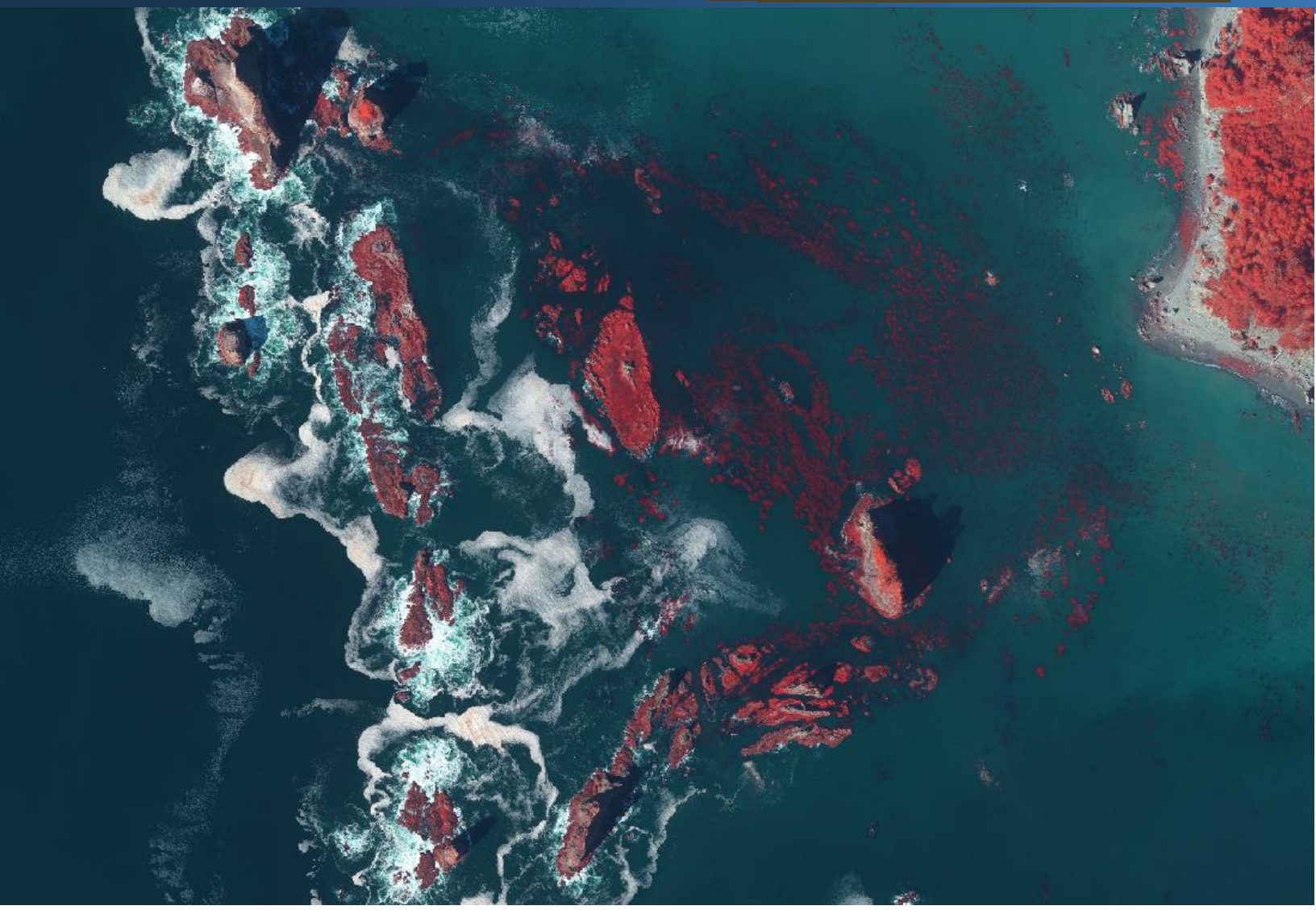
NV5 GEOSPATIAL

April 5, 2023



Kelp and Seagrass 4-band Orthophotography

WASHINGTON STATE DEPT OF NATURAL RESOURCES

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TABLE OF CONTENTS

Cover Photo: View of Open Coast AOI at 1:4,000 scale.

INTRODUCTION

On June 30th, 2022, NV5 was contracted by the Washington DNR to collect 4-band imagery for the Puget Sound located in northwestern Washington. This report accompanies the delivered imagery and support files, and documents data acquisition procedures, processing methods, and results of all accuracy assessments. Project acquisition details are shown in Table 1, the project extent can be seen in Figure 1, and a complete list of contracted deliverables provided to the Washington DNR can be found in Table 2.

Table 1: Acquisition dates, acreages, and data types collected for the Kelp and Seagrass photo project

Project Site	Contracted Acres	Buffered Acres	Acquisition Date	Acquisition Window (PST)	Deliver Date	Air Craft	Sensor	Elevation (ft)
Admiralty Inlet	62,423	70,819	07/25/2022 07/26/2022	08:30 – 09:58 08:31 – 09:48	11/07/2022	N777Q N777Q	Falcon Prime Falcon Prime	8,200 8,200
Aquatic Reserves	51,572	54,523	07/26/2022 07/27/2022	10:31 – 10:34 10:18 – 10:52	11/17/2022	FTNY FTNY	DMC III DMC III	11,800 11,800
North Puget Sound	133,896	140,517	07/27/2022 10/11/2022	10:18 – 10:52 11:39 – 12:51	01/05/2023	FTNY FTNY	DMC III DMC III	11,800 11,800
Open Coast	93,902	99,121	09/20/2022	14:10 – 16:35	11/17/2022	N5549A	Falcon M2	8,200
San Juan	243,494	247,089	08/30/2022 09/09/2022 10/12/2022	12:34 – 14:19 09:33 – 10:14 11:58 – 12:12	01/11/2023	GVSP FTNY FTNY	DMC III DMC III DMC III	9.800 11,600 11,700
Saratoga Whidbey	67,264	71,965	07/26/2022	08:31 – 10:03 09:51 – 10:20	11/17/2022	N5549A N777Q	Falcon M2 Falcon Prime	8,200 8,200
Squaxin	69	133	08/08/2022	09:32 – 09:35	11/17/2022	N5549A	Falcon M2	8,200
Straight of Juan de Fuca	102,538	111,143	08/29/2022	09:51 – 11:38 10:00 – 11:56	11/17/2022	N5549A N7818A	Falcon M2 Falcon Prime	8,200 8,200
Tacoma Narrows	5,019	7,903	08/08/2022	08:49 – 09:26	11/17/2022	N5549A	Falcon M2	8,200

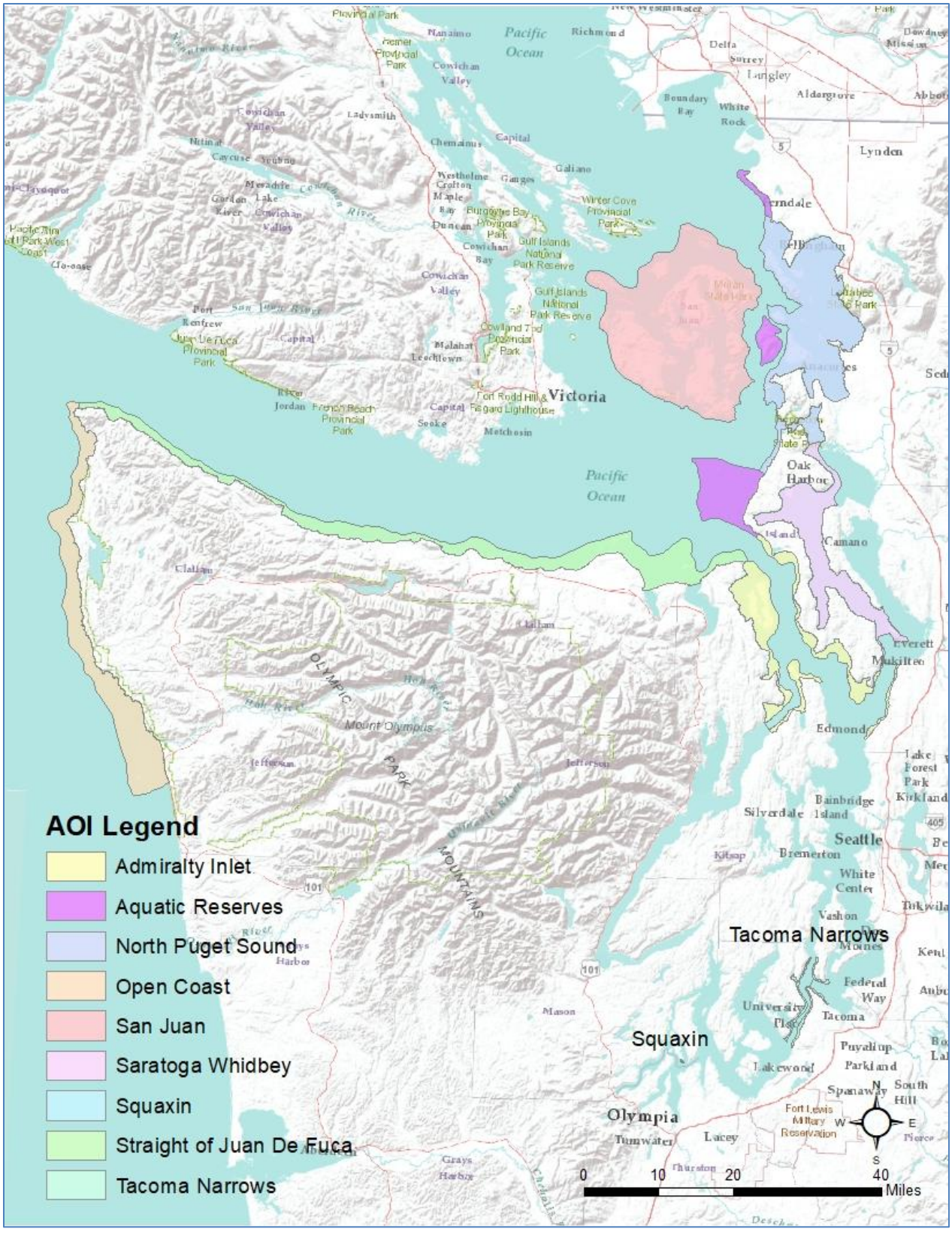

Figure 1: Location map of AOIs surveyed for the Kelp and Seagrass project

Table 2: Orthophoto products delivered to the Washington DNR

Projection: Washington State Plane South Horizontal Datum: NAD83 (HARN) Vertical Datum: NAVD88(Geoid12b) Units: US Survey Feet			
Deliverable		**File Count**	**Total Data Size**
Vectors	Photo Flight Plan (*.kml)	14	6 MB
	Photo Survey Flight Index Footprints (*.shp)	11	10.8 MB
	Ortho Tile Index	9	2 MB
	ArcGIS Geodatabase (*.gdp)	9	5.2 MB
	• Ground Control		
	• Flight Lines		
	• Job Survey Boundary		
	• Orthophoto Mosaic Tile Index		
	• Photo Center Points		
Digital Imagery	4-band (RGBI) Imagery		
	• Tiled Imagery Mosaics (*.tiff)	6,622	827 GB
	• Tiled Imagery Mosaics (*.sid)	6,622	60.4 GB
	• AOI Imagery Mosaic Compressions (*.sid)	9	122 GB
	• Raw Frames (8bit, *.tiff)	9,656	5.28 TB
	• Raw Frames (16bit, *.tiff) (Geoterra Only)	5,827	8.49 TB
Documents	Orthophoto Metadata Report (*.pdf)	9	1.2 MB
	Camera Calibration Report (*.pdf)	12	16.3 MB
	Airborne GNSS (*.txt)	16	1.8 MB

ACQUISITION

Aerial photo acquisition was a joint effort between Geoterra and Peregrine Aerial Surveys, in coordination with NV5. The acquisition teams targeted sun angles between 25° and 45°, low tides, calm sea states and cloud free conditions. In some instances, targeted environmental condition requirements were relaxed with client approval to ensure completion of the project within the necessary time window. Figure 2 displays photo acquisition flightlines by date.

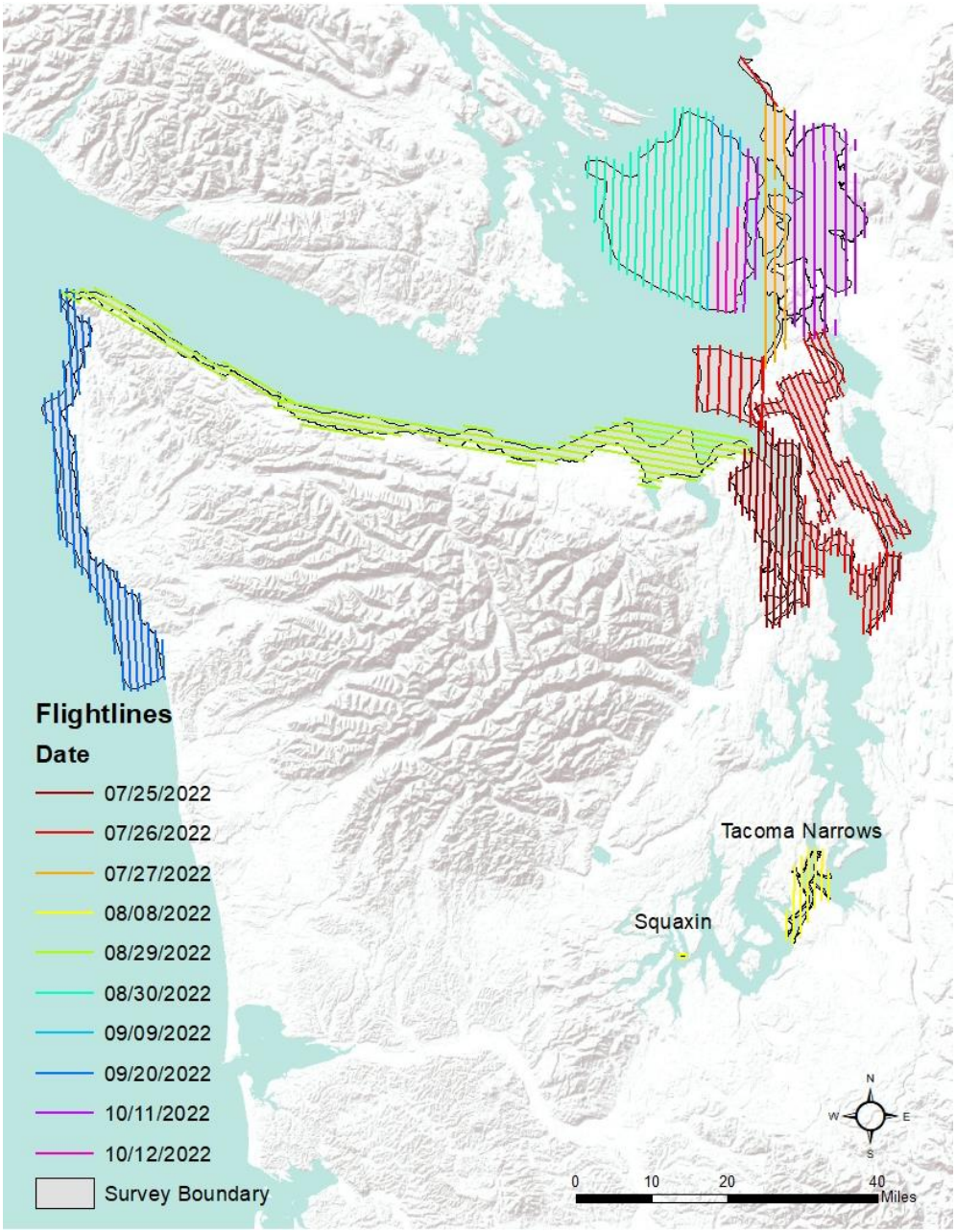

Figure 2: Acquisition Overview Map for the Kelp and Seagrass photo survey.

Digital Imagery

The aerial imagery acquisition was a joint effort between Geoterra and Peregrine Aerial Surveys. Geoterra deployed an UltraCam Falcon Prime and UltraCam Falcon Mark 2 (identical interior orientations), manufactured by Vexcel. Peregrine utilized a DMC III camera manufactured by Leica, camera specifications can be found in Table 3 and Table 4. The systems were gyro-stabilized and simultaneously collected panchromatic and multispectral (RGB, NIR) imagery.

Table 3: UltraCam Falcon Camera manufacturer's specifications

UltraCam Falcon Prime and Mark II	
Focal Length	100.5 mm
Data Format	RGB NIR
Pixel Size	6.0 µm
Image Size	17,310 x 11,310 pixels
Frame Rate	2.0 seconds
FOV	55 x 37 degrees

Table 4: DMC III Camera manufacturer's specifications

DMC III	
Focal Length	92 mm
Data Format	RGB NIR
Pixel Size	3.9 µm
Image Size	25,728 x 14,592 pixels
Frame Rate	2.0 seconds
FOV	57 x 34 degrees

For the Puget Sound Kelp and Seagrass study area, images were collected in 4 spectral bands (red, green, blue, and NIR) with 80% along track overlap and 40% sidelap between frames. The acquisition flight parameters were designed to yield a native pixel resolution of ≤ 6 inches (15 cm). Orthophoto specifications particular to the Kelp and Seagrass photo project are in Table 5.

Table 5: Project-specific orthophoto specifications

Digital Orthophotography Specifications	
Equipment	UltraCam Falcon, UltraCam M2, DMC III
Spectral Bands	Red, Green, Blue, NIR
Ground Sampling Distance (GSD)	≤0.5 ft
Along Track Overlap	≥80%
Cross Track Overlap	≥40%
Flight Altitude (AGL)	Variable by sensor
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Image	8-bit GeoTiff

Ground Survey

Monumentation

Monument locations were selected with consideration for client preference, satellite visibility, field crew safety, and optimal location for GSP coverage. The survey monuments listed in Table 6 provided redundant control (1Hz) within 20 nautical miles of the NV5 ground survey. Each monument had two separate occupations with different heights of instrument (HI) using Trimble R7's (Zephyr Geodetic Model 2 RoHS antenna). Monument coordinates are presented in Table 6 and shown in Figure 3.

Table 6: Monuments used to support the Kelp and Seagrass ground survey. Coordinates are on NAD83 (HARN) datum

Monument PID	Latitude	Longitude	Ellipsoid (m)
BBAY	48 53 56.66428	-122 46 10.02479	-7.928
BELI	48 45 18.95007	-122 28 44.23878	10.889
CHCM	48 00 38.20699	-122 46 33.06174	20.707
COUP	48 13 02.30253	-122 41 08.11687	21.329
JOBO	48 33 44.51834	-122 26 14.21597	-11.218
MKAH	48 22 14.41053	-124 35 21.14638	23.961
OLMP	47 02 41.43270	-122 53 42.72623	2.944
P401	47 56 13.85773	-124 33 25.21041	36.513
P402	47 45 58.37851	-124 18 21.17257	24.05
P403	48 03 44.34175	-124 08 27.09162	285.016
P423	47 17 16.43548	-122 56 28.29779	40.299
PFLD	47 53 54.60780	-122 16 55.79701	160.617

Monument PID	Latitude	Longitude	Ellipsoid (m)
PNNL	48 04 45.39097	-123 02 42.35286	-15.498
PRDY	47 23 28.88757	-122 36 34.00093	82.856
PTAA	48 07 00.56954	-123 29 39.63890	67.151
SC02	48 32 46.28366	-123 00 27.33689	-14.721
SEQM	48 05 29.08082	-123 06 48.69406	35.008
SKGT	48 26 00.35365	-122 20 32.82654	-6.416
UFDA	47 45 18.01646	-122 40 02.63848	76.92
WADNR_KELP_01	48 29 07.35904	-122 55 19.32088	30.601

Air Targets

Ground survey data were collected by NV5 Geospatial to adjust aircraft positional and attitude data and to perform an accuracy assessment of final orthophoto products. NV5 Geospatial collected hard surface air targets typically on high visibility road markings or painted chevrons. High contrast road markings typically consisted of stop bars, turn arrows or cement corners. Air target points were surveyed throughout the Kelp and Seagrass study area, prior to imagery acquisition, using fast static or RTK techniques (Figure 3). Air target point data (Point ID, Easting, Northing, Orthometric Elevation) were provided to WADNR in the flight data geodatabase (Flight_Index.gdb) within the GIS Data folder of each AOI.

Figure 3: Location map of ground survey data collected for the Kelp and Seagrass photo project

Digital Imagery

The collected digital photographs went through multiple processing steps to create final orthophoto products. Initially, images were corrected for geometric distortion to yield level02 image files. Next, images were color balanced and levels were adjusted to exploit the full 14bit histogram and finally output as level03 pan-sharpened 8bit TIFF images. Photo position and orientation were calculated by linking the time of image capture to the smoothed best estimate of trajectory (SBET). Within Inpho's Match AT softcopy photogrammetric software, analytical aerial triangulation was performed using ground control, automatically generated tie points, and camera calibration information.

Adjusted images were orthorectified using the best publicly available DEM to remove displacement effects from topographic relief inherent in the imagery. The resulting images were mosaicked within Inpho's Ortho Vista blending seams and applying automated project color-balancing. The final mosaics were inspected and edited for seam cutlines across above ground features such as buildings and other man-made features. Special care was taken to use glare free imagery in the final mosaic. The processing workflow for orthophotos is summarized in Table 7.

Table 7: Orthophoto processing workflow

Orthophoto Processing Step	Software Used
Resolve GPS kinematic corrections for the aircraft position data using kinematic aircraft GPS (collected at 2 Hz), onboard IMU (collected at 200 Hz) and PPP data	Inertial Explorer v8.90
Develop a smooth best estimate trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	Inertial Explorer v8.90
Create an exterior orientation file (EO) for each photo image with omega, phi, and kappa.	Inertial Explorer v8.90
Convert Level 00 raw imagery data into geometrically corrected Level 02 image files.	UltraMap v4 or HxMap
Apply radiometric adjustments to Level 02 image files to create Level 03 Pan-sharpened TIFFs.	UltraMap v4 or HxMap
Apply EO and camera calibration parameters to photos; perform aerial triangulation using automatically generated tie points and ground control processed on project datum	Inpho Match AT v10.0.2
Import DEM and generate individual ortho frames.	Inpho OrthoMaster v10.0.2
Mosaic orthorectified imagery, blending seams between individual photos and correcting for radiometric differences between them.	OrthoVista/SeamEditor v10.0.2
Review seamlines and edit to make sure most nadir part of each image is used and that water glare is reduced or eliminated and seams don't cut through buildings or other manmade features.	OrthoVista/SeamEditor v10.0.2

Orthophoto Absolute Accuracy

Image accuracy was assessed using air target points, collected by NV5, which were used in the aerial triangulation procedure as control points. These points were found in the final adjusted orthophoto mosaics and the displacement was recorded for further statistical analysis. This methodology was applied to all air targets which intersected each AOI boundary. Note that some air targets fell outside the AOI boundaries but within the footprint of the full aerial imagery acquisition; for example there were eleven air target points surveyed for Tacoma Narrows but all were outside the AOI boundary thus none could be used for an absolute accuracy assessment.

Image orthorectification was performed using the best publicly available DEM, the quality of the DEM used for this process directly effects horizontal accuracy of the final orthophoto products such that erroneous elevations due to temporal differences, DEM survey methodology or coarse DEM resolution can cause offsets in the resulting orthophotos. In some areas of the Kelp and Seagrass photo project offsets were observed, primarily along the inland areas of the shoreline. So while control point residuals in the aerial triangulation report (provided below) are within the accuracy specifications for the project the DEM contributed to horizontal offsets which in some cases fell outside of spec.

Accuracy reporting for both ASPRS guidelines and the National Standard for Spatial Data Accuracy (NSSDA) require at least twenty independent check points per aerial triangulation block for validation, in the case of the Kelp and Seagrass photo project all air targets were used as control points (no independent check points were withheld) in the aerial triangulation procedure due to the limited amount of control available. Table 8, Table 9 and Table 10 present the summary photo accuracy statistics for control points in all AOIs.

Table 8: Orthophotography accuracy statistics for Admiralty Inlet, Aquatic Reserves and North Puget Sound

		Admiralty Inlet			Aquatic Reserves			North Puget Sound		
		Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$
Count		5			3			6		
Mean	*ft*	-0.139	0.030	-0.139	0.038	-0.104	0.111	-2.921	1.195	3.156
	m	-0.042	0.009	-0.042	0.012	-0.032	0.034	-0.890	0.364	0.962
RMSE	*ft*	0.203	0.177	0.269	0.224	0.457	0.509	6.696	2.483	7.142
	m	0.062	0.054	0.082	0.068	0.139	0.155	2.041	0.757	2.177
1σ	*ft*	0.166	0.195	0.256	0.270	0.546	0.609	6.601	2.384	7.018
	m	0.050	0.059	0.078	0.082	0.166	0.186	2.012	0.727	2.139
1.96σ	*ft*	0.325	0.382	0.501	0.529	1.069	1.193	12.938	4.673	13.755
	m	0.099	0.117	0.153	0.161	0.326	0.364	3.943	1.424	4.193

Table 9: Orthophotography accuracy statistics for Open Coast, San Juan and Saratoga Whidbey

		Open Coast			San Juan			Saratoga Whidbey		
		Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$
Count		5			17			5		
Mean	*ft*	0.252	0.038	0.255	-2.228	0.496	2.283	-0.091	0.250	0.266
	m	0.077	0.012	0.078	-0.679	0.151	0.696	-0.028	0.076	0.081
RMSE	*ft*	0.618	0.262	0.672	12.011	2.424	12.253	0.404	0.411	0.576
	m	0.188	0.080	0.205	3.661	0.739	3.735	0.123	0.125	0.176
1σ	*ft*	0.631	0.290	0.695	12.166	2.445	12.409	0.440	0.365	0.572
	m	0.192	0.088	0.212	3.708	0.745	3.782	0.134	0.111	0.174
1.96σ	*ft*	1.237	0.569	1.362	23.845	4.793	24.321	0.863	0.715	1.121
	m	0.377	0.173	0.415	7.268	1.461	7.413	0.263	0.218	0.342

Table 10: Orthophotography accuracy statistics for Squaxin, Straight of Juan de Fuca and Tacoma Narrows

		Squaxin			Straight of Juan de Fuca			Tacoma Narrows		
		Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$	Air Targets$_x$	Air Targets$_y$	Air Targets$_{xy}$
Count		0			6			1		
Mean	*ft*	NA	NA	NA	0.151	0.150	0.213	0.631	0.025	0.631
	m	NA	NA	NA	0.046	0.046	0.065	0.192	0.008	0.192
RMSE	*ft*	NA	NA	NA	0.291	0.535	0.609	0.631	0.025	0.631
	m	NA	NA	NA	0.089	0.163	0.186	0.192	0.008	0.192
1σ	*ft*	NA	NA	NA	0.273	0.563	0.625	NA	NA	NA
	m	NA	NA	NA	0.083	0.171	0.191	NA	NA	NA
1.96σ	*ft*	NA	NA	NA	0.534	1.103	1.225	NA	NA	NA
	m	NA	NA	NA	0.163	0.336	0.373	NA	NA	NA

Overview

Aerial triangulation was performed in nine blocks to support kelp and eel grass mapping of the Puget Sound and surrounding areas. The nine blocks consisted of 156 flight lines flown at a scale of 1:1,200 between July 25th and October 12th, 2022. Block adjustments were made to ground control established by NV5 referencing NAD83(HARN) horizontal datum and NAVD 1988 vertical datum (Geoid12b). Digital imagery along with ground control and camera calibration data were used as input to Inpho's Match AT softcopy photogrammetry program. Of the 91 total surveyed air target points all were used for aerial triangulation and zero were withheld from the block adjustment as independent check points.

Admiralty Inlet

Air target points used in the aerial triangulation adjustment are listed with their location in Table 11, and RMSE values can be found in Table 12.

Table 11: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 13 Total Points					**Control Point Residuals (US ft) -** 13 Total Points		
Point ID	**X**	**Y**	Z	**# Photo Measurements**	**X**	**Y**	Z
AT034	1142182.49	982273.2	70.21	4	0.0342	-0.0972	-0.0095
AT036	1123015.94	1039895.88	98.22	5	-0.1051	0.0887	-0.0167
AT038	1105607.94	1055939.76	112.2	2	0.0427	0.0144	0.6512
AT039	1175739.35	907661.44	12.02	5	0.0267	-0.1145	0.413
AT040	1111958.16	911570.85	95.39	10	-0.1127	0.066	-0.002
AT041	1129194.32	943767.81	39.59	4	0.1405	-0.035	0.194
AT042	1102136.31	963111.47	147.62	7	0.0479	0.019	-0.7499
AT043	1083771.6	996325.68	101.1	9	0.0065	0.0002	-0.8472
AT077	1189948.64	923736.69	65.83	10	0.0987	0.1518	1.0856
AT086	1088368.88	1031689.29	18.94	4	-0.0275	-0.0114	-0.1438
AT087	1082255.62	1024503.46	124.2	2	0.0598	-0.0372	-0.696
AT088	1193612.92	940868.51	191.6	5	-0.1194	-0.0262	0.1014
AT093	1129867.62	945310.93	16.96	10	-0.0922	-0.0186	0.0202

Table 12: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 13 Total Points		
US survey feet		
X	Y	Z
0.0815	0.0691	0.5268

Aquatic Reserves

Air target points used in the aerial triangulation adjustment are listed with their location in Table 13, and RMSE values can be found in Table 14.

Table 13: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 9 Total Points					Control Point Residuals (US ft) - 9 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT037	1103078.68	1057500.82	177.03	3	0.0506	0.0405	0.2498
AT038	1105607.94	1055939.76	112.2	5	-0.0047	-0.0011	0.2985
AT052	1114250.47	1278970.33	177.07	6	0.0345	-0.2583	-1.5589
AT053	1090799.67	1306495.27	96.76	4	0.0099	-0.0403	-0.5481
AT055	1089057.18	1066221.04	70.67	11	0.2795	0.0244	0.2119
AT056	1097780.75	1083459.68	245.73	12	-0.2577	-0.2399	0.4598
AT061	1109766.11	1163318.38	117.16	7	-0.3494	0.1719	1.4353
AT066	1113219.3	1242228.52	32.73	3	0.1817	0.3139	-1.0319
AT089	1093088.97	1076934.66	28.02	6	0.0556	-0.0112	0.4837

Table 14: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 9 Total Points		
US survey feet		
X	Y	Z
0.1846	0.1687	0.8497

North Puget Sound

Air target points used in the aerial triangulation adjustment are listed with their location in Table 15, and RMSE values can be found in Table 16.

Table 15: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 13 Total Points					Control Point Residuals (US ft) - 13 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT045	1130971.91	1114649.96	347.53	4	-0.0328	0.0763	0.2423
AT052	1114250.47	1278970.33	177.07	2	-0.069	-0.0702	-2.6586
AT054	1144432.04	1264857.48	95.91	2	0.01	0.0942	1.0289
AT056	1097780.75	1083459.68	245.73	4	0.1292	-0.3474	-4.9761
AT057	1155835.1	1257629.14	69.09	8	-0.1104	0.175	1.4957
AT058	1162532.89	1178668.87	8.48	14	-0.053	-0.191	2.0286
AT059	1173844.35	1198051.63	41.85	6	0.1119	0.3451	-0.0567
AT060	1127818.9	1169177.65	20.12	13	-0.0082	-0.0757	2.3632
AT061	1109766.11	1163318.38	117.16	7	-0.0796	0.2178	-2.0982
AT062	1153809.09	1144236.35	11.86	8	0.1211	-0.0565	3.0148
AT064	1161679.6	1153842.88	25.98	14	-0.2015	-0.0961	2.7324
AT065	1159579.48	1225194.35	52.47	4	0.0153	0.099	0.6642
AT066	1113219.3	1242228.52	32.73	5	0.167	-0.1706	-3.7806

Table 16: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 13 Total Points		
US survey feet		
X	Y	Z
0.1038	0.1821	2.4897

Open Coast

Air target points used in the aerial triangulation adjustment are listed with their location in Table 17, and RMSE values can be found in Table 18.

Table 17: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 6 Total Points					Control Point Residuals (US ft) - 6 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT002	677037.9	889703.66	114.6	10	-0.0493	0.1121	0.0399
AT004	631131.56	961397.97	249.89	2	0.2292	-0.1533	0.7758
AT005	625550.83	965774.43	15.33	8	-0.0437	0.0166	-0.4357
AT008	628715.03	1120504.19	19.35	4	0.0056	-0.0003	-0.0575
AT009	626600.27	1125688.4	17.81	3	0.0001	-0.0205	0.1107

Control Point Coordinates (US ft) – 6 Total Points					Control Point Residuals (US ft) - 6 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT094	626001.42	970499.1	16.46	5	-0.1418	0.0453	-0.4333

Table 18: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 6 Total Points		
US survey feet		
X	Y	Z
0.1133	0.0804	0.4075

San Juan

Air target points used in the aerial triangulation adjustment are listed with their location in Table 19, and RMSE values can be found in Table 20. During processing the aerial triangulation staff designated four points as anomalies, these points are identified in Table 21 and were removed from further processing.

Table 19: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 12 Total Points					Control Point Residuals (US ft) - 12 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT069	1052992.83	1155819.01	190.64	5	0.0697	-0.1932	0.7833
AT070	1049492.63	1159190.27	202.01	12	0.5213	0.0634	-0.45
AT071	1041685.95	1147196.21	61.41	4	-0.0243	-0.36	0.0768
AT072	1026288.51	1159583.29	190.25	8	-0.5146	-0.0709	-0.3174
AT073	994025.28	1191868.61	12.79	4	0.13	0.2855	0.4564
AT074	999665.77	1206271.71	65.13	8	0.6528	0.1373	-0.1136
AT075	1057796.34	1238111.48	41.01	12	-0.5511	-0.1418	-0.8524
AT079	1062866.98	1188910.21	68.72	4	-0.0111	0.0964	-0.2111
AT080	1054939.57	1173067.53	35.07	9	0.1683	0.0099	-0.0706
AT081	1029745.1	1178110.93	99.64	4	-0.2277	-0.1918	0.8762
AT082	1048722.61	1199951.97	32.5	6	-0.1165	-0.012	-0.0597
AT084	1035466.54	1208379.26	53.46	10	-0.0967	0.3773	-0.1178

Table 20: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 12 Total Points		
US survey feet		
X	Y	Z
0.3406	0.2011	0.4748

Table 21: Points designated as anomalies in the San Juan aerial triangulation procedure

Control Point Anomalies- 5 Total Points	
Point ID	Comment
AT067	Large XY offset, could not be resolved
AT068	Caused significant offsetting between lines 32/33. Control point was not visible in 33 due to partial vegetation cover. Could not be resolved.
AT078	Could not make out the bench in the imagery.
AT085	Obstructed by pole lean and dock and/or structure.

Saratoga Whidbey

Air target points used in the aerial triangulation adjustment are listed with their location in Table 22, and RMSE values can be found in Table 23.

Table 22: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 12 Total Points					Control Point Residuals (US ft) - 12 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT034	1142182.49	982273.2	70.21	4	0.0888	0.0412	-0.0824
AT035	1185876.4	970048.5	128.56	5	0.2541	0.1272	-0.357
AT037	1103078.68	1057500.82	177.03	9	0.0591	0.0574	-0.2357
AT038	1105607.94	1055939.76	112.2	2	0.0448	0.0403	-0.2481
AT044	1120524.05	1086671.57	151.26	4	0.1281	0.1041	-0.6342
AT045	1130971.91	1114649.96	347.53	7	-0.1975	-0.0617	-0.0403
AT046	1152868.95	1072161.84	10.55	4	0.1084	0.0319	-0.195
AT047	1160866.29	1025239.95	120.06	9	-0.0241	-0.0942	0.054
AT048	1173251.56	993079.63	44.71	10	-0.2313	-0.1537	0.8351
AT049	1153355.4	1013784.87	10.22	10	-0.0856	0.0369	0.4515
AT050	1145773.52	1044333.53	160.97	5	-0.1477	-0.2606	-0.0918
AT055	1089057.18	1066221.04	70.67	2	0.003	0.1314	0.544

Table 23: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 12 Total Points		
US survey feet		
X	Y	Z
0.1379	0.1146	0.3981

Squaxin

Air target points used in the aerial triangulation adjustment are listed with their location in Table 24, and RMSE values can be found in Table 25.

Table 24: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 1 Total Points					Control Point Residuals (US ft) - 1 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT034	1142182.49	982273.2	70.21	4	0.0888	0.0412	-0.0824
AT033	1048919.87	676394.22	37.79	4	0	0	0

Table 25: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 1 Total Points		
US survey feet		
X	Y	Z
0	0	0

Straight of Juan de Fuca

Air target points used in the aerial triangulation adjustment are listed with their location in Table 26, and RMSE values can be found in Table 27.

Table 26: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 14 Total Points					Control Point Residuals (US ft) - 14 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT011	641587.41	1132038.1	22.72	6	0.0292	0.3105	0.461
AT012	686153.25	1106726.79	18.54	5	0.0086	-0.4041	0.1092
AT013	726672.77	1088615.81	17.2	5	0.0915	0.0746	0.1549
AT014	724293.44	1085927.72	56.19	8	0.0177	0.0929	-0.5558
AT015	762321.85	1064230.51	126.21	7	-0.0977	-0.1237	0.5184

Control Point Coordinates (US ft) – 14 Total Points					Control Point Residuals (US ft) - 14 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT016	798303.86	1051078.42	28.48	8	-0.0695	0.1916	0.1811
AT017	858150.38	1047273.73	22.65	5	0.0154	-0.0555	0.2908
AT018	922165.23	1029936	18.06	9	0.015	0.0533	-0.0286
AT019	975056.32	1027705.59	125.81	4	0.1027	-0.0862	-0.0523
AT020	1001132.58	1037775.42	10.87	5	-0.2789	-0.5202	1.035
AT021	1015381.97	1012365.82	25.72	8	0.1044	0.0623	-0.3709
AT086	1088368.88	1031689.29	18.94	4	0.0389	0.3213	-0.6405
AT087	1082255.62	1024503.46	124.2	2	0.0681	0.0687	-0.7764
AT092	1059080.86	1018293.18	164.01	4	-0.0455	0.0147	-0.3258

Table 27: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 14 Total Points		
US survey feet		
X	Y	Z
0.0971	0.2271	0.4837

Tacoma Narrows

Air target points used in the aerial triangulation adjustment are listed with their location in Table 28, and RMSE values can be found in Table 29.

Table 28: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates (US ft) – 11 Total Points					Control Point Residuals (US ft) - 11 Total Points		
Point ID	X	Y	Z	# Photo Measurements	X	Y	Z
AT022	1126225.42	687612.93	234.2	2	-0.0697	0.2966	1.6993
AT023	1123025.64	714726.29	159.05	4	0.1065	0.089	-0.5228
AT024	1136097.1	709554.87	367.27	6	-0.3151	0.0697	0.4217
AT025	1129646.29	719336.26	247.37	10	-0.1699	0.0921	0.0509
AT026	1143351.57	722514.51	31.77	8	-0.0192	0.0219	0.002
AT027	1122529.8	738912.35	56.2	5	-0.1419	0.147	0.6403
AT028	1134700.96	752409.49	32.13	5	0.1442	0.314	-0.0989
AT029	1118227.48	696879.46	214.56	5	0.468	-0.5136	-0.0301
AT030	1130195.04	745167.3	356.2	4	0.1794	-0.4578	-1.5293
AT031	1131232.52	704513.46	13.55	6	-0.2676	-0.281	-0.2734

Control Point Coordinates (US ft) – 11 Total Points					Control Point Residuals (US ft) - 11 Total Points		
Point ID	**X**	**Y**	Z	**# Photo Measurements**	**X**	**Y**	Z
AT090	1129572.1	719374.5	243.49	10	0.0853	0.2221	-0.3598

Table 29: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 11 Total Points		
US survey feet		
X	**Y**	Z
0.2165	0.2749	0.7571

GLOSSARY

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96-sigma (σ) Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set.

Accuracy: The statistical comparison between known points (air target points) and the same point found in photo mosaics. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

> **Root Mean Square Error (RMSE):** A statistic used to approximate the difference between ground control points and the same point in the orthoimagery. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Overlap: The area shared between images, typically expressed as percent forward and side overlap.