MOVEMENT PATTERNS OF ANADROMOUS BULL TROUT ALONG THE COAST OF WASHINGTON'S OLYMPIC PENINSULA

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14. ABSTRACT

The U.S. Navy conducts military training and testing activities in Pacific Northwest range areas to maintain combat readiness. These activities require coordination with federal agencies to ensure compliance with the Endangered Species Act (ESA). NOAA National Marine Fisheries Service (NMFS) is responsible for regulatory oversight and permitting for ESA-listed marine species under its jurisdiction, whereas the U.S. Fish and Wildlife Service is the regulatory authority for the coterminous United States distinct population segment of bull trout in both freshwater and marine environments. This project provides spatial information relevant to Navy range areas and supports informed management decisions that balance operational requirements with conservation objectives for ESA-listed species. This study was designed to improve understanding of marine movement patterns of anadromous bull trout (*Salvelinus confluentus*), a federally threatened species, along the Olympic Peninsula coast of Washington State and to evaluate their potential spatial overlap with the U.S. Navy's Northwest Training and Testing (NWTT) Study Area. Using acoustic telemetry, bull trout movements were monitored between freshwater systems (the Hoh River and Kalaloch Creek) and adjacent coastal marine waters through a network of in-river receivers and a marine acoustic array deployed along Washington's state marine boundary located approximately 3-nautical-miles (3-nm) offshore.

Submitted in Support of the U.S. Navy's 2025 Annual Marine Species Monitoring Report for the Pacific

In April 2025, an acoustic receiver array consisting of 42 receivers was deployed along the 3-nm boundary off Washington State's Olympic Peninsula (hereafter referred to as the 3-nm array). For the purposes of this study, "nearshore" refers to marine waters landward of the 3-nm boundary (i.e., Washington State waters), and "offshore" refers to waters seaward of the 3-nm boundary (i.e., federal waters). Receivers were spaced approximately 900 m apart to increase the likelihood of detection through overlapping receiver ranges. The array was recovered and data were downloaded in October 2025. In addition to the 3-nm array, acoustic receivers were deployed in the Hoh River and Kalaloch Creek to record tagged fish presence and movement. A subset of the Hoh receivers was downloaded and redeployed in August and October of 2025, and the Kalaloch receivers were downloaded in September of 2025 and January of 2026.

A total of 30 bull trout were acoustically tagged during the study period, including 15 individuals in Kalaloch Creek and 15 individuals in the Hoh River. Individuals were captured and tagged primarily between April and September 2025. Ten of the 15 bull trout tagged in Kalaloch Creek were subsequently detected on Hoh River receivers, with first detections occurring beginning in May 2025; however, none of these individuals were detected on the 3-nm array. In total, two tags were detected in marine waters. One tag was detected by multiple receivers in the 3-nm array near Destruction Island; however, the observed movement pattern was inconsistent with typical bull trout behavior and likely reflects tag transport by a marine predator. Despite this, these detections confirm that the 3-nm array was operational and capable of detecting offshore tag presence. A second bull trout tagged in the Hoh River was detected on a receiver deployed in Grays Harbor, with no intervening detections on marine receivers prior to its subsequent detection at the mouth of the Hoh River.

Five tagged bull trout (four originally tagged in Kalaloch Creek and one originally tagged in the Hoh River) were detected on the Kalaloch Creek receiver beginning in December 2025, indicating a return movement that necessarily involved marine transit. Data from the winter deployment of the 3-nm array have not yet been downloaded; therefore, it is not yet possible to determine whether these individuals crossed the 3-nm boundary or entered the NWTT Study Area during this period. However, results from the 2025 study period based on data downloaded in October 2025 indicate that bull trout exhibited limited movement beyond the 3-nm zone during their spring–summer migration period, with minimal observed spatial overlap with NWTT.

To further assess potential seasonal movements, a reduced acoustic array consisting of 21 receivers, spaced approximately 1,800 m apart, will continue to operate along the 3-nm line throughout winter 2025–2026 to monitor movement of tagged bull trout between the Hoh River and Kalaloch Creek. The 3-nm array was reduced from 42 to 21 receivers to allow a subset of receivers to be relocated near Pacific Beach. This relocation maintains coverage along the broader coastal migratory corridor while preserving the ability to detect offshore movements of tagged bull trout. This modification does not affect interpretation of detections recorded during the 2025 field season.

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EXECUTIVE SUMMARY

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INTRODUCTION

Bull trout (*Salvelinus confluentus*) are a species of char within the family Salmonidae and are native to cold-water systems of Washington, Oregon, Idaho, Nevada, Montana, and western Canada. Across their range, bull trout have declined in distribution and abundance and are listed as a threatened species under the Endangered Species Act (64 FR 58910; November 1, 1999). The species exhibits substantial variability in life-history strategies, including resident, fluvial, adfluvial, and anadromous forms. Resident individuals complete their entire life cycle within a single stream or watershed, whereas migratory bull trout move between spawning and rearing habitats and larger downstream environments. Along coastal rivers of the Olympic Peninsula, Washington, some bull trout exhibit an anadromous life history, spawning in freshwater and migrating into marine waters for growth or movement among river systems.

Maintenance of diverse life-history strategies is considered important for bull trout recovery because such diversity may contribute to genetic variability, population connectivity, and resilience to environmental change (Rieman and Dunham, 2000; USFWS, 2008). This is particularly relevant for small or geographically isolated populations where anadromy may reduce demographic isolation and support long-term persistence (Rieman and Allendorf, 2001). However, anadromous behavior may also expose bull trout to marine stressors, including interactions with fisheries targeting other salmonids and activities associated with U.S. Navy training and testing in coastal waters. Understanding the frequency, extent, and spatial expression of anadromy is therefore important for effective bull trout conservation and recovery planning.

Most research on bull trout life history and movement has focused on interior freshwater systems, where populations are entirely fluvial or adfluvial (Goetz, 1989; Swanberg, 1997). In contrast, although marine occupancy and migration timing of bull trout have been investigated in the inland marine waters of Puget Sound (e.g., Goetz 2016; Goetz et al., 2021), relatively little information exists on the extent of anadromy and marine habitat use by bull trout in tidally influenced coastal rivers that discharge directly into the Pacific Ocean. In portions of Canada and Southeast Alaska, studies of char in marine environments often do not distinguish bull trout from the morphologically similar Dolly Varden (*Salvelinus malma*), limiting species-specific inference (McPhail and Baxter, 1996). Evidence of bull trout occurrence in marine waters has been derived from museum records, otolith chemistry, and telemetry studies in Washington and British Columbia, which collectively suggest substantial variability in life-history expression and marine use among individuals and populations (Brenkman et al., 2007). Prior work by Brenkman et al. (2007) near the Hoh River documented multiple anadromous strategies, ranging from limited marine exposure to frequent saltwater movements.

Despite this evidence, the spatial extent of bull trout use of coastal and offshore marine habitats along the Washington coast remains poorly characterized. This uncertainty is particularly relevant within the Navy's Northwest Training and Testing (NWTT) Study Area, where training and testing activities occur in offshore waters. Previous studies indicate that some bull trout may enter marine environments beyond nearshore areas; however, the proportion of individuals that do so and the degree of spatial overlap with the NWTT Study Area remain unclear. These

knowledge gaps are partly due to small sample sizes of anadromous individuals and limited detection coverage within the nearshore zone in earlier studies.

Bull trout along the Olympic Peninsula exhibit predictable seasonal movement patterns associated with spawning and marine foraging. Radiotelemetry and otolith chemistry studies in the Hoh River basin have demonstrated that many anadromous individuals enter freshwater from late spring through summer, ascend to spawning areas by early fall, and subsequently return to marine waters to overwinter, with some individuals making repeated migrations among coastal river systems (Brenkman and Corbett, 2005; Brenkman et al., 2007; Smith and Huff, 2023). Because bull trout densities in marine waters are low and capture offshore is not feasible, tagging must occur while fish are concentrated in freshwater habitats. Sampling during winter and early spring targets adults prior to marine emigration and includes individuals occupying non-natal overwintering streams that must transit coastal marine corridors to reach spawning habitats in adjacent basins. Tagging during this period therefore provides a biologically appropriate and logistically feasible approach for quantifying subsequent marine movements and connectivity among coastal watersheds.

Study objectives

The primary objectives of this study were to 1) use acoustic telemetry to improve understanding of marine movement patterns of anadromous bull trout along the coast of the Olympic Peninsula, and to 2) assess their potential spatial overlap with the NWTT Study Area. By combining in-river receivers with marine acoustic array, this work was intended as a focused investigation of nearshore and offshore movements. Results from this study are intended to inform future research design and support management decisions related to bull trout conservation and Navy training and testing activities in coastal Washington waters.

METHODS

Study area

This study focused on bull trout behavior within the Hoh River, Kalaloch Creek, and marine waters along coastal Washington. The Hoh River and Kalaloch Creek drainages are largely managed by the National Park Service. The Hoh River is a glacially influenced, cold-water river that flows directly into the Pacific Ocean and has a negligible estuary. Kalaloch Creek drains directly into the Pacific Ocean approximately 17 km south of the Hoh River and has a smaller watershed area (45 km^2). Kalaloch Creek drops steeply to the coast and includes a short (approximately 2 km), tidally influenced, low-gradient estuary. The surrounding region, including the Hoh Rainforest, receives high annual precipitation (mean of approximately 358 cm), most of which occurs between November and April. There is no upland hydrologic connection between the Hoh River and Kalaloch Creek; therefore, detection of the same bull trout in both drainages requires marine migration.

Permitting

All required permits and approvals for fish handling, tagging, and acoustic receiver deployment were obtained prior to initiating field activities. Fish capture, handling, and tagging were conducted under approved federal and state permits, including authorization from the U.S. Fish and Wildlife Service, the Washington Department of Fish and Wildlife, the National Park Service, and an Oregon State University Animal Care and Use Protocol (ACUP). Deployment of marine acoustic receivers was conducted in coordination with applicable federal and state compliance processes. Project review was initiated through submission of a Joint Aquatic Resources Permit Application (JARPA), which facilitated coordinated review by relevant state and federal agencies. Federal authorizations included a Rivers and Harbors Act Section 10 permit, ESA Section 7 consultation, National Historic Preservation Act (NHPA) Section 106 consultation, and authorization under a NOAA National Marine Sanctuary permit for work within the Olympic Coast National Marine Sanctuary (OCNMS).

Disclosed permitting issues: Critical revisions to the experimental design, specifically with regard to mooring placement, were forced due to delayed permit review processing at the Washington Department of Natural Resources (WDNR) that were reported in the previous annual progress report for this project. The permit review delay has continued unresolved and prevented deployment of acoustic receivers within 0-3nm as is depicted in the figures submitted herein. While viable scientific data to meet overarching project goals was collected, the permit restrictions effectively prevented the research team from meeting the funding objectives needed for USFWS consultation. To achieve the project goals as close as possible with this unforeseen constraint, the research team devised an alternative study design placing moorings parallel to the shoreline along the 3nm line, extending north-south for approximately 40 km from just south of La Push to the Queets River. The transect of receivers will allow for monitoring fish crossing the 3-nm line but this effectively changes the purpose of the funding and study for requisite USFWS consultation. As is reported herein and depicted in the included figures, data was not able to be collected within 0-3nm due to delayed permit review and processing at WDNR.

Acoustic receiver network deployment

A total of 42 acoustic receivers were deployed along Washington's 3-nm offshore boundary (approximately 5.6 km from shore) in a north–south orientation, spaced approximately 900 m apart (Table 1, Figure 1). The 3-nm array extended from approximately 10 km south of the mouth of the Quillayute River (47.8017° N, −124.627° W) to approximately 3.5 km south of the mouth of the Queets River (47.5026° N, −124.425° W), spanning approximately 36.5 km (19.7 nautical miles) along the coastline. Receivers in the 3-nm array were deployed on April 22, 2025. To maintain a minimum distance of 3-nm from all land masses, receiver locations were positioned farther offshore in the vicinity of Destruction Island (Figure 1). Acoustic receivers were not deployed closer to shore due to permitting constraints associated with state-managed aquatic lands. All receivers were serviced on October 15, 2025, at which time units were cleaned, downloaded, and re-formatted. Following servicing, every other receiver (n = 21; approximately

1,800 m spacing) was redeployed to operate through winter 2025–2026 (Table 1, Figure 2). Receivers removed from the 3-nm array were reallocated to an alternative deployment configuration farther south, near Pacific Beach and north of Grays Harbor, within the Quinault Range of the NWTT Study Area (Figure 3).

Table 1 Deployment information for marine acoustic receivers deployed in the 3-nm array off of the coast of Washington's Olympic Peninsula. Table includes receiver ID, geographic coordinates, bottom depth in fathoms and meters, initial deployment date, and re-deployment date following October servicing.

ID	Latitude	Longitude	Depth (fathoms)	Depth (m)	Deploy date	Re-deploy date
M1	47.521	-124.428	10	18	4/22/2025	10/15/2025
M2	47.530	-124.430	9	16	4/22/2025	NA
M3	47.539	-124.433	10	18	4/22/2025	10/15/2025
M4	47.547	-124.435	11	20	4/22/2025	NA
M5	47.556	-124.439	11	20	4/22/2025	10/15/2025
M6	47.565	-124.441	11	20	4/22/2025	NA
M7	47.574	-124.444	11	20	4/22/2025	10/15/2025
M8	47.582	-124.449	11	20	4/22/2025	NA
M9	47.591	-124.453	11	20	4/22/2025	10/15/2025
M10	47.599	-124.456	11	20	4/22/2025	NA
M11	47.608	-124.456	10	18	4/22/2025	10/15/2025
M12	47.617	-124.459	10	18	4/22/2025	NA
M13	47.622	-124.470	12	22	4/22/2025	10/15/2025
M14	47.621	-124.483	12	22	4/22/2025	NA
M15	47.622	-124.496	13	24	4/22/2025	10/15/2025
M16	47.624	-124.510	14	26	4/22/2025	NA
M17	47.627	-124.521	14	26	4/22/2025	10/15/2025
M18	47.631	-124.534	16	29	4/22/2025	NA
M19	47.636	-124.544	16	29	4/22/2025	10/15/2025
M20	47.644	-124.552	17	31	4/22/2025	NA
M21	47.652	-124.558	17	31	4/22/2025	10/15/2025
M22	47.660	-124.563	18	33	4/22/2025	NA
M23	47.669	-124.566	19	35	4/22/2025	10/15/2025
M24	47.678	-124.565	18	33	4/22/2025	NA
M25	47.687	-124.564	16	29	4/22/2025	10/15/2025
M26	47.696	-124.561	16	29	4/22/2025	NA
M27	47.704	-124.557	15	27	4/22/2025	10/15/2025

M28	47.712	-124.550	14	26	4/22/2025	NA
M29	47.720	-124.546	13	24	4/22/2025	10/15/2025
M30	47.727	-124.554	14	26	4/22/2025	NA
M31	47.735	-124.560	14	26	4/22/2025	10/15/2025
M32	47.743	-124.567	14	26	4/22/2025	NA
M33	47.751	-124.573	14	26	4/22/2025	10/15/2025
M34	47.759	-124.580	14	26	4/22/2025	NA
M35	47.765	-124.590	15	27	4/22/2025	10/15/2025
M36	47.772	-124.599	15	27	4/22/2025	NA
M37	47.780	-124.604	14	26	4/22/2025	10/15/2025
M38	47.787	-124.613	14	26	4/22/2025	NA
M39	47.794	-124.621	15	27	4/22/2025	10/15/2025
M40	47.802	-124.627	16	29	4/22/2025	NA
M41	47.512	-124.427	15	27	4/22/2025	10/15/2025
M42	47.503	-124.425	15	27	4/22/2025	NA

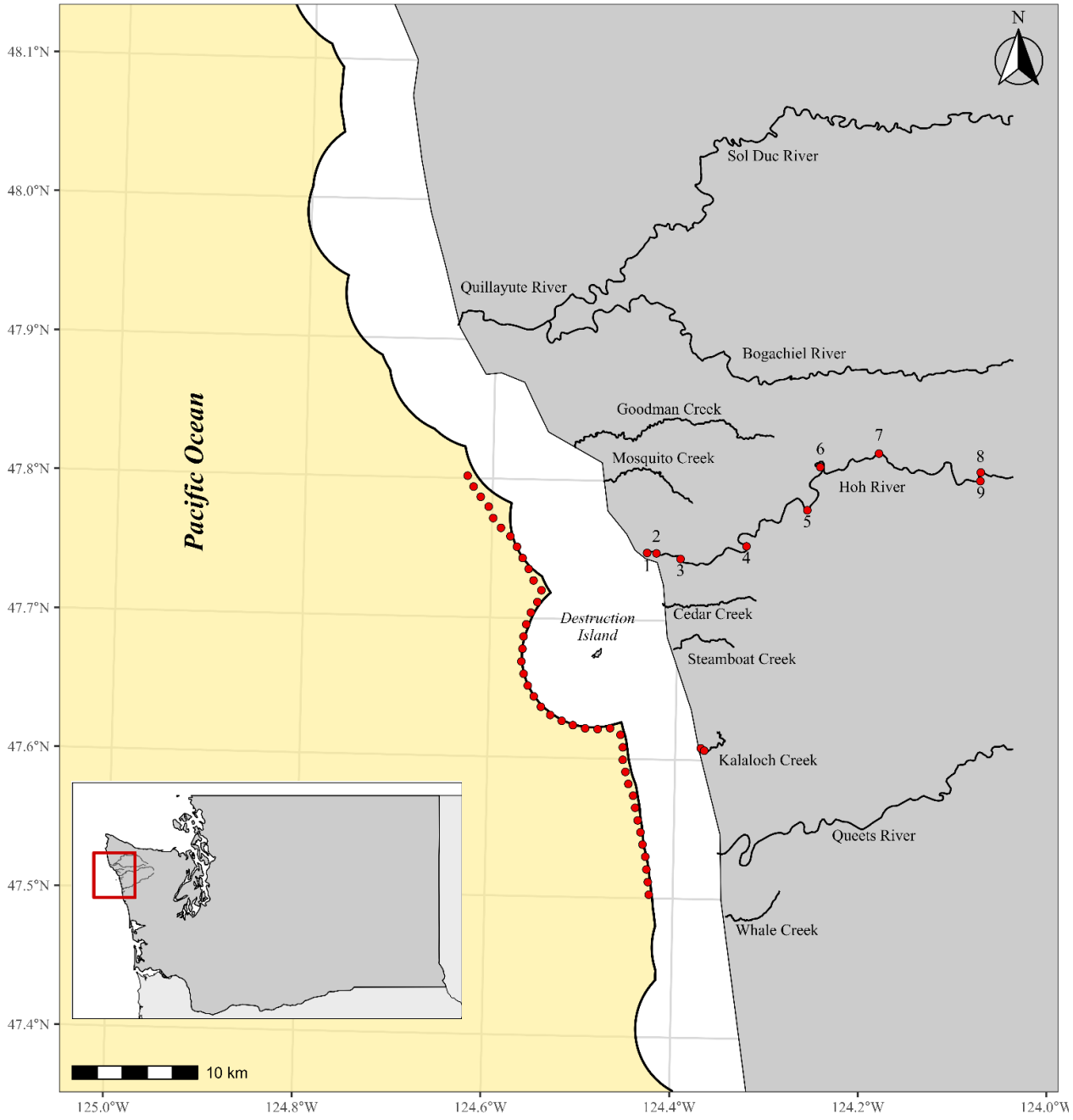

Figure 1 Map of Navy-managed acoustic receivers deployed along the 3-nm array off the Washington coast (n = 42), as well as receivers deployed within the Hoh River and Kalaloch Creek. The yellow shaded area delineates the NWTT Study Area.

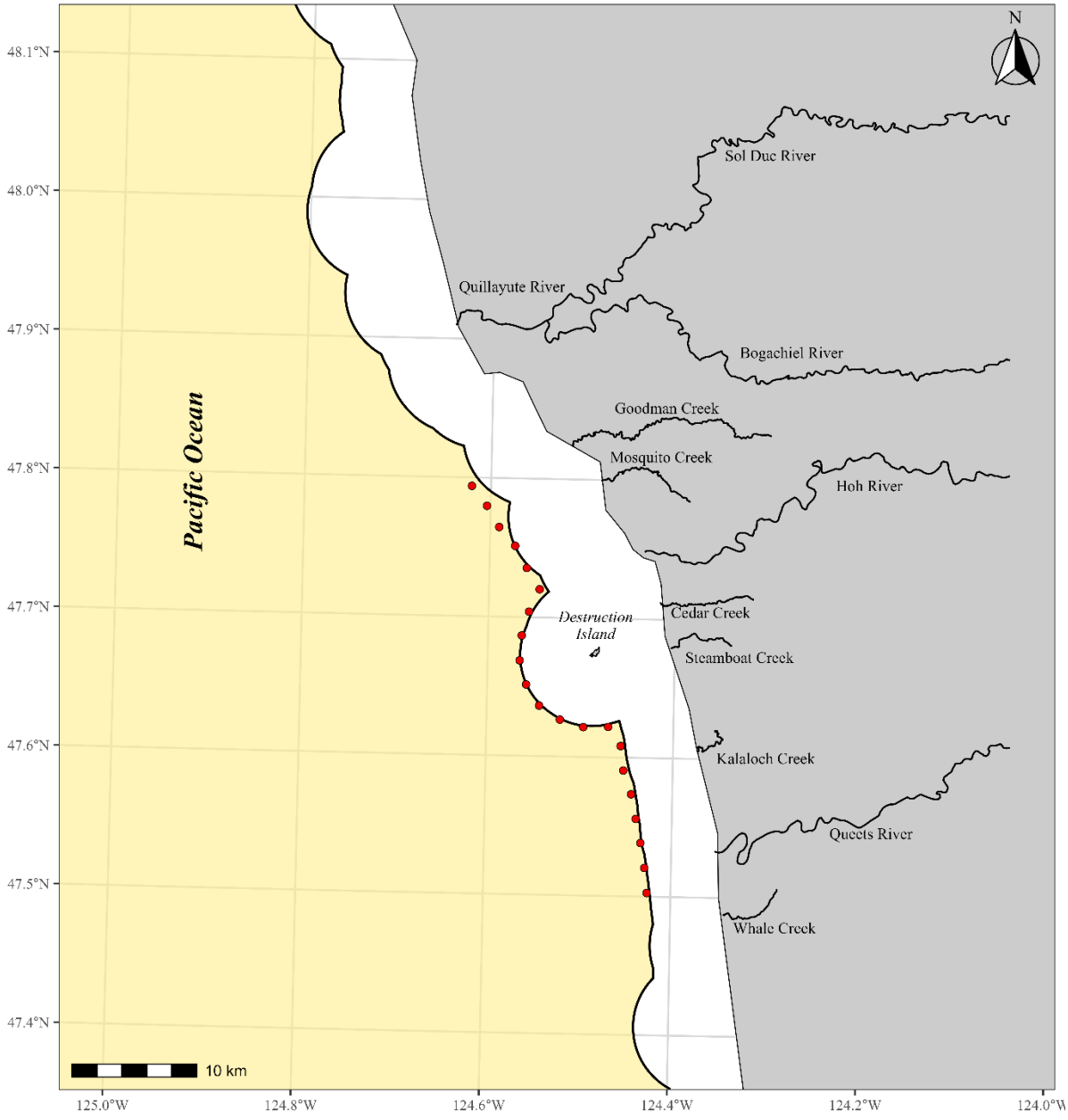

Figure 2 Map of receivers deployed along the 3-nautical-mile array off the Washington coast showing the reduced marine configuration (n = 21 receivers). Receivers were spaced approximately 1,800 m apart and deployed in October 2025; recovery and data download are planned for spring 2026. The yellow shaded area delineates the NWTT Study Area.

In addition to the 3-nm marine array, acoustic receivers were deployed in the Hoh River and Kalaloch Creek to record tagged fish presence and movement (Table 2). The Hoh River array consisted of nine receivers managed and maintained by the Hoh Tribe. The Kalaloch Creek array consisted of two receivers managed by the U.S. Navy, including one near the river mouth at the U.S. Highway 101 bridge crossing and one approximately 1 km upstream from the bridge.

We also incorporated detection data from a collaborative network of acoustic receivers deployed along the Washington outer coast (Figure 3). This network included receivers managed by NOAA NMFS, additional Navy-funded projects, and other regional research partners. These externally managed receivers were not deployed as part of the present study but were integrated into analyses to improve spatial coverage and to document detections occurring outside the primary 3-nm array and riverine receivers.

Table 2 Deployment information for freshwater acoustic receivers deployed in the Hoh River and Kalaloch Creek. Table includes receiver ID, geographic coordinates, deployment and retrieval dates, and relative river position. The Hoh River receivers were managed by the Hoh Indian Tribe, and the Kalaloch Creek receivers were managed by the Navy.

ID	Latitude	Longitude	Deploy date	Download date	River position
Hoh 01	47.749	-124.434	5/15/2025	10/15/2025	Mouth
Hoh 02	47.748	-124.424	4/30/2025	10/15/2025	*Lower
Hoh 03	47.745	-124.398	4/30/2025	10/15/2025	Lower
Hoh 04	47.755	-124.328	4/30/2025	8/11/2025	Lower-Mid
Hoh 05	47.781	-124.264	4/30/2025	10/15/2025	Mid
Hoh 06	47.813	-124.25	8/1/2025	10/15/2025	Mid
Hoh 07	47.823	-124.188	4/30/2025	10/15/2025	Upper-Mid
Hoh 08	47.804	-124.079	5/1/2025	10/15/2025	Upper
Hoh 09	47.810	-124.079	4/30/2025	10/15/2025	Upper
Kalaloch 01	47.609	-124.373	4/20/2025	1/1/2026	Mouth (near Hwy 101 bridge)
Kalaloch 02	47.607	-124.369	5/20/2025	9/30/2025	Lower (1km up from 101 bridge)

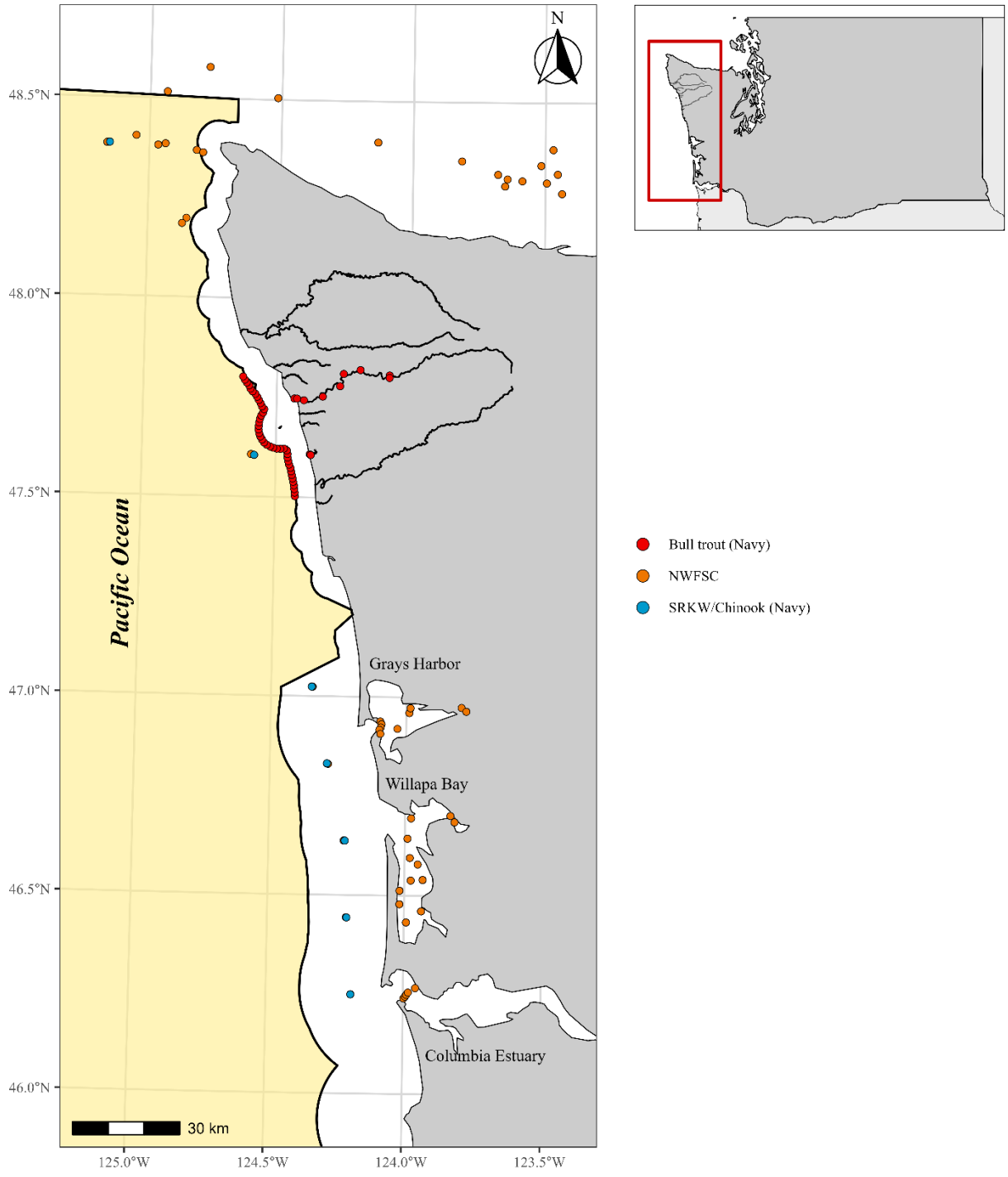

Figure 3 Map of acoustic receiver deployment locations along the Washington coast that were active during the study period (January 1 to October 1, 2025). Receiver symbols are color-coded by managing project, including Bull trout (Navy), SRKW/Chinook (Navy), and the Northwest Fisheries Science Center (NWFSC). The yellow shaded area delineates the NWTT Study Area.

Fish sampling

A total of 30 bull trout were tagged during the study period, including 15 individuals in Kalaloch Creek and 15 individuals in the Hoh River (Table 3). The primary tagging effort occurred between late April and May 2025, during which 18 bull trout were tagged (15 in Kalaloch Creek and 3 in the Hoh River). Additional sampling was conducted in Goodman, Mosquito, Cedar, and Steamboat Creeks; however, no bull trout were captured in these drainages despite substantial effort. Access was not available for the Queets River or Whale Creek. Given lower-than-expected encounter rates during the spring sampling window, tagging efforts were extended beyond the primary sampling period, with subsequent efforts focused on the Hoh River to increase the sample size of tagged fish. Additional sampling in the Hoh River yielded 12 additional tagged fish, primarily captured in May, June, and August (Table 3).

At each sampling location, bull trout were captured using hook and line with artificial lures and barbless hooks. All captured fish met minimum size requirements for tagging (≥250 mm fork length) and were acoustically tagged. Individuals were surgically implanted with 69 kHz acoustic transmitters (VEMCO V9 or V16), with expected battery lives of approximately 291 days and up to 7 years, respectively (Table 3). All V9 transmitters were programmed to transmit temperature and pressure. All tags were programmed with a randomized transmission interval of 60–150 s to reduce signal collision and extend battery life. Under typical environmental conditions, estimated detection range of the transmitters was approximately 500 m.

Analysis

Detection data were compiled, downloaded, and processed using standardized quality-control procedures. Data were screened to remove duplicate detections, false positives, and other erroneous records. Analyses were restricted to receivers that recorded at least one bull trout detection during the study period. For each tagged bull trout, the transmitter identification code, transmitter serial number, tagging date, fish fork length (mm), total number of detections, and number of unique receivers with detections are summarized in Table 3.

Table 3 Summary of bull trout acoustically tagged in 2025, including transmitter configuration, capture information, estimated tag life, fork length (mm), and detection metrics. The "Sensors" column indicates whether transmitters were equipped with pressure and temperature sensors (°C/P). Detection metrics are based on acoustic detections aggregated into 4-hour time bins, such that multiple detections within a bin were treated as a single presence event. Metrics include total detection events and detection events by environment (Marine, Kalaloch Creek, and Hoh River).

Tag ID	Sensors	Capture date	Tag life	Length (mm)	Capture system	Total detections	Marine detections	Kalaloch detections	Hoh detections
44557	none	1/23/2025	7 years	584	Hoh	8	1	0	7
40491	none	3/18/2025	291 days	282	Hoh	7	0	0	7
309	P/°C	4/28/2025	291 days	364	Kalaloch	45	0	41	4
311	P/°C	4/28/2025	291 days	455	Kalaloch	223	0	19	204
313	P/°C	4/28/2025	291 days	550	Kalaloch	19	0	2	17

315	P/°C	4/28/2025	291 days	538	Kalaloch	28	0	19	9
317	P/°C	4/28/2025	291 days	637	Kalaloch	0	0	0	0
319	P/°C	4/28/2025	291 days	490	Kalaloch	14	0	4	10
307	P/°C	4/28/2025	291 days	490	Kalaloch	8	0	8	0
305	P/°C	4/28/2025	291 days	475	Kalaloch	22	0	17	5
303	P/°C	4/28/2025	291 days	524	Kalaloch	8	0	8	0
301	P/°C	4/28/2025	291 days	390	Kalaloch	124	0	84	40
299	P/°C	4/28/2025	291 days	360	Kalaloch	148	0	144	4
297	P/°C	4/28/2025	291 days	535	Kalaloch	10	0	0	10
321	P/°C	4/30/2025	291 days	312	Kalaloch	23	0	17	6
333	P/°C	5/14/2025	291 days	310	Kalaloch	15	0	15	0
335	P/°C	5/14/2025	291 days	300	Kalaloch	2	0	2	0
40121	none	5/15/2025	291 days	375	Hoh	96	56	0	42
43974	none	5/15/2025	7 years	500	Hoh	150	0	129	21
43977	none	5/15/2025	7 years	410	Hoh	28	0	0	28
44559	none	6/6/2025	7 years	525	Hoh	24	0	0	24
43968	none	6/13/2025	7 years	442	Hoh	58	0	0	58
43971	none	6/13/2025	7 years	497	Hoh	3	0	0	3
339	P/°C	8/5/2025	291 days	414	Hoh	0	0	0	0
331	P/°C	8/5/2025	291 days	459	Hoh	0	0	0	0
341	P/°C	8/6/2025	291 days	243	Hoh	0	0	0	0
43969	none	8/6/2025	7 years	662	Hoh	0	0	0	0
44553	none	8/22/2025	7 years	650	Hoh	0	0	0	0
355	P/°C	8/27/2025	291 days	425	Hoh	248	0	0	248
353	P/°C	10/15/2025	7 years	284	Hoh	0	0	0	0

Notes: P = pressure; °C = Temperature in degrees Celsius

RESULTS

Data recovery

All 42 marine acoustic receivers deployed in the 3-nm array were successfully recovered and downloaded in October of 2025. At the time of this report, nine receivers from the Hoh River array had been downloaded. In Kalaloch Creek, the receiver deployed near the U.S. Highway 101 bridge crossing was downloaded and redeployed in January of 2026. The second receiver, located approximately 1 km upstream from the U.S. Highway 101 bridge, recorded no detections of tagged bull trout and was not redeployed after its servicing in September of 2025.

Tagged fish size distributions

Between the current tagging study and a prior tagging study conducted in 2019 (Smith and Huff, 2023), a total of 47 bull trout were measured and acoustically tagged in the Hoh River and Kalaloch Creek. Median fork length differed by capture location, with fish captured in the Hoh

River exhibiting a larger median fork length (425 mm, n = 21) than those captured in Kalaloch Creek (364 mm, n = 26; Figure 4). However, mean fork length did not differ significantly between systems (Welch's two-sample t-test, t = 0.93, df = 41.6, p = 0.36).

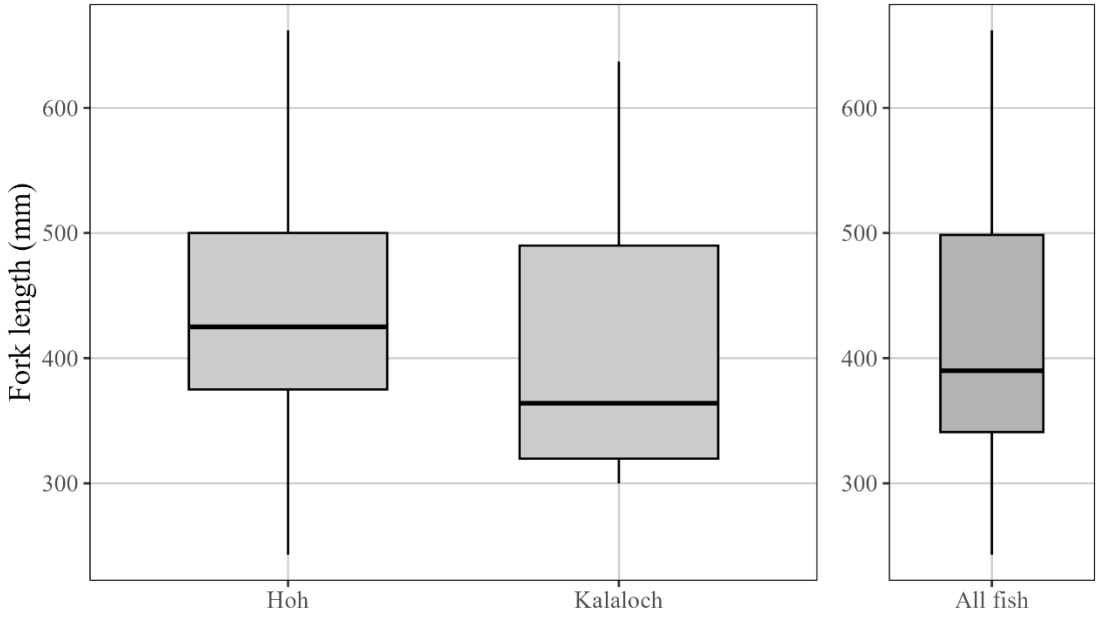

Figure 4 Fork-length distribution of tagged bull trout (n = 47). Fork length measurements include fish tagged in 2025 (n = 30) as well fish tagged in a 2019 study conducted by Smith and Huff (n = 17, Smith & Huff; 2023). Boxes show interquartile ranges, center lines indicate medians, and whiskers extend to 1.5× the interquartile range.

Movements of Kalaloch-tagged bull trout

Ten of the 15 bull trout tagged in Kalaloch Creek during the 2025 study were subsequently detected on Hoh River receivers (Table 4, Figure 5, Figure 6). Fish were last detected on the Kalaloch receiver and first detected on Hoh River receivers in mid-May. Apparent marine residency spanned from two days to roughly three months. Once detected in the Hoh River, individuals were recorded over extended periods, indicating continued river residence rather than rapid passage through the system. None of the fish tagged in Kalaloch Creek were detected on marine receivers during the study period, and no individuals exhibited detection patterns consistent with repeated transitions between freshwater and marine environments once in the Hoh River.

Table 4 Bull trout tagged in Kalaloch Creek in 2025 that were subsequently detected in the Hoh River. For each individual, the table reports tag date, capture location, the last observed detection in Kalaloch Creek (used to define exit from the freshwater system), the date of first detection on a Hoh River receiver, and the number of days spent in the marine environment (calculated as the elapsed time between last Kalaloch detection and first Hoh River detection). Additional metrics include the date of last Hoh River detection (prior to upstream movement toward spawning grounds) and apparent mainstem residency (days between first and last Hoh River detections).

Tag ID	Tag date	Capture system	Last Kalaloch detection	First Hoh detection	Marine days	Last Hoh detection	Mainstem days
299	4/28/2025	Kalaloch	5/10/2025	5/13/2025	3	5/26/2025	13
311	4/28/2025	Kalaloch	5/10/2025	5/13/2025	3	7/14/2025	62
301	4/28/2025	Kalaloch	5/15/2025	5/16/2025	2	5/28/2025	11
313	4/28/2025	Kalaloch	5/8/2025	6/12/2025	35	6/23/2025	10
319	4/28/2025	Kalaloch	5/2/2025	6/13/2025	42	6/24/2025	11
297	4/28/2025	Kalaloch	4/28/2025	6/19/2025	53	6/27/2025	7
315	4/28/2025	Kalaloch	5/8/2025	6/24/2025	47	7/4/2025	10
309	4/28/2025	Kalaloch	5/12/2025	7/7/2025	56	7/11/2025	4
321	4/30/2025	Kalaloch	5/12/2025	8/2/2025	82	8/6/2025	3
305	4/28/2025	Kalaloch	5/7/2025	8/19/2025	104	8/25/2025	6

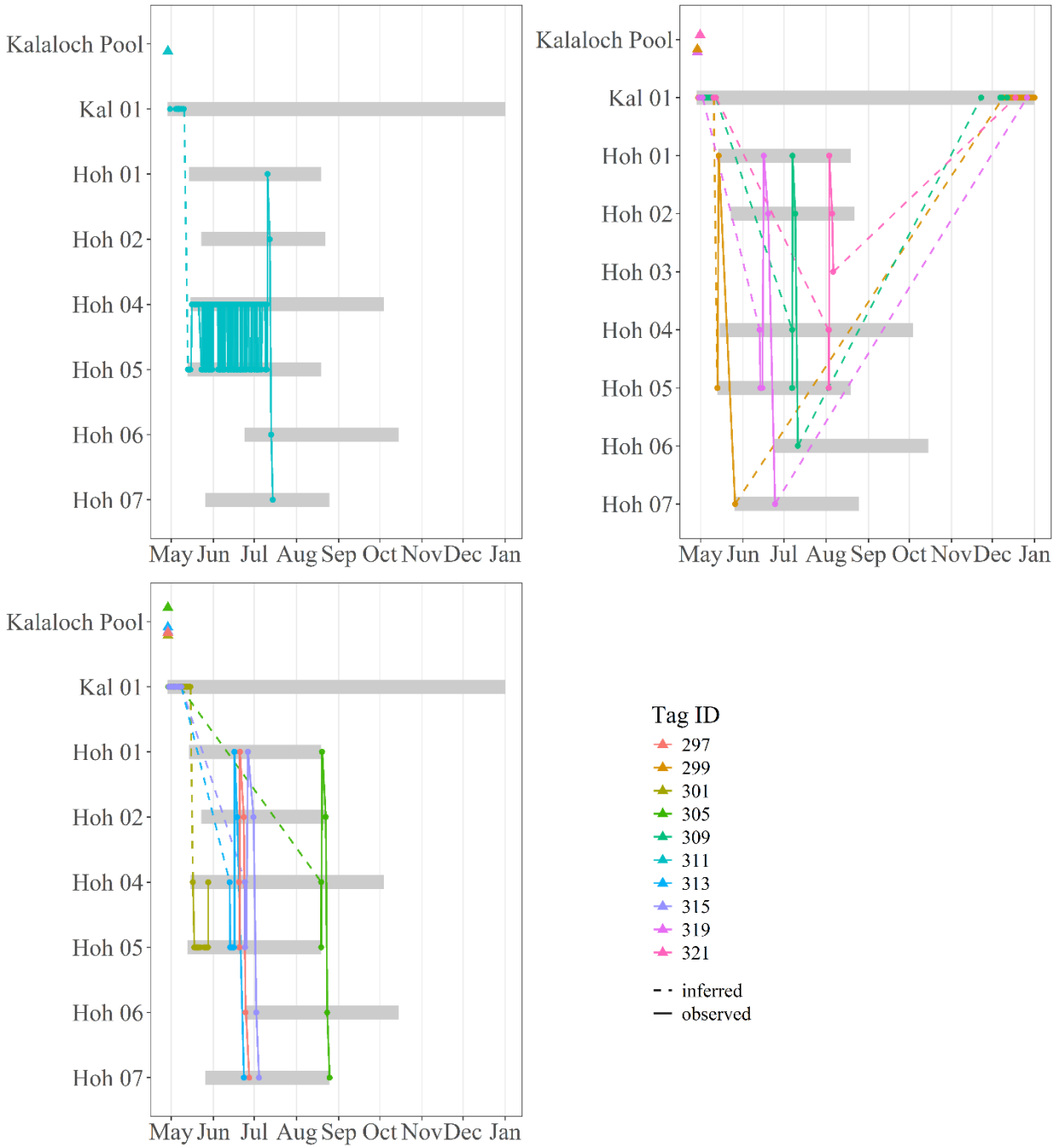

Figure 5 Detection-history schematics for bull trout tagged in Kalaloch Creek in 2025 that were subsequently detected on Hoh River receivers. The x-axis shows date and the y-axis lists receiver locations, with Hoh River receivers ordered from downstream (Receiver 1 at the mouth) to upstream (Receiver 7). Triangles denote tagging dates, colored points represent acoustic detections, solid lines indicate observed movements between receivers, and dashed lines indicate inferred movements when detections occurred at nonadjacent locations (e.g., transitions between Kalaloch Creek and the Hoh River). Gray horizontal bars denote receiver deployment periods.

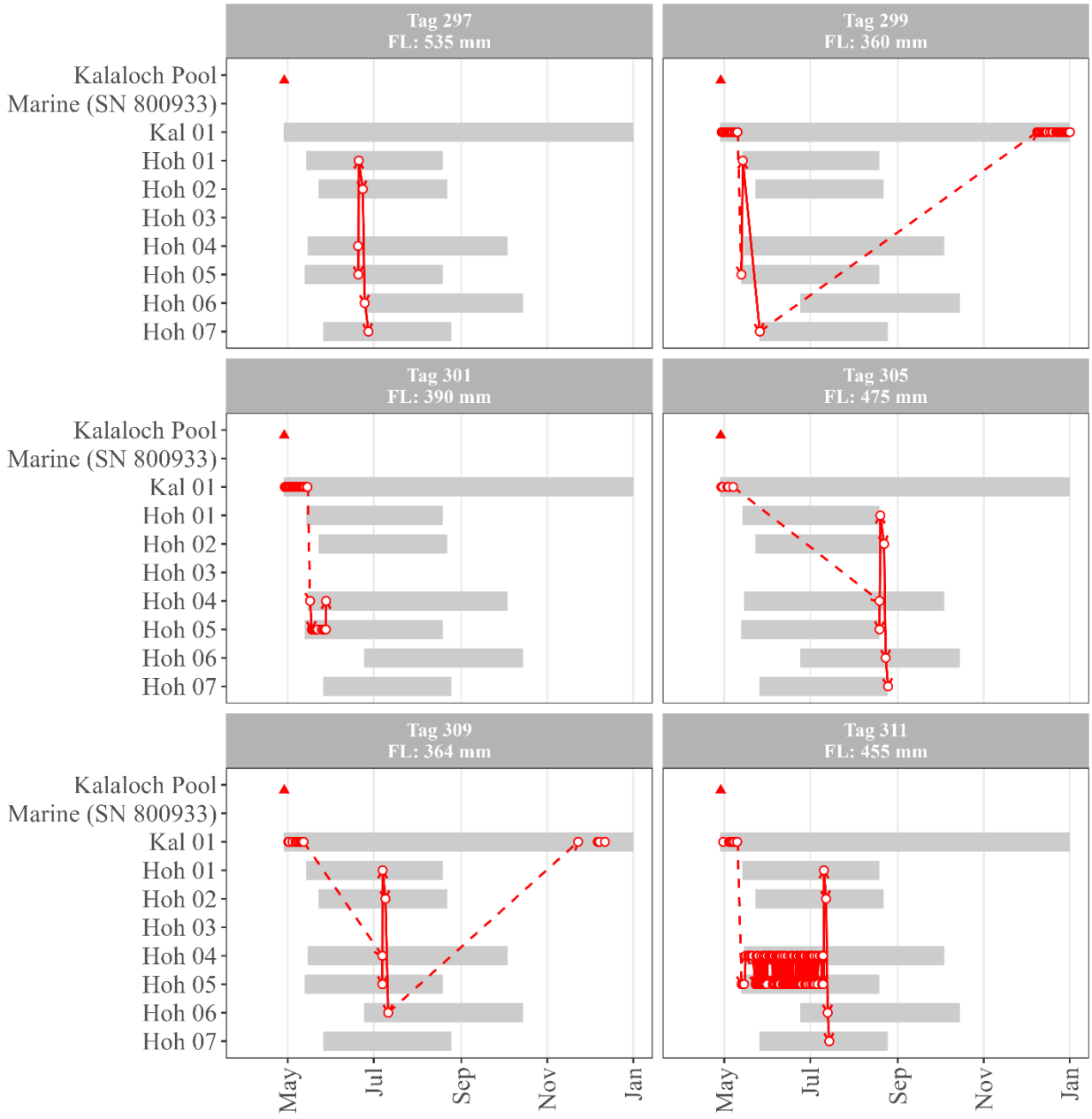

Figure 6 Schematic representation of detection histories for anadromous bull trout tagged in Kalaloch Creek in 2025 that subsequently returned to the Hoh River. Each panel shows the detection history of an individual fish with the Tag ID and fork length shown in panel headers. The x-axis shows the date and the y-axis lists receiver locations. Triangles indicate capture date. Gray horizontal bars denote periods when receivers were deployed and available to detect tagged fish. Solid red lines indicate observed movements between receivers based on successive acoustic detections, whereas dashed red lines indicate inferred movements when detections occur at a destination receiver without a corresponding detection at the immediately preceding location (part 1 of 2).

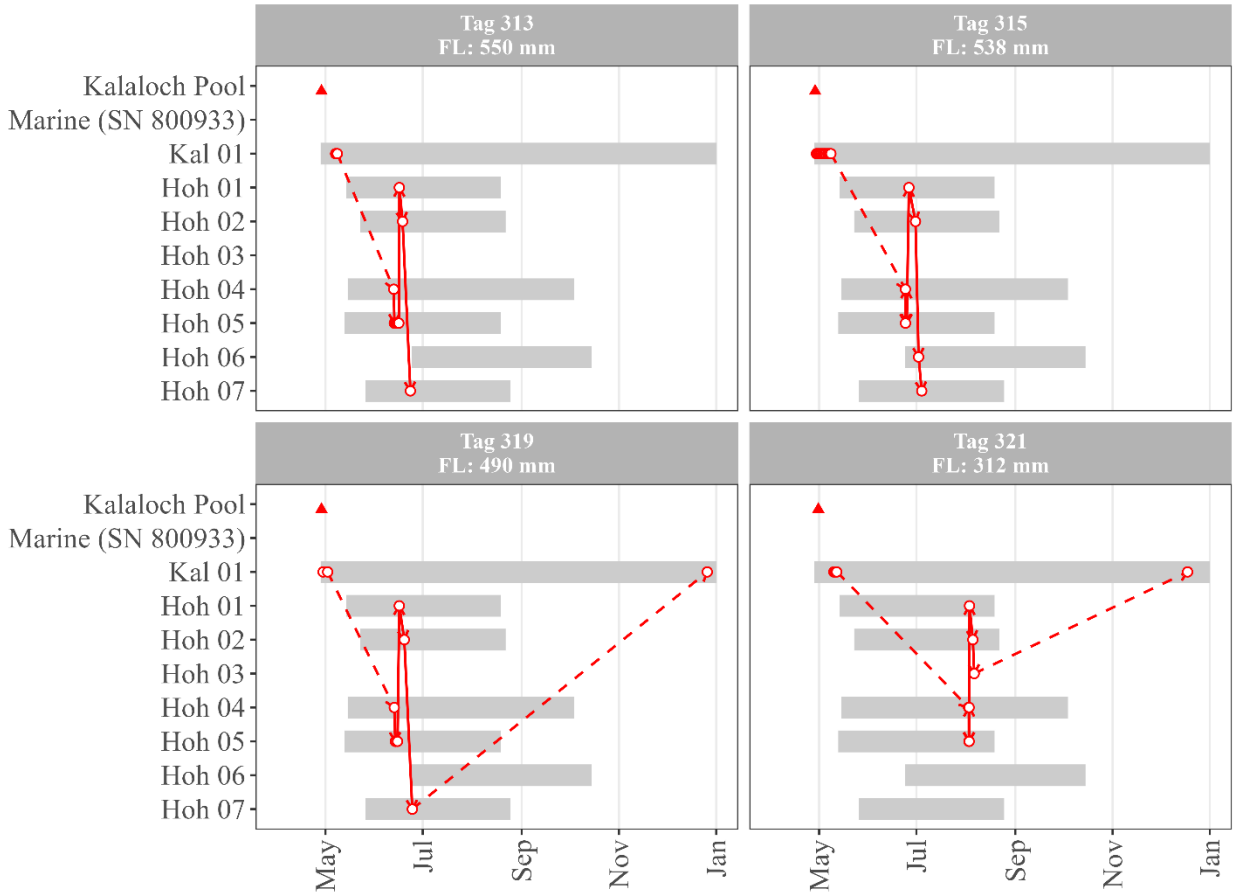

Figure 6 (continued)

Kalaloch return timing

Because the Hoh River receivers have not been recovered since initial servicing, the timing of exit from the Hoh River into marine waters could not be determined for these tagged individuals. The Hoh Tribe anticipates downloading the Hoh River receiver array by April 2026. As of January 1, 2026, five tagged bull trout were detected in Kalaloch Creek (Table 5). Four of these individuals were originally tagged in Kalaloch Creek, and one was originally tagged in the Hoh River. The first detections in Kalaloch Creek occurred during the first week of December 2025 (Table 5, Figure 7).

Table 5 Winter arrival timing of tagged bull trout detected in Kalaloch Creek.

Tag ID	Capture System	Kalaloch arrival
309	Kalaloch	12/6/2025
43974	Hoh	12/7/2025
299	Kalaloch	12/8/2025
321	Kalaloch	12/18/2025
319	Kalaloch	12/26/2025

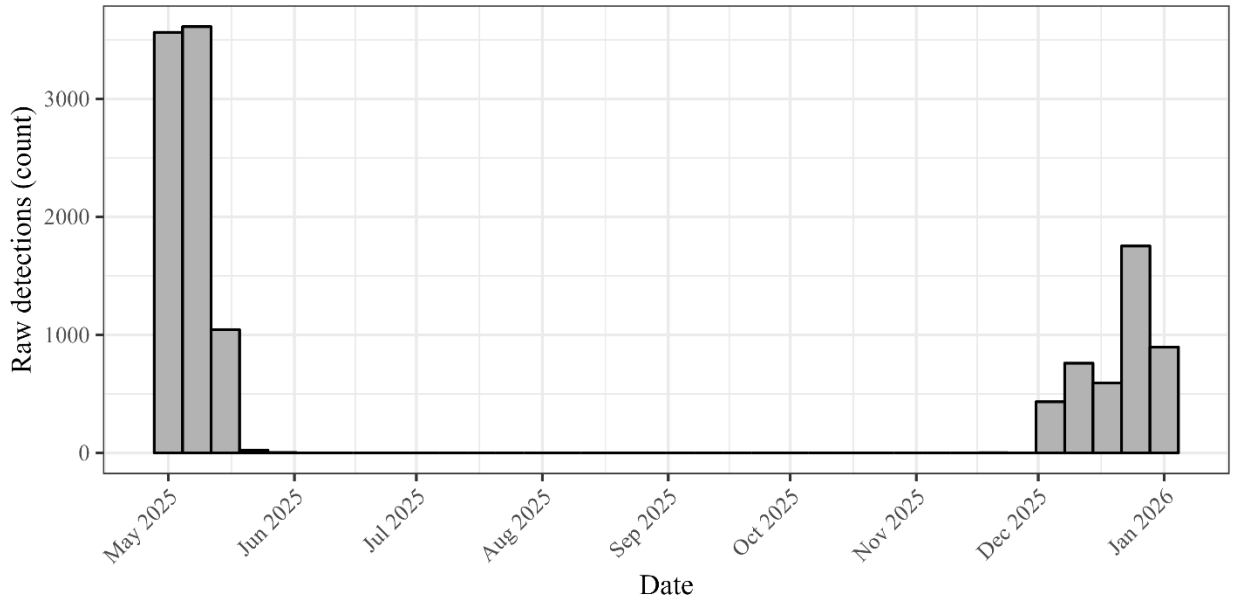

Figure 7 Histogram of raw acoustic detections for bull trout tagged in Kalaloch Creek during 2025. Bars represent the total number of detections recorded at Kalaloch Creek receivers across all tagged individuals, aggregated in 7-day bins. Detection counts indicate a pronounced spring residency period following tagging, an extended summer–early fall absence, and a subsequent return period beginning in early December.

Movements of Hoh River–tagged bull trout

Bull trout tagged in the Hoh River exhibited a range of river-resident behaviors (Figure 8, Figure 9). Several individuals were detected across multiple Hoh River receivers, indicating movement among river reaches following tagging. A subset of Hoh-tagged fish were detected repeatedly on a single receiver only, with no detections at additional upstream or downstream locations. These detection patterns are consistent with limited post-tagging movement, early mortality, tag shedding, or prolonged residency near the capture location.

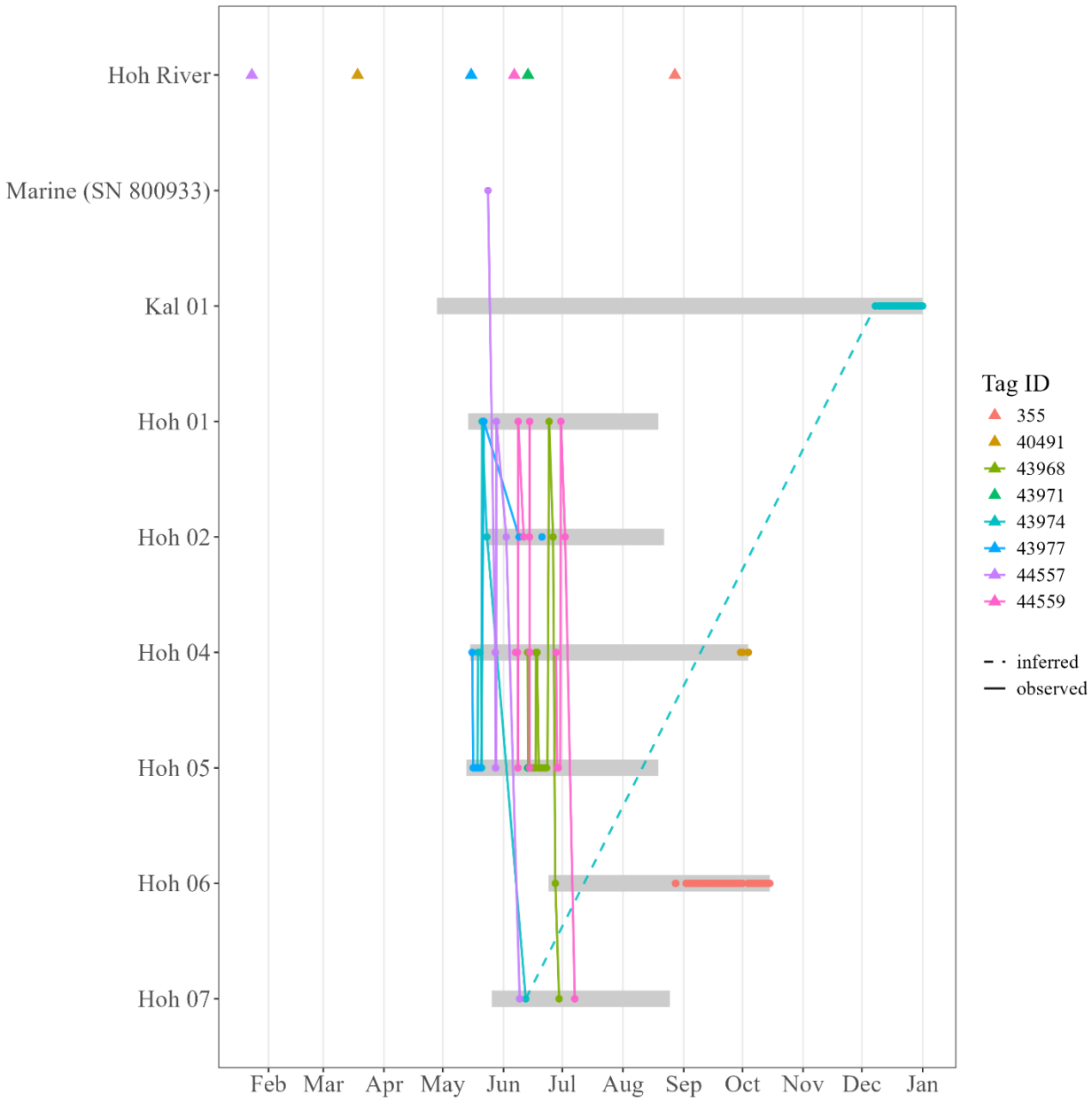

Figure 8 Detection-history schematic for bull trout tagged in the Hoh River in 2025. The x-axis shows date and the y-axis lists receiver locations, with Hoh River receivers ordered from downstream (Receiver 1 at the river mouth) to upstream (Receiver 7). Triangles denote tagging dates, colored points represent acoustic detections, solid lines indicate observed movements between receivers, and dashed lines indicate inferred movements when detections occurred at nonadjacent locations (e.g., transitions between Kalaloch Creek and the Hoh River). Gray horizontal bars denote receiver deployment periods. Several individuals were detected repeatedly at a single receiver only, a pattern potentially consistent with early post-tagging mortality, tag shedding, or prolonged stationary behavior near the capture location.

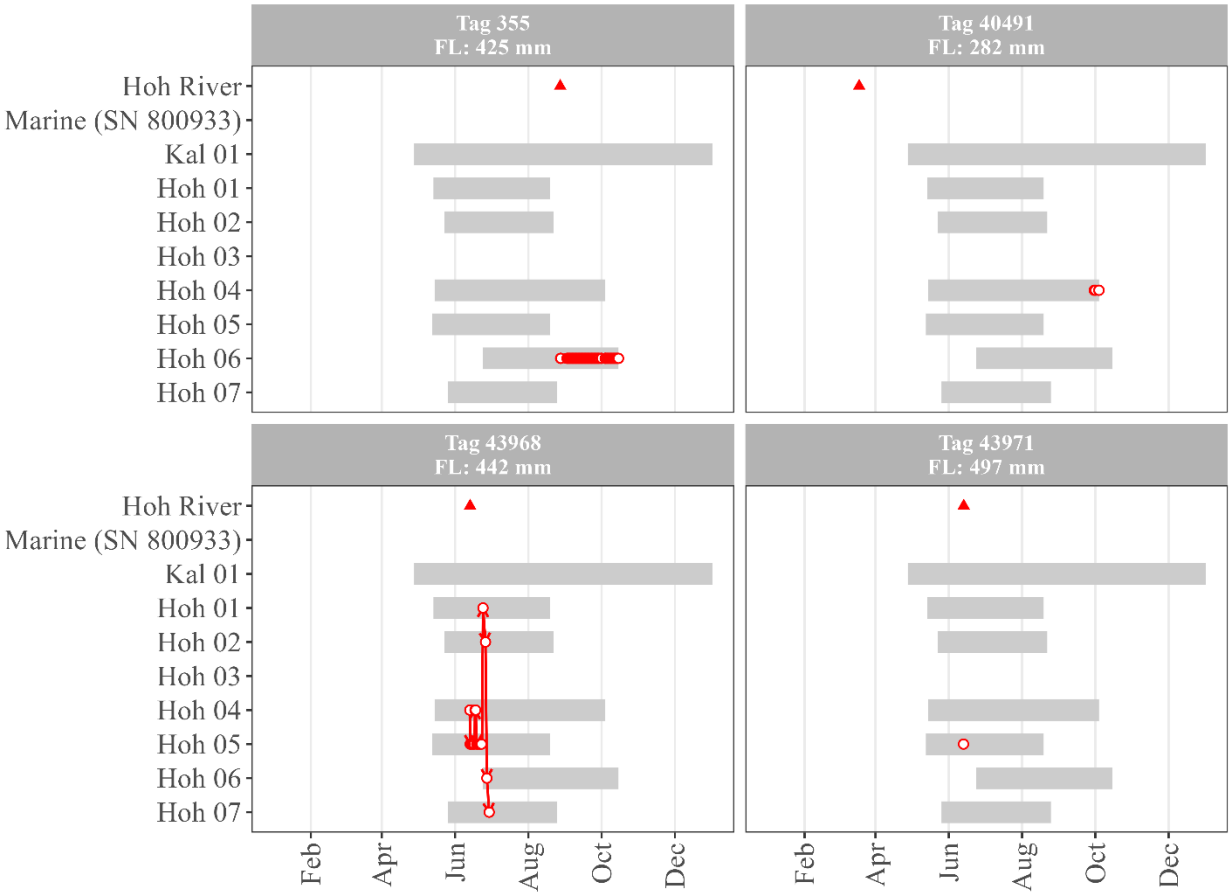

Figure 9 Detection-history schematics for individual bull trout tagged in the Hoh River. Each panel shows a single fish (Tag ID and fork length in header). The x-axis shows date and the y-axis lists receiver locations. Triangles denote capture dates and gray horizontal bars indicate receiver deployment periods. Solid red lines represent observed movements between receivers based on successive detections, and dashed red lines indicate inferred movements when detections occurred at a receiver without a detection at the immediately adjacent location (part 1 of 2).

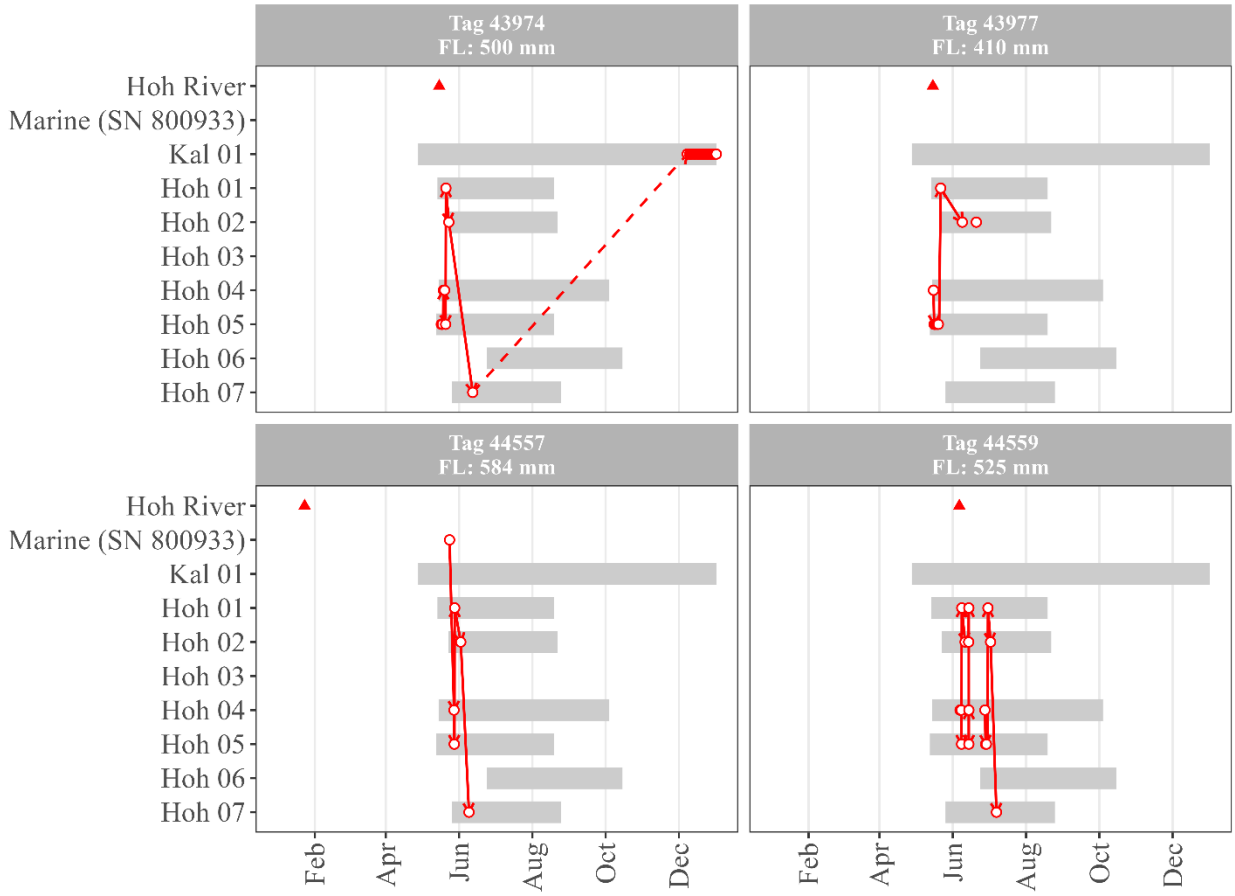

Figure 9 (continued)

Marine detections

Marine detections were rare overall. One Hoh River–tagged individual (Tag ID 40121, tagged in May 2025) accounted for the majority of marine detections, exhibiting extensive and rapid movements among multiple marine receivers deployed in the 3-nm array outside of Destruction Island, as well as near the mouth of the Hoh River (Figures 10 – 12). The movement pattern for this individual was inconsistent with typical bull trout behavior and is most plausibly explained by tag transport by a marine predator. This individual was tagged by the Hoh Tribe on our behalf using one of their transmitters, which did not include pressure or temperature sensors. Consequently, we were unable to use depth or thermal data to further evaluate whether the observed detections were consistent with predator-mediated transport.

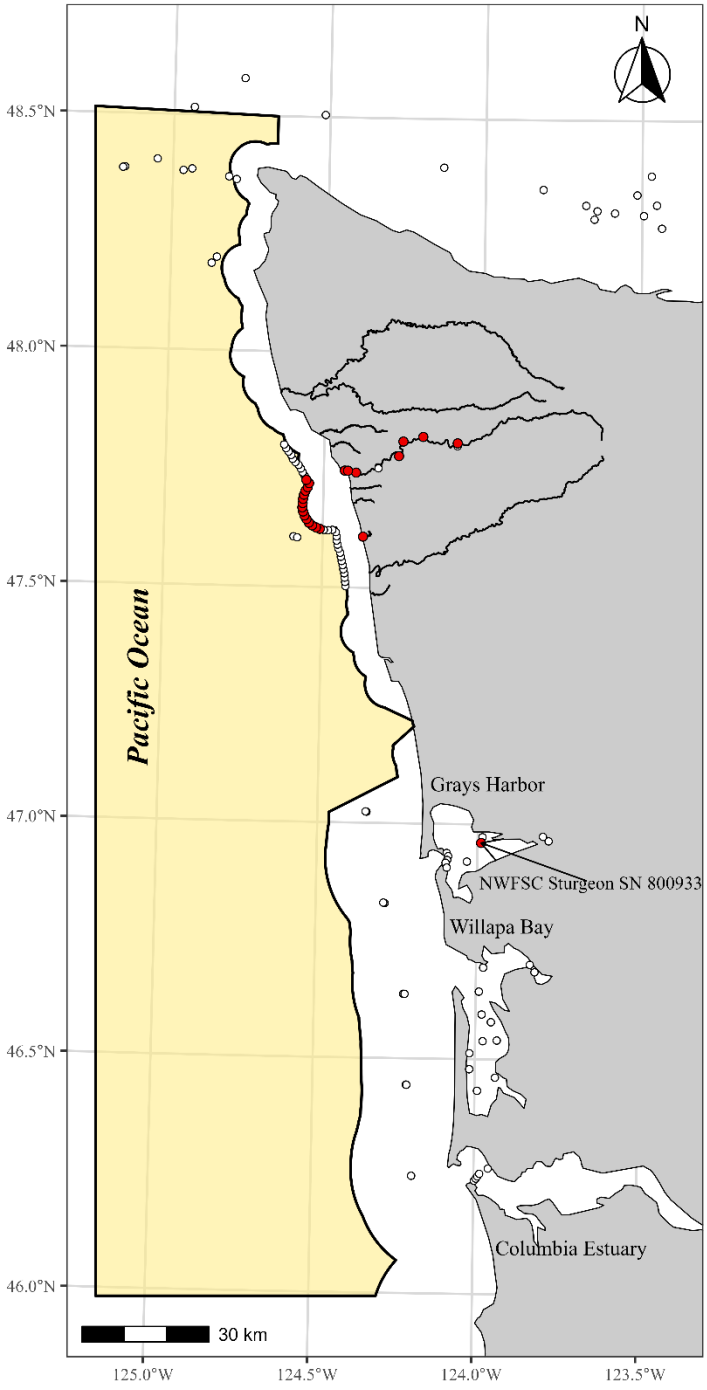

Figure 10 Map of acoustic receiver locations and bull trout detections within the study region. Receivers that recorded at least one bull trout detection ($n \geq 1$) are shown in red; receivers deployed during the study period that did not record bull trout detections are shown as open circles. The Northwest Training and Testing (NWTT) Study Area is indicated by the yellow shaded polygon. One individual (Tag ID 40121) accounted for widespread detections across multiple marine receivers; this pattern is atypical for bull trout and may reflect tag transport by a marine predator.

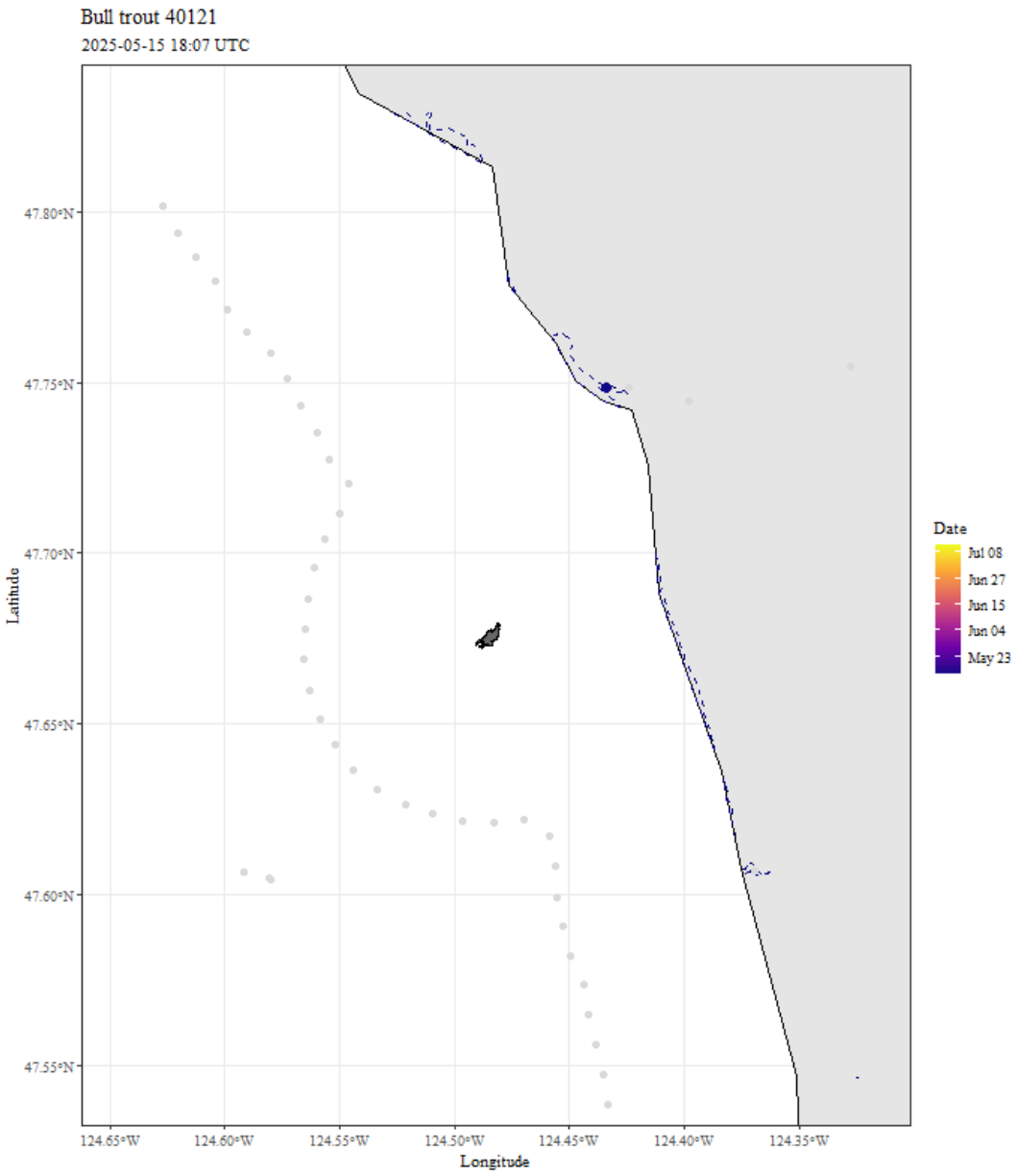

Figure 11 Animated visualization of acoustic detections for tag 40121 along the Washington coast during 2025. Gray points indicate acoustic receiver locations deployed during the study period. The colored points show the receiver location where the fish was detected at that time step, with color denoting detection date (earlier detections shown in darker colors and later detections in lighter colors). The detection sequence spans multiple marine receivers distributed along the coastline, with repeated detections near the mouth of the Hoh River and slightly upriver. The extent and apparent rate of movement are atypical for bull trout and may reflect tag transport by a marine predator.

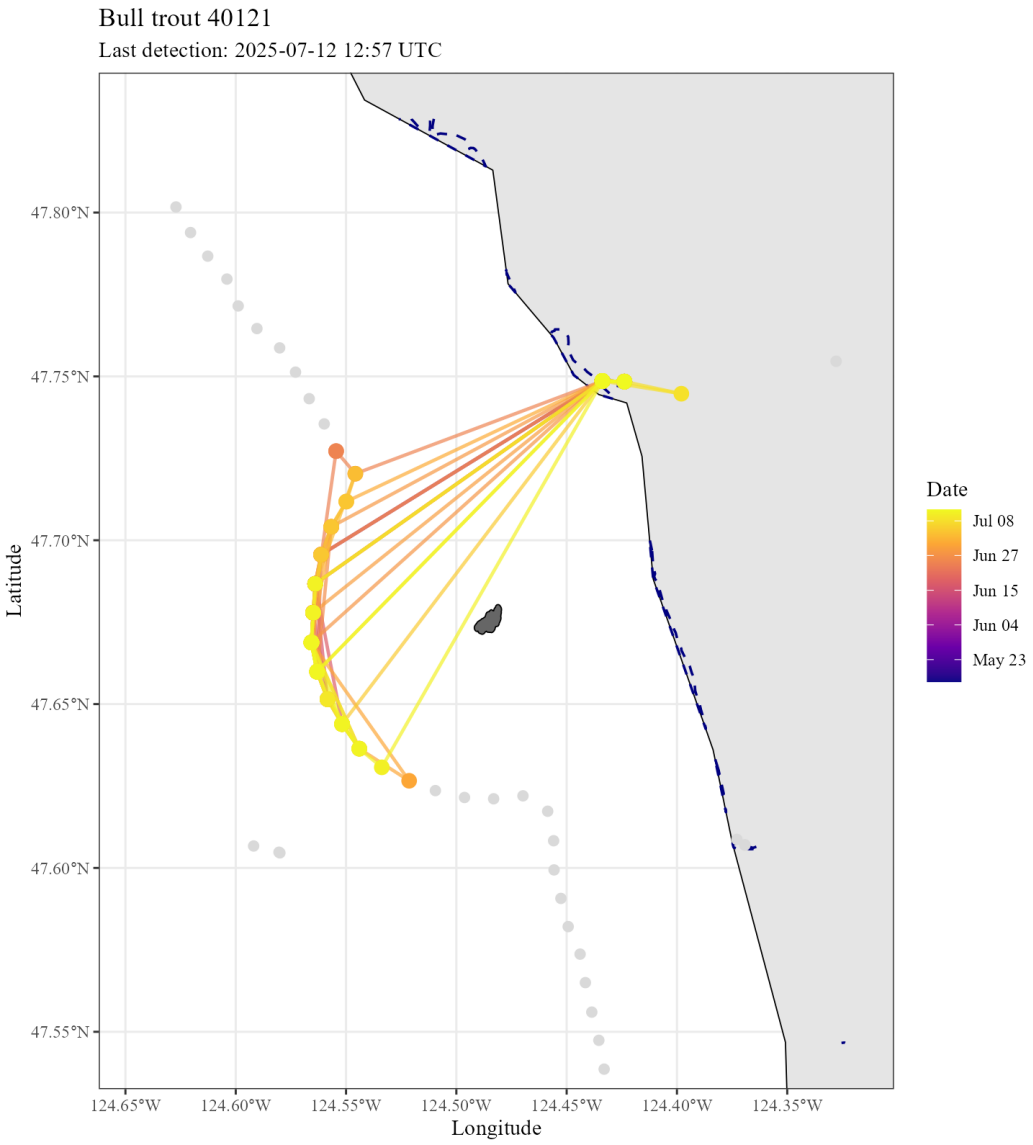

Figure 12 Static summary of the full detection track for bull trout Tag ID 40121 during 2025. Gray points represent acoustic receiver deployment locations. Colored points indicate receiver locations where detections occurred (color scaled by detection date; darker = earlier, lighter = later), and lines connect detections in chronological order. Detections occurred across multiple marine receivers along the Washington coast, including repeated detections near the mouth of the Hoh River and slightly upstream. The spatial extent and apparent rate of movement are atypical for bull trout and may reflect tag transport by a marine predator.

A second Hoh River-tagged fish (Tag ID 44557, tagged in January 2025) was detected in Grays Harbor on May 24, 2025, and subsequently detected in the Hoh River beginning on May 27, 2025, despite no detections on intervening marine receivers along the coast (Figures 13 – 15). The absence of intermediate detections suggests coastal movement along a nearshore pathway, and the subsequent return to the Hoh River is consistent with anadromous behavior.

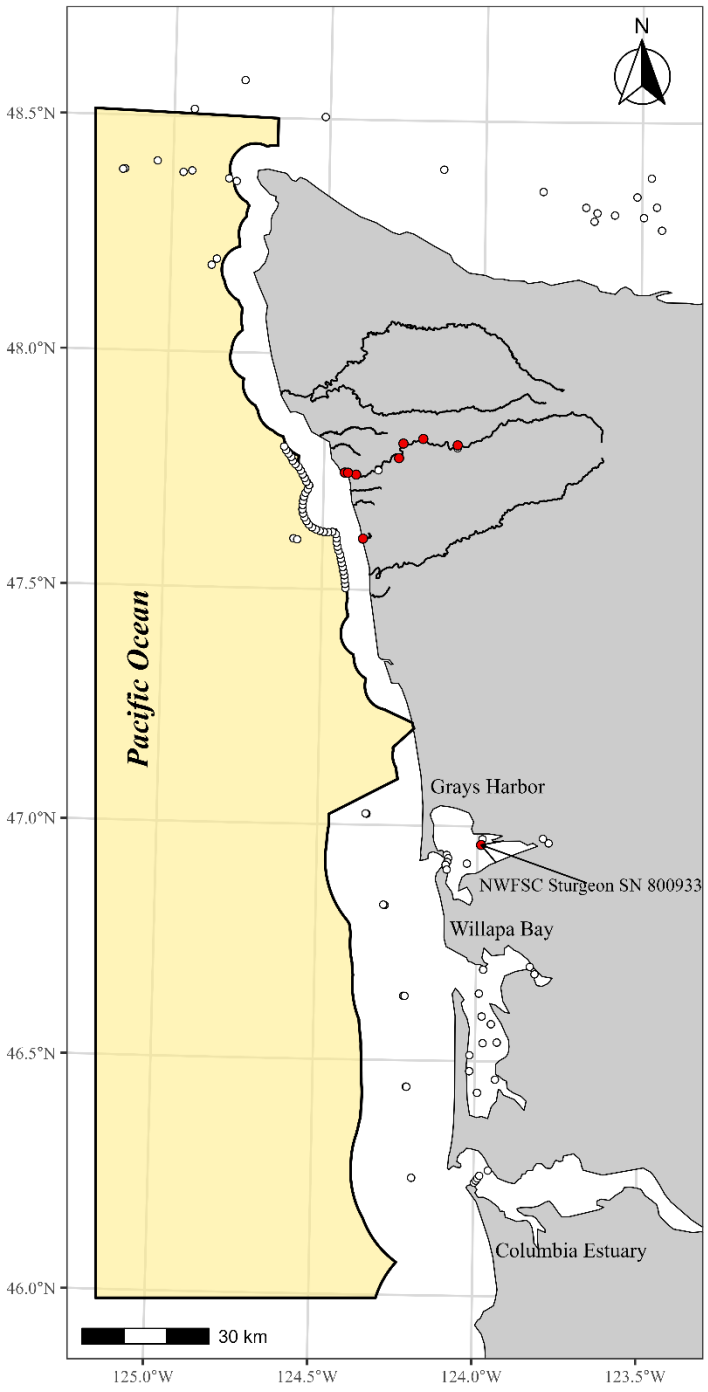

Figure 13 Map of receiver locations and bull trout detections within the study region, excluding detections from Tag ID 40121. With this individual removed, substantially fewer marine receivers recorded bull trout detections, and all remaining marine detections occurred within 3 nautical miles of the shoreline. The Northwest Training and Testing (NWTT) Study Area is indicated by the yellow shaded polygon.

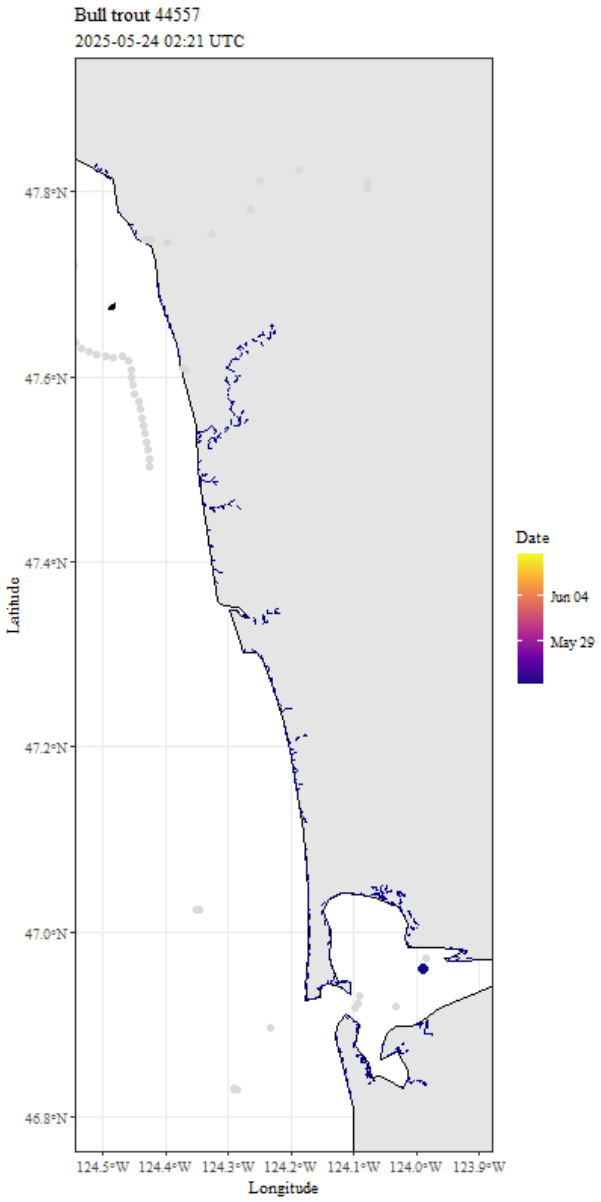

Figure 14 Animated visualization of acoustic detections for bull trout Tag ID 44557, tagged in the Hoh River in January 2025. Gray points indicate receiver deployment locations. Colored points represent detection locations at each time step, with color denoting detection date (earlier detections darker, later detections lighter). The first post-tagging detection occurred in Grays Harbor on May 23, 2025, followed by detections in the Hoh River. Because no marine receivers recorded detections between these locations, a synthetic offshore waypoint was inserted to represent likely coastal transit and to prevent the inferred movement path from crossing land. This waypoint does not represent an observed detection. The absence of intermediate marine detections suggests movement occurred outside receiver detection ranges or along nearshore areas not covered by marine receivers.

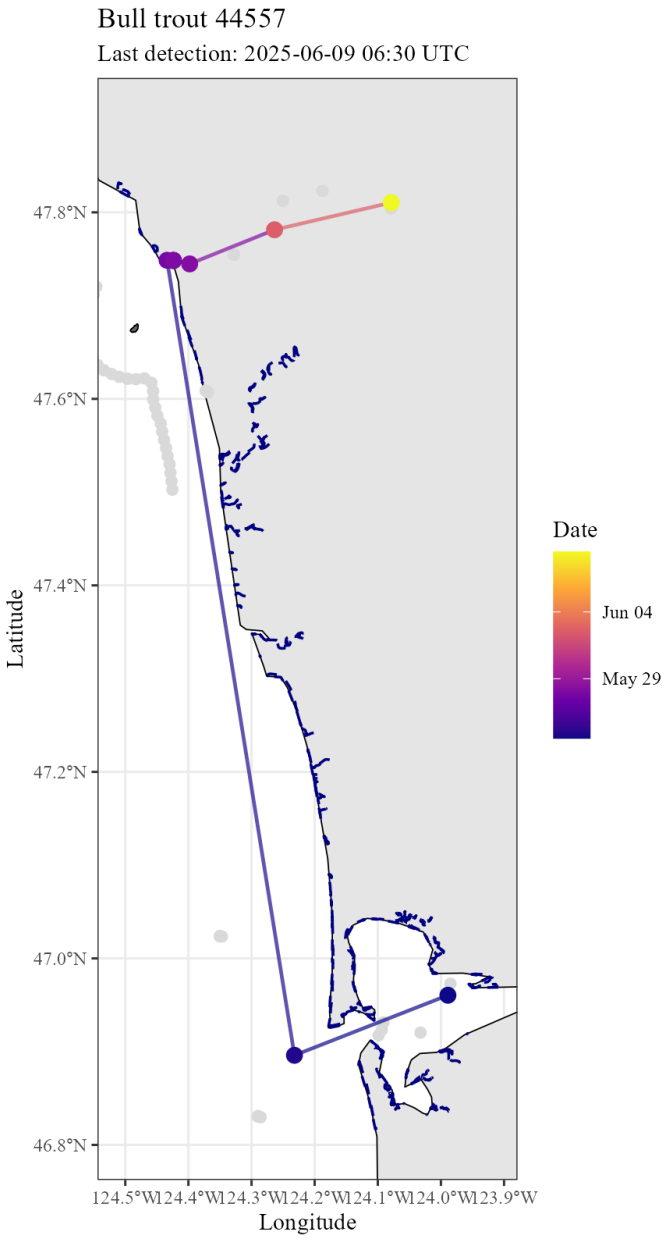

Figure 15 Static summary of the full detection track for bull trout Tag ID 44557. Gray points represent acoustic receiver deployment locations. Gray points indicate receiver deployment locations. Colored points represent detection locations at each time step, with color denoting detection date (earlier detections darker, later detections lighter). The first post-tagging detection occurred in Grays Harbor on May 23, 2025, followed by detections in the Hoh River. A synthetic offshore waypoint was inserted between these detections to visually represent likely marine transit and to prevent the inferred movement path from crossing land; this waypoint does not represent an observed detection. The lack of intermediate marine detections indicates that coastal movement likely occurred beyond receiver detection ranges or along nearshore areas not covered by marine receivers.

DISCUSSION

Anadromous bull trout tagged in Kalaloch Creek entered the Hoh River primarily between mid-May and mid-June, consistent with patterns described by Brenkman and Corbett (2005) and Smith and Huff (2023). After river entry, no detections indicated movement back into the marine environment. Later-arriving fish exhibited shorter residency windows in the mainstem (i.e., the primary river channel downstream of major spawning tributaries), consistent with results reported by Smith and Huff (2023). Here we calculated residency as the interval between first and last mainstem detection. Final detections for both Kalaloch Creek- and Hoh River-tagged fish generally occurred in June or July, after which fish presumably continued upstream toward spawning habitats. Spring/summer marine occupancy was concentrated between late April and late July.

A prior acoustic telemetry study conducted in 2019 documented a single offshore detection of a Kalaloch Creek–tagged bull trout at approximately 5.6 nautical miles from shore, with no subsequent detections thereafter (Smith and Huff, 2023). At the time, this event was interpreted cautiously as a potential offshore excursion. However, the 2025 study recorded a similarly anomalous marine detection pattern for Tag ID 40121, characterized by extensive and rapid movements among multiple receivers along the 3-nm array that were inconsistent with expected bull trout behavior and most plausibly explained by tag transport by a marine predator. These observations suggest that the isolated offshore detection reported in 2019 may likewise reflect predator-mediated transport rather than voluntary offshore habitat use by bull trout. In contrast, inter-river movements documented in both studies, including directed transit between Kalaloch Creek and the Hoh River and subsequent return movements, are consistent with nearshore corridor use. Reinterpretation of the 2019 offshore event in light of the 2025 detection patterns, therefore, strengthens the inference that anadromous bull trout along the Olympic Peninsula primarily utilize nearshore marine habitats for directed inter-basin movement, with little evidence of routine movement beyond the 3-nm boundary.

No Kalaloch Creek-tagged bull trout were detected on marine receivers during their migration back to the Hoh River. This absence of offshore detections suggests that marine movements between these systems likely occurred within nearshore waters shoreward of the detection range of the marine receiver network, with movements confined to the nearshore zone during spring transit between coastal drainages. The five additional bull trout tagged in Kalaloch Creek that were not subsequently re-detected in the Hoh River may have moved to other coastal drainages, remained in marine habitats, failed to return to freshwater during the study period, or experienced mortality.

Winter detections in Kalaloch Creek are consistent with prior evidence that this system functions as an overwintering habitat for anadromous bull trout. Five tagged individuals including four originally tagged in Kalaloch Creek and one originally tagged in the Hoh River were detected in Kalaloch Creek beginning in early December, following an extended absence during summer and fall. These detections refine our understanding of the seasonal timing of re-entry, indicating overwinter use of small tributaries such as Kalaloch Creek. Because Hoh River receivers have not been downloaded since October 2025, the timing of exit from the Hoh River could not be

directly estimated. In addition, offshore receivers were not downloaded during this winter period, precluding evaluation of whether any individuals moved beyond the 3-nm line prior to re-entry into Kalaloch Creek. These uncertainties will be addressed following recovery and downloading of the offshore array and Hoh River receivers (planned for Spring, 2026), which will allow assessment of winter marine movements relative to the 3-nm line.

Results from this study further demonstrate that coastal bull trout populations along the Olympic Peninsula exhibit variable expression of anadromous behavior, with some individuals moving between adjacent river systems via nearshore marine habitats. Although movements beyond the 3-nm line were not detected, observed inter-river movements and consistent seasonal migration timing indicate that nearshore marine corridors likely play an important role in facilitating anadromy in these systems. Conservation of these migratory pathways may enhance population resilience by supporting life-history diversity and maintaining genetic connectivity among otherwise small or isolated populations. Movement among suitable freshwater habitats, including overwintering in small tributaries, may reflect reduced competition and favorable energetic conditions relative to larger coastal rivers.

KEY CONCLUSIONS FOR BULL TROUT MARINE RESIDENCY

- Spring movements from Kalaloch Creek to the Hoh River occurred via a short, nearshore marine window (late April–late July).
- Several individuals subsequently returned to Kalaloch Creek in December, which necessarily involved a second marine transit. Because arrivals began in early December, marine residence for this winter leg likely occurred during the last few weeks of November, however, transit was not directly detected by receivers in the 3-nm array because data from the winter deployment have not yet been downloaded.
- Both spring and winter transits appear confined to the inner coastal corridor, with no detections beyond the 3-nm line.
- Observed patterns suggest episodic nearshore marine use tied to inter-river movement rather than prolonged coastal residency.

ACKNOWLEDGEMENTS

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