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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric
Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Fisheries Science Center
2725 Montlake Blvd. E, Seattle, WA 98112
206-637-2514 • Fax: 503-861-2589

Acoustic tag glider deployments in the NWTT to detect tagged salmon and collect environmental profile data


Image generated by Huff using DALL•E

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Joseph M. Smith
David D. Huff

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14. ABSTRACT

Three acoustic tag glider deployments were conducted in Washington's (WA) coastal portion of the Northwest Training and Testing (NWTT) Study Area between September 2019 and June 2020. This survey was conducted with funding from the U.S. Navy Pacific Fleet to determine the utility of glider-based acoustic tag detection in a highly mobile fish, Chinook salmon. The primary objective was to expand the detection range of a U.S. Navy-funded stationary, moored acoustic tag receiver array by extending the detection beyond the shelf edge and in other deeper locations, such as marine canyons where the moored acoustic receiver units were not feasible to deploy. Another objective was to associate tagged fish detections with environmental data to identify potential relationships between Chinook salmon occurrence and water characteristics that the profiling glider sensors could measure. Our first glider deployment, operated by Applied Physics Lab – University of Washington (APL-UW) from 30 August to 23 September 2019, detected five unique tags in the northern and middle portions of the WA Coast. These detections occurred in relatively saline and cooler water, but there was no clear pattern in chlorophyll concentration relative to the tag detections. Our second deployment operated by Oregon State University (OSU), from 8 September to 2 October 2019, detected four unique tags (one of these was a green sturgeon tagged as part of a different study). The salmon were detected in the northern WA coast near the previous APL-UW glider detections. The green sturgeon was detected near the end of the deployment period on October 1st near Grays Harbor, WA. The salmon detections for this deployment also occurred in cooler and higher salinity waters. For the third glider deployment, the APL-UW glider was deployed again on 14 June 2020 near Grays Harbor, WA. This glider failed to make surface communications on 17 June 2020 and ejected its recovery weight on 18 June

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2020, leaving it stranded at the surface. The glider was recovered a few days later, and detection data were successfully downloaded. Two tagged Chinook salmon and one tagged steelhead were detected near Willapa Bay, WA, in relatively cool, higher salinity waters. There were many fewer detections on the glider deployments over the same time period than on the stationary receiver array. However, several detections occurred in deep water, which was unsuitable for moored receivers. The environmental data profiles were potentially valuable for understanding fish occurrence. Still, future acoustic tag glider deployments would benefit from using tags that report the depth of the fish to determine its position in the environmental profile.

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Executive Summary

Three acoustic tag glider deployments were conducted in Washington's (WA) coastal portion of the Northwest Training and Testing (NWTT) Study Area between September 2019 and June 2020. This survey was conducted with funding from the U.S. Navy Pacific Fleet to determine the utility of glider-based acoustic tag detection in a highly mobile fish, Chinook salmon. The primary objective was to expand the detection range of a U.S. Navy-funded stationary, moored acoustic tag receiver array by extending the detection beyond the shelf edge and in other deeper locations, such as marine canyons where the moored acoustic receiver units were not feasible to deploy. Another objective was to associate tagged fish detections with environmental data to identify potential relationships between Chinook salmon occurrence and water characteristics that the profiling glider sensors could measure. Our first glider deployment, operated by Applied Physics Lab – University of Washington (APL-UW) from 30 August to 23 September 2019, detected five unique tags in the northern and middle portions of the WA Coast. These detections occurred in relatively saline and cooler water, but there was no clear pattern in chlorophyll concentration relative to the tag detections. Our second deployment operated by Oregon State University (OSU), from 8 September to 2 October 2019, detected four unique tags (one of these was a green sturgeon tagged as part of a different study). The salmon were detected in the northern WA coast near the previous APL-UW glider detections. The green sturgeon was detected near the end of the deployment period on October 1st near Grays Harbor, WA. The salmon detections for this deployment also occurred in cooler and higher salinity waters. For the third glider deployment, the APL-UW glider was deployed again on 14 June 2020 near Grays Harbor, WA. This glider failed to make surface communications on 17 June 2020 and ejected its recovery weight on 18 June 2020, leaving it stranded at the surface. The glider was recovered a few days later, and detection data were successfully downloaded. Two tagged Chinook salmon and one tagged steelhead were detected near Willapa Bay, WA, in relatively cool, higher salinity waters. There were many fewer detections on the glider deployments over the same time period than on the stationary receiver array. However, several detections occurred in deep water, which was unsuitable for moored receivers. The environmental data profiles were potentially valuable for understanding fish occurrence. Still, future acoustic tag glider deployments would benefit from using tags that report the depth of the fish to determine its position in the environmental profile.

Background

Photo: Kristian Foden-Vencil, Jack Barth, Steve Pierce, and David Huff deploy glider “Bob.”

The United States (U.S.) Navy conducts military training and testing in Pacific Northwest range areas to prepare combat-ready military forces, whereas NOAA Fisheries is responsible for managing threatened and endangered species in marine waters and providing permits to the U.S. Navy. NOAA Fisheries and the U.S. Navy share the common goals of minimizing the impact of military training and testing activities on protected 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 other species.

This project specifically supports Pacific salmonid studies in the offshore waters of the existing Northwest Training Range Complex (NWTRC) and offshore Naval Undersea Warfare Center Keyport Range Complex (together known as the Northwest Training and Testing (NWTT) Study Area). In particular, this project addresses a region critical to Navy monitoring objectives and species of interest under current and future monitoring plans.

Characterizing the distribution and behavior of fish in nearshore marine environments is time-consuming and expensive. For species listed under the Endangered Species Act, conserving critical habitats requires detailed information on temporal and spatial habitat use patterns and, ideally, the relative importance of migration corridors, aggregation, and foraging areas. Understanding where, when, and why these animals occupy specific habitats (e.g., depth, distance from shore, bottom type, temperature, dissolved oxygen, current, etc.) is necessary to improve the effectiveness of marine spatial planning, fisheries management, and restoration and recovery of listed species. The goal of this study is to determine the utility of glider-based acoustic tag detection in a highly mobile fish, Chinook salmon. The primary objective was to expand the detection range of a US Navy-funded stationary, moored acoustic tag receiver array by extending the detection beyond the shelf edge and in other deeper locations, such as marine canyons where the moored acoustic receiver units were not feasible to deploy. Another objective was to associate tagged fish detections with environmental data to identify potential relationships between Chinook salmon occurrence and water characteristics that the profiling glider sensors could measure.

Slocum gliders are autonomous underwater vehicles (AUVs) that can move vertically and horizontally through the water column by changing their buoyancy. This allows them to cover large ocean areas and collect data at various depths. They can be equipped with various sensors, including those for measuring temperature, salinity, and dissolved oxygen, as well as for detecting acoustic signals. Oliver et al. (2013), Haulsee et al. (2015), Moser et al. (2022) used this method to study the relationship between marine organisms (such as sharks and sturgeon) and their habitats. They used an AUV with an acoustic receiver to detect fish with coded acoustic transmitters. This approach successfully determined fine-scale habitat associations of marine organisms across large areas. For example, an AUV-mounted receiver detected 97% of acoustic transmissions when within 250 m of test tags (Unpublished Data, 2019) while simultaneously recording environmental data such as temperature, salinity, dissolved oxygen, turbidity, current, and chlorophyll concentration. This allowed for the investigation of the water column habitat characteristics.

We combined fixed-site receiver arrays with AUV (Slocum glider) operations to study marine habitat use by Chinook salmon bearing acoustic transmitters. Slocum gliders have been previously used off the Oregon Coast to study coastal ocean dynamics and can fly from the sea surface to within a few meters of the bottom in water depths of 20 to 1000 meters (m). This makes them well-suited for observing Chinook salmon, typically in nearshore areas and depths beyond 200 m. AUV-mounted receivers have advantages over moored receiver arrays, as they can scan large areas in a short amount of time. AUVs can travel up to 20 kilometers (km) daily, enabling them to identify tagged salmon in areas where they are likely to gather. We assessed detections from both platforms and summarized AUV data on Chinook salmon occurrence and environmental features in the coastal ocean. By detecting tagged Chinook salmon, we could gain insight into their habitat use and behavior and better understand their ecology.

Methods

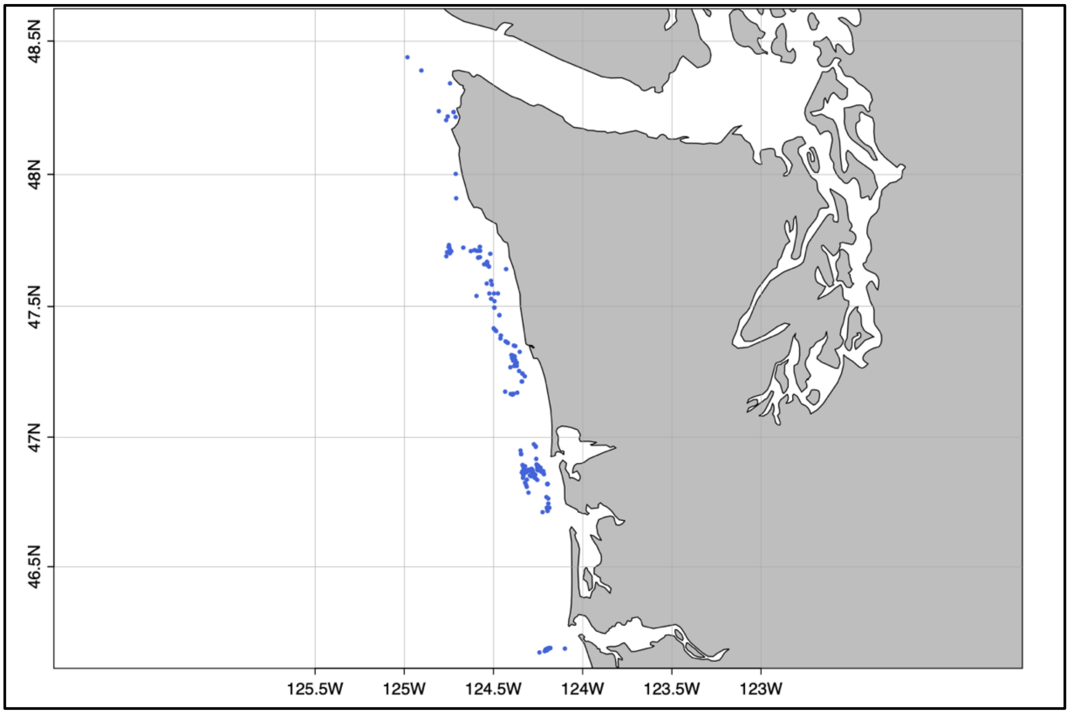


Figure 1. *Chinook salmon tagging locations.*

Chinook salmon were tagged in locations along the Washington Coast (Figure 1). Chinook salmon were caught with hook and line. Each individual was immediately put into anesthetic (25 milligrams/Liter; AQUI-S® 20E) until the fish reached level III anesthesia (i.e., total loss of equilibrium and no reaction to touch stimuli, ~4 minutes (min.)). The use of AQUI-S® 20E was used under INAD (Investigational New Animal Drugs) permit #11-47. Once anesthetized, the fork length (nearest cm) was measured, scales were taken from the preferred area for aging, and a fin clip was taken from the anal fin for genetic analysis. To implant the transmitter, a 15 mm incision was made with a sterile scalpel, the V9 transmitter and a PIT (Passive Integrated Transponder) 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. Chinook salmon were surgically implanted with InnovaSea 69 kHz V9-2x transmitters (diameter = 9 millimeters (mm), length = 28 mm, weight = 4.5 grams in air, power output = 146 dB, battery life = 651 days, random ping rate between 60 and 120 seconds). After surgery, the fish was placed in a recovery tank of fresh seawater with an aerator until the fish was vigorously swimming and recovered (~5-10 min.). After recovery, the fish was released near the capture location. The latitude, longitude, and time of fish release were recorded for each individual. We deployed InnovaSea 69 kHz VR2AR acoustic receivers along the coast of Washington State to detect acoustically tagged Chinook salmon (Figure 1).

Deployment #1 - September 2019

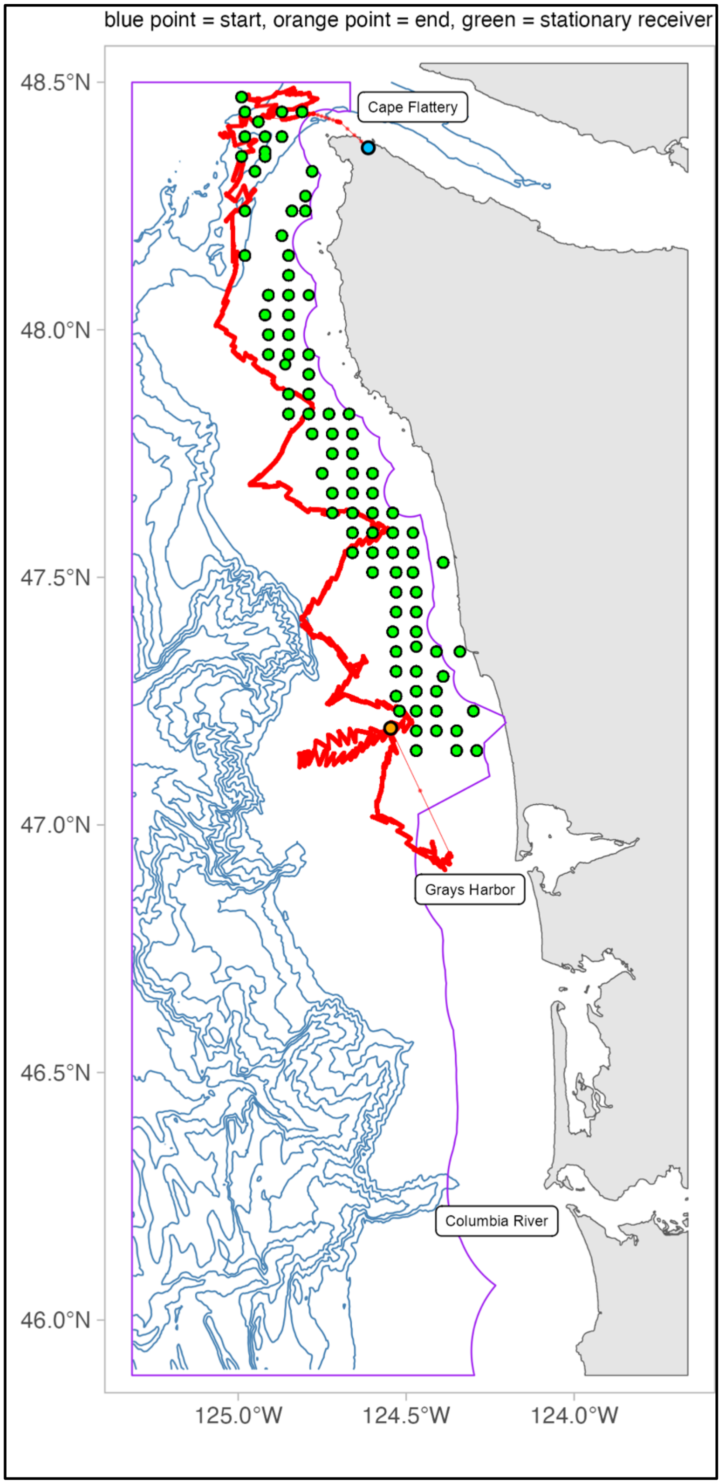


Figure 2. *Husker glider (APL-UW) map of glider path during this deployment. The northernmost point of land is Cape Flattery, WA, and the southernmost portion is just north of Grays Harbor, WA. The purple line indicates the NWTT Study area. Blue isobath lines occur at 200 m intervals.*

Justin Shapiro (APL-UW) prepared a Slocum coastal glider nicknamed Husker for ballasted for 200m deployment along the Washington Olympic Coast. Justin equipped the glider with a Vemco VR2W 69 kHz receiver and a Seabird Scientific unpumped CTD. The vehicle was deployed in the Strait of Juan de Fuca and flown in a zig-zag pattern down the Olympic Peninsula. NOAA operates a grid of fixed moorings, funded by the Navy, equipped with 69 kHz receivers along the Olympic Coast between the 30 and 60m isobaths. The glider path covered as many fixed receiving stations as possible while ensuring vehicle safety. The goal was to read tag IDs from tagged Chinook salmon, correlate measurements made by fixed receivers with the receiver mounted to the glider, and fly the glider between the 30m isobath and the 200 m isobath to extend the coverage of the 69 kHz receiving array out to the 200 m isobath. We recovered the glider in 23 September 2019, eight miles offshore of Westport, Washington (see Figure 2). During the deployment, we detected 33 tag pings from 5 unique tags, not including known IDs of test tags.

Deployment #2 - September 2019

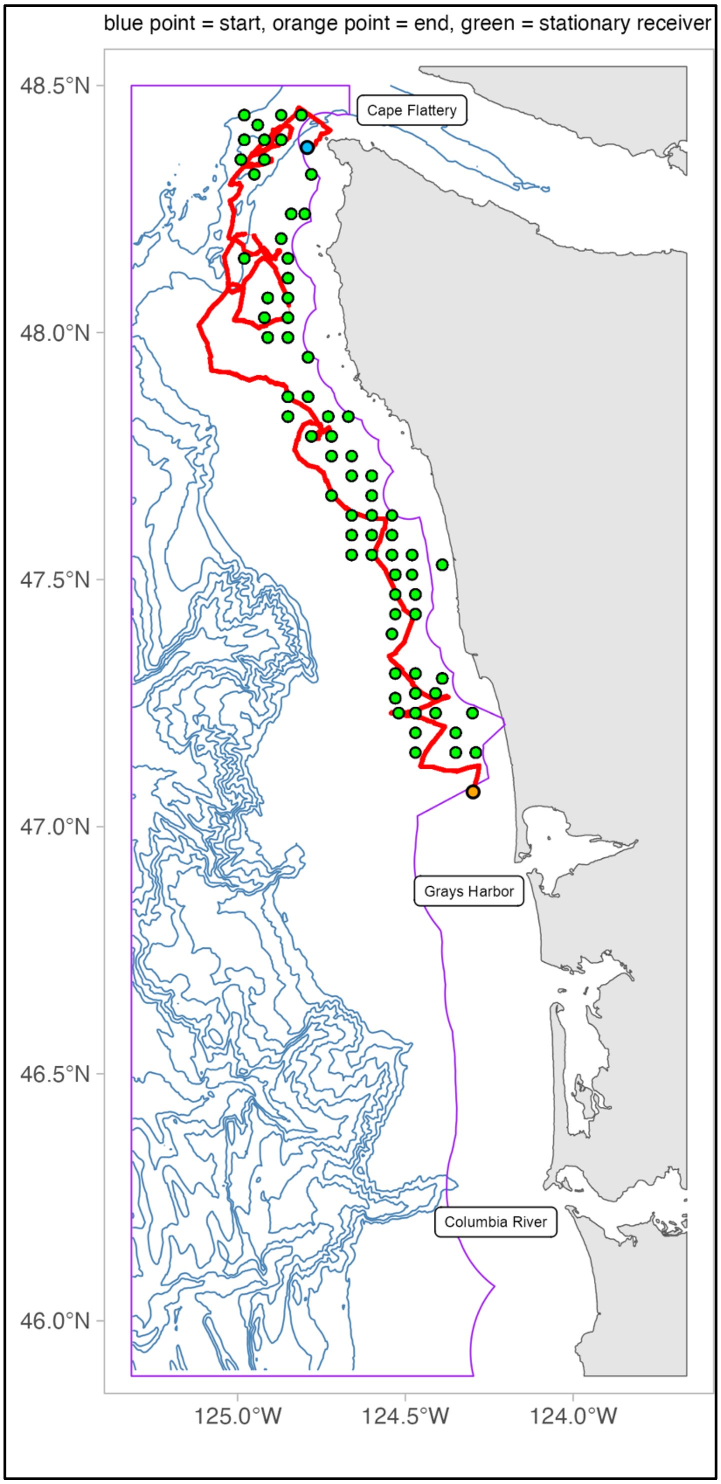


Figure 3. *Bob glider (OSU) map of glider path during this deployment. The northernmost point of land is Cape Flattery, WA, and the southernmost portion is just north of Grays Harbor, WA. The purple line indicates the NWTT Study area. Blue isobath lines occur at 200 m intervals.*

Anatoly Erofeev, Steve Pierce, and Jack Barth (OSU) prepared a Slocum coastal glider nicknamed Bob ballasted for 200m deployment along the Washington Olympic Coast. They equipped the glider with an upward facing and a downward facing Vemco VR2W 69 kHz receiver and a Seabird Scientific CTD. This glider was also equipped with chlorophyll and oxygen sensors. The vehicle was deployed in the Strait of Juan de Fuca and flown in a zig-zag pattern down the Olympic Peninsula (Figure 3). This deployment, from 8 September to 2 October 2019, detected four unique tags (one of these was a green sturgeon tagged as part of a different study). The salmon were detected in the northern WA Coast near the previous APL-UW glider. The green sturgeon was detected near the end of the deployment period on October 1st near Grays Harbor, WA.

Deployment #3 - June 2020

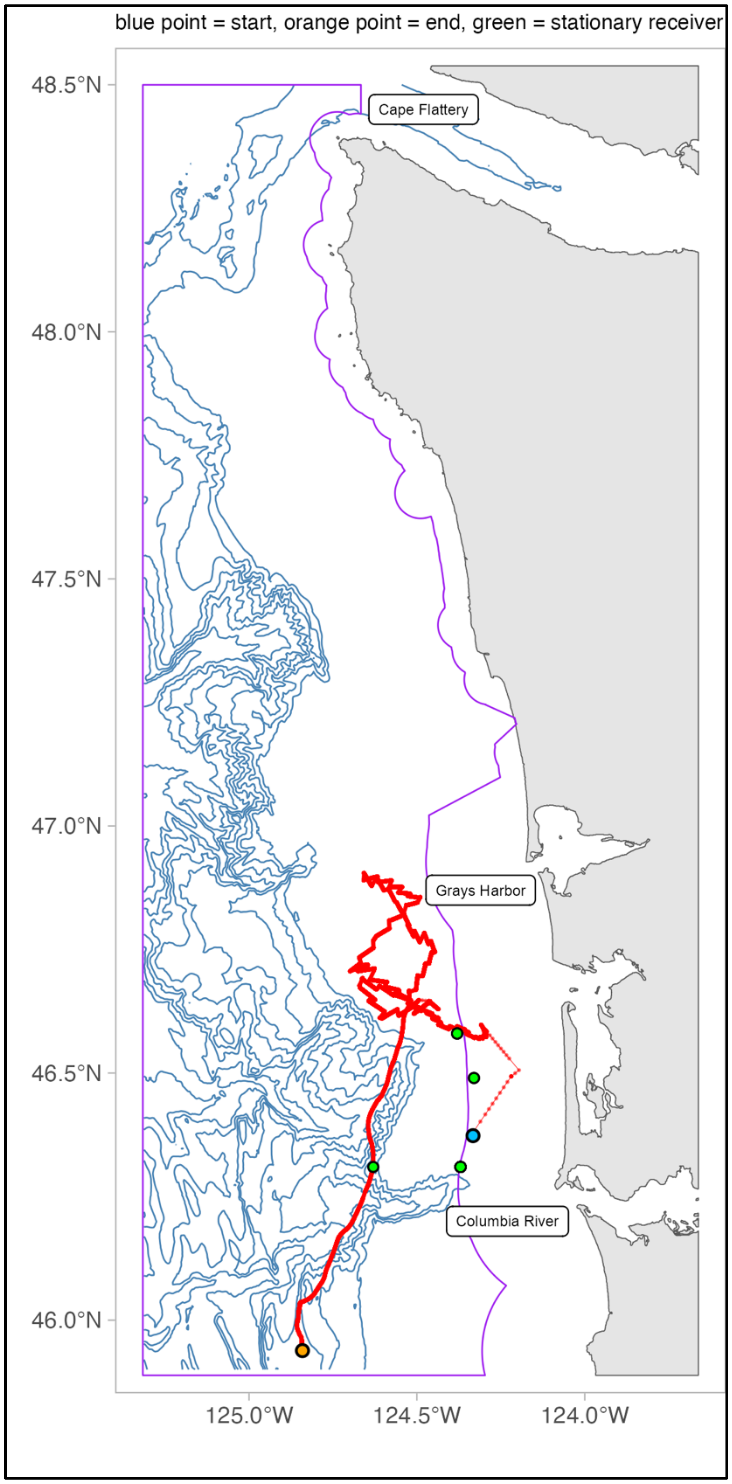


Figure 4. *Saul glider (APL-UW) map of glider path during this deployment. The northernmost point of land is Grays Harbor, WA, and the southernmost portion is just north of Columbia River mouth, WA. The purple line indicates the NWTT Study area. Blue isobath lines occur at 200 m intervals.*

Justin Shapiro (APL-UW) prepared a Slocum 200 m Coastal glider nicknamed Saul for deployment along the Washington Coast. Justin equipped the glider with a Vemco VR2W 69 kHz receiver and a Seabird Scientific unpumped CTD. During the glider deployment (14-18 June 2020; Figure 4), the Pacific Northwest experienced an intense heat wave that enhanced the strength of the Columbia River plume, driving a lens of fresh water over much of the coastal shelf. As the glider used here is a legacy system with a small buoyancy pump and no thruster capability, it could not cope with extreme stratification. The glider began struggling to make surface communications late on 17 June 2020 and ejected its recovery weight on the afternoon of 18 June 2020, leaving it stranded at the surface. An emergency recovery effort was mustered as the glider began drifting at approximately two kts southward in the coastal current. Fortunately, OSU's R/V Pacific Storm steamed into Westport, WA, after completing an Ocean Observatories Initiative cabled array service cruise that night. The vessel agreed to find the AUV and departed from the Westport marina on the morning of 19 June and proceed with recovery that day. Around 1700 local time on the 19th the AUV was spotted and the vessel managed a glider recovery by 1800. It was noted that the glider pressure vessel vacuum and battery voltage dropped significantly during recovery, indicating a breach of the pressure vessel and significant seawater intrusion. The recovered glider was retrieved by APL-UW personnel and it was discovered that one of the bulkhead connectors had been sheared off and that it had taken on significant water. The glider data storage cards were recoverable, and all engineering and science data was available without significant additional effort.

We merged the tag detection data with all Slocum Glider data to provide vehicle location and depth at the time of tag detection, in addition to estimates of effective detection range. Three tags were detected, two were Chinook salmon and one was a tagged steelhead.

Results- Environmental Data and Tag Detections

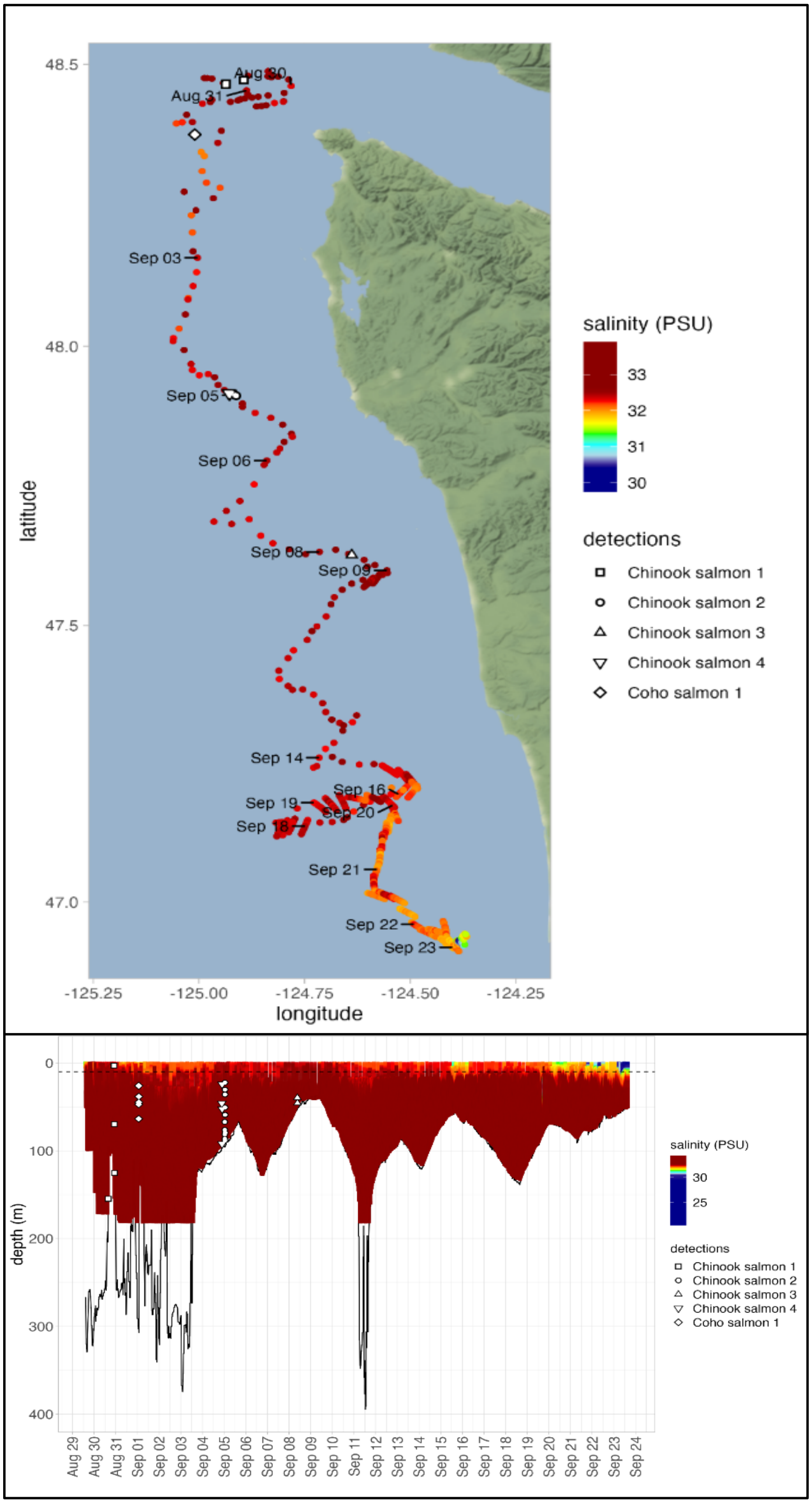


Figure 5. *Deployment #1, UW 'Husker' glider salinity and tag detections. The upper panel depicts the 2-D spatial resolution of salinity at 10m depth. The lower panel depicts the corresponding vertical profile during the same period. The black line on the lower portion of the lower plot denotes the bottom depth. Salinity data were collected only to the glider profile depth; 'no data' plot regions are white.*

Salinity- Nearly all detected fish occurred in relatively higher salinity water in which the 10 m depth salinity value was 32-34 PSU (Practical Salinity Unit) (Figure 5, 6, 7). The symbols in each plot indicate the depth of the glider when the tag was detected and not the depth of the tag itself. However, we characterized the 10 m depth salinity distribution horizontally because it provided a reasonable estimate of the overall salinity environment. Notably, salmon were only detected in areas with high-salinity water at the surface, even when fresh surface water was nearby. The green sturgeon was detected beneath fresh surface water. However, green sturgeon are strongly bottom oriented.

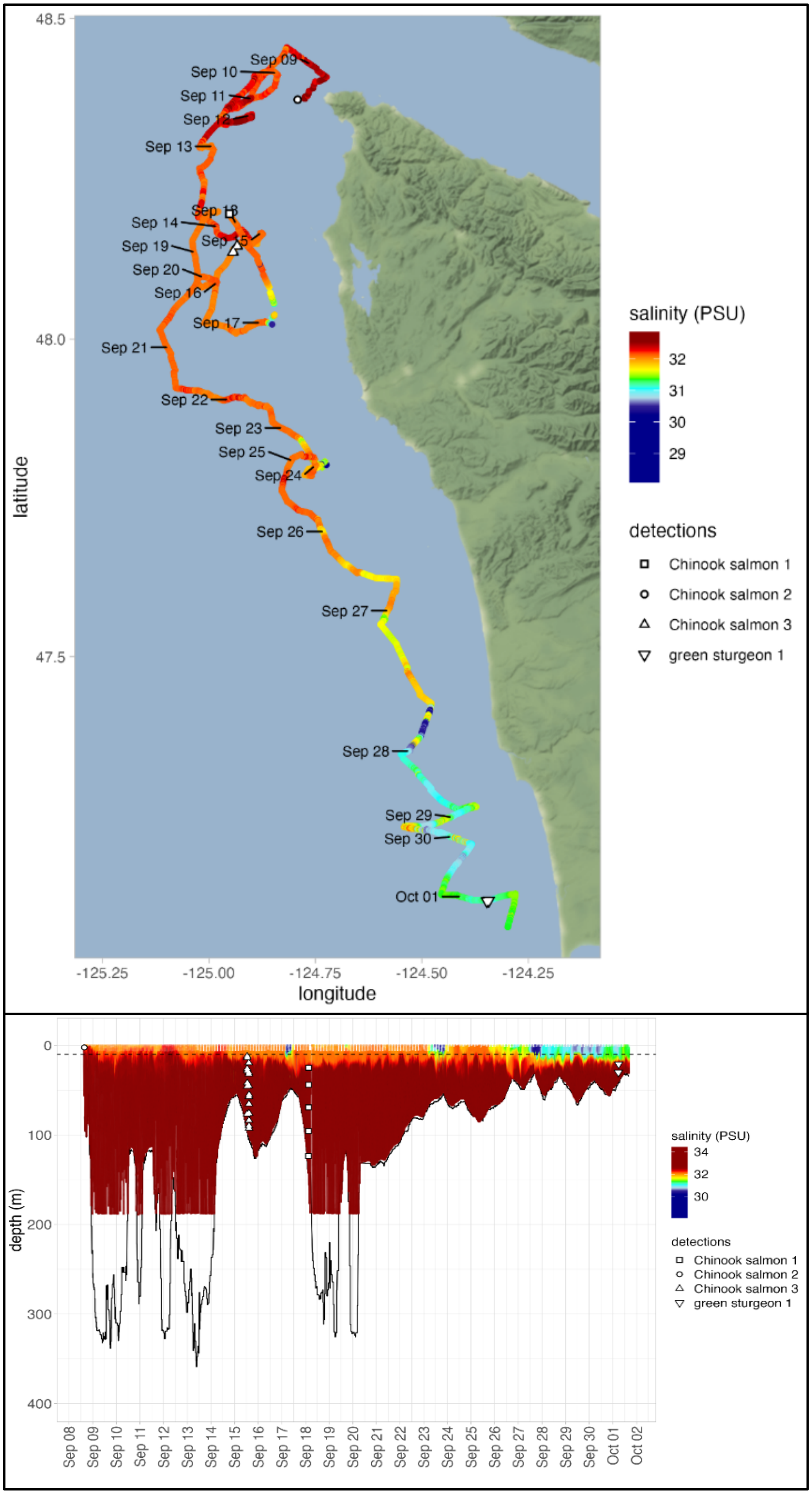


Figure 6. *Deployment #2, OSU 'Bob' glider salinity and tag detections. The upper panel depicts the 2-D spatial resolution of salinity at 10m depth. The lower panel depicts the corresponding vertical profile during the same period. The black line on the lower portion of the lower plot denotes the bottom depth. Salinity data were collected only to the glider profile depth; 'no data' plot regions are white.*

Temperature- The symbols in each plot indicate the depth of the glider when the tag was detected and not the depth of the tag itself (Figure 8, 9, 10). In the first and second deployments, there was a weak pattern in the relationship between surface water temperature and fish detections. This pattern is one in which detections are adjacent to or near the margins of relatively cool and warm water masses. The third deployment was short-duration and had weak surface temperature gradients and few tag detections. The first two deployments recorded cooler water temperatures farther to the north and warmer water temperatures in the south. The cooler surface water temperatures extended farther south earlier in the season, as did the tag detections. For example, cooler temperatures were recorded near the middle of the glider deployment #1 trajectory near the mid-coast of Washington on 9 September 2019 (Figure 8). In contrast, glider deployment #2 began in the same location at the tip of Cape Flattery 10 days later than deployment #1 and only detected cool water north of Lake Ozette, near Cape Flattery, WA (Figure 9).

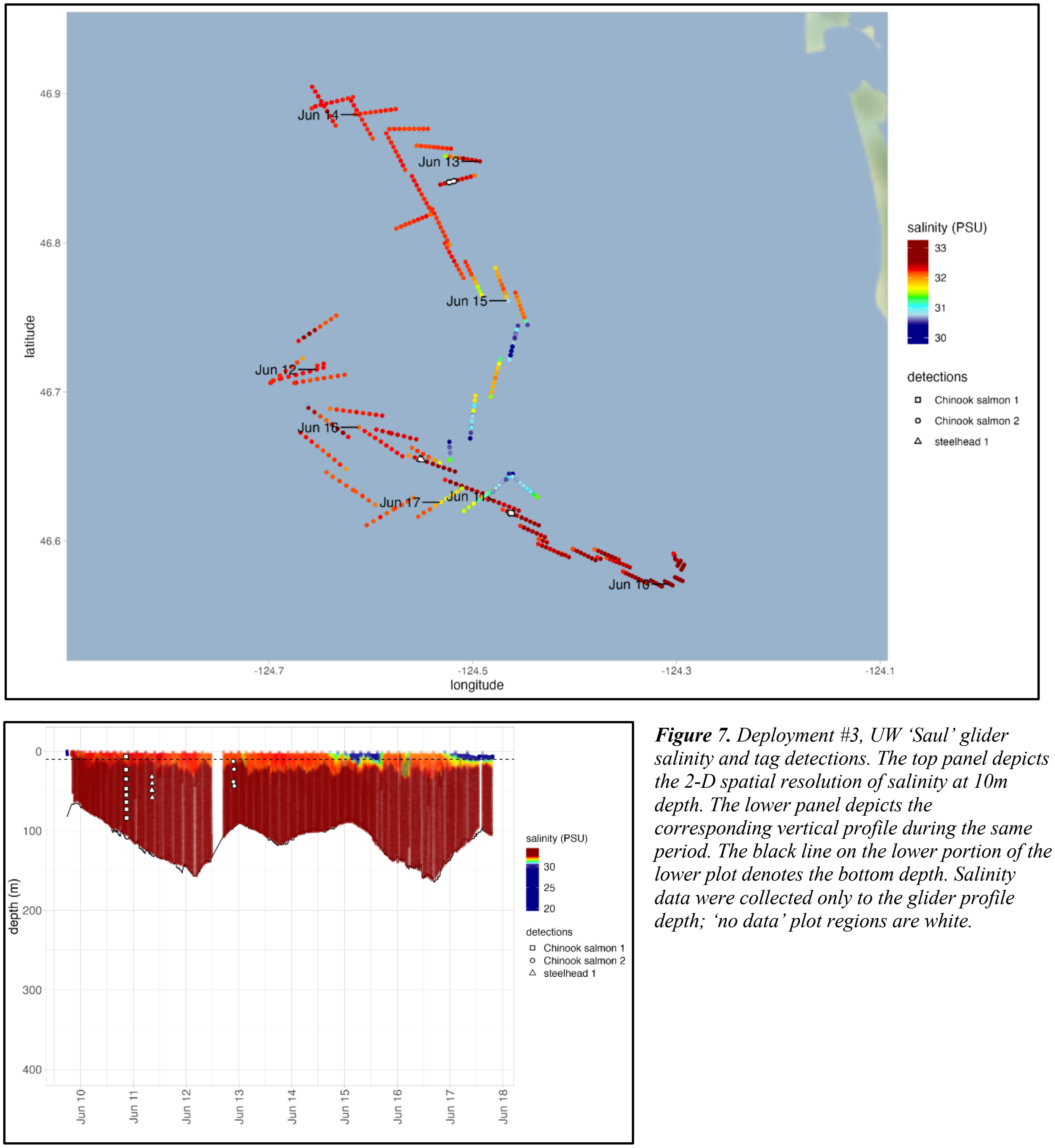


Figure 7. *Deployment #3, UW 'Saul' glider salinity and tag detections. The top panel depicts the 2-D spatial resolution of salinity at 10m depth. The lower panel depicts the corresponding vertical profile during the same period. The black line on the lower portion of the lower plot denotes the bottom depth. Salinity data were collected only to the glider profile depth; 'no data' plot regions are white.*

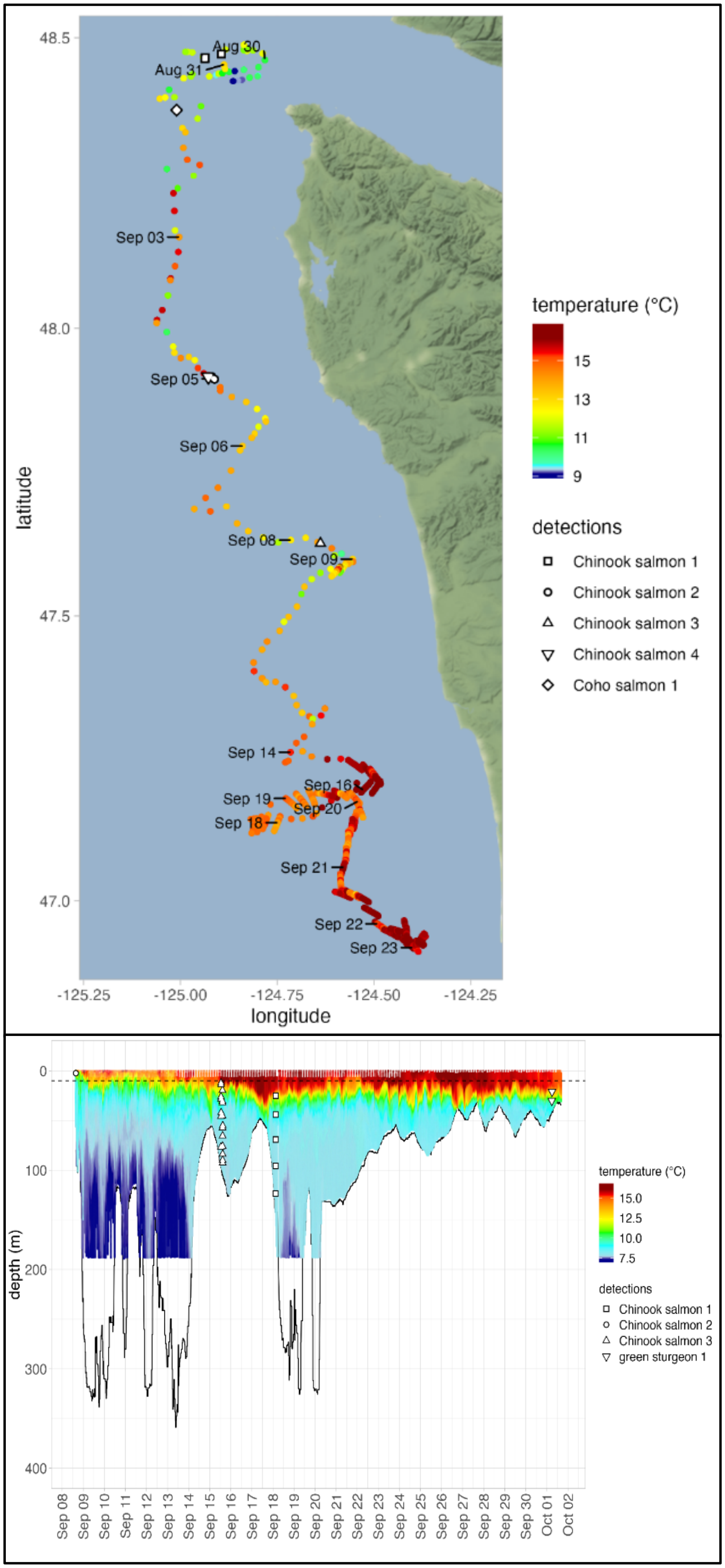


Figure 8. *Deployment #1, UW ‘Husker’ glider temperature and tag detections. The top panel depicts the 2-D spatial resolution of temperature at 10m depth. The bottom panel depicts the corresponding vertical profile during the same period. The black line on the lower portion of the bottom plot denotes the bottom depth. Data were collected only to the glider profile depth; ‘no data’ plot regions are white.*

Chlorophyll- Similar to the temperature data pattern, there was limited evidence that detections occurred near distinct high chlorophyll concentrations. There were so few tag detections that the evidence of this pattern was inconclusive, but it would be intriguing to examine additional data that could support the hypothesis that distinct high chlorophyll concentration areas were also locations where salmon aggregated. The glider profiles also described the depth of the chlorophyll concentration throughout the trajectory (Figure 11); this is a type of data that is not readily available from satellite images. The high chlorophyll areas also correspond to cool-warm surface water interfaces (e.g., 11, 15, and 23 September 2019) in which the surface temperatures are less than 15°C.

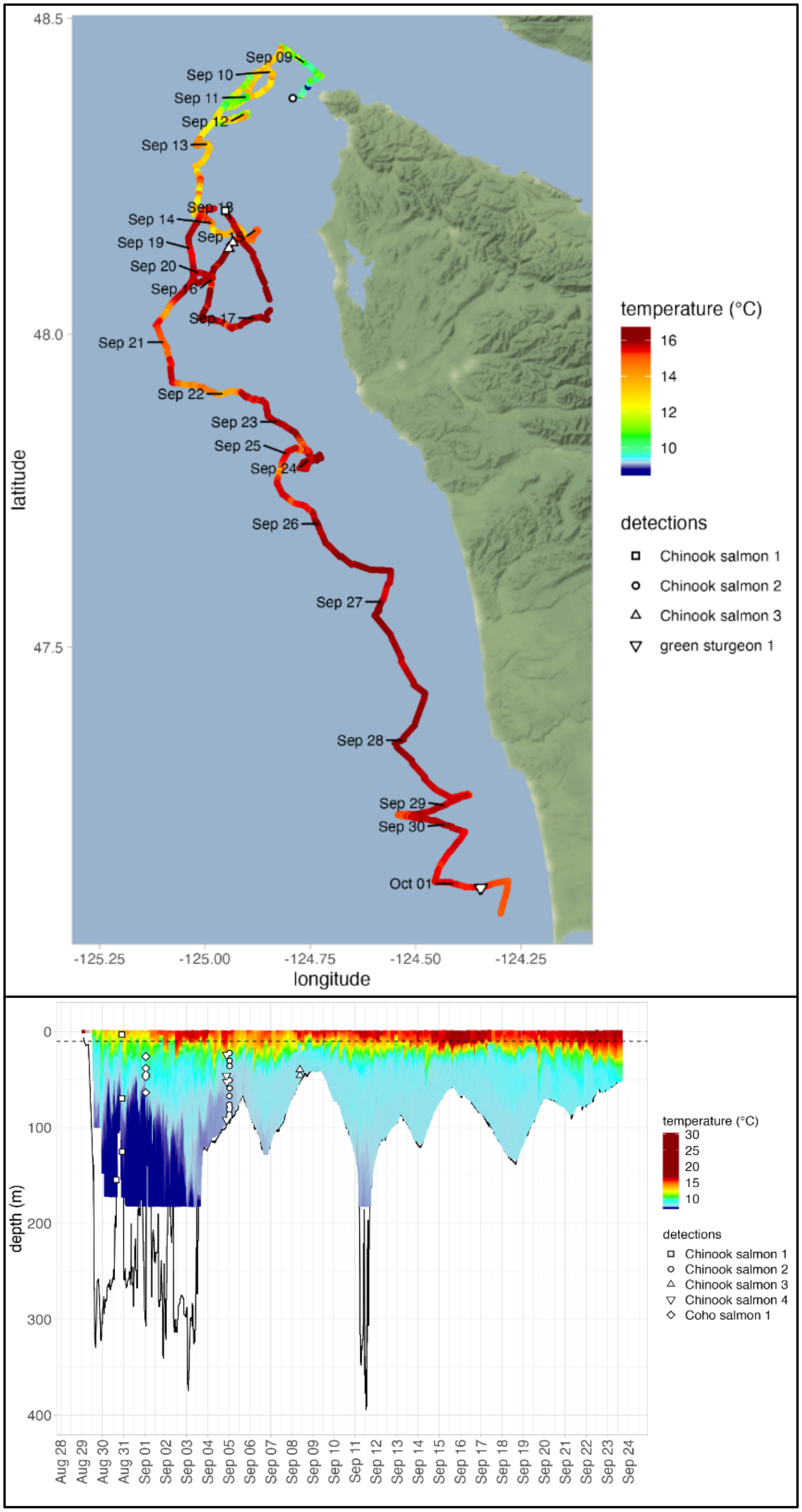
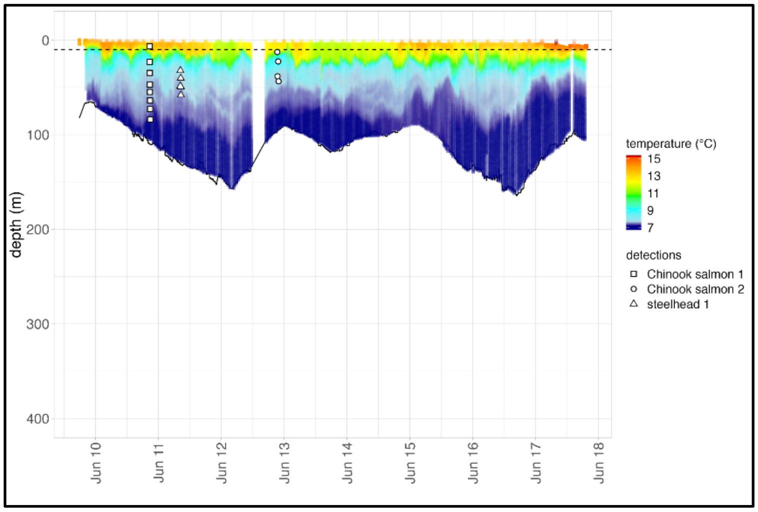


Figure 9. *Deployment #2, OSU 'Bob' glider temperature and tag detections. The left panel depicts the 2-D spatial resolution of temperature at 10m depth. The right panel depicts the corresponding vertical profile during the same period. The black line on the lower portion of the right plot denotes the bottom depth. Data were collected only to the glider profile depth; 'no data' plot regions are white.*

Oxygen- Throughout the glider trajectory, there were no surface waters with low enough oxygen to be stressful or induce a behavioral response to move away from an area (Figure 12). Intrusions of lower oxygen water toward the surface occurred near more rapid linear bathymetry changes per day (e.g., 11, 15, and 23 September 2019). When compared with the temperature, chlorophyll, and to a lesser extent, salinity profiles, these patterns in oxygen levels and bottom depth are consistent with areas of localized upwelling. These upwelling areas could be persistent or occur frequently depending on seasonal ocean current dynamics or the relative strength of prevailing currents to push cooler, lower oxygenated waters toward the surface.

Figure 10. *Deployment #3, UW 'Saul' glider temperature and tag detections. The top panel depicts the 2-D spatial resolution of salinity at 10m depth. The lower panel depicts the corresponding vertical profile during the same period. The black line on the lower portion of the lower plot denotes the bottom depth. Salinity data were collected only to the glider profile depth; 'no data' plot regions are white.*



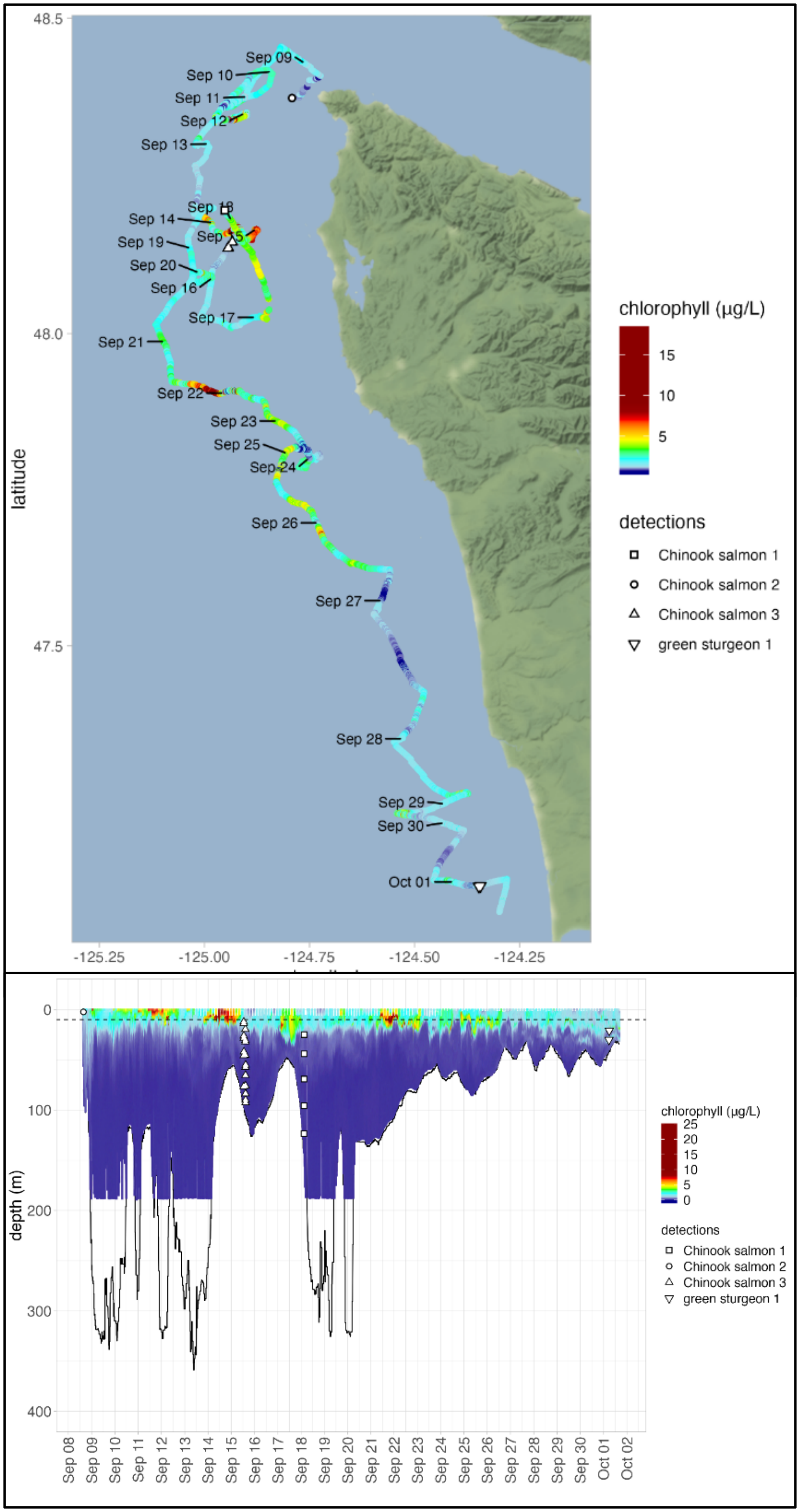


Figure 11. *Deployment #2, OSU 'Bob' glider chlorophyll and tag detections. The top panel depicts the 2-D spatial resolution of chlorophyll at 10m depth. The lower panel depicts the corresponding vertical profile during the same period. The black line on the lower portion of the depth plot denotes the bottom depth. Data were collected only to the glider profile depth; 'no data' plot regions are white.*

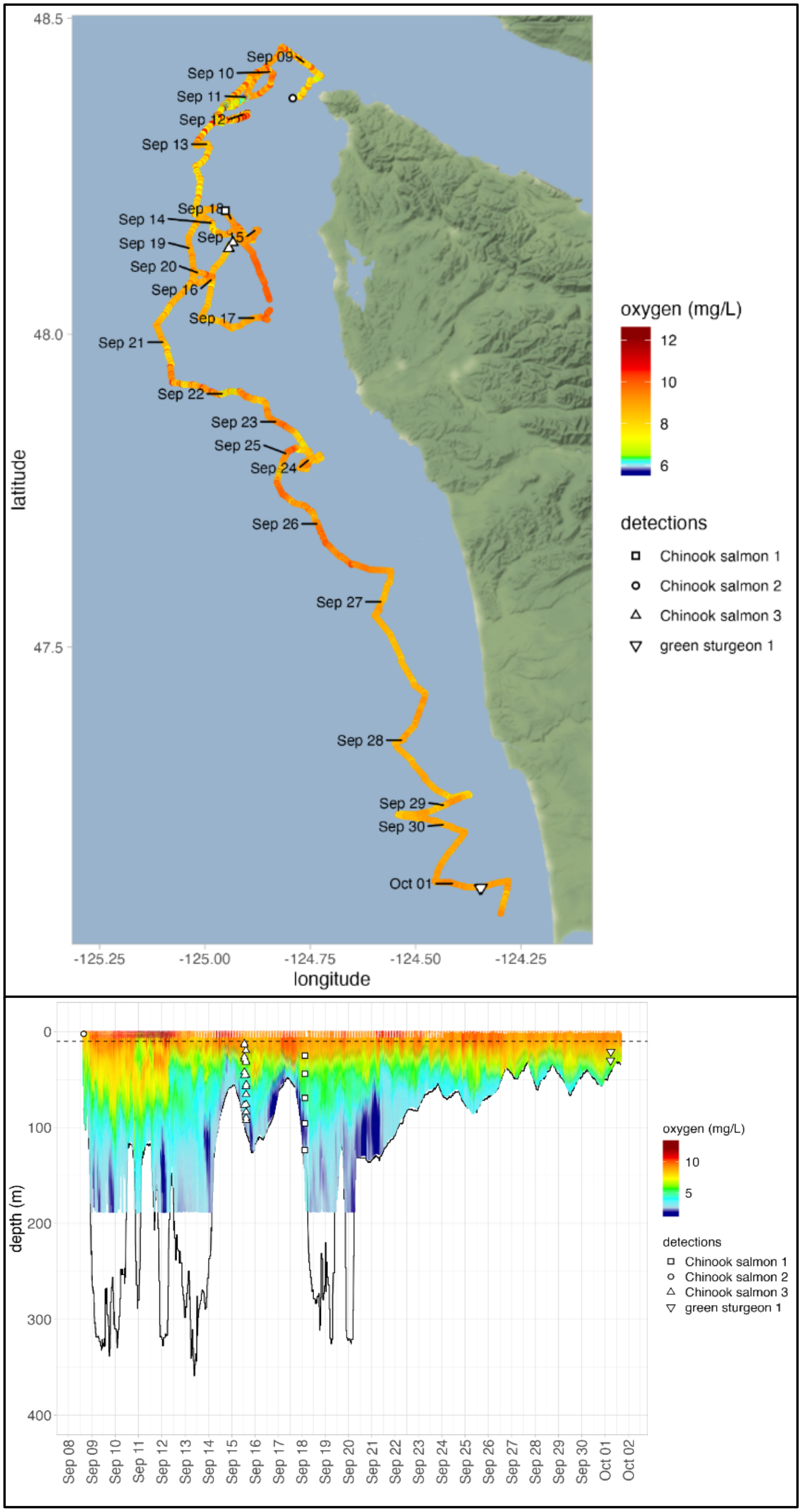


Figure 12. *Deployment #2, OSU 'Bob' glider oxygen and tag detections. The top panel depicts the 2-D spatial resolution of oxygen at 10m depth. The lower panel depicts the corresponding vertical profile during the same period. The black line on the lower portion of the depth plot denotes the bottom depth. Data were collected only to the glider profile depth; 'no data' plot regions are white.*

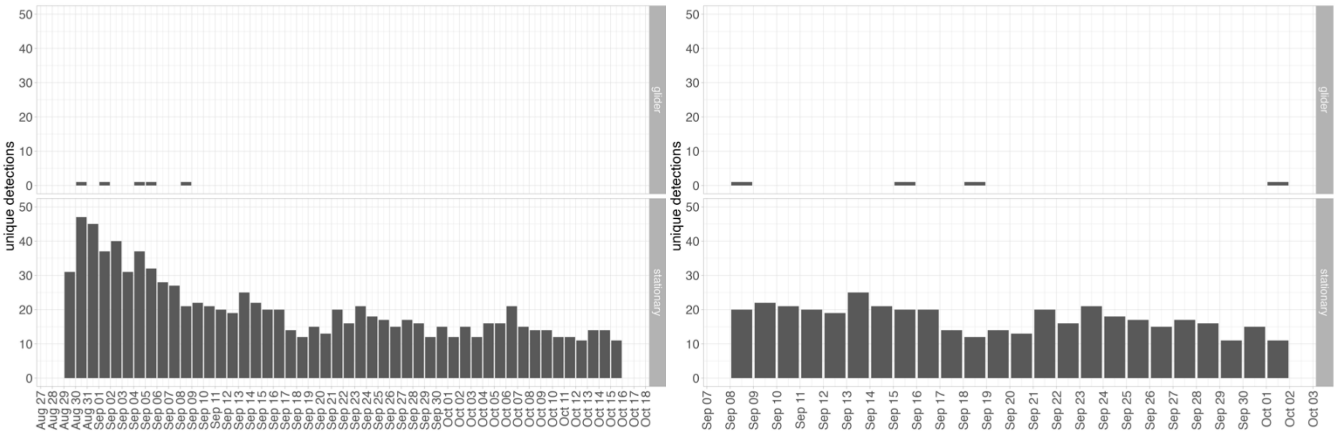


Figure 13. *Comparison between unique detections at stationary receivers (bottom panels) and glider-based receivers (top panels) each day for UW glider 'Husker' on the left and OSU glider 'Bob' on the right.*

Stationary versus glider-based detections- There were many fewer detections on the glider deployments over the same time period than on the stationary receiver array (Figure 13). The comparison is between many (~100) receivers versus a single glider. Although a comparison between the average number of detections per receiver during the period that the gliders were deployed and the detections per receiver in the stationary array (Table 1) confirmed that the stationary receivers recorded more detections per day on average than the glider mounted receivers. It is worth noting that the glider used during deployment #2 (OSU-Bob) had upward and downward facing receivers. This configuration could have improved its tag detection capability, which is consistent with greater detections per day for glider deployment #2 (Table 1).

Table 1. *Average detections per receiver per day during the same period within the receiver array compared to the glider mounted receiver.*

	Stationary Array	Glider
Deployment #1 (UW/APL)	0.23	0.10
Deployment #2 (OSU)	0.26	0.17

Conclusions

Although there were relatively few detections compared to the stationary array, the detections occurred in locations that had noticeably greater indicators of biological productivity than surrounding areas. These locations with tag detections were near bathymetric features that could have been associated with localized persistent high productivity zones. One avenue of future research would be a focused study of fish habitat use in these and other similar areas. It seems likely that the AUVs would be more useful for providing environmental profiles and should be used in combination with moored stationary receivers. One advantage of using AUVs is the ability to report detections in near-real time, thereby allowing researchers to adapt to fish movements by placing additional stationary receivers strategically or perhaps by performing active fish tracking from a boat. Another advantage is that several salmon detections occurred in deep water, which was unsuitable for moored receivers. The environmental data profiles were potentially valuable for understanding fish occurrence, but moored receivers would be necessary to increase the number of tag detections in an area with environmental data. Future acoustic tag glider deployments would also benefit from using tags that report the depth of the fish (Currently available) to determine its position in the environmental profile.

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