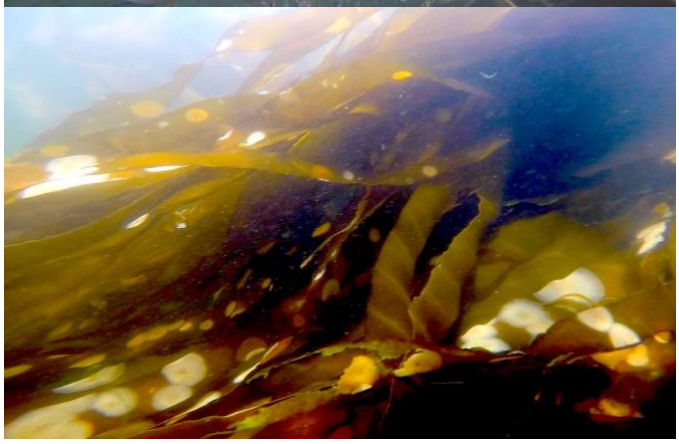
Bull Kelp Monitoring in Island County, 2019
Island County Marine Resources Committee






Clockwise, from upper left:
Juvenile herring school at Ebey's Landing (L. Rhodes). Shiner perch at Polnell Point (L. Rhodes). Bryozoan colonies on kelp at Polnell Point (L. Rhodes). Kelp surveyors at Ebey's Landing (R.Yukubousky).

Report submitted in partial fulfillment of WA Department of Ecology grant SEANWS-2018-IsCoPH-00011, Task 2.2 (Monitoring: Kelp)
Project period: October 2018– September 2019
Report date: September 30, 2019
Project lead: Linda Rhodes
Project participants
Kayak surveys: Ron Beier, Barbara Bennett, Vernon Brisley, Linda Rhodes
Temperature logger surveys: David Davis, Barbara Hardman
Aerial imaging: Gregg Ridder, Vernon Brisley

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PUGETSOUND PARTNERSHIP

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Key Observations for 2019

- Emergent beds were larger earlier in the season at all monitored beds than in previous years of monitoring.
- An abundance of juvenile herring was observed throughout the summer in the Ebey's Landing (Admiralty Inlet) bed.
- Kelp crab were observed only in the Possession Sound bed.
- Surface temperatures exceeded 17°C at all beds at least once during the survey period.

I. Introduction

Kelp forests represent significant habitat for a wide variety of invertebrate and vertebrate animals, and may also influence other submerged aquatic vegetation (Mann 2000; Graham et al 2007). In addition to providing structural habitat, primary productivities of kelp forests match or exceed those of tropical rain forests, marine reefs and estuaries, and warm temperate forests (Mann 1972a; Mann 1972b). In Washington State, two species of kelp are dominant: giant kelp (*Macrocystis integrifolia*) and bull kelp (*Nereocystis leutkeana*). While both species occur along Washington's outer coast and coastal Strait of Juan de Fuca, bull kelp is the species found along shorelines of the inner Salish Sea (Mumford 2007).

Following a state-wide moratorium of commercial harvest of wild kelp and seaweeds in 1988, Washington State Department of Natural Resources (WDNR) initiated annual aerial surveys of coastal aquatic vegetation from Port Townsend Bay to the Columbia River. These surveys have continued for nearly every year, and in 2010, surveys were extended to include the resources of the Smith and Minor Island Aquatic Reserve (SMIAR), which is contained entirely within Island County. In the latest analysis of coastal kelp from 2013 to 2014 (excluding SMIAR), decline in planimeter area of bull kelp around Port Townsend was ~14%, and range-wide decline in planimeter area of both kelps was 38% (Van Wagenen 2015).

Focused *in situ* surveys of bull kelp beds in South Puget Sound have uncovered disturbing trends of progressive shrinkage of bed areas (Berry, 2017; Berry, 2019). In addition to loss of canopy area, maximum depth for beds decreased and condition of individual kelp appeared poor, with an abundance of epiphytes, endophytes, and kelp crab. Whether these disturbing patterns occur in other parts of Puget Sound is unknown, but does raise concerns about the status of bull kelp throughout the region.

The earliest comprehensive evaluation of kelp resources was conducted in 1911, where over half of the total tonnage of bull kelp in the American portion of the Salish Sea was estimated to be located within the jurisdiction of modern Island County (Rigg 1915). Uncertainty about the distribution of bull kelp in areas not monitored by WDNR overlaid by anticipated changes in marine conditions attributable to climate are motivations to conduct an inventory and assessment of this resource in Island County. The Island County Marine Resources Committee (MRC) considered this to be an important activity to conduct under its

sponsorship. Efforts were initiated in 2015 to select kelp beds and test a kayak-based survey protocol. These efforts were expanded in 2016, and have continued through 2019.

II. Scope of Project and Objectives

This report reports on the project period from fall 2018 through summer 2019. Boat-based surveys and aerial imaging occur from early to late summer, often through September. Due to the close co-incidence of the end of the field season and the report deadline, not all of the 2019 data is included in this report.

Objectives for 2019 included:

1. Collect data from previously surveyed kelp beds by boat-based surveys to extend observations from 2015, 2016, 2017, and 2018.
2. Conduct aerial imaging of the Island County coastline for detecting kelp beds.
3. Test temperature loggers for measuring temperatures at multiple depths.
4. Collect images of animals and plants within the kelp beds.
5. Trial an infrared camera method for quantifying bulb density.

III. Project Progress in 2018 - 2019

Objective 1. Collect data from previously surveyed kelp beds by boat-based surveys.
The two beds that were surveyed in 2016 - 2018 were also surveyed in 2019: Ebey's Landing and Polnell Point (Figure 1). The Ebey's Landing bed is located in Admiralty Inlet and receives full marine influence from the Strait of Juan de Fuca. The Polnell Point bed is located at the head of Saratoga Passage between Whidbey and Camano Islands, and it receives strong freshwater influence from the Skagit River. A third bed, Possession Point, was surveyed in 2017 - 2018. It is located at the confluence of Admiralty Inlet, Possession Sound, and the Central Basin of Puget Sound, and it receives both marine and riverine influences, as well as potential anthropogenic effects from the Central Basin.

Objective 2: Conduct aerial imaging of the Island County coastline for detecting kelp beds.
Much of the flight protocol had already been developed by Gregg Ridder for the MRC's eelgrass surveys. For kelp imaging, two major adjustments to the eelgrass protocol were made. First, flights are conducted in August or September, when beds achieve maximum area for the year. Second, a paired near infra-red (IR) camera was added to the visible light (RGB) camera to allow discrimination of surface vs submerged kelp, and to improve accuracy of identification.

Objective 3: Test temperature loggers for measuring temperatures at multiple depths.
Previous experience indicated that inexpensive alcohol-based thermometers had variable accuracy, could be difficult to read, and only surface temperature data could be collected. Although handheld electronic thermometers, such as a YSI instrument, could be used, these instruments are expensive (> $1,000) and vulnerable to being lost overboard from a kayak. As an affordable alternative, Onset programmable temperature loggers were tested at all three bed locations for collection of surface, midwater, and demersal temperatures. A

deployable system with three (3) loggers was developed, and the protocol was used by two separate field teams. In addition, replicate loggers that were deployed in the Possession Bed in June 2018 were successfully retrieved in June 2019, providing the first full year of bottom temperatures in a kelp bed.

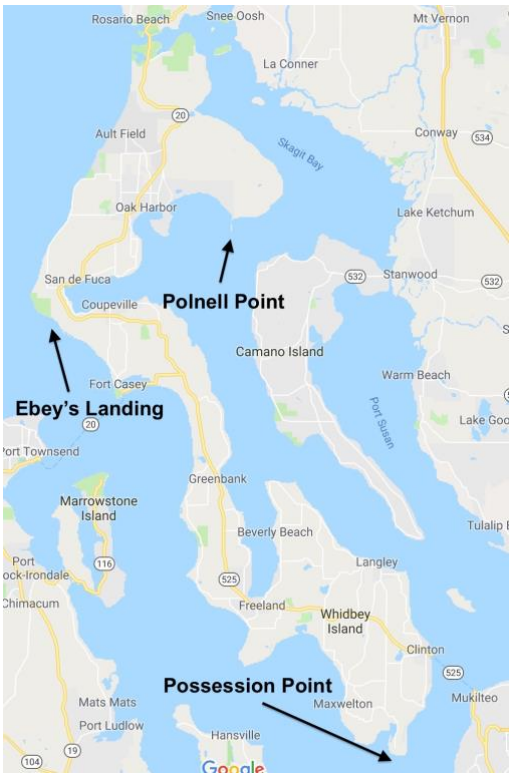

Figure 1. Approximate locations of kelp beds and names of beds surveyed in 2019.

Objective 4: Collect images of animals and plants within kelp beds.
In 2017, we first collected images of submerged aquatic vegetation (SAV) with a small-scale drop camera rig using a GoPro which was deployed from a kayak. Although knowledgeable WA Department of Natural Resources staff indicated the quality was sufficient for SAV identification, no trained or qualified individuals are available for reviewing. Subsequently, we discontinued drop-camera image collection and returned to using a pole-mounted camera for underwater imaging.

Objective 5: Develop an infrared camera method for quantifying bulb density
The initial version of the survey protocol attempted to include bulb density quantification, but was discontinued due to unreliable results. A kayak-based method using a near-infrared camera was developed and tested.

III. Results: Due to the deadline for this report (September 30, 2019), this short report does not include all information for the 2019 field season.

A. Collect data from previously surveyed kelp beds by boat-based surveys.

Ebey's Landing

This bed is located outside of entrance to Admiralty Inlet, and it has been surveyed for four consecutive years (2015, 2016, 2017, 2018). As expected for a site with strong marine influence, surface salinities narrowly fluctuated between 32.5 and 34 ppt. Composite visible (red-green-blue or RGB) and near infra-red (NIR) images taken on September 6, 2018, show that much of the kelp that is visible at low tide is actually at the surface (Figure 2).

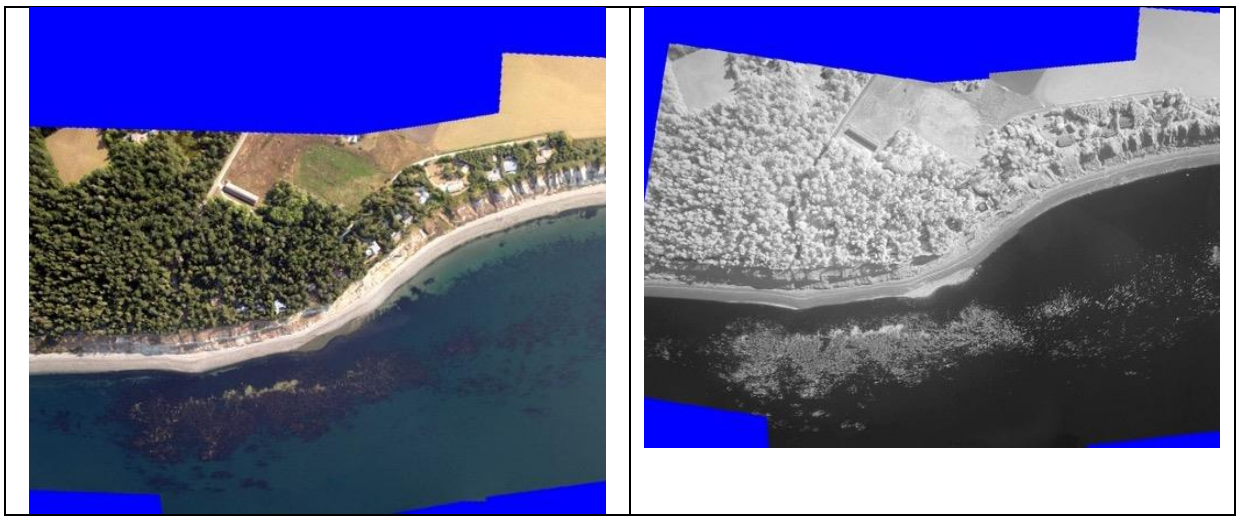

Figure 2. Ebey's Landing bull kelp bed on September 6, 2018, contrasting appearance in visible light (left) with near infra-red (right). Note that most of the kelp is visible at the surface in the near infra-red image. Photos by Gregg Ridder and Vernon Brisley; composite by Gregg Ridder.

Bed area increased consistently from June through August, with a progressive expansion of the bed margin (Figure 3A). Compared to previous years, this bed was much larger at the same time of year in 2019 (Figure 3B). The dramatic increase in size at the last survey in 2019 was due to the merger of the usually surveyed bed with another bed located to the southeast. In the five years of surveys, this was the first time this merger occurred.

A.	B.

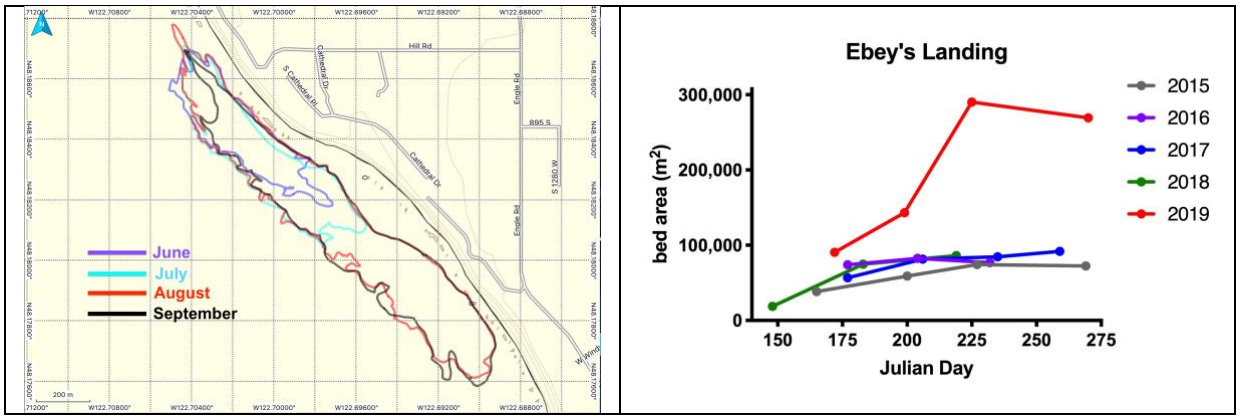

Figure 3. Ebey's Landing kelp bed survey areas. (A) Monthly perimeters of the surveyed bed at a zero-foot tidal height in 2019. (B) Comparison of bed areas from 2015 - 2019 across the survey dates.

Surface temperatures and salinities at the Ebey's Landing bed are relatively stable across the months, probably due to the strong marine influence from the Strait of Juan de Fuca. Surface temperatures increase during the summer, typically peaking in August (Figure 4A). In 2016, the first (June) temperature was unusually high, possibly a residual effect of "The Blob", although subsequent temperatures that year were closer to those observed in other years. Salinity was also very similar across the season and years, except for 2019, which exhibited lower salinity than in previous years (Figure 4B).

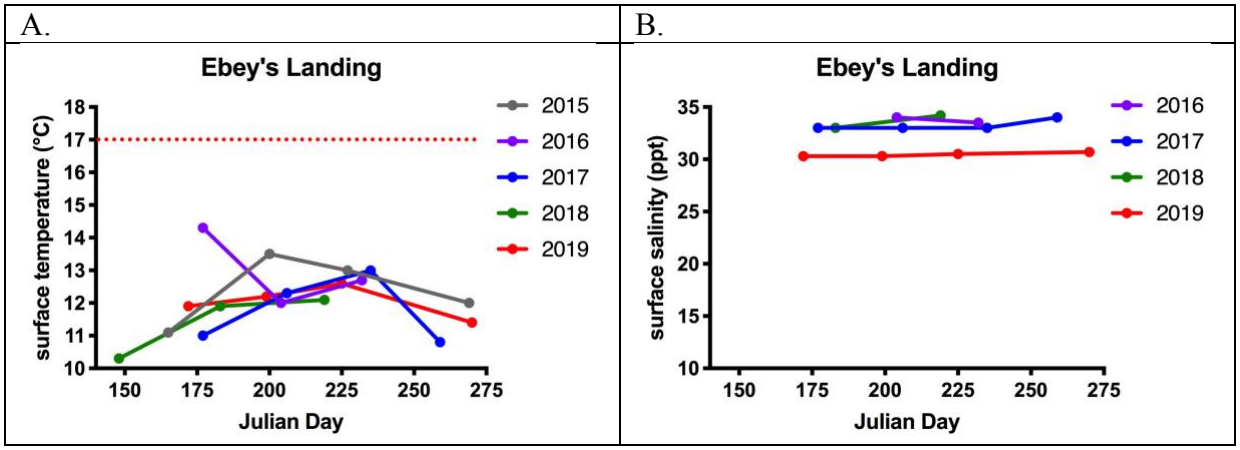

Figure 4. Ebey's Landing kelp bed mean surface temperatures and salinities. (A) Mean surface temperatures for the five years of surveys. The red dotted line at 17°C indicates a potential threshold temperature for detrimental effects on bull kelp physiology. (B) Mean surface salinities for the last four years of surveys.

Polnell Point

This bed is located at the eastern end of Crescent Harbor, and approximately 13 km from the south fork of the Skagit River. The bed is within the influence of this large freshwater influx.

Comparison of visible light and near infrared images of this bed shows that by September 6, 2018, most of the bed is strongly expressed at the surface (Figure 5).

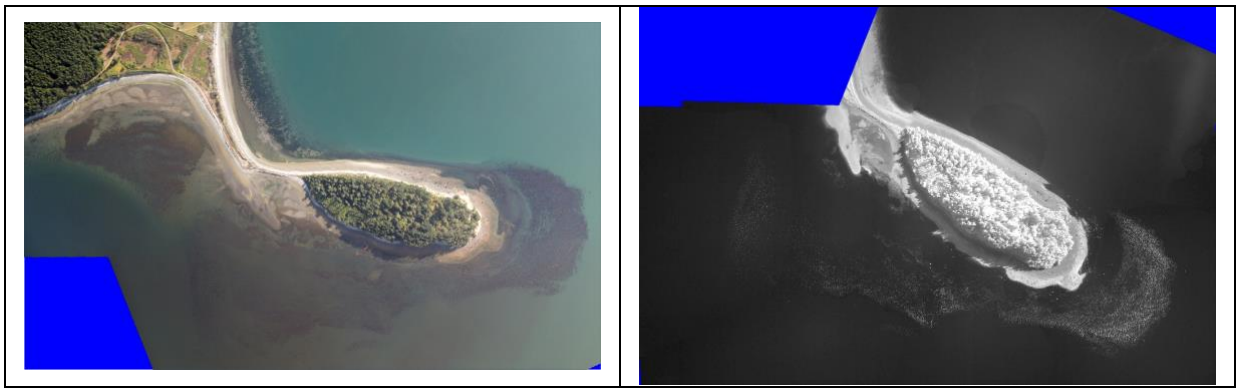

Figure 5. Polnell Point bull kelp bed on September 6, 2018, showing the large area of the bed. Photos by Gregg Ridder and Vernon Brisley; composite by Gregg Ridder.

Earlier in the season, bull kelp shows along the southwest margin of the point, expanding south and north throughout the summer (Figure 6A). The majority of the bed at Polnell Point emerges at the surface relatively late in the season, relative to Ebey's Landing, sometimes with rapid expansion late in the summer (Figure 6B). In 2019, the bed appeared slightly earlier and was larger than in the previous three years of surveys (Figure 6B).

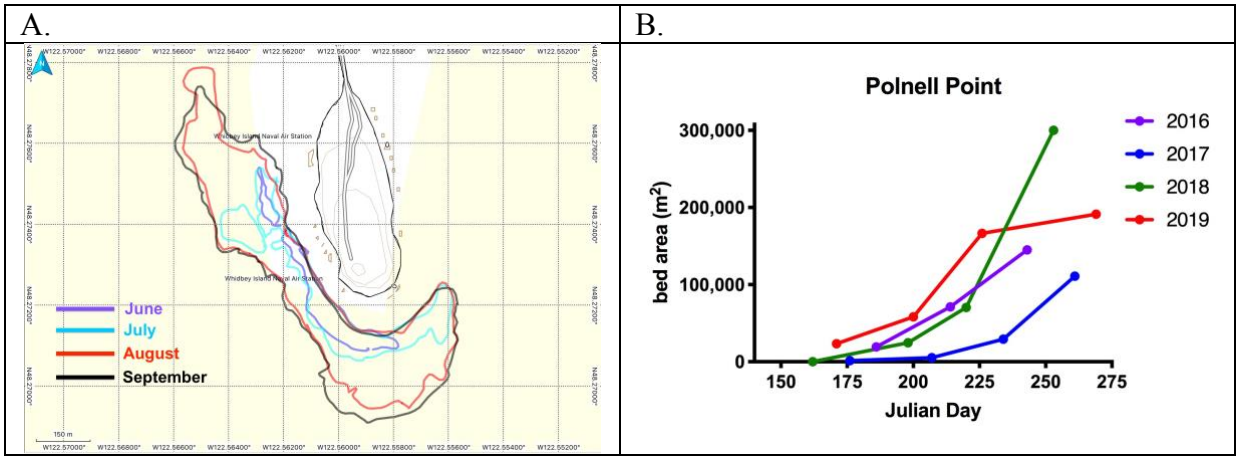

Figure 6. Polnell Point kelp bed survey areas. (A) Monthly perimeters of the surveyed bed at a zero-foot tidal height in 2019. (B) Comparison of bed areas from 2016 - 2019 across the survey dates.

Because this bed is close to the south fork of the Skagit River, higher temperatures and lower salinities in surface waters were expected. Surface temperature maxima can occur at different times during the summer, and in 2019 it occurred in mid-August (Figure 7A). However, surface temperatures in June and July of 2019 were much lower than observed in previous years, such as in 2016, where all survey temperatures were close to or exceeded a potential threshold temperature for physiological impact for bull kelp (Figure 7A). Mean surface salinities can fluctuate widely, depending on water movements. But in 2019, surface

salinity remained between 20 and 25 parts per thousand (ppt) throughout the summer (Figure 7B).

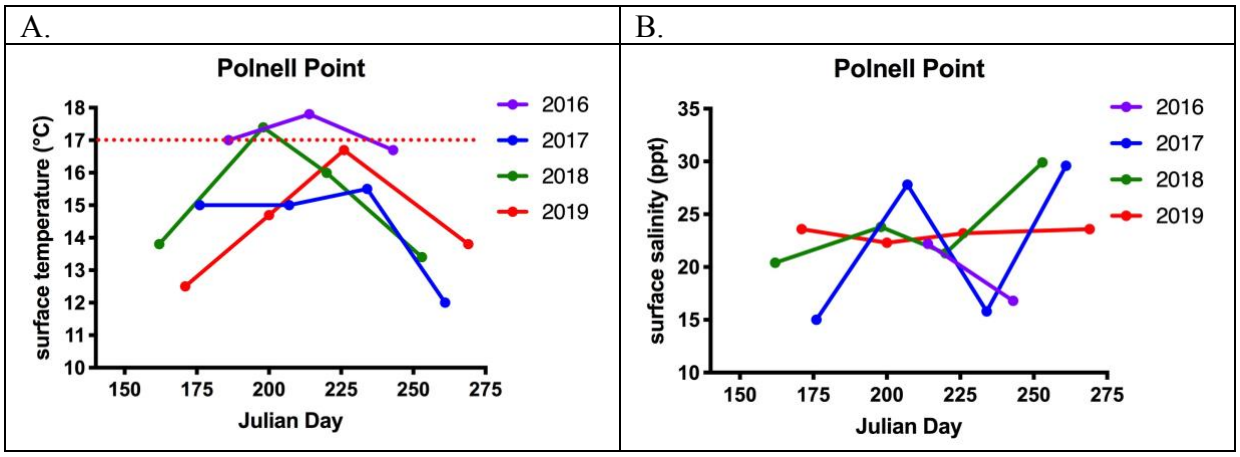

Figure 7. Polnell Point kelp bed mean surface temperatures and salinities. (A) Mean surface temperatures for the four years of surveys. The red dotted line at 17°C indicates a potential threshold temperature for detrimental effects on bull kelp physiology. (B) Mean surface salinities for the four years of surveys.

Possession Point

This bed is located south of Possession Point and at the convergence of Admiralty Inlet, Central Puget Sound, and Possession Sound. As a result, it is likely to receive fluctuating influences of marine waters and river inputs. Possession Point is an extremely popular fishing location and diving area, which may be due in part to its kelp bed. Although aerial assessment has identified kelp beds on either side of the Cultus Bay outflow, the surveyed bed is located to the east of the outflow and bounded by a stationary aid to navigation (Figure 8).

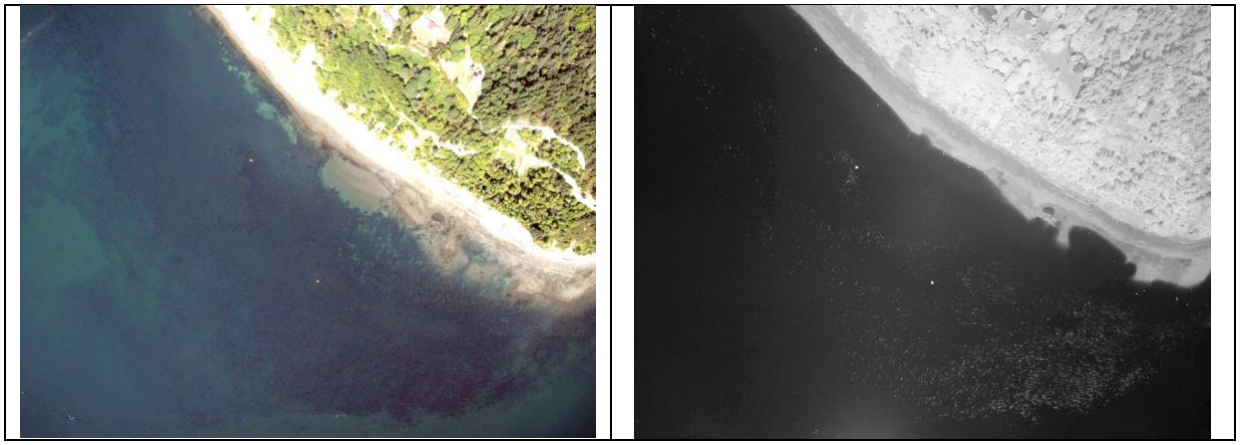

Figure 8. Possession Point bull kelp bed on August 31, 2018, contrasting appearance in visible light (left) with near infra-red (right). Note that nearly all of the kelp is visible at the surface in the near infra-red image. Photos by Gregg Ridder and Vernon Brisley.

Possession Point has been surveyed since 2017, when a single survey in August was conducted. Bed growth begins at the eastern end and expands westward through the summer (Figure 9A). In 2019, the bed emerged larger and remained larger than in 2017 and 2018 (Figure 9B).

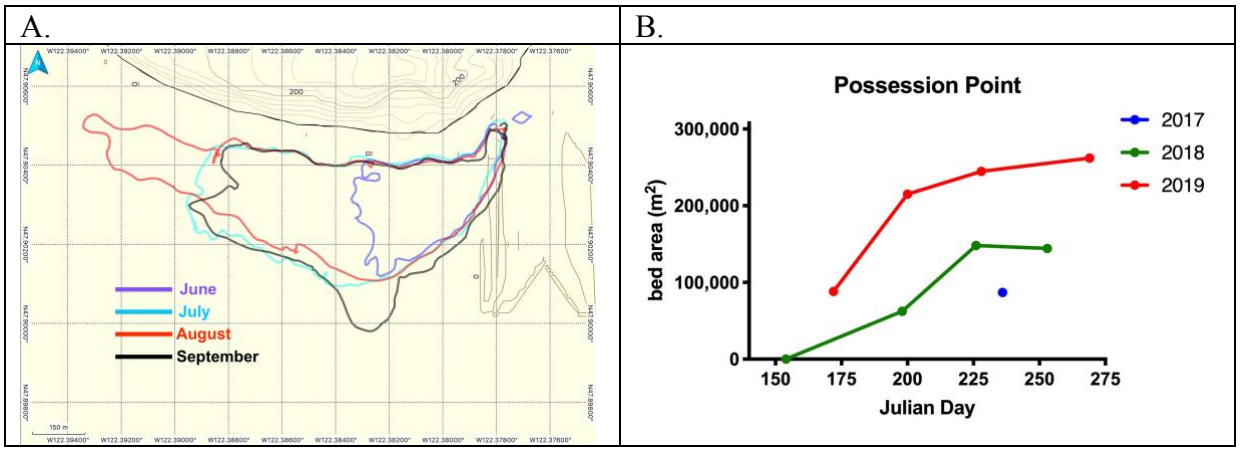

Figure 9. Possession Point kelp bed survey areas. (A) Monthly perimeters of the surveyed bed at a zero-foot tidal height in 2019. (B) Comparison of bed areas from 2017 - 2019 across the survey dates.

Surface temperatures at the Possession Point bed were higher and salinities were slightly lower than at the Ebey's Landing bed (compare Figure 10 with Figure 4). This pattern is consistent with Possession Point receiving waters from both marine and river sources. Although surface temperatures peaked in August in both 2018 and 2019, they did not exceed the putative physiological threshold of 17°C (Figure 10A).

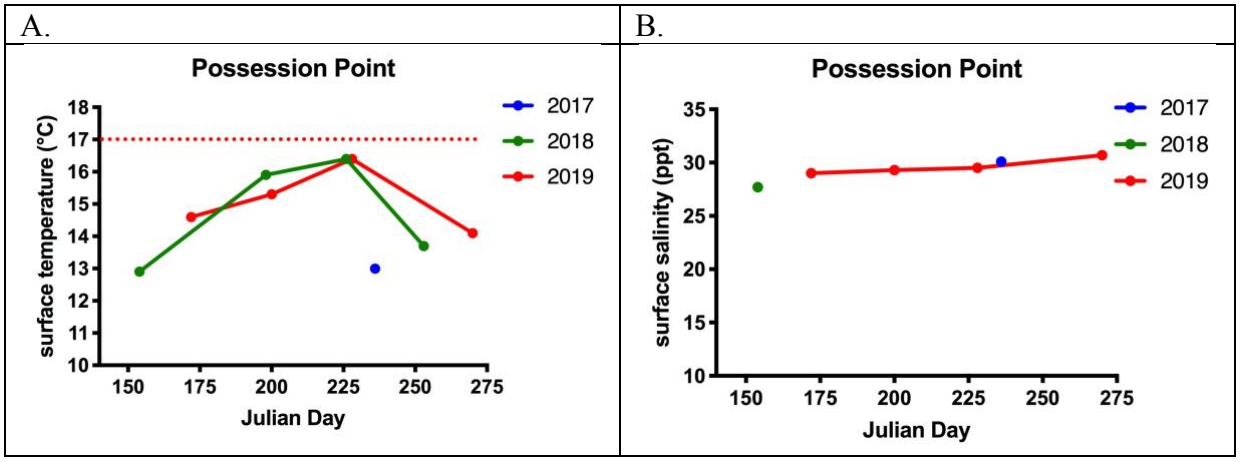

Figure 10. Possession Point kelp bed mean surface temperatures and salinities. (A) Mean surface temperatures for the past three years of surveys. The red dotted line at 17°C indicates a potential threshold temperature for detrimental effects on bull kelp physiology. (B) Mean surface salinities for the past three years of surveys.

B. Aerial Imaging

Aerial imaging analysis lags by one year, so results for 2018 are reported here. In 2019, aerial imaging from a small private airplane was conducted on August 28, 2019, but images have not yet been analyzed.

Aerial imaging from a small private airplane was conducted on August 27 - 28, 2018 and on September 6, 2018. The Island County shoreline was simultaneously photographed using a visible light (RGB) camera and a near infra-red (NIR) camera. A total of 1,986 images were collected and georeferenced to the airplane's GPS data. These images were reviewed independently by two people using the same criteria for identifying images containing bull kelp. After independent assessment, the reviewers discussed and resolved discrepancies, and a map displaying shoreline with associated bull kelp beds was constructed (Figure 11).

Figure 11. Map of Island County showing the amount of shoreline (red) with associated bull kelp beds in 2018.

The estimate of the amount of shoreline with associated bull kelp was ~ 17.3 miles, which is approximately 9% of Island County's shoreline.

C. Test temperature loggers for measuring temperatures at multiple depths

A system of Onset temperature loggers that could be deployed from a kayak or small boat was created (Figure 12). Among the 3 loggers, one is positioned at ~ 1 foot from the surface, one at ~ 1 foot from the bottom, and one at ~ halfway of the water depth. This allows a basic measurement of temperatures in the water column, which are experienced by kelp throughout the survey season. This system was tested by one of the kayak survey teams (Ebey's Landing, Polnell Point) and a separate volunteer team conducting strictly temperature logger tests at Possession Point.

A.	B.
	

Figure 12. Rig for temperature profile measurements from small boats. (A) Onset temperature loggers can be moved to any position on the line which is weighted with a rock in a cotton sock and buoyed with the float. (B) Example of retrieving temperature rig from a kayak.. Right photo by Rich Yukubousky.

At Ebey's Landing, mean temperatures exhibited little variation across the months and little variation in the water column (Figure 13). At Polnell Point, mean surface temperatures ranged > 5°C, progressively increasing from June through August. Midwater and bottom temperatures were similar within each month, suggesting mixing in the lower portion of the water column (Figure 13). At both sites, only one measurement exceeded 17°C, a potential threshold for a physiologically detrimental temperature to bull kelp.

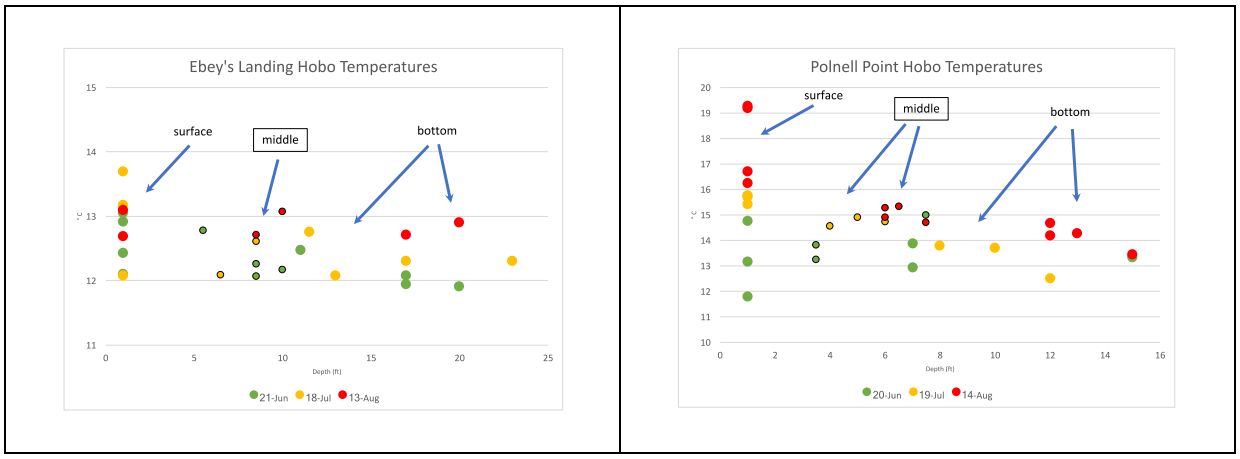

Figure 13. Mean water column temperatures collected by Onset temperature loggers during the zero-tide surveys at Ebey's Landing (left) and Polnell Point (right). Loggers are deployed near the surface, near the bottom, and at approximately half of the water depth.

At Possession Point, a dedicated temperature logger team collected measurements independent of the kayak surveys, and were able to collect data at a higher frequency. Mean surface temperatures exceeded 17°C in early August and mid-September (Figure 14). Midwater and bottom temperatures were similar across all the timepoints, except for September 15, when the midwater temperatures were within 1-2°C of the surface temperature (Figure 14).

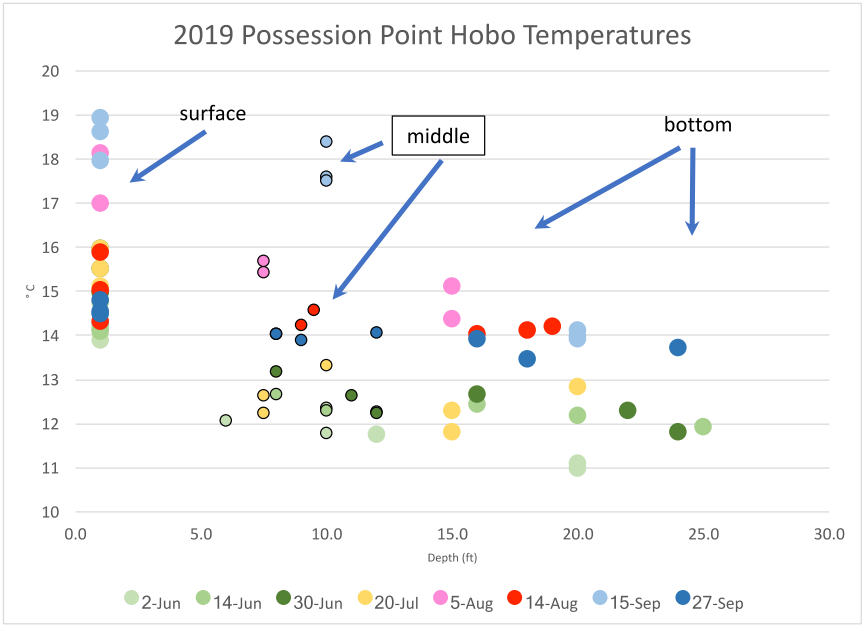

Figure 14. Mean water column temperatures collected by Onset temperature loggers at Possession Point throughout the survey season. Loggers are deployed near the surface, near the bottom, and at approximately half of the water depth.

In addition to testing Onset temperature loggers for water column temperature measurements, NOAA divers from Northwest Fisheries Science Center (Kelly Andrews, Nick Tolimeri) deployed four (4) loggers on the bottom in the Possession Point kelp bed on June 25, 2018. The loggers were retrieved on July 3, 2019. All 4 loggers had excellent concordance of measurement until ~ 11 months into the deployment (Figure 13). Although there were a few temperature spikes exceeding 16°C in July 2018 and May 2019, nearly all measurements remained within the range of 8 - 14°C (Figure 15). These data represent the first, full year of benthic temperature measurement in a bull kelp bed in Puget Sound.

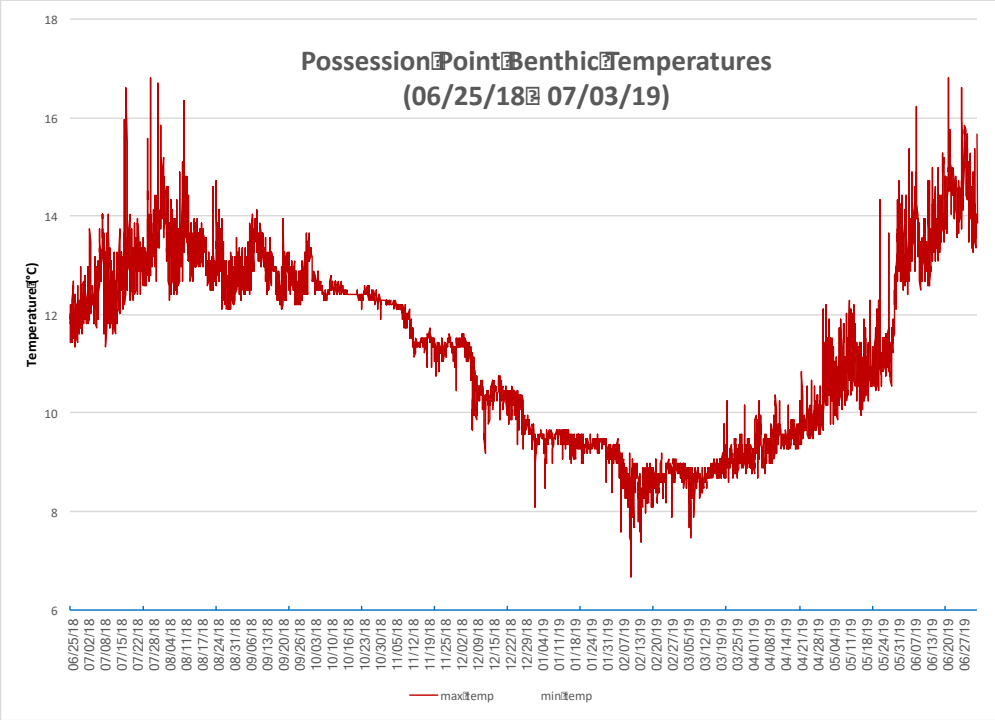

Figure 15. Maximum and minimum temperatures measured by Onset temperature loggers deployed in the Possession Point kelp bed from June 25, 2018 through July 3, 2019.

D. Collect images of animals and plants within kelp beds

The cumulative reports (2015 - 2019) of animals & plants observed in beds are contained Appendix 2. In addition to noting organisms above & below the water during the boat-based surveys, 3 sets of qualitative estimates of abundance were routinely made at each survey (reported in Appendix 1):

- Sori
- Bryozoans on kelp
- Kelp crab

Sori were abundant at all beds, at nearly each monthly survey. Kelp crab were observed only at Possession Point, with highest abundances during the July and August surveys. Bryozoan abundance had different temporal patterns among the beds. At Ebey's Landing, bryozoan abundance appeared to decline through the season. At Polnell Point and Possession Point, bryozoans were absent or in low abundance in June and July but increased through the season (Appendix 1).

E. Trial an infrared camera method for quantifying bulb density

The original protocol for boat-based surveys included a method for estimating bulb density, but the method was not feasible for a wide range of reasons. However, even semi-quantitative estimates of bulb density can be a valuable parameter in characterizing kelp beds. A method utilizing a near-infrared camera on a pole was explored. Briefly, the camera is mounted on top of an 8-foot pole at a fixed angle. On land, the field of view is measured and the area captured in a photograph is calculated (Figure 16A). On the boat, the same pole, fixed angle, and camera with lens is used to capture 4 quadrats around the boat (Figure 16B).

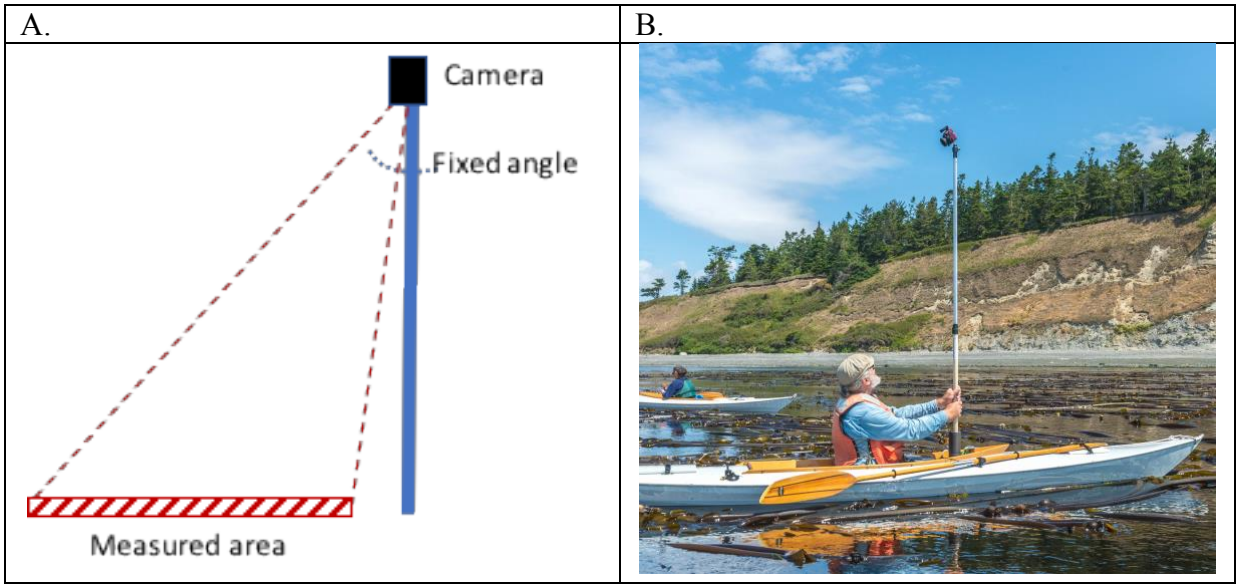

Figure 16. Prospective method of imaging to estimate bulb densities with a near infrared camera. A. Sketch of camera mounted on pole at a fixed angle, with a measured area on land. B. Image of prospective method on the water. Photo by Rich Yukubousky.

A comparison of sample images shows that counting bulbs can be done from photographs (Figure 17). Even with a high density of bulbs (left side of Figure 15), counting is relatively straightforward. Although visible (RGB) images could be used (lower photos in Figure 17), the near infrared images allow unequivocal identification of bulbs at the surface (upper photos in Figure 17). Although this approach has potential, it has several requirements. Water conditions need to be calm, without chop or shorter interval swells. The pole must be held as vertical as possible throughout the rotation. And, of course, there is a risk of water damage to the camera, unless it is waterproof/water-resistant.

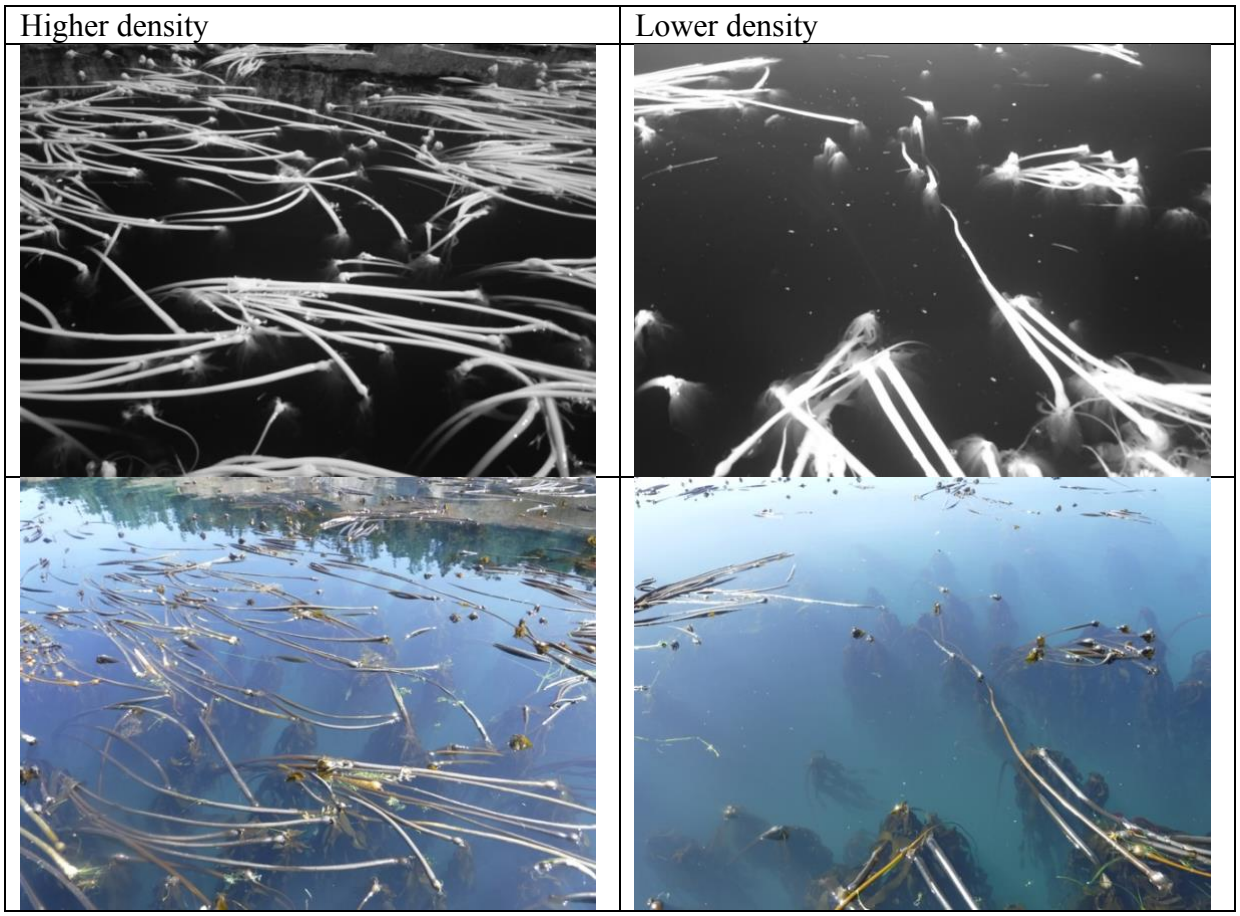

Figure 17. Photographs taken from a kayak with a camera mounted at a fixed angle on an 8-foot pole, showing both higher density (left) and lower density (right) beds. Images with a near infrared camera (upper images) show only bulbs at the surface, while images with a visible light camera (lower images) show both surface and subsurface bulbs.

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Lowell Point 2016-2017

	2016 (0' tide height)				2017 (0' tide height)		
	July	**August**	**September**	**September (2nd bed)**	**June**	**July**	**August**
bed area (m2)	51,543	71,187	72,775	1,652	0	15,995	55,631
perimeter length (m)	1,800	1,900	1,840	407.5	0	750	1,708
mean surface temp (°C)	17.0	17.7	14.4	14.4	15.5	14.0	14.4
minimum bed depth (m)	2.74	1.83	2.74	---	---	2.74	2.7
maximum bed depth (m)	4.57	6.10	7.01	---	---	8.23	5.9
mean bed depth (m)	3.66	3.91	4.67	---	---	5.09	4.13
minimum salinity (ppt)	26	---	---	---	---	---	---
maximum salinity (ppt)	27	---	---	---	---	---	---
mean salinity (ppt)	26.7	---	---	---	---	---	---

	2016 (0' tide height)				2017 (0' tide height)					2018 (0' tide height)	
	June	**July**	**mid August**	**late August**	**May**	**June**	**July**	**August**	**September**	**June**	**July**
bed area (m2)	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
perimeter length (m)	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
mean surface temp (°C)	12.2	11.9	13.3	12.2	8.9	9.6	11.7	12.4	11.1	11.9	12
minimum bed depth (m)	0.30	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1	0.1
maximum bed depth (m)	4.42	3.96	5.79	5.88	3.81	3.81	---	5.79	6.10	2.3	4.4
mean bed depth (m)	2.36	2.21	2.89	2.94	1.90	1.90	---	2.90	3.05	1.6	2.3
minimum salinity (ppt)	---	---	---	---	---	---	---	---	---	---	---
maximum salinity (ppt)	---	---	---	---	---	---	---	---	---	---	---
mean salinity (ppt)	---	---	---	---	---	---	---	---	---	---	---
kelp crab abundance	---	---	---	---	---	---	---	---	---	absent	absent
sori abundance	---	---	---	---	---	---	---	---	---	present (abundant)	present (abundant)
bryozoan abundance	---	---	---	---	---	---	---	---	---	present (few)	present (few)

Notes "xx" indicates area & perimeter cannot be accurately determined because inner perimeter can not be tracked

	2016 (0' tide height)			2017 (0' tide height)		2018 (0' tide height)		
	July	**August**	**September**	**June**	**July**	**June**	**July**	**August**
bed area (m2)	16,315	15,008	13,722	5,496	14,585	---	19,624	30,287
perimeter length (m)	1,200	898	829	620	827	---	644	837
mean surface temp (°C)	14.2	14.4	12.6	9.42	9.63	12.3	12.8	12.5
minimum bed depth (m)	0.30	0.30	0.15	0.17	0	0.6	---	---
maximum bed depth (m)	4.42	4.27	4.72	3.96	3.35	5.5	---	---
mean bed depth (m)	2.36	2.28	8.00	1.98	1.68	2.6	---	---
minimum salinity (ppt)	---	---	---	---	---	---	---	---
maximum salinity (ppt)	---	---	---	---	---	---	---	---
mean salinity (ppt)	---	---	---	---	---	---	---	---

	2015 (0 - 0.5' tide height)				2015 (4 - 5' tide height)				2016 (0' tide height)			2017 (0' tide height)				2018 (0' tide height)			2019 (0' tide height)			
	June	July	August	September	June	July	August	September	June	July	August	June	July	August	September	May	July	August	June	July	August	September
bed area (m2)	38,384	59,151	74,302	79,992		48,419	56,004	64,460	73,946	82,492	76,781	56,802	81,554	84,713	91,759	18,662	74,876	86,136	90,447	143,123	290,162	269,300
perimeter length (m)	1,288	1,448	1,931	2,092		1,287	1,609	1,770	1,600	1,900	1,700	1,400	1,500	1,500	2,240	1,100	1,800	2,000	2,300	2,300	4,500	4,200
transect length (m)	148	483	483	644		483	644	483	---	---	---	---	---	---	---	---	---	---	---	---	---	---
bulb density (bulbs m-2)	1.95	1.50	1.55	2.02		0.78	0.64	0.87	---	---	---	---	---	---	---	---	---	---	---	---	---	---
mean surface temp (°C)	11.0	13.5	13.0	12.0		13.0	14.0	12.5	14.3	12.0	12.7	11.0	12.3	13.0	10.8	10.3	11.9	12.1	11.9	12.2	12.6	11.4
minimum bed depth (m)	1.22	1.83	2.29	1.22		3.05	3.35	3.05	1.52	1.68	1.37	---	1.68	1.40	1.07	0.80	1.80	2.10	---	---	---	---
maximum bed depth (m)	4.42	5.49	7.01	0.76		6.40	7.01	7.01	6.10	6.25	7.32	5.49	6.25	7.62	7.32	7.50	6.40	6.70	6.10	7.01	7.32	25
mean bed depth (m)	2.92	3.58	4.42	4.11		4.50	5.27	4.83	3.96	4.17	4.32	---	3.76	4.20	4.14	5.50	4.20	4.00	---	---	---	---
minimum salinity (ppt)	---	---	---	---		---	---	---	---	34.0	33.0	32.0	32.0	32.5	33.5	---	32.5	34.0	29.9	30.3	30.4	30.7
maximum salinity (ppt)	---	---	---	---		---	---	---	---	34.0	34.0	33.0	33.0	33.0	34.0	---	33.5	34.5	30.5	30.3	30.6	30.8
mean salinity (ppt)	---	---	---	---		---	---	---	---	34.0	33.5	32.5	32.2	32.8	33.8	---	33.0	34.2	30.3	30.3	30.5	30.7
kelp crab abundance	---	---	---	---		---	---	---	---	---	---	---	---	---	---	absent	1 seen	absent	absent	absent	absent	absent
sori abundance	---	---	---	---		---	---	---	---	---	---	---	---	---	---	many	many	many	many	many	many	moderate
bryozoan abundance	---	---	---	---		---	---	---	---	---	---	---	---	---	---	absent	few	few	moderate	few	few	absent

sori older at west end
bryozoans larger at west end
blades ragged
many other epiphytes

	2016 (0' tide height)			2017 (0' tide height)				2018 (0' tide height)				2019 (0' tide height)			
	July	early August	late August	June	July	August	September	June	July	August	September	June	July	August	September
bed area (m2)	19,117	71,187	145,003	1,471	5,321	29,340	110,908	0	24,687	70,348	300,040	23,270	58,263	166,409	191,303
perimeter length (m)	1,211	1,900	3,500	200	377	1585	2,877	0	1,800	3,400	4,200	1,100	2,620	3,100	3,000
mean surface temp (°C)	17.0	17.7	16.7	15.0	15.0	15.5	12.0	13.8	17.4	16.0	13.4	12.5	14.7	16.7	13.8
minimum bed depth (m)	2.74	1.83	3.96	0.61	0.61	---	1.83	1.20	0.80	3.00	2.44	---	---	---	---
maximum bed depth (m)	3.66	6.10	6.10	0.61	2.44	---	4.57	6.10	3.50	4.70	5.49	2.10	4.88	4.57	5.48
mean bed depth (m)	3.15	3.91	5.28	0.61	1.52	4.15	3.35	3.00	2.20	3.90	3.72	---	---	---	---
minimum salinity (ppt)	---	20.5	16.0	15.0	27.5	---	29.5	19.0	23.0	19.5	29.5	21.7	19.1	23	22.7
maximum salinity (ppt)	---	24.0	17.5	15.0	28.0	---	30.0	21.0	24.0	24.5	30.0	25.5	26.3	23.7	24.7
mean salinity (ppt)	---	22.2	16.8	15.0	27.8	15.8	29.6	20.4	23.8	21.3	29.9	23.6	22.3	23.2	23.6
kelp crab abundance	---	---	---	---	---	---	---	absent	absent	absent	absent	absent	absent	absent	absent
sori abundance	---	---	---	---	---	---	---	present	moderate	many	few	many	many	many	moderate
bryozoan abundance	---	---	---	---	---	---	---	few	few	abundant (southern bed); moderate (western bed)	> 50% unaffected, but affected plants heavily infested	absent	few	many	moderate (large colonies mostly on stipes)
Notes						Parameters for only beds 1,2,3,& 6 included here, because could not measure beds 4 & 5 in September	Parameters for beds matching those reported for August.	only few bulbs present, near shore						bryozoans dense & large on east side; fewer on west side	blades narrow or missing; bryozoans large & on stipes on west side; bryozoans on blades & stipes on south side

	2017 (0' tide height)	2018 (0' tide height)					2019 (0' tide height)			
	August	early June	late June	July	August	September	June	July	August	September
bed area (m2)	86,896	0	108,798	62,277	148,047	144,405	88,291	215,140	244,824	262,152
perimeter length (m)	1,500	0	1,600	1,400	2,100	2,300	1,600	3,259	3,200	2,600
mean surface temp (°C)	13.0	12.9	14.7	15.9	16.4	13.7	14.6	15.3	16.4	14.1
minimum bed depth (m)	3.05	0.80	1.80	0.90	1.80	2.13	---	0.91	1.83	7.50
maximum bed depth (m)	3.96	4.60	4.30	4.60	4.60	5.49	3.50	4.72	4.88	19.00
mean bed depth (m)	3.54	3.10	3.00	2.70	2.90	3.45	---	2.82	3.38	3.68
minimum salinity (ppt)	30.0	27.5	---	---	---	---	29	29	29	30
maximum salinity (ppt)	30.5	28.0	---	---	---	---	29	30	30	31
mean salinity (ppt)	30.1	27.7	---	---	---	---	29	29.3	29.5	30.7
kelp crab abundance	---	---	few	many (n = 50)	many (many ≥1 per stalk)	many (fewer than in July)	few	moderate	moderate	few
sori abundance	---	---	present (many)	present (many torn & empty)	present (new & torn)	present	absent	many	many	few
bryozoan abundance	---	---	medium	high	high	high	absent	many	moderate	moderate
notes		only few bulbs present, near shore				stalks fuzzy with growth	kelp crab predom on east edge of bed		more bryozoans along east & shore sides of bed	south lobe of perimeter may not have been captured in August due to rough conditions; kelp condition deterioratin g with rotting stipes, missing blades, epiphytic green algae; bulbs not pliable; total number of kelp decreased

Appendix 2. Anecdotal observations in bull kelp beds by site and month of survey. Number observed, estimate of density, and/or estimate of distribution. "---" indicates no observation made.

Site	Month, Year	Birds	Mammals	Fish	Invertebrates
Ebey's Landing	June, 2015	Great blue heron fishing (2)	---	---	Dungeness crab zoea (high density throughout bed)
	July, 2015	Great blue heron fishing (1)	---	---	---
	August, 2015	Great blue heron fishing (2)	---	Unidentified small fish schools (few throughout bed)	---
	September, 2015	Heerman's gulls (>50); glaucous winged gulls (few); Western gulls (few)	---	Schools of small (<100 mm) salmonid-like fish; occasional jumping adult salmonids; perch-like fish (many throughout bed)	*Aurelia* jelly (few)
	June, 2016	Great blue heron fishing (1)	---	---	---
	July, 2016	Great blue heron fishing (2); rhinoceros auklet resting (1); bald eagle fishing (1); pigeon guillemot fishing (6)	river otter fishing & eating large sculpin (1)	Schools of small (4-6 cm) forage fish (high density throughout bed)	*Phacellophora* jellies (2); *Aurelia* jelly (1)
	August, 2016	Harlequin ducks fishing (8, females); bald eagle fishing (1); great blue heron fishing (1); pigeon guillemot fishing (1)	---	Schools of small (4-6 cm) forage fish (high density throughout bed); aggregates of shiner perch (multiple throughout bed)	*Phacellophora* jellies (2); bryozoans on fronds (numerous); large kelp crab (1)

	June, 2017	bald eagle (1); common loons fishing (2); great blue heron on kelp (1)	---	large school of forage fish in bed	---
	July, 2017	great blue heron on kelp (2); bald eagle (1); cormorant fishing (2)	---	many schools of small (≤5 cm) shiner perch	*Aurelia* sp. jellies (few)
	August, 2017	great blue heron fishing (3); Heermans gulls (6)	---	tubesnouts loafing in kelp blads (~24); many schools of herring ~ 25 mm TL; numerous schools of medium-large (6-10 cm TL) shiner perch	---
	September, 2017	Western grebe diving at margin (1); great blue heron on kelp (1); Heermans gulls (6); common loons (1 male, 1 female, 2 juveniles)at margin (4)	sea lion cruising margin (1)	NO forage fish schools	*Phacellophora* jellies (4); bryozoan colonies (*Membranipora* sp.) covering all submerged & exposed kelp parts
	May, 2018	< 6 Bonaparte's gulls (male & female)	---	few small schools (< 20 fish) of small fish (< 30 mm)	---
	July, 2018	bald eagle (hungting by skimming); 3 pair pigeon guillemots fishing within bed	harbor seal at bed perimeter (1)	multiple schools of forage fish; scattered shiner perch schools; school of tiny (< 20 mm) stickleback-like fish feed at surface)	---
	August, 2018	great blue heron hunting from kelp (1); 5-12 pigeon guillemots fishing within bed	harbor seal at bed perimeter (1)	numerous large schools of forage fish & perch	---

	June, 2019	pigeon guillemot fishing (2)	---	many small schools of shiner perch throughout bed	abundant aggregates of crab zoea in western portion of bed (photos, collected)
	July, 2019	~10 Heermans gulls, resting; 2 pigeon guillemot, fishing; 3 great blue heron, fishing on kelp	1 river otter fishing in shallow part of bed (may have a nest nearby because of possible kit squeals)	few schools of possible herring in kelp	---
	August, 2019	~12 Heermans gulls, feeding; ~ 12 other types of gulls, feeding; 2 rhinoceros auklets (male & female), fishing; 2 great blue heron, fishing on kelp	sea lion, cruising along outer margin of bed	numerous herring schools in kelp, feeding at surface	---
	September, 2019	>30 gulls, including ~ 10 Heermans gulls, feeding; 2 common loons, fishing; 3 great blue heron, fishing on kelp	---	few large herring schools in kelp	---
	June, 2016	---	---	---	---

Ben Ure Island (Cornet Bay)	July, 2016	Pigeon guillemot fishing (1); many other birds heard; great blue heron (several)	---	---	large Dungeness crab (1); *Nucella* sp. (numerouos throughout); *Sabellidae* sp (1 colony); *Evasteria* sp (1); *Pisaster ochraceus* (1); *Strongylocentrotus droebachiensis* (1); limpets (few); *Katharina tunicata* (1); unidentified invertebrate (see data sheet);
	August, 2016	gulls; loons	harbor seal (1)	---	*Strongylocentrotus droebachiensis*; *Cucumaria miniata* (several); *Phacellophora* jellies (many)
	September, 2016	gulls; pigeon guillemots (fly-bys);	harbor seal (1)	unidentified fish jumping	*Phacellophora* jellies (many)
	May, 2017	bald eagles	---	small fish splashing at surface at margin	*Pisaster ochraceus*; sea cucumber; *Strongylocentrotus droebachiensis* (14); chitons; *Katarina tunicata; Tonicella lineata*
	June, 2017	pigeon guillemots (fly-bys)	---	small fish splashing at surface	*Evasteria troschelii*; orange sea cucumbers; chitons (many)
	July, 2017	---	---	---	orange sea cucumbers
	August, 2017	Pigeon guillemots fishing (2-4)	---	---	---

	September, 2017	Great blue herons (3); pigeon guillemots; kingfisher	harbor seal (2)	---	orange sea cucumbers
	July, 2018	pigeon guillemots actively fishing throughout bed; bald eagle (1); great blue heron (1)	harbor seal (1)	slender silver fish jumping near outer bed border	numerous *Cucumaria miniata* above waterline
Hoypus Point	July, 2016	Pigeon guillemot in bed (1); many other birds above & from land	---	Unindentified fish (6-12" TL) jumping (3)	---
	August, 2016	Great blue heron on kelp (3)	harbor seal (1)	unidentified large fish jumping (1)	*Phacellophora* jellies (many)
	September, 2016	great blue herons on shore (3); gulls on kelp (many); loons (3)	---	unidentified large fish jumping (1)	*Phacellophora* jellies (many)
	June, 2017	---	---	---	---
	July, 2017	---	---	---	---
Polnell Point	July, 2016	Pigeon guillemot with gunnel-like fish & sculpins (2); great blue heron resting (8-10); bald eagle resting (1); apparent pigeon guillemot nests in cliffs	harbor seal on rock (1)	perch-like fish (few)	*Phacellophora* jellies (few)
	early August, 2016	Great blue heron resting (2); pigeon guillemot fishing (2)	harbor seals on rocks (3)	perch-like fish schools (numerous throughout bed)	*Phacellophora* jelly (1); bryozoans on fronds (numerous)
	late August, 2016	Great blue heron resting (1); harlequin ducks in bed (2, females); unidentified gulls (few)	harbor seals on rocks (3)	shiner perch schools (few)	*Phacellophora* jellies (numerous, 1-5' bells); bryozoans on fronds (numerous, ≤ 1.5" diameter)

	June, 2017	bald eagle (1); pigeon guillemots (2); great blue heron (2)	harbor seals on rocks (7)	shiner perch schools of ~20-30 fish	---
	July, 2017	pigeon guillemots (2); great blue heron (1); large osprey picked up large (~20-25 cm) perch from bed, then chased by bald eagle, dropped fish which was recovered by eagle	harbor seals on rocks (5 adults, 1 pup)	small (< 5 cm) shiner perch schools (few)	---
	August, 2017	pigeon guillemot fishing (5); bald eagle (1)	harbor seal in water (3)	small (≤ 2.5 cm) shiner perch schools (numerous)	*Phacellophora* jellies (12)
	September, 2017	bald eagle (1); great blue heron on rock (1)	---	---	*Phacellophora* jellies (3); bryozoan colonies (*Membranipora* sp.) on all submerged kelp parts
	June, 2018	bald eagle (1) water strike; great blue heron on shore (2); pigeon guillemot fishing (4)	harbor seals on rocks & in water (4)	schools of small (~ 3 cm) shiner perch	---
	July, 2018	great blue heron on rocks (2); medium-sized falcons around bluff & vocalizing (2); pigeon guillemot fishing (4-5)	harbor seals on rocks & in water (5)	few small perch-like fish	---
	August, 2018	great blue heron on rocks (2); rhinoceros auklet fishing (1); pigeon guillemot fishing (2)	harbor seals on rocks & in water (5)	multiple schools of perch-like fish	numerous ochre stars on larger rocks, 2-8" size

	September, 2018	great blue heron fishing from kelp (1); bald eagles on bluff (2)	harbor seals on rocks & in water (5)	---	---
	June, 2019	bald eagle hunting from rock (1)	harbor seals on rocks & in water (6)	few small (<5 cm) sculpin-like fish in shallows	abundant "marine snow"-like deposits on submerged aquatic vegetation
	July, 2019	2 great blue heron on rocks in bed; 2 pigeon guillemot, fishing	11 harbor seals on rocks (including 3 pups); 1 harbor seal in water	many small schools (< 20 individuals) of smal fish (< 4 cm total length) in kelp; few pile perch (~ 12 cm total length) darting among kelp	abundant "marine snow"-like deposits on submerged aquatic vegetation; few seastarts on rocks & on bottom
	August, 2019	1 great blue heron, fishing in shallow kelp; 4 pigeon guillemot, fishing in bed; 6-8 pigeon guillemot fishing at southern margin; 2 rhinoceros auklets (male+female) fishing at edge of bed	4 harbor seals on rocks & in water	many small schools of small fish(< 4 cm total length), often feeding at surface; primarily shiner perch & few larger pile perch	sea stars on rocks & on bottom
	September, 2019	1 great blue heron, fishing on kelp; 1 pigeon guillemot, fishing; 1 rhinoceros auklet, fishing in bed; 1 black oystercatcher along shoreline	2 harbor seals on rocks; 1-2 harbor seals in water	few small schools of small fish (< 4 cm total length), feeding at surface	---
Lowell Point (Camano Island State Park)	July, 2016	Pigeon guillemot fishing (6); Bonaparte gulls (numerous)	---	perch-like fish (numerous throughout bed)	Bryozoans on fronds (up to 40% of surface area); kelp crab on fronds (4-5);

					Phacellophora jellies (3)
	August, 2016	None observed	---	---	Bryozoans on fronds; *Phacellophora* jellies (4)
	June, 2017	---	---	---	---
	July, 2017	---	---	---	bryozoan colonies very small (*Membranipora* sp.)
	August, 2017	---	---	---	---
Possession Point	August, 2017	Caspian terns diving (8)	harbor seal (2) & sea lion (1) on rock in bed	numerous large forage fish schools in bed; multiple large (~ 12") jumpers, possibly salmon; multiple small (<2") shiner perch schools	~20% of kelp have ≥1 kelp crab (numerous bulbs eaten away); live amphipods on water surface
	June, 2018	bald eagle water strike (1); great blue heron on shore (4); few auklet-like birds; pigeon guillemot (2)	sea lion in water (1); harbor seals on rocks & in water (6)	school of smal (~ 3 cm) shiner perch; few smaller schools of tiny (< 2 cm) fish	red rock crab (1)
	July, 2018	---	---	---	many kelp crab
	August, 2018	---	harbor seals (2)	schools of 2-3" fish; starry flounder (2)	many kelp crab
	September, 2018	---	---	starry founder (1)	many kelp crab
	June, 2019	pigeon guillemot (2); bald eagle fishing; kingfisher; great blue herons fishing (3)	harbor seals (3-5)	few small fish (mostly 1", one is 8")	segmented worm on kelp; small white jellyfish ~ 30 mm (5)
	July, 2019	3 great blue heron; tern, fishing in bed; 6 pigeon	4 harbor seal	many schools of small fish, 4-12 cm in length, some may be salmonids	many red rock crab on bottom

		guillemot, fishing for gunnels in bed			
	August, 2019	2 great blue heron, fishing; 1 pigeon guillemot	8-10 harbor seal on offshore rocks	schools of ~ 5 cm fish	---
	September, 2019	1 common loon; 1 great blue heron, fishing; grebe, many cormorant; several species of Alcids (possibly auklets, murrelets, guillemots)	harbor seal; harbor porpoise at outer bed edge	---	---