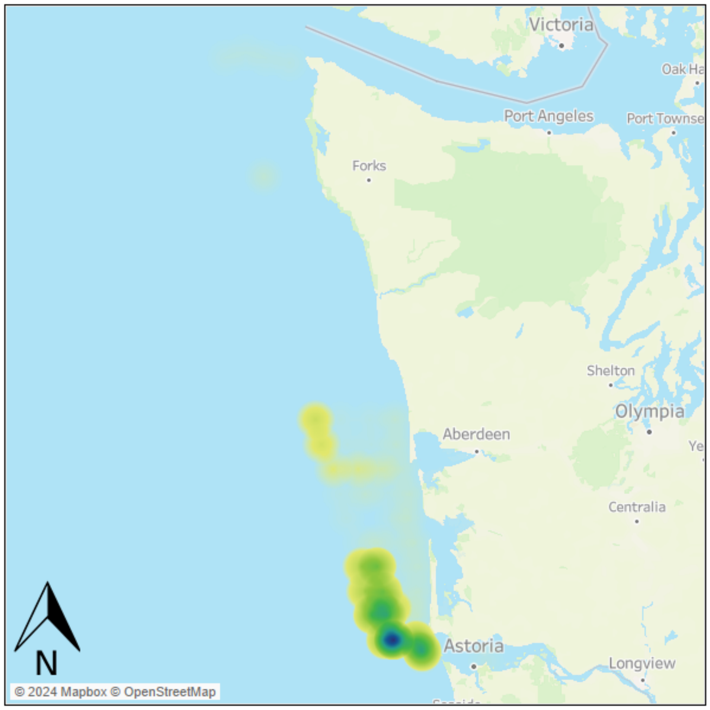

Figure 3. *Density plot of smolts of Chinook salmon detection activity throughout the acoustic array in 2023. The darkest the color the higher the number of detections.*

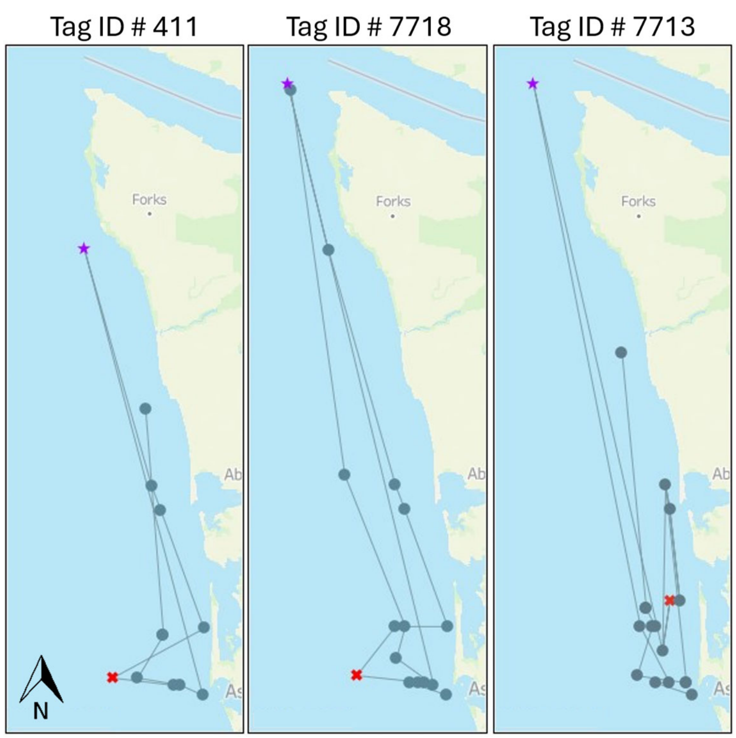

Figure 4. *Movement patterns of three smolts of Chinook salmon. Purple stars indicate the initial detection station, while red crosses mark the final detection station.*

Killer Whale detections (preliminary results)- From the first recovered SoundTraps, nearly 14,000 audio files were obtained, translating to 14,000 continuous hours of recording. This information is currently being analyzed to extract data on the presence and movements of Southern Resident killer whales off the coast of Washington. The files collected through the SoundTraps underwent a decimation process to reduce computational load and improve analysis efficiency. Subsequently, Long-Term Spectral Average (LTSA) representations were created for each monitoring station. These LTSA representations offer a comprehensive overview of the acoustic signals over time, highlighting temporal and frequency patterns that are essential for understanding the behaviors of marine mammals. Using Triton software, detailed analyses were conducted to identify specific vocalizations of marine mammals, such as killer whales (Figure 5).

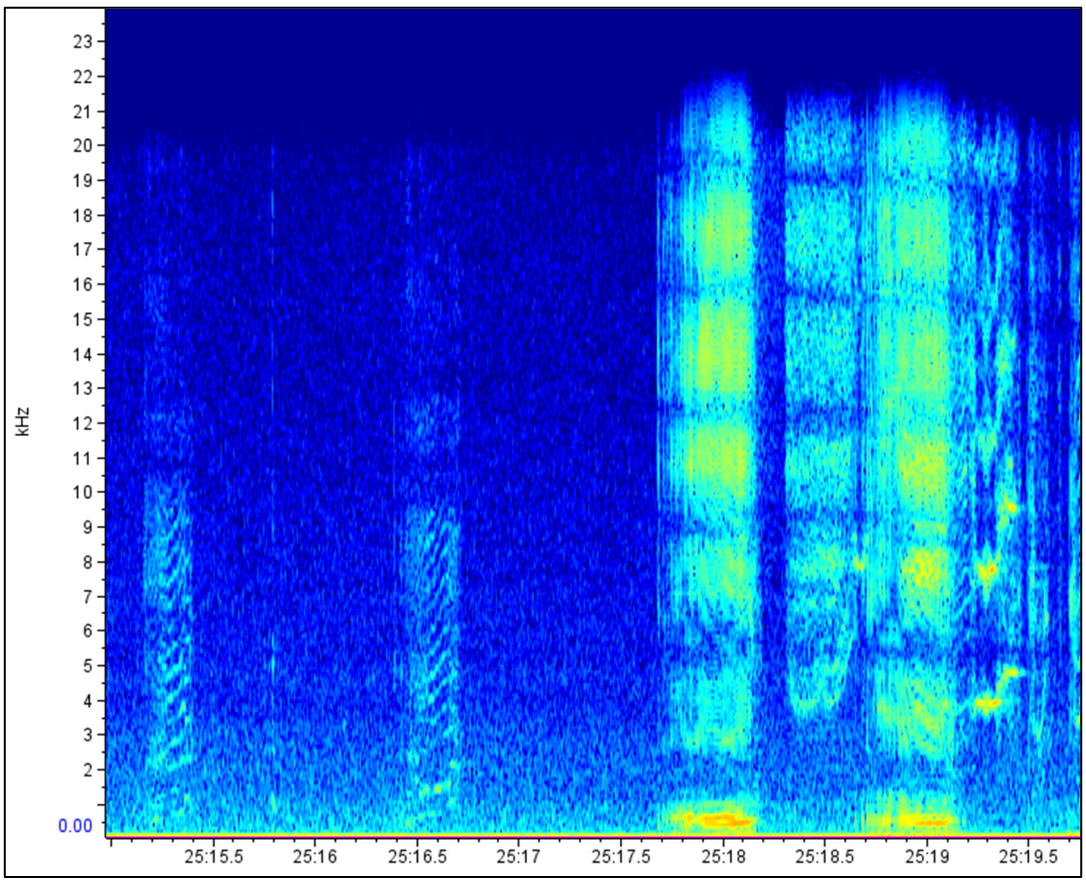

Figure 5. *Killer whale calls found in the LTSA files from station # 3.*

Additionally, a specialized algorithm was employed to detect sounds emitted by vessels within the LTSA data. This analysis provided valuable information about the presence and frequency of human activities in the study areas, allowing for an assessment of their potential impact on marine mammal populations, particularly the Southern resident orcas.

IOOS Buoy Integrated acoustic tag detection- attachment design was sufficiently compact to be integrated into the NSIF without interfering with any core OOI instrumentation. The receivers proved effective, recording 86 unique acoustically tagged individuals [825 total detections]. This highlights the ecological importance of the NWTT Study Area as a migratory conduit for out-migrating Chinook salmon smolt and the endangered Southern DPS green sturgeon, as well as other migratory marine fish species. It provides insights into the temporal patterns and species diversity utilizing the NWTT Study Area.

At the nearshore station CE06 ISSM a total of 799 detections of marine animals, tagged with Vemco 69kHz acoustic transmitting tags, were recorded, detecting five unique species: white sharks, sevengill sharks, soupfin sharks, green sturgeon, Chinook salmon. Offshore station CE07 SHSM recorded 26 detections of two tagged species: steelhead and green sturgeon, with steelhead detected only at this offshore station. This observed variation in detections and species assemblages between receiver stations along the continental shelf underscore the importance of implementing acoustic arrays across varied bathymetries and marine habitats to obtain comprehensive ecological insights.

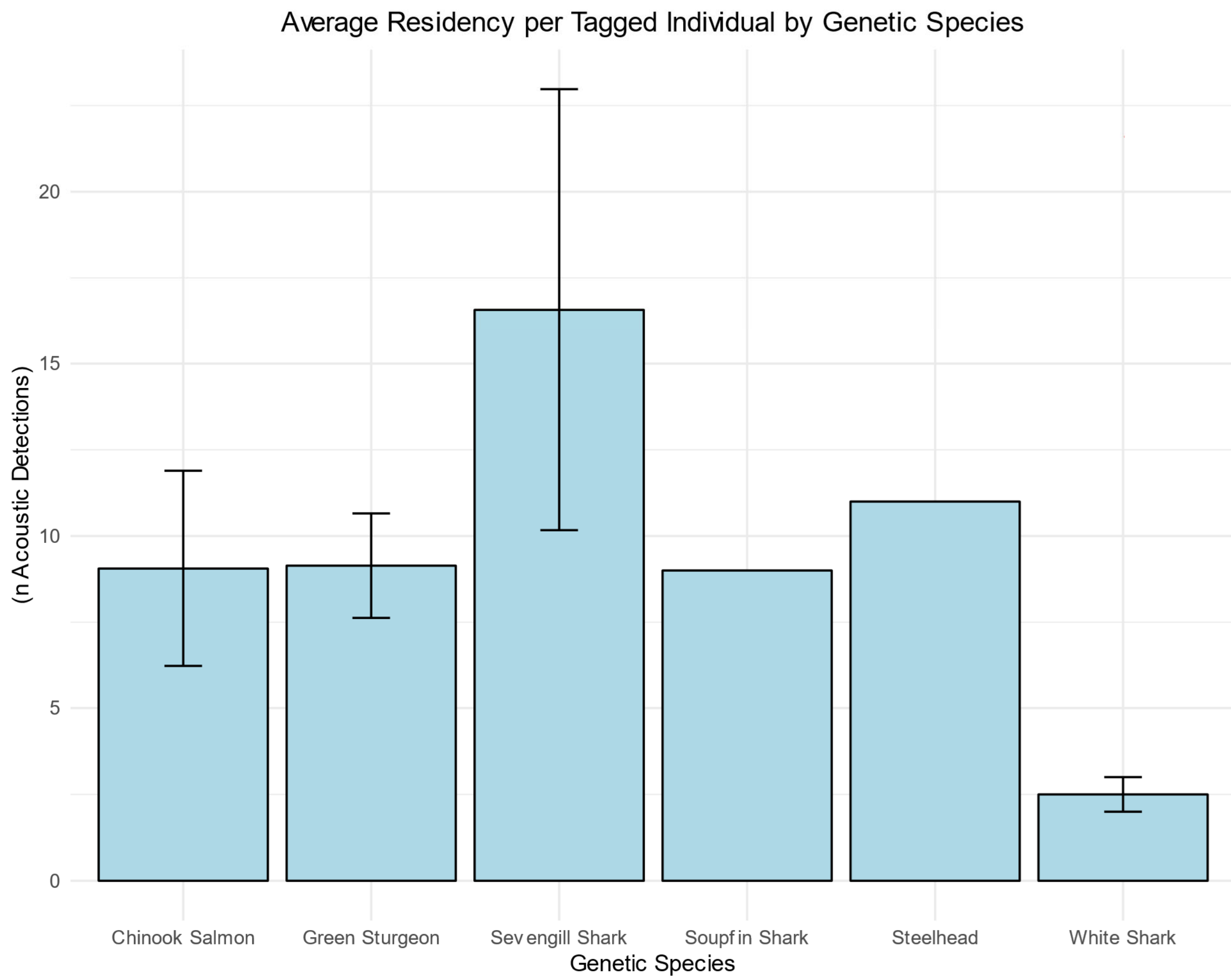

Figure 6: *Bar plot representing the average number of detections per tagged individual (proxy for residence times) for each of the six marine species detected at acoustic receiver stations CE06 ISSM and CE07 SHSM. The plot illustrates the average number of detections that occured for eachindividual of a given species. Error bars indicate the species specific standard error [S.E. (Chinook salmon) = 2.146, S.E. (green sturgeon) = 1.515, S.E. (sevengill shark) = 6.403, S.E. (white shark) = 0.500. Error bars for the soupfin shark and steelhead are not included due to detection of only one unique individual (S.E. = NA)].*

Analysis of acoustic detection data revealed variation in the number of detections per tagged individual, both across and within species within the monitored regions of station CE06 ISSM and CE07 SHSM. Among tagged marine species, green sturgeon accounted for 63.20% of all recorded detections and 66.28% of all unique tagged individuals. A total of 57 distinct tagged green sturgeon were detected, averaging 9.14 detections per individual. 18 distinct tagged Chinook salmon were detected, with a mean of 9.10 detections per individual, and 7 sevengill sharks were detected, with a mean of 16.57 detections per individual. Additionally, one soupfin shark, one steelhead and two white sharks were detected at stations CE06 ISSM and CE07 SHSM with mean detections per individual of 11.00, 9.00 and 2.50 respectively (Figure 6).

Project Challenges and Operations Update

Moorings and salmon tagging- The project has encountered several challenges that have resulted in delays to the scheduled timeline. These challenges include failures in mooring release mechanisms, difficulties in procurement processes, a temporary unavailability of NOAA funds allocated for this project since October 2023 to present, and personnel changes. It is noteworthy that travel expenses for project personnel were not reimbursed by NOAA, and there were restrictions on contract engagements and purchases by NOAA for more than six months.

Despite these obstacles, field operations were conducted from Neah Bay with support from collaborators at Oregon State University and biologists from the Makah Tribe. An unforeseen cancellation by the scheduled vessel due to crew health issues necessitated a swift adaptation. The project team successfully retrieved and redeployed several moorings in winter 2024. This involved the use of specialized equipment to manage the more complex moorings, significantly increasing the time and financial resources required for these activities. This phase of fieldwork also necessitated adherence to sanctuary requirements regarding the retrieval of all mooring components, further escalating operational demands. Following this, additional opportunities for fieldwork were capitalized on to service southern moorings, encompassing data download, battery and memory card replacements, and other maintenance and deploy all of the remaining moorings in the OCNMS. Challenges in personnel availability necessitated reliance on external support to accomplish these tasks within a constrained timeframe.

Upon completion of mooring operations, the project will shift focus to the tagging of Chinook salmon, aiming to optimize the timing for tagging activities to coincide with the return of spring-run fish. This effort is anticipated to yield valuable movement data, regardless of the specific run timing of the tagged fish.

Data Processing- The project's acoustic data processing efforts are conducted within the Marine Mammal Bioacoustics and Ecology Laboratory, overseen by Kate Stafford. This team is responsible for the analysis of SoundTrap data, with the aim of developing automated detectors for killer whale acoustics to support NOAA management priorities. The process involves annotation and identification analysis by a dedicated team, including contributions from students. Preliminary results have already identified the presence of Southern Resident killer whales in the study area, with further analyses ongoing to refine and expand these findings. In parallel, the salmon data is processed by NOAA and OSU project members with the assistance of a NOAA contractor, leveraging a computer science background to facilitate this work.

The culmination of these efforts is expected to contribute significantly to the understanding of Chinook occurrence and stock origin along the Coastal Washington area, with implications for the management and conservation of Southern Resident killer whales.

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