**Oregon State University
Marine Mammal Institute**

Ocean Ecology Lab

Characterizing Behavior and Distribution of Chinook Salmon, Southern Resident Killer Whales, and Other Whales in Offshore Marine Waters of Washington (Progress Report)

Photo Credit: Astrid van Ginneken, Center for Whale Research

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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 National Oceanic and Atmospheric Administration (NOAA) Fisheries is responsible for managing threatened and endangered species in marine waters and providing permits to the U.S. Navy for training and testing. 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 (*Oncorhynchus tshawytscha*) and Southern Resident killer whales (SRKW) in the Northwest Training and Testing Study Area (NWTTSA) Range. The authors used acoustic telemetry to examine salmon movement behavior and overlap with SRKW occurrence. By tracking Chinook salmon, SRKW's primary prey, the project provides information to guide actions to conserve both species. The data will help adjust activities to minimize harm to these protected species. From February to October 2024, an array of moorings designed to detect both acoustically tagged fishes and vocalizing marine mammals was maintained on the outer coast of Washington State.

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These 15 moorings each included an InnovaSea VR2AR acoustic receiver to detect 69 kHz transmitting tags implanted in Chinook salmon, green sturgeon (*Acipenser medirostris*), sixgill sharks (*Hexanchus griseus*), and soupfin sharks (*Galeorhinus galeus*) that have been deployed by researchers in the United States and Canada. In addition, each mooring was outfitted with a continuously recording Ocean Instruments SoundTrap 600 to detect vocalizing marine mammals, with a focus on killer whales.

The locations and movements of Chinook salmon were recorded and used to assess their spatial distribution and behavior. SRKW detections were also collected from February 2023 to October 2024 at 15 passive acoustic moorings on the Washington coast. These acoustic moorings, in combination with the 69 kHz receivers, are currently in operation.

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. Phases I and II of a three phase process for full integration have been completed. In phase I we completed hardware attachment. In Phase II, we completed software integration and implemented near real-time data communication, transmitting updated logs of acoustic detection data to the OOI raw data server. Phase III, currently underway, will enable the delivery of detection data and associated species identifications via public-facing interface on the Northwest Association of Networked Ocean Observing Systems (NANOOS) portal.

15. SUBJECT TERMS
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Table of Acronyms

NOAA	National Oceanic and Atmospheric Administration
SRKW	Southern Resident killer whales
NWTTSA	Northwest Training and Testing Study Area
OOI	Ocean Observatories Initiative
NANOOS	Northwest Association of Networked Ocean Observing Systems
ESA	Endangered Species Act
MMPA	Marine Mammal Protection Act
ESU	Evolutionarily Significant Unit
NWFSC	Northwest Fisheries Science Center's
PAM	passive acoustic monitoring
ISSM	Inshore Surface Mooring
SHSM	CE07 Shelf Surface Mooring
LTSA	Long-Term Spectral Average
IOOS	Integrated Ocean Observing System

Executive Summary

The U.S. Navy conducts military training and testing in Pacific Northwest range areas to prepare combat-ready military forces, whereas National Oceanic and Atmospheric Administration (NOAA) Fisheries is responsible for managing threatened and endangered species in marine waters and providing permits to the U.S. Navy for training and testing. 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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The locations and movements of Chinook salmon were recorded and used to assess their spatial distribution and behavior. SRKW detections were also collected from February 2023 to October 2024 at 15 passive acoustic moorings on the Washington coast. These acoustic moorings, in combination with the 69 kHz receivers, are currently in operation.

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. Phases I and II of a three phase process for full integration have been completed. In phase I we completed hardware attachment. In Phase II, we completed software integration and implemented near real-time data communication, transmitting updated logs of acoustic detection data to the OOI raw data server. Phase III, currently underway, will enable the delivery of detection data and associated species identifications via public-facing interface on the Northwest Association of Networked Ocean Observing Systems (NANOOS) portal.

Background

The U.S. Navy engages in military training and testing within Pacific Northwest waters 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 SRKWs and certain Evolutionarily Significant Units (ESUs) of Chinook salmon, both ESA-listed, share their habitats. Since 2014, the Navy has supported the NOAA Northwest Fisheries Science Center's (NWFSC) research to map the SRKW's offshore distribution and identify essential habitats. Beginning in 2018, the Navy also sponsored the NWFSC to track the offshore distribution of Chinook salmon. Beginning in 2024, the Navy sponsored Oregon State University to maintain an array of acoustic moorings to track the occurrence of SRKW and detections of fishes tagged with acoustic transmitters, including Chinook salmon, on the outer coast of Washington. NOAA Fisheries and the U.S. Navy share the common goals of minimizing the impact of military training and testing activities on protected species and the environment without compromising training and testing requirements. This work provides vital geographic and distributional data for protected species within the NWTTSA 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 and SRKW vocalizations.

Research efforts to bolster SRKW recovery have explored 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, Stewart et al. 2021, 2023), and the general decline in Chinook salmon numbers could potentially hinder SRKW recovery by leading to decreased birth rates and increased mortality rates (Stewart et al. 2021). Spring-run Chinook salmon utilize coastal habitats along the west coast of Vancouver Island and Washington State during their migration and marine residency (Tucker et al. 2011). 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—passive recording of SRKW vocalizations—and acoustic ultrasonic transmitting tags. Both are described in the following text.

SoundTraps, also known as passive acoustic monitoring (PAM) devices, are used to monitor 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 (Williams et al. 2014). 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 generally quieter open ocean areas to coastal areas often dominated by anthropogenic noise-sources. These soundscapes can have implications for the ability of SRKW to communicate and find prey (Vagle et al. 2018, Holt et al. 2021, Tennessen et al. 2024). 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 the three SRKW pods, currently totaling 73 individuals, 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 NWTTSA 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 study seeks to provide a more comprehensive understanding of SRKW seasonal movements and occupancy along the outer coast of Washington State, and the relationship between SRKW distribution and Chinook salmon prey distribution, assisting with 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 involves attaching or implanting acoustic ultrasonic transmitting tags in a target 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 detection 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 migrations, such as those originating from the Columbia River and traveling to the Gulf of Alaska, while others undertake shorter migrations, remaining in marine waters proximate to their natal rivers, like those from the Columbia River that migrate to Washington State's coast. In this investigation, acoustic tags implanted in Chinook salmon are monitored using acoustic receiver moorings to study their spatial distribution and behavioral patterns within the vicinity of the NWTTSA study area along Washington State's coastline. These findings are being integrated with SRKW location data to evaluate the concurrence of both species' movements over time throughout this region.

Operating over prolonged deployment periods, these acoustic listening stations, comprised of both ultrasonic acoustic receivers and PAM devices, consistently monitor and record the presence of tagged and vocalizing marine animals within their range while also contributing to regional collaborative acoustic telemetry 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 NWTTSA 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) receiver 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 acoustic detections 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 NWTTSA and broader Northeast Pacific. The near real-time availability of acoustic telemetry 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 - Beginning in 2024, Chinook salmon were captured using hook and line in coastal marine waters off Washington State, primarily from the Columbia River mouth north to Grays Harbor, with additional sampling conducted near La Push, Washington, within the footprint of the stationary acoustic receiver array. Captured fish represented juvenile and sub-adult Chinook salmon; life stage was inferred post-capture based on fork length rather than used as a capture criterion. The full list of tagged Chinook salmon for this study period (n=63) is provided in Supplemental Table 1. 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 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, established area for aging (posterior to the dorsal fin and above the lateral line), and a fin clip was taken from the anal fin for genetic analysis. No explicit minimum size threshold was imposed; fish were selected based on suitability for surgical implantation of acoustic and PIT tags following established tagging guidelines (Smith et al. 2024). 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 (Supplemental Table 1).
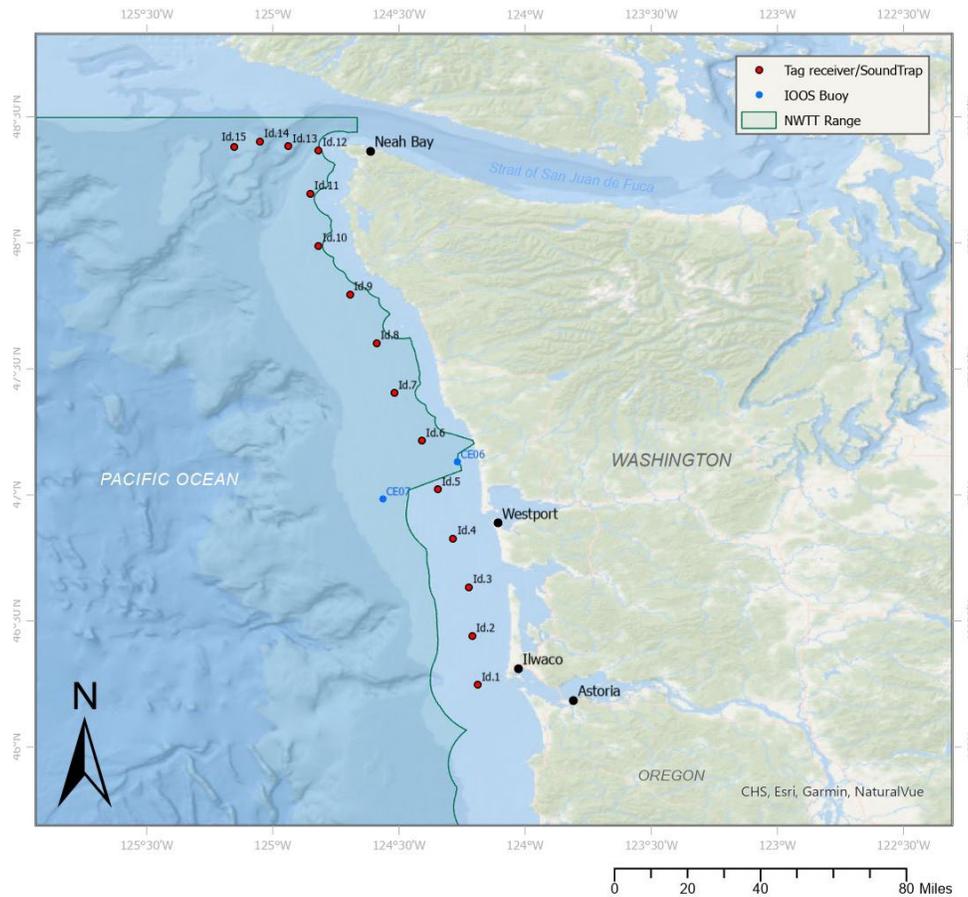
Figure 1. *Map of acoustic receiver/Sound Trap mooring and Integrated Ocean Observing System (IOOS) buoy locations along the Washington Coast. Each mooring has a 69 kHz receiver and a Sound Trap that records animal vocalizations.*

Acoustic mooring servicing and data downloads - This project includes the servicing, maintenance, and data download of acoustic mooring stations deployed in 2023 and 2024 (Table 1). Acoustic mooring stations were equipped with 69 kHz acoustic telemetry receivers and PAM devices along the WA coast (Fig. 1). The PAM devices (Soundtrap 600s) were programmed to continuously record at a sampling rate of 192 kHz. Each mooring was also equipped with a VR2AR 69 kHz acoustic receiver to detect acoustically transmitting implanted tags. Each instrument was spaced approximately 20 km apart near the 50m isobath to provide relatively dense coverage for SRKW monitoring along the entire Washington Coast. Four stations were spaced more closely (~10km apart) in an east-west orientation offshore of Cape Flattery, as this is a known hotspot for SRKW, particularly during summer months (Figure 1).

Successful PAM coverage is presented in Figure 2. In several cases, recording gaps exist due to equipment malfunction, programming errors, or equipment loss. Northern stations (11, 12, and 14) provided continuous coverage from May 2023 to October 2024. Southern stations 1-4 provided continuous coverage from November 2023 to October 2024. A substantial gap in recording coverage exists for central Washington coast stations from October 2023 to March

2024 (Figure 2). Passive acoustic data from predefined stations were sent to be screened by designated Navy personnel and returned before analyses began.

Table 1. *Acoustic Mooring Deployment Timetable. Due to instrument recording errors or equipment loss, * indicates that the station of this period had no data from Soundtrap or VR2AR equipment, and ** indicates that the station of this period had data only from VR2AR equipment.*

STATION	DEPLOYED	LATITUDE	LONGITUDE
1*	3/7/23	46.28806	-124.20248
2*	3/7/23	46.64569	-124.24042
3	3/7/23	46.3769	-124.22416
4	3/7/23	46.46721	-124.23036
5	3/7/23	46.5571	-124.23074
6**	3/7/23	46.73421	-124.26362
7**	3/7/23	46.91157	-124.32828
8	3/7/23	47.09018	-124.3841
9**	3/7/23	46.82288	-124.29245
10	3/7/23	47.00001	-124.37742
11	5/10/23	48.369542	-124.81474
12	5/10/23	48.384543	-124.93873
13	5/10/23	48.405473	-125.04616
14	5/10/23	48.38431	-125.15512
1	10/26/23	46.25	-124.19
2	10/26/23	46.4435	-124.212
3	10/26/23	46.637	-124.224
4	11/17/23	46.8305	-124.286
5	2/13/24	47.02411	-124.34805
6	2/22/24	47.21823	-124.41136
7	2/22/24	47.40688	-124.52004
8	2/22/24	47.60405	-124.59058
9	2/22/24	47.12347	-124.64472
11	2/10/24	48.1982	-124.85245
12	2/9/24	48.36954	-124.82
13*	2/9/24	48.38454	-124.93873
14	2/9/24	48.40443	-125.0506
15	2/9/24	48.38431	-125.15512
1	2/13/24	46.24986	-124.19006
2	2/13/24	46.44357	-124.21194
3	2/13/24	46.63715	-124.22426
4	2/13/24	46.83054	-124.28619
1	7/8/24	46.25	-124.19025

|			
2	7/8/24	46.44365	-124.21192
3	7/8/24	46.63708	-124.22406
4	7/8/24	46.82999	-124.28599
5	7/8/24	47.02383	-124.34789
7	7/8/24	47.40699	-124.52001
8	7/9/24	47.60408	-124.59097
9	7/9/24	47.79801	-124.69597
10	7/9/24	47.99144	-124.8198
11	7/9/24	48.19793	-124.85201
15	7/9/24	48.38431	-125.15512
14	7/9/24	48.4044	-125.05094
12	7/9/24	48.36953	-124.81994
12	10/7/24	48.36961	-124.82035
13	10/7/24	48.38453	-124.93932
15	10/7/24	48.38518	-125.1535
14	10/7/24	48.40381	-125.05032
11	10/7/24	48.19808	-124.85382
10*	10/7/24	47.99106	-124.81996
9*	10/7/24	47.7979	-124.69577
8	10/8/24	47.60672	-124.59193
7*	10/8/24	47.40731	-124.51945
6*	10/8/24	47.21765	-124.41019
5	10/8/24	47.02347	-124.34692
4	10/8/24	46.82969	-124.28577
3	10/8/24	46.63715	-124.22408
2	10/8/24	46.44396	-124.21148
1	10/8/24	46.24998	-124.19084
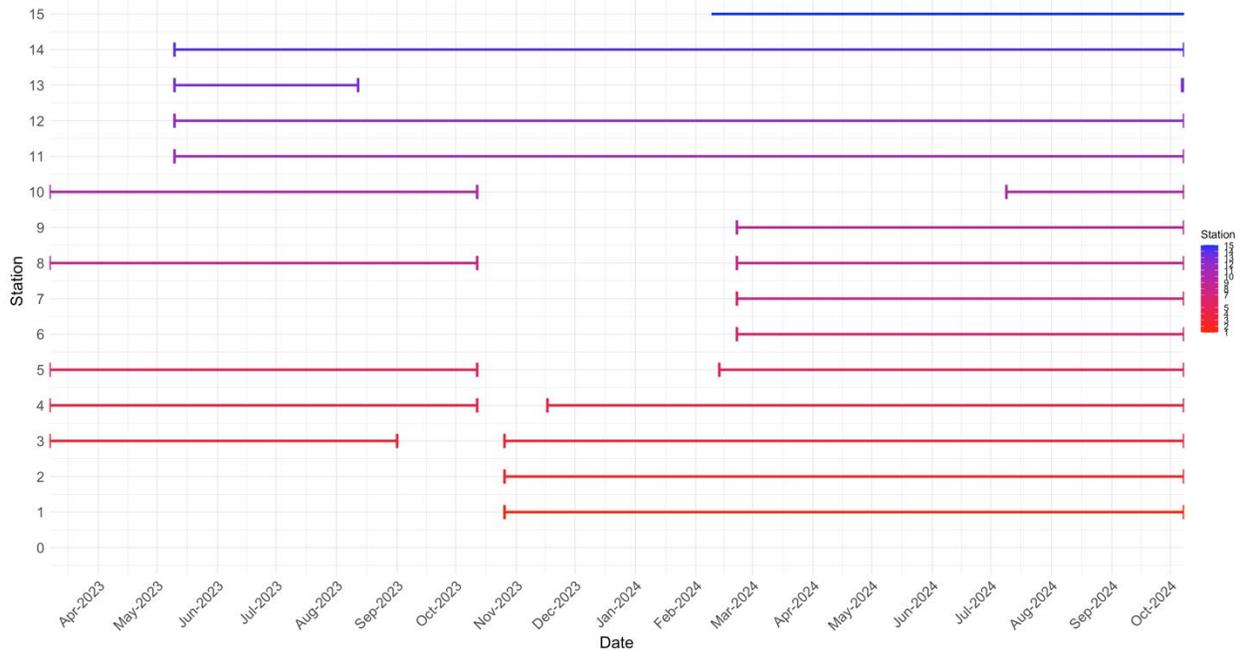
Figure 2. *Timeline of hydrophone data coverage for SoundTrap 600 instruments on the Washington coast. Refer to text for a timeline of mooring deployments and maintenance. Station numbers correspond to the map in Figure 1. Plot made using R.4.1.0 (R Core Team, 2021).*

Killer whale manual and automated detection - 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 in Matlab, LTSAs were carefully inspected by experienced analysts to identify specific vocalizations of marine mammals, such as killer whales, humpback whales, and Pacific white-sided dolphins. Analysts manually classified killer whale vocalizations into separate call types, allowing for the identification of SRKW, Northern Resident killer whales (NRKW), and Transient/ mammal-eating killer whales. A custom classifier (Myers et al. in prep) was then manually built in BirdNET-Analyzer (version 1.5.0; Kahl et al. 2021). We extracted manually validated samples of fish-eating killer whales (both SRKW and NRKW), mammal-eating killer whales, humpback whales, Pacific white-sided dolphins (the only confirmed delphinid species identified in recordings), vessel noise, mooring self-noise, and background sound from hydrophone deployments between March and August 2023. This set of 7,663 samples (not evenly distributed among classes) was randomly split 80/20 into training and testing data. We then applied the trained classifier across all recordings from our hydrophone deployments in 2023 and 2024.

Preliminary analysis of killer whale seasonality – To evaluate seasonal changes in killer whale occupancy, we selected three acoustic moorings representing the Columbia River, Westport Washington (central coast), and the northern tip of Washington. We summarized detections of SRKW from March 2023 – September 2023 into presence (confirmed detection of SRKW for

any amount of time) or absence (no detection of SRKW) for every day. We analyzed seasonal trends in the probability of presence using a Generalized Additive Model to allow for non-linear responses, with day of the year as the predictor variable and presence of SRKW as the response variable (using a logit link and binomial response distribution). The day of year relationship was fit independently for each acoustic mooring within the same model.

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 Inshore Surface Mooring (ISSM) and CE07 Shelf Surface Mooring (SHSM) in spring/summer 2023 (Figure 1). Selection of the OOI Coastal Endurance Array buoys, particularly CE06 ISSM and CE07 SHSM, for this project was strategic due to their proximity to the Navy's Study Area. Situated near Grays Harbor, Washington, 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. Phase II successfully advanced the software integration of VR2c-cabled receivers into the OOI Coastal Endurance Array electronics, supporting the transmission of acoustic detection data within the NWTTSA. Station CE07 SHSM, deployed on March 30, 2024, with a VR2c unit integrated into the OOI electronics, served as a successful trial run, providing near-real-time detection data of tagged individuals within the detection range. Simultaneously, Station CE06 ISSM, deployed on April 1, 2024, with a non-integrated VR2W unit, ensured continued acoustic coverage of the area during the integration trial of Station CE07 SHSM. Following the Fall 2024 OOI mooring replacement, both stations were redeployed with integrated VR2c units; CE07 SHSM on October 5, 2024, and CE06 ISSM on October 8, 2024. Near-real-time data from these stations is now available on OOI's raw data server, marking the successful completion of Phase II.

As Phase II concludes, the project progresses into Phase III, which is ongoing. This phase focuses on developing a software driver to facilitate seamless data transfer from the OOI raw

data server to the publicly accessible NANOOS platform, along with the development of a graphical user interface to enhance the accessibility and usability of near-real-time acoustic telemetry detection data.

Results and Discussion

Chinook salmon tag deployments – In 2023 & 2024, 63 Chinook salmon were caught and implanted with acoustic tags (Supplemental Table). Of these 63 Chinook, 15 were detected by at least one acoustic receiver within the Washington coast array (Fig. 1), a total of 248 times.

Acoustic tag detections – From March 2023 – October 2024, 54 unique tagged Chinook salmon (including those tagged by the SOBAD project, and those tagged by other research groups with available metadata, including the Washington Department of Fish & Wildlife and the Department of Fisheries & Oceans - Canada) were detected 1,430 times on the acoustic array, with the majority of detections occurring at Station 1 and 2 (north of the Columbia River mouth) and Station 6 (central Washington coast north of Westport (Table 2). Green sturgeon were detected 1,460 times (72 individuals), sevengill sharks detected 1,319 times (31 individuals), and soupfin sharks detected 186 times (8 individuals) (Table 2, Fig. 3). Monthly detections of each species at each station are presented in Supplemental Tables 2-5.

Table 2. Detections of tags with known metadata (e.g. species, deployment date and location) from March 2023 to October 2024, grouped by both station number and species. If blank, no known tags were detected. See supplemental tables 2-5 for monthly detections of each species at each station.

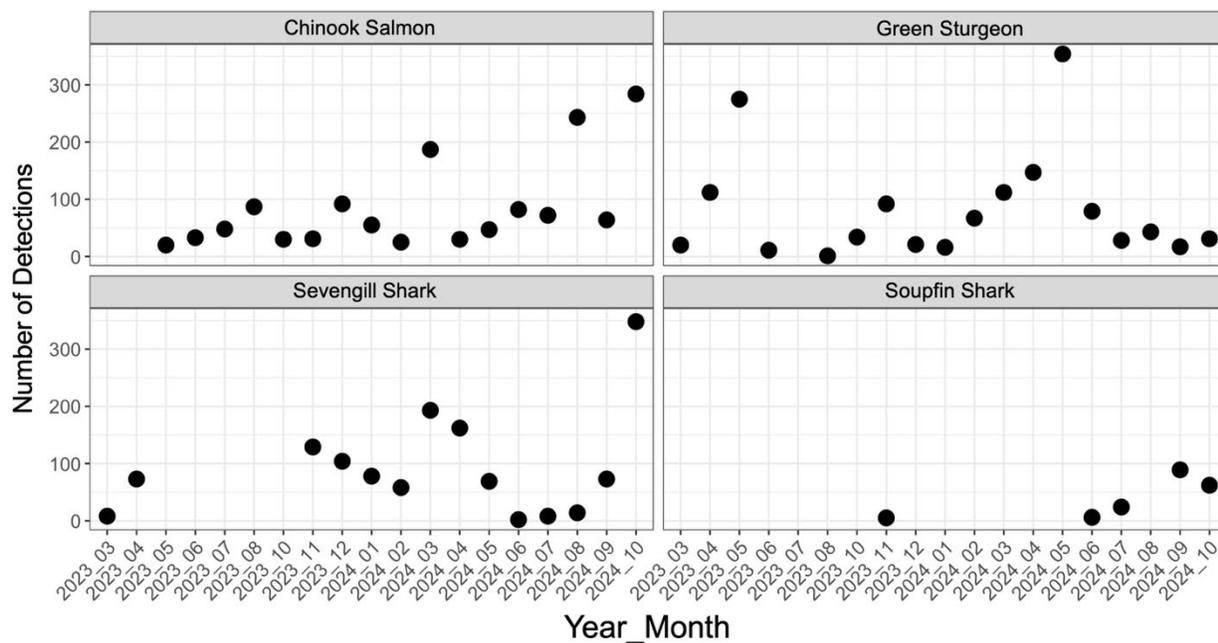| Station	Chinook Salmon	Green Sturgeon	Sevengill Shark	Soupfin Shark
Station1	277	263	116	112
Station2	289	171	451	26
Station3	107	131	179	4
Station4	47	321	60	28
Station5	111	164	177	
Station6	210	106	217	10
Station7		4	34	
Station8	10	33	57	
Station9	136	207	6	6
Station10	16	9	18	
Station11	167	21	4	
Station12	48	9		
Station13		1		
Station15	12	20		
Totals	1430	1460	1319	186

Figure 3. Monthly raw detections of tags with known metadata detected by all VR2AR acoustic receivers, separated by species. Plots show data from March 2023 – October 2024.
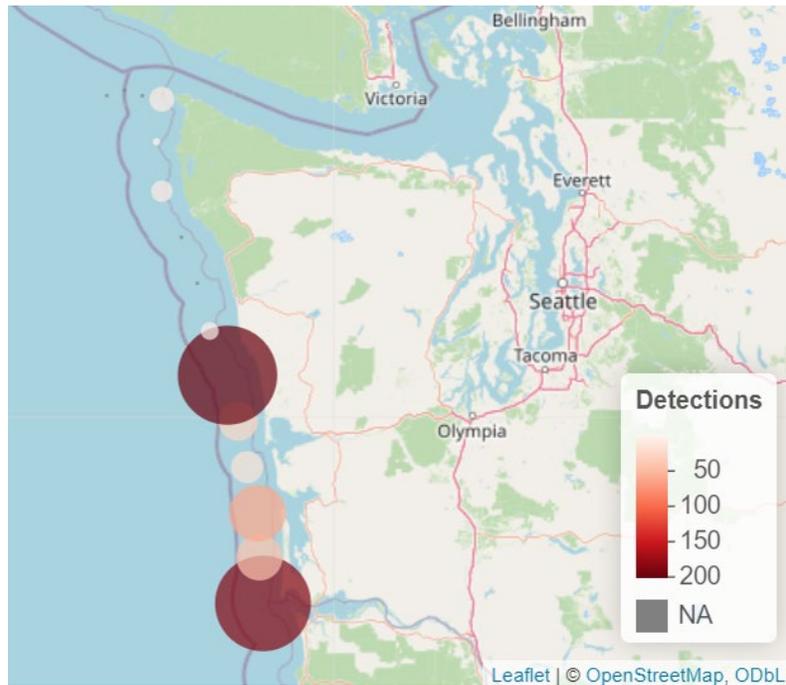
Figure 4. *Density map displaying the number of Chinook salmon detections of implanted acoustic tags recorded by VR2AR receivers based on location of each mooring. Circle size and color both correspond to number of detections at each acoustic mooring station.*

Killer Whale detections (preliminary manual results)- Since March 2023, 90,465 hours of passive acoustic recordings have been collected. Long-Term Spectral Average (LTSA) representations have been created for each monitoring station. From March to August 2023, 47 out of 103 killer whale detections that occurred near the heavily trafficked ports of Neah Bay (Station 13), Westport (Station 10), and Ilwaco, WA (Station 3) were classified as SRKWs using manual identification of distinct call types (Fig. 5). A binomial generalized additive model illustrating the seasonal variation in the probability of SRKW presence was examined for these three mooring stations as representative, preliminary samples spanning the full coast of Washington State (southern / Columbia River; central; and northern / Strait of Juan de Fuca) (6). In the early winter, SRKW detections were less likely in the north, most likely near the Columbia River, and intermediate on the central coast of Washington. As the year progressed, detection probability increased in the north, peaking in the early summer months before declining in the early fall. Detection probability on the central and southern coast of Washington declined steadily through the winter, spring, and summer months.
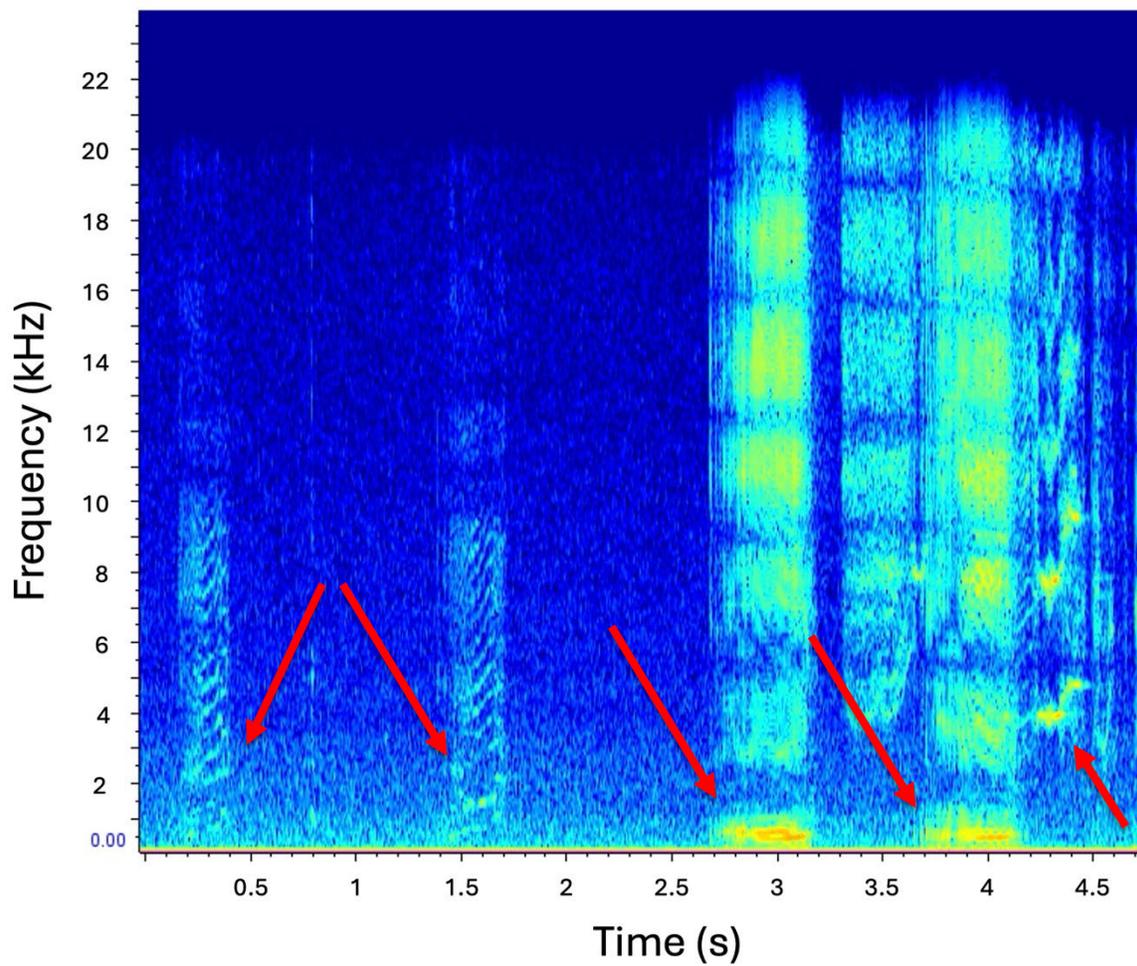
Figure 4. Examples of killer whale vocalizations found in the LTSA files from Station # 3. Red arrows indicate killer whale vocalizations.
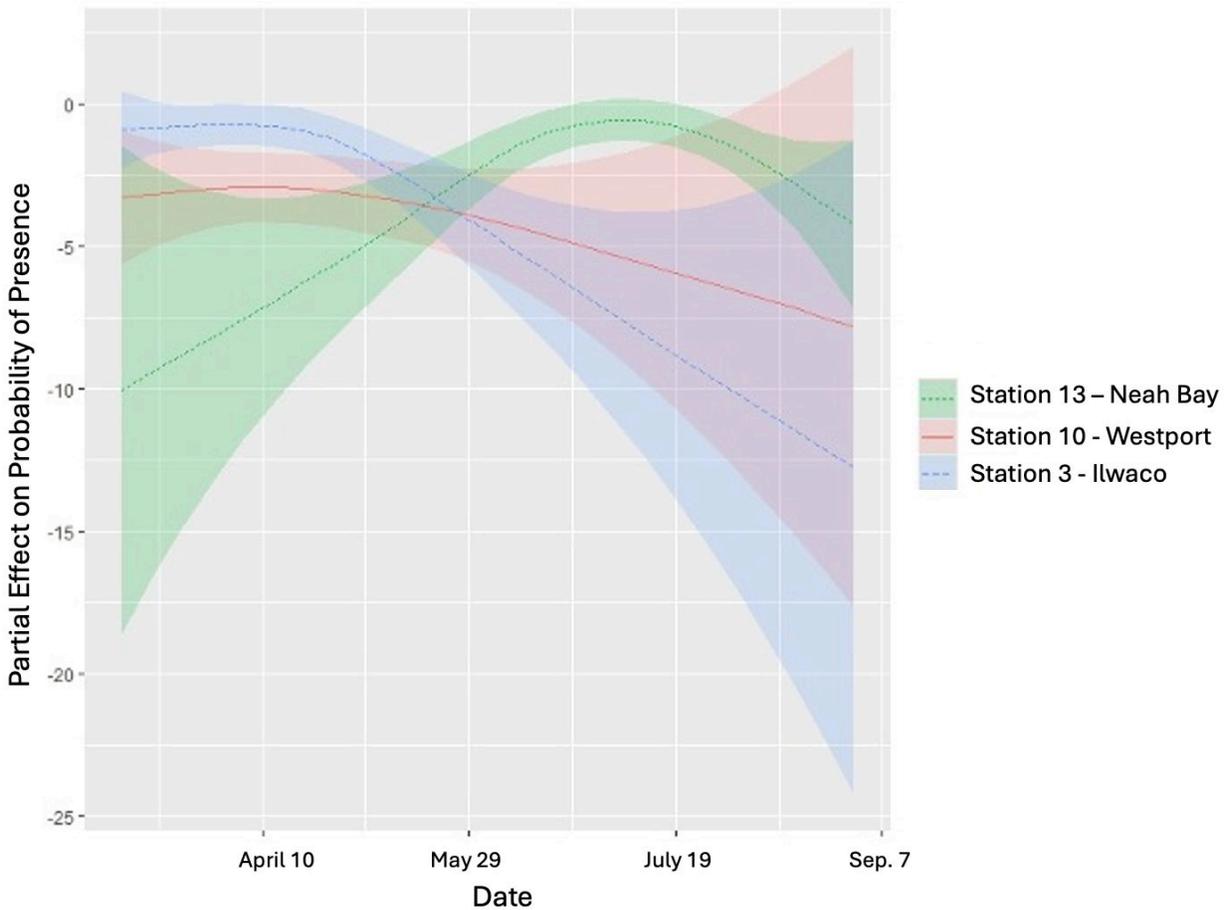
Figure 2. *Seasonal variations in the probability of SRKW presence (partial effect of day on probability of presence displayed on the y-axis) throughout the year (x-axis) at three acoustic mooring locations in 2023.*

Vessel sounds were detected within LTSA data by the ship-detector "remora" function in the "Triton" package in R (Marine BioAcoustics Research Collaborative 2019, Solsona-Berga et al. 2020, R Core Team, 2021). This analysis has 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 SRKW. From March to August 2023 at Stations 3, 10 and 13, SRKW detections coincided with vessel traffic 67% of the time at Station 3, and 100% of the time at Station 10 and Station 13, suggesting a heightened risk of disturbance and acoustic masking during foraging efforts at Westport and Neah Bay, respectively. Vessel traffic, and its overlap with SRKWs, will be analyzed for the 2024 acoustic data in future reports.

Killer whale and other marine mammal detections (preliminary automated classifier results) - The custom classifier performed with 98-100% accuracy for each class in the test dataset. We then applied the classifier across all data from our hydrophone deployments (Figure 7).

Figure 7. Preliminary results of the automated classifier for fish-eating killer whales. Lines represent the bi-weekly rolling averages of hours per day with detections of fish-eating killer whales. Lines for each station are color coded, with more red stations in the south and more blue stations in the north. Station numbers refer to the map in Figure 1. Note that passive acoustic receivers were not active for all months. See the instrument recording timeline in Figure 2.

Figure 8. *Preliminary results of the automated classifier for mammal-eating killer whales. Lines represent the bi-weekly rolling averages of hours per day with detections of mammal-eating killer whales. Lines for each station are color coded, with more red stations in the south and more blue stations in the north. Station numbers refer to the map in Figure 1. Note that passive acoustic receivers were not active for all months. See the instrument recording timeline in Figure 2. Note that the secondary filtering process to eliminate false positives, described for fish-eating killer whales, has not yet been applied to mammal-eating killer whale or other marine mammal data.*

Although the custom classifier performed well on the test dataset, given the quantity of data processed, we expected a high total number of false positives for most classes. Therefore, individual detections were automatically grouped into "acoustic encounters" for each class and further filtered encounters to identify those with the highest probability of accurate classification. First, we included only detections with a confidence score greater than 0.9 for each class. We grouped these detections into "encounters," defined as a period with at least three detections and a break of no more than 5 min between detections. Next, we calculated the mean confidence score, median confidence score, number of detections, encounter duration, detections per minute, and the proportion of detections in the encounter with a confidence score greater than 0.99.

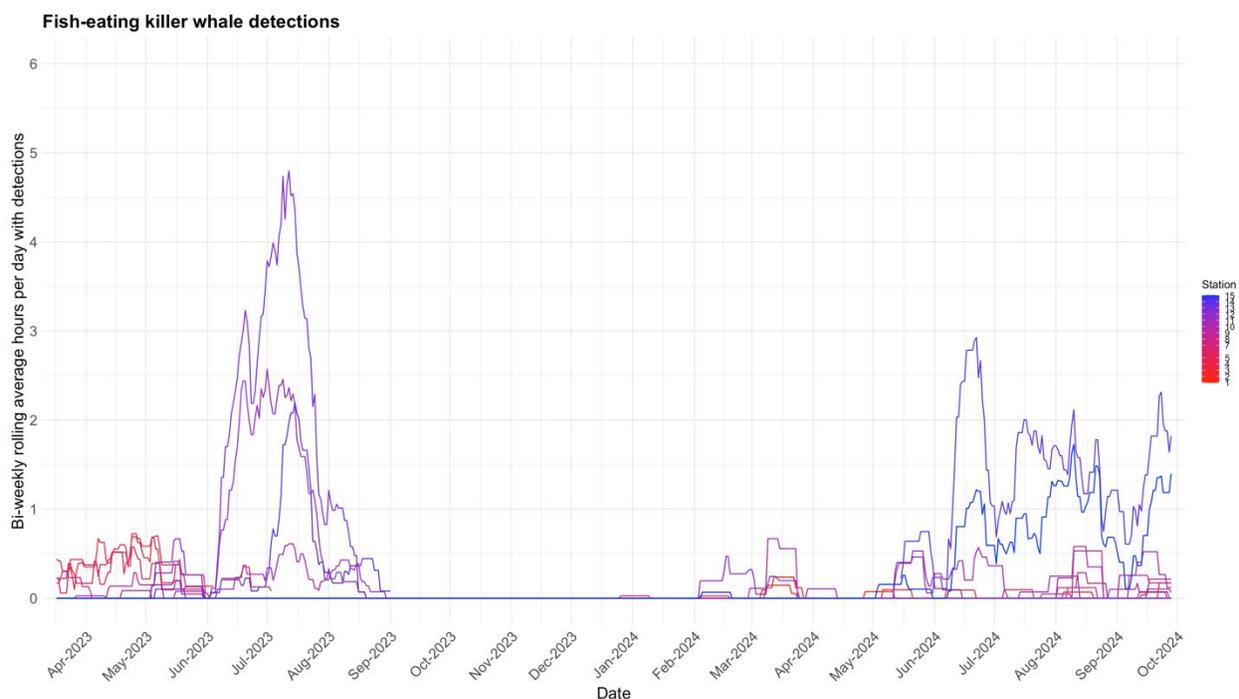**Figure 9.** *Preliminary results of the automated classifier for humpback whales. Lines represent the bi-weekly rolling averages of hours per day with detections of humpback whales. Lines for each station are color coded, with more red stations in the south and more blue stations in the north. Station numbers refer to the map in Figure 1. Note that passive acoustic receivers were not active for all months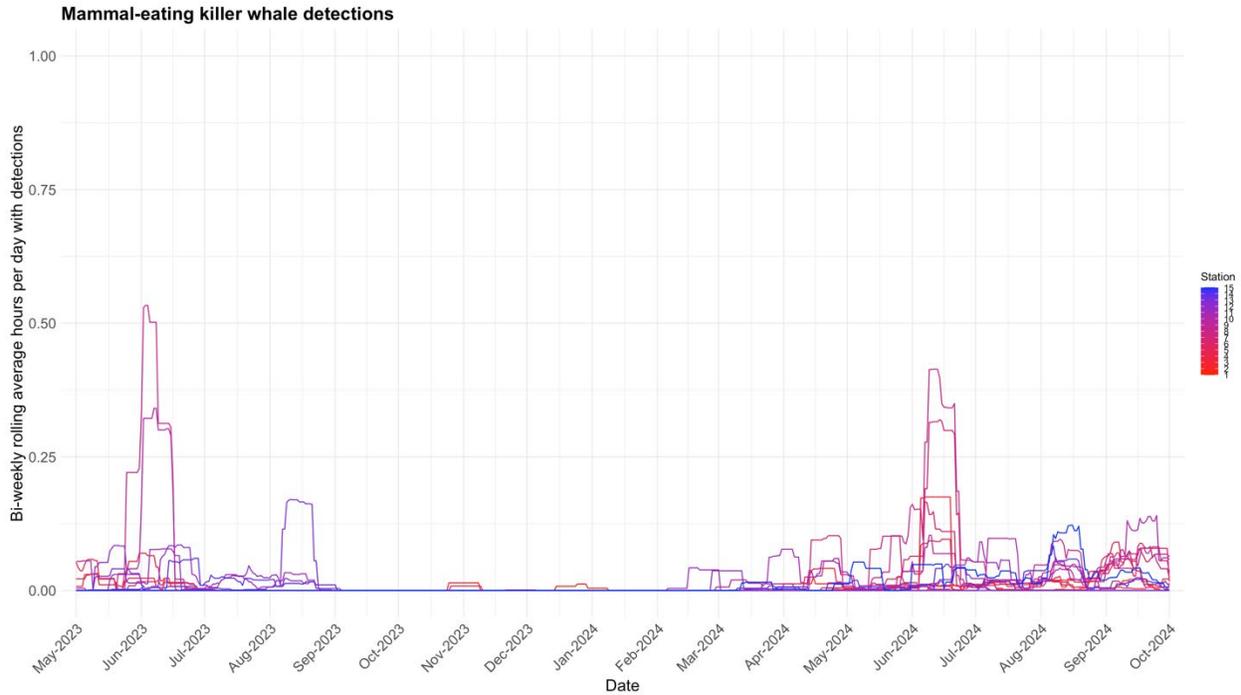. See the instrument recording timeline in Figure 2. Note that the secondary filtering process to eliminate false positives, described for fish-eating killer whales, has not yet been applied to humpback whale or other marine mammal data.*

To minimize the impact of false positive detections on our analyses, we developed logistic regression models to predict the probability that fish-eating (resident) killer whale encounters were true positives. First, we manually checked 667 encounters classified as fish-eating killer whales for the presence or absence of fish-eating killer whale vocalizations. A majority (68%) of encounters were false positives; however, false positive encounters were significantly shorter in duration than true fish-eating killer whale encounters (ANOVA, p = < 2e-16). On average, true positive fish-eating killer whale encounters lasted 36.93 min (s = 52.75, with encounters defined as above, with a break of no more than 5 min between detections), whereas the mean duration of false positive encounters was 11.87 min (s = 15.36).

We then utilized the encounter-level metrics calculated above to fit logistic regression models to predict the probability that each encounter was a true positive. Logistic regression models were built using all possible combinations of potential explanatory variables described above (mean confidence score, encounter duration, etc.); excluding redundant variables (e.g., number of detections and detections per minute). Models were compared using Akaike information criterion (AIC) scores. The best model included mean confidence score, number of detections, encounter duration, and the proportion of detections with confidence score greater than 0.99.

We then applied this model to predict the probability that each acoustic encounter classified to fish-eating killer whales was a true positive. Finally, we filtered fish-eating killer whale encounters to include only those with a predicted true positive probability greater than 0.9, and proceeded with the analysis. Including only encounters with a predicted true probability greater than 0.9 restricts the predicted false positive rate to less than .10. Because true positive encounters were longer than false positive encounters, excluding encounters with lower true positive probabilities had a relatively small impact on the total amount of time killer whales were detected.

A similar process will be used to identify the highest probability true positive encounters for mammal-eating killer whales, humpback whales, and Pacific white-sided dolphins. However, in the interim, we selected only those encounters for each class with a mean confidence score in the 90th percentile or higher. For all classes, we then used these high probability acoustic encounters to sum the number of detection hours per day at each station and calculated a 14-day rolling average.
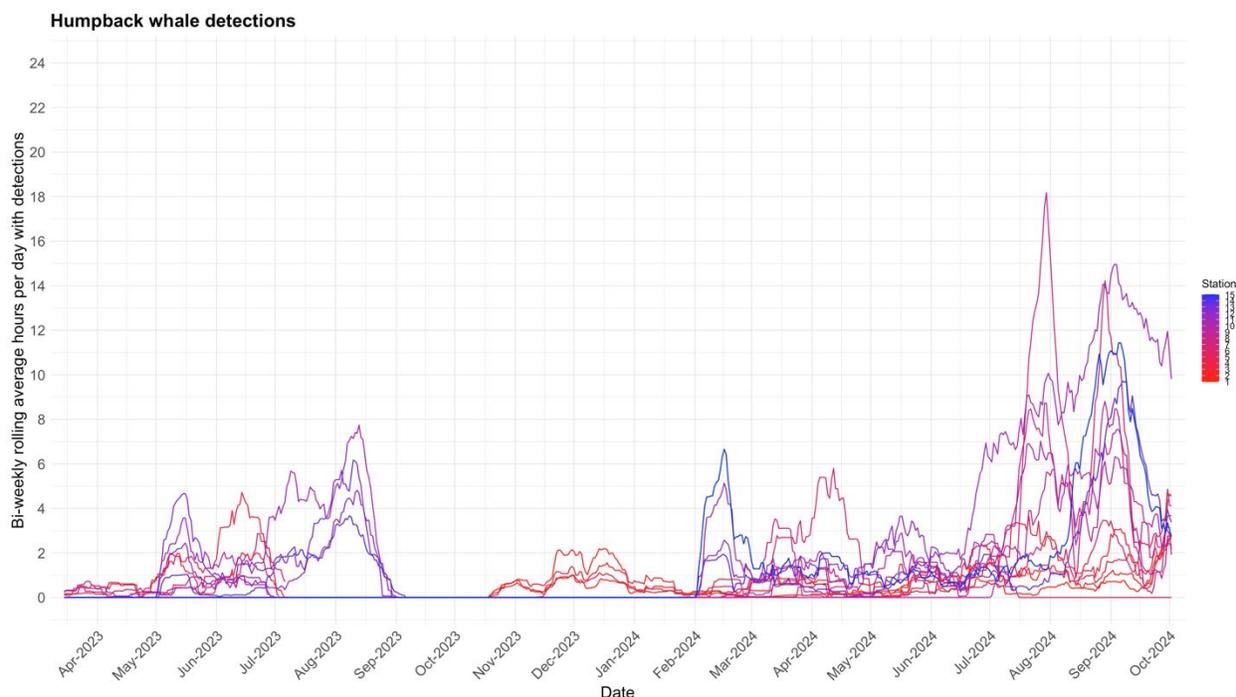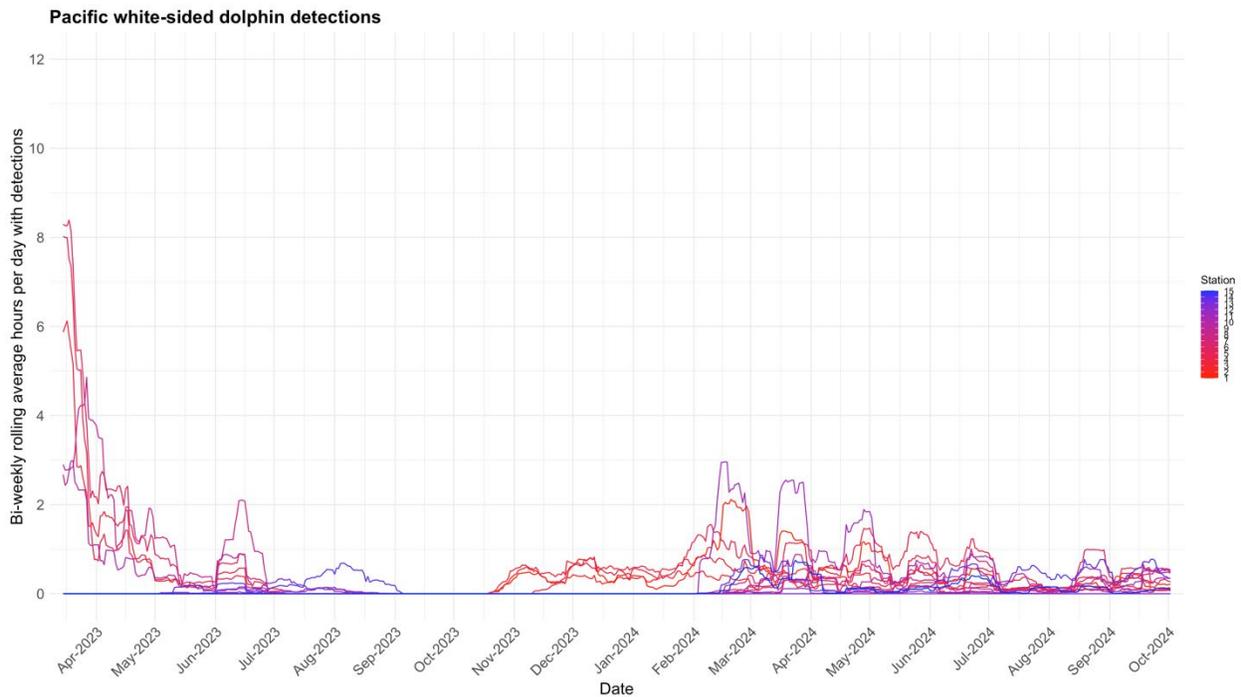

Figure 10. *Preliminary results of the automated classifier for Pacific white-sided dolphins. Lines represent the bi-weekly rolling averages of hours per day with detections of Pacific white-sided dolphins. Lines for each station are color coded, with more red stations in the south and more blue stations in the north. Station numbers refer to the map in Figure 1. Note that passive acoustic receivers were not active for all months. See the instrument recording timeline in Figure 2. Note that the secondary filtering process to eliminate false positives, described for fish-eating killer whales, has not yet been applied to Pacific white-sided dolphins or other marine mammal data.*

IOOS Buoy Integrated acoustic tag detection- Attachment design was sufficiently compact to be integrated into the Near Surface Instrument Frame (NSIF) without interfering with any core OOI instrumentation. The receivers proved effective, recording 86 unique acoustically tagged individuals [825 total detections].

The nearshore station, CE06 ISSM (located near Grays Harbor), recorded a total of 799 detections of marine animals, tagged with Vemco 69kHz acoustic transmitting tags, detecting five unique species: white shark (*Carcharodon carcharias*), sevengill shark, soupfin shark, green sturgeon, Chinook salmon. During this same time frame, Offshore station CE07 SHSM recorded 26 detections of two tagged species: Steelhead (*Oncorhynchus mykiss*) 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.
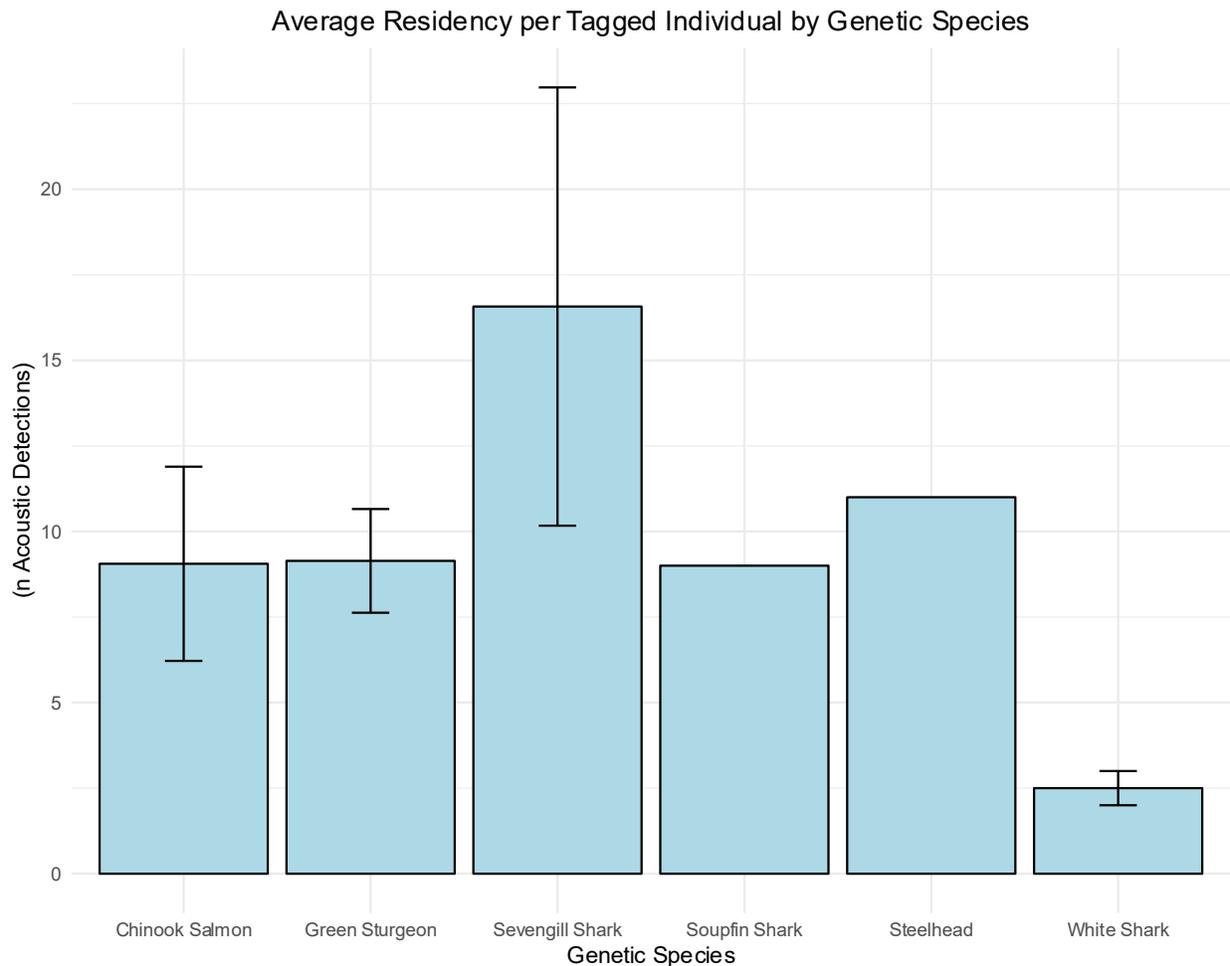
Figure 11: *Bar plot representing the average number of detections per tagged individual (proxy for residence times) for each of the six marine species detected at acoustic receiver stations CE06 ISSM and CE07 SHSM between Spring 2020 and Fall 2023. The plot illustrates the average number of detections that occurred for each individual 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 11).

Since the successful integration of VR2c-cabled receivers into the OOI Endurance Array electronics in Fall 2024, four species; Chinook salmon, green sturgeon, sevengill shark, and soupfin shark—have been detected across both stations. A total of 53 unique tagged individuals were recorded, with the nearshore station CE06 ISSM detecting 47 individuals, indicating a continuing trend of higher activity compared to the offshore station CE07 SHSM, which detected seven individuals. Notably, only one tagged individual, a green sturgeon, was detected at both stations during this period.
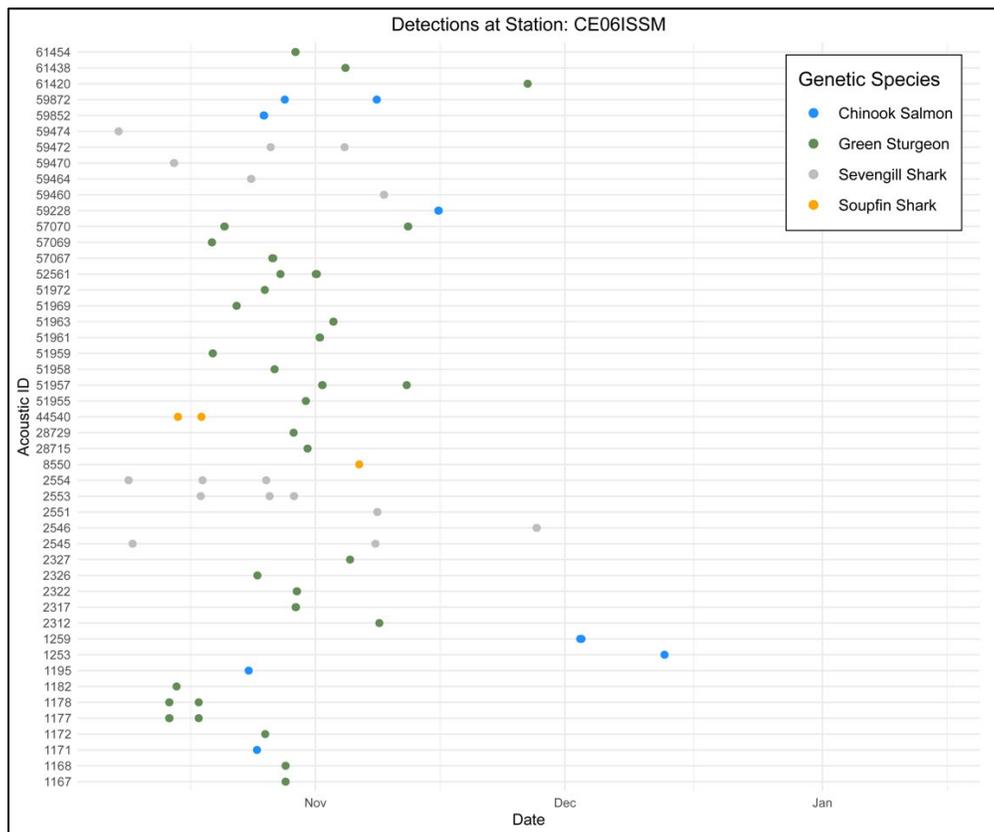
Figure 12: Abacus plot showing the timeline of transmitted near realtime acoustic detections for marine species tagged with Vemco-coded 69kHz acoustic transmitting tags since VR2c-cabled receiver integration at station CE06 ISSM. Each row corresponds to a unique individual with individual points representing detection instances and the color indicating the genetic species of the tagged individual.

Project Challenges and Operations Update

In 2023 and the beginning of 2024, the field team made repeated trips to different locations on the coast of Washington State (e.g. Ilwaco, Westport, Neah Bay) to recover, download, service, and re-deploy distinct portions of the acoustic array using single-day boats. This was extremely logistically challenging; required multiple extended good-weather windows, which is particularly challenging in fall, winter, and early spring; and made it impossible to access some portions of the planned acoustic array. Beginning in summer 2024, we modified our operating model to service the entire acoustic array in a single 3-day cruise using a multi-day research vessel capable of covering the entire Washington coast in a single cruise from Astoria, OR to Port Angeles, WA, or vice versa. This modification significantly streamlined field efforts, allowing us to recover, download, and redeploy the entire array on a single cruise. This dramatically improves our chances of successfully collecting continuous, year-round acoustic data, as only a single good-weather window is required to service receivers in fall and spring.

Acknowledgments

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Supplemental Tables

Supplemental Table 1. Tagged Chinook salmon with fork length, adipose mark, tag ID, Tag Date, and Release Coordinates.

Length mm	Adipose Clip	Tag ID	Tag Date	Latitude	Longitude
710	AD	A69-9002-1105	2023-07-11	46.2159	-124.1981
455	NO	A69-9002-1107	2024-03-19	46.32948	-124.21738
560	NO	A69-9002-1111	2024-07-24	46.3249	-124.2081
480	AD	A69-9002-1113	2024-07-24	46.32514	-124.20472
575	NO	A69-9002-1115	2024-07-24	46.32422	-124.21806
560	NO	A69-9002-1117	2024-07-24	46.31857	-124.20022
550	AD	A69-9002-1119	2024-07-24	46.33041	-124.19038
570	NO	A69-9002-1121	2024-07-29	46.32882	-124.09502
610	NO	A69-9002-1123	2024-07-29	46.32882	-124.09502
570	AD	A69-9002-1125	2024-07-29	46.32872	-124.09566
392	NO	A69-9002-1127	2024-07-29	43.34269	-124.09238
650	NO	A69-9002-1129	2024-07-29	46.35699	-124.0969
480	NO	A69-9002-1131	2024-07-29	46.35581	-124.08494
450	AD	A69-9002-1133	2024-07-30	46.23967	-124.2141
525	NO	A69-9002-1135	2024-07-30	46.23504	-124.19126
530	AD	A69-9002-1137	2024-07-30	46.23453	-124.18594
330	NO	A69-9002-1139	2024-07-30	46.23252	-124.18296
510	NO	A69-9002-1141	2024-07-30	46.2387	-124.2087
495	NO	A69-9002-1143	2024-07-30	46.23543	-124.20382
530	NO	A69-9002-1145	2024-07-30	46.23378	-124.17455
700	NO	A69-9002-1147	2024-08-24	46.233889	-124.151111
580	NO	A69-9002-1149	2024-08-24	46.239444	-124.153889
380	NO	A69-9002-1181	2024-10-12	47.05425	-124.3948
251	NO	A69-9002-1183	2024-10-12	47.05425	-124.3948
270	NO	A69-9002-1151	2024-10-12	47.05425	-124.3948
218	AD	A69-9002-1153	2024-10-12	47.05425	-124.3948
275	NO	A69-9002-1155	2024-10-12	47.05425	-124.3948
520	NO	A69-9002-1157	2024-10-12	47.05425	-124.3948
500	AD	A69-9002-1159	2024-10-12	47.05425	-124.3948
285	AD	A69-9002-1161	2024-10-12	47.05425	-124.3948
550	AD	A69-9002-1163	2024-10-12	47.05425	-124.3948
505	AD	A69-9002-1165	2024-10-12	47.05425	-124.3948
500	AD	A69-9002-1167	2024-10-12	47.05425	-124.3948
420	AD	A69-9002-1169	2024-10-12	47.05425	-124.3948
530	AD	A69-9002-1171	2024-10-12	47.05425	-124.3948
270	AD	A69-9002-1173	2024-10-12	47.05425	-124.3948
245	AD	A69-9002-1177	2024-10-12	47.05425	-124.3948
440	NO	A69-9002-1175	2024-10-12	47.05425	-124.3948
350	AD	A69-9002-1179	2024-10-12	47.05425	-124.3948
490	NO	A69-9002-1185	2024-10-12	47.05425	-124.3948
550	AD	A69-9002-1187	2024-10-12	47.05425	-124.3948
270	AD	A69-9002-1189	2024-10-12	47.05425	-124.3948
575	AD	A69-9002-1191	2024-10-12	47.05425	-124.3948
265	AD	A69-9002-1193	2024-10-13	47.05425	-124.3948
280	AD	A69-9002-1195	2024-10-13	47.05425	-124.3948
340	AD	A69-9002-1197	2024-10-13	47.05425	-124.3948
278	AD	A69-9002-1199	2024-10-13	47.05425	-124.3948
540	AD	A69-9002-1201	2024-10-13	47.05425	-124.3948
490	NO	A69-9002-1203	2024-10-13	47.05425	-124.3948
525	AD	A69-9002-1205	2024-10-13	47.05425	-124.3948
524	AD	A69-9002-1207	2024-10-13	47.05425	-124.3948
290	AD	A69-9002-1209	2024-10-13	47.05425	-124.3948
270	AD	A69-9002-1211	2024-10-13	47.05425	-124.3948
295	AD	A69-9002-1263	2024-11-26	46.9892	-124.26985
280	NO	A69-9002-1261	2024-11-26	47.0002	-124.26812
310	NO	A69-9002-1249	2024-11-26	47.05425	-124.3948

290	AD	A69-9002-1251	2024-11-26	47.05425	-124.3948
230	NO	A69-9002-1253	2024-11-26	47.05425	-124.3948
505	AD	A69-9002-1255	2024-11-26	47.05425	-124.3948
260	AD	A69-9002-1257	2024-11-26	47.05425	-124.3948
235	AD	A69-9002-1259	2024-11-26	47.05425	-124.3948
475	NO	A69-9002-1237	2024-11-26	47.05425	-124.3948
281	AD	A69-9002-1239	2024-11-26	47.05425	-124.3948

Supplemental Table 2. Detections of acoustically tagged Chinook salmon on the Washington Coast array. Sta. indicates the station number (see Figure 1), and numbers within cells indicate the raw number of tag detections on each station by month. The thick line denotes the transition from 2023 to 2024. Blank boxes indicate no detections.

Sta.	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
15																	10	2		
14																				
13																				
12				18	6	24														
11			20	15	42	63										8	19			
10																	3	13		
9														12		66	25	33		
8																	10			
7																				
6											25	174	3			8				
5												13	15					5		78
4																				47
3															29			11	10	57
2										73	47				18		2	27	21	101
1								30	31	19	8						3	152	33	1

Supplemental Table 3. Detections of acoustically tagged green sturgeon on the Washington Coast array. Sta. indicates the station number (see Figure 1), and numbers within cells indicate the raw number of tag detections on each station by month. The thick line denotes the transition from 2023 to 2024. Blank boxes indicate no detections.

Sta.	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
15																		20		
14																				
13																				1
12				9																
11			1	2	1							1	3			1	1	11		
10	2		7																	
9		8										18	49	73	23		24	12		
8			18									9			6					
7		2	2																	
6		9	14											1	46	36				
5	7	25	3									34	14	29	50					2
4	5	57	228											5	25					1
3	6	11	2											4	75	28				5
2								3	39	21	16	12	18	22	4	12	2			22
1								31	53			3	21	10	125	2	1		17	

Supplemental Table 4. Detections of acoustically tagged sevengill sharks on the Washington Coast array. Sta. indicates the station number (see Figure 1), and numbers within cells indicate the raw number of tag detections on each station by month. The thick line denotes the transition from 2023 to 2024. Blank boxes indicate no detections.

Sta.	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
15																				
14																				
13																				
12																				
11														4						
10		15																	3	
9	5																		1	
8		30											6							21
7	3	26																	5	
6												25	174	17	1					
5												30	13	23	15		3		23	70
4														1	6					53
3		2												70	29				20	58
2									86	85	56			29	18	2		14	15	146
1									43	19	22	3		18			5		6	

Supplemental Table 5. Detections of acoustically tagged soupfin sharks on the Washington Coast array. Sta. indicates the station number (see Figure 1), and numbers within cells indicate the raw number of tag detections on each station by month. The thick line denotes the transition from 2023 to 2024. Blank boxes indicate no detections.

Sta.	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
15																				
14																				
13																				
12																				
11																				
10																				
9																6				
8																				
7																				
6																	10			
5																				
4																	5			23
3																			4	
2									5											21
1																	9		85	18