NATURAL RESOURCES

Recreational Kelp Harvest Study at Libbey Beach

Smith and Minor Islands Aquatic Reserve

September 2019

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WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES

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Cover Photo: Libbey Beach.

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Executive Summary

The Washington State Department of Natural Resources (DNR) manages 2.6 million acres of state-owned aquatic lands for the benefit of current and future citizens of Washington State. DNR established the Aquatic Reserves Program to promote preservation, restoration, and enhancement of state-owned aquatic lands that provide benefits to the health of native aquatic habitats and species in the state of Washington (WAC 332-30-151).

DNR is the state steward for seaweed resources, and recreational seaweed harvest is co-managed with the Washington Department of Fish and Wildlife (WDFW) on all state-owned aquatic lands, including the aquatic reserves. Recreational harvesters are required to obtain permits and limit collecting to under ten-pound per person per day. DNR additionally recommends, but does not require, that kelp is harvested sustainably (leaving the meristem where blade growth occurs), so that harvested individuals survive and continue growing.

Recreational intertidal kelp harvest is popular during spring and summer low tides on western Whidbey Island beaches in the Smith and Minor Islands Aquatic Reserve (SMIAR). Local residents perceived a sizable increase in the number of seaweed harvesters at several beaches, particularly Libbey Beach, and were concerned about harvest impacts and overharvest. Little is known about recreational kelp harvest pressure, harvester practices and potential harvest impacts in the aquatic reserve. To address this knowledge gap, the SMIAR Citizen Stewardship Committee and the DNR Aquatic Reserve Program jointly conducted a two-part study at Libbey Beach:

1) **Harvester surveys**: From 2015-2018, the SMIAR Citizen Stewardship Committee and DNR observed spatial and temporal harvester patterns, measured wet weight of harvester buckets, and conducted harvester interviews at Libbey Beach.
2) **Kelp harvest treatment study:** From 2017-2018, DNR led a treatment study to investigate within-year and between-year effects of kelp harvested using two different methods: a) sustainable harvest (cut 30 cm above the holdfast), and b) unsustainable harvest (cut at the stipe) of *Alaria marginata* (winged or ribbon kelp) and *Saccharina* spp. (split-leaf kelp and sugar kelp).

Key Findings

Our findings confirm previous research that unsustainable harvest impacts the kelp resource by precluding regrowth. This study also shows that even in areas with relatively high kelp density, early season unsustainable harvest of individuals > 50 cm have the potential to reduce kelp density into the following year. Additionally our results indicate that sustainable harvest allows kelp to survive and grow and is preferred to unsustainable harvest. Recreational kelp harvester survey results further suggest that some harvesters were not consistently harvesting sustainably and were trimming kelp too close to the meristem.

- Unsustainable harvest in May 2017 negatively impacted density of *A. marginata* and *Saccharina* spp. > 50 cm in total length within year and into the following year compared to control and sustainable harvest plots.

- Unsustainably harvested kelp did not recover or continue to grow after trimming, while sustainably harvested kelp survived and continued to grow.
- In 2018, approximately 66% of the 12 harvest buckets surveyed contained kelp cut at the stipe or too close to the stipe (unsustainably harvested), showing that some harvesters were not consistently cutting sustainably.
- Most harvesters collected at or under the 10 lbs daily limit (84% at/under limit, 16 % over, n=289).
- *A. marginata* and *Saccharina* spp. were the primary species harvested.
- Peak harvest occurred in April and May and tapered in June and July.

Recommendations

DNR's longstanding policy has been to recommend sustainable harvest and allow unsustainable harvest. Sustainable harvest protects the meristem, which is the area near stipe-blade interface where the blade grows. We recommend that DNR consider a more precautionary management approach which requires sustainable harvest. This is a low-cost conservation technique that allows for recreational harvest, while still protecting local kelp populations. Education would need to accompany any rule changes because harvesters generally reported, sometimes in error, that they were harvesting sustainably.

Sustainable harvest techniques are only one aspect of recreational harvest management. Little is known about the scope and intensity of harvest at sites throughout Washington State. Further research is needed to determine best practices related to harvest limits, seasons and species.

Table of Contents

List of Acronyms

SMIAR	Smith and Minor Island Aquatic Reserve
DNR	Washington State Department of Natural Resources
RCW	Revised Code of Washington
WAC	Washington Administrative Code
WDFW	Washington State Department of Fish and Wildlife

List of Kelp Terms

A. marginata	*Alaria marginata* (ribbon or winged kelp)
***Saccharina* spp.**	*Saccharina groenlandica* (split-leaf kelp) and *Saccharina latissima* (sugar kelp)
Sporophyte	The commonly recognized, macroscopic phase of the kelp life cycle. Distinct from the microscopic gametophyte phase.
Frond	Vegetative leaf-like blade of a kelp plant
Stipe	Stem-like structure of a kelp plant
Holdfast	Root-like structure that attaches a kelp plant to rocky substrate
Sporophylls	Leaf-like structures (located on the stipe of *Alaria marginata*) where spores develop
Sorus/sori	Cluster of spores, located on sporophylls of *Alaria marginata* and the frond of *Saccharina* spp.

1. Introduction

1.1 Washington Seaweed Harvest Regulations

Washington State Department of Natural Resources (DNR) is the state steward for seaweed resources, and DNR and Washington Department of Fish and Wildlife (WDFW) jointly oversee harvest. Recreational seaweed harvest in Washington State requires a combination fishing license or personal use seaweed and shellfish license. Harvesters are allowed a ten-pound daily limit on all state-owned aquatic lands and privately owned-tidelands (RCW 79.135.410 (1)). Commercial seaweed harvest is prohibited in Washington State, except harvest of *Macrocystis* spp. for use in herring spawn-on-kelp fishery, which hasn't occurred for decades in Washington state (RCW 79.135.410 (2) and (3)).

Recreational seaweed harvest is closed in state parks except at Fort Ebey, Fort Flagler and Fort Worden from April 16 - May 15 each year (WAC 352-32-350 (1)). In state parks, sustainable harvest is required; short-stemmed kelps, such as *A. marginata* and *Saccharina* spp., must be cut at least 30 cm above the holdfast with a knife or similar instrument. Tearing and raking are not permitted (WAC 352-32-350 (3)).

1.2 Aquatic Reserves Program

DNR is steward of more than 2.6 million acres of state-owned aquatic lands. DNR has established eight aquatic reserves to protect and restore important native ecosystems of special educational, scientific and/or environmental value.

Smith and Minor Islands Aquatic Reserve (SMIAR) encompasses 36,308 acres of state-owned aquatic land from Whidbey Island westward around Smith and Minor Islands. SMIAR has a diverse macroalgae community and abundant intertidal seaweed, which make the cobble beaches on the west shore of Whidbey Island popular for seaweed harvest during spring and summer low tides. This study took place at Libbey Beach, near Fort Ebey State Park.

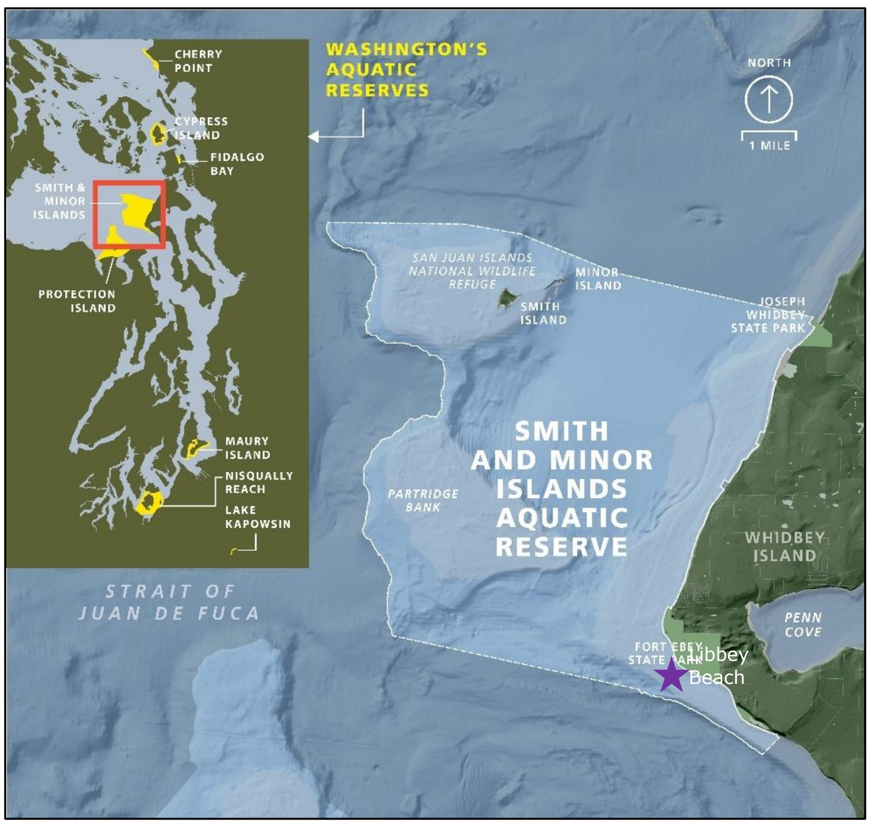

Figure 1. Washington State Aquatic Reserves and Smith and Minor Islands Aquatic Reserve. The purple star identifies the Libbey Beach where this study took place.

1.3 Study Goals

This study explores recreational seaweed harvester practices and potential impacts of two harvest methods on kelp at Libbey Beach. We focused on the three intertidal kelp species commonly harvested in this area: *Alaria marginata* (winged or ribbon kelp), *Saccharina groenlandica* (split-leaf kelp) and *Saccharina latissima* (sugar kelp).

The aim of the harvester surveys was to determine (a) harvest pressure and seasonal harvest timing, (b) species preference, (c) harvest methods, and (d) adherence to daily wet-weight limit. We also developed educational materials to promote harvest best-practices.

The goal of the treatment experiment was to assess within-year and between-year kelp harvest impacts and recovery using two different trimming methods (harvest treatments). We used recovery metrics similar to Young (2003): (a) recovery to pre-harvest density, and (b) recovery to pre-harvest length.

While previous research shows that sustainable harvest above the meristem early in the growing season may have minimal impacts to the kelp resource, it was unknown if the effects of unsustainable harvest would still be detectable at the end of the season and into the following year in an area with high kelp density. It was also unknown if spores released from nearby kelp plants outside the plots disperse in the harvested plots and recruit at sufficient numbers to cover the impact of unsustainable harvest (mimicking spatially patchy harvest). We were also interested in whether there would be detectable difference between control plots and sustainably harvested plots.

1.4 Target Species

Alaria marginata (*A. marginata*) and *Saccharina* spp. are among the over 20 large brown seaweed species known as kelp found in Washington State (Mumford 2007; Gabrielson et al. 2012). Both types are typically found in high-energy environments with rocky substrates and are known to be harvested for a variety of edible dishes (Klinkenberg 2017; Garza 2012). Harvester surveys from 2015 to 2016 confirmed these are the most commonly harvested kelp species at Libbey Beach.

Figure 2. *Alaria marginata* at Libbey Beach.

A. marginata is among the most abundant kelp species in the mid-low intertidal range in the Pacific Northwest. *A. marginata* is characterized by a well-developed holdfast, a short stipe with numerous oval-shaped reproductive sporophylls and a vegetative blade with a single midrib (Klinkenberg 2017). *A. marginata* is an annual that recruits in late winter or early spring and grows rapidly (up to 6m) with extensive sori development on the sporophylls. Spores are released and dispersed in the fall and winter with the onset of storms and increased wave action (McConnico & Foster 2005).

Saccharina groenlandica and *Saccharina latissima* are similar kelp species that are considered indistinguishable in the field. We suspect that the majority of the *Saccharina* spp. in our study is *S. groenlandica* due to habitat characteristics at Libbey Beach (wave exposed, high energy area) and darker, thicker appearance of the blade. However, since we did not confirm species identification in the lab or with genetics, we group these species together and refer to them collectively as *Saccharina* spp. throughout this report (Druehl & Clarkston 2016).

Figure 3. *Saccharina* spp. at Libbey Beach.

Saccharina spp. is a perennial found in the extreme low intertidal to shallow subtidal with a range from Alaska to central California. *Saccharina* spp. has a small, branched holdfast, short stipe and a thick, dark brown blade (up to 2m) with no midrib. The blade may be intact or split into two or more segments and sori develop directly on the blade (Klinkenberg 2017; Druehl & Clarkston 2016). Both *A. marginata* and *Saccharina* spp. exhibit intercalary growth from a meristem at the stipe-blade interface (Abbott & Hollenberg 1976).

1.5 Harvest Impacts

The majority of kelp harvest impact studies focus on commercially harvested seaweed species and answer questions related to (1) recovery time following harvest, (2) effects of harvest timing, harvest method, and percentage harvested on recovery and (3) impacts on community dynamics (Levitt et al. 2002; Thompson et al. 2010; van Tamelen & Woodby 2001, Edosa 2010, Steen et al. 2016, Borras-Chavey et al. 2012, Young 2003). Several studies on the California and Oregon coast have focused on *A. marginata* or species with comparable life history and reproductive strategies (Young 2003, McConnico & Foster 2005, Hutto et al. 2009, Thompson et al. 2010).

Cutting kelp at the stipe removes the meristem and prevents regrowth of the blade following harvest, while trimming the blade above the meristem allows for regrowth (Levitt et al. 2002; Young 2003; Thompson et al. 2010). Young found that due to its rapid growth, *A. marginata* can be harvested twice during the growing season (once in April or May and again in August) without reducing density the following year, as long as the plant is cut ~ 30 cm above the stipe (2003). Thompson et al.

found that early season *Postelsia palmaeformis* (an annual kelp) blade trimming allowed for regrowth and had minimal spore production impacts, while late season harvest, even when cut above the meristem, markedly reduced spore production (2010). Levitt et al. showed that leaving 20-30 cm of blade material when harvesting the subtidal perennial kelp, *Ecklonia maxima*, facilitated regrowth of the plant, while 10 cm from the base of the blade and 2 cm from the base of the blade reduced or completely inhibited regrowth (2002).

There is evidence that in moderate amounts, harvest (i.e. 50% of individuals, cut at the fronds) can spur increased recruitment. Increases in light penetration and growth space facilitated by selective harvest may actually benefit populations and support juvenile growth (Borras-Chavez 2012, Young 2003). However, complete clearing of larger *A. marginata* did not result in smaller understory individuals growing into larger size classes or developing large sporophylls (McConnico & Foster 2005).

In addition, McConnico and Foster found that cutting and scraping of 1m^2 plots of *A. marginata* in July on California's Big Sur Coast dramatically decreased recruitment the following year (2005). This suggests that dispersal among *A. marginata* is highly localized, and that complete biomass removal reduces the recovery potential of populations. They also showed that *A. marginata* invests in growth in the spring, with a transition to reproduction later in the summer and fall (McConnico & Foster 2005). Hutto et al. confirmed this tradeoff and found that removal of the blade after the spring growth-focused period markedly reduced reproductive potential with lower zoospore output per mm^2 of soral tissue (2009). For species like *Saccharina* spp. that develop sori on their fronds, loss of surface area may directly reduce reproductive output.

A. marginata size was found to be positively correlated to fertility and few individuals less than 50 cm were fertile. Therefore, persistence of larger sporophytes (adult macroscopic kelp plant) into the fall when spore release is highest is critical to the population (McConnico & Foster 2005).

2. Methods

2.1 Study Area

This study was conducted at Libbey Beach in the Smith and Minor Islands Aquatic Reserve (SMIAR) on the west side of Whidbey Island. Libbey Beach Park is a popular beach access with parking lot and small picnic area managed by Island County. Harvester surveys were carried out at the top of the beach access stairs and the treatment experiment was conducted just south of the public access to limit trampling by harvesters and beachcombers.

The study site is a mixed gravel, cobble and boulder beach that is exposed to high wind and wave energy from the Strait of Juan de Fuca. Fall and winter storms move cobbles and boulders and may bring influxes of sandy substrate. The site has a diverse, structurally complex algal community. The mid-low intertidal is dominated by diverse red and brown macroalgae such as *Odonthalia* spp., *Neorhodomela larix,* and *Mazzaella* spp. Kelp species present included *Alaria marginata*, *Egregia menziesii*, *Saccharina setchelli*, *Pterygophora californica*, *Cymathere triplicate*, *Costaria costata* and *Pleurophycus gardneri*. *Nereocystis luetkeana* is prevalent in the low intertidal to shallow subtidal. The seagrass *Phyllospadix* sp.is present.

Figure 4. Study area at Libbey Beach County Park public access (WDOE 2016).

2.2 Harvester Practices

In May 2015, the Smith and Minor Islands Aquatic Reserve Citizen Stewardship Committee (CSC) began interviewing recreational kelp harvesters and weighing harvester buckets at the Libbey Beach access during low tides each month. The interviews were unstructured with a list of possible interview questions. Questions included: (1) What species do you harvest, (2) Do you know how to harvest sustainably and do you know why it is important to harvest sustainably, (3) How often do you harvest, and (4) How do you use the seaweed? Harvesters selected species harvested and percent bucket composition from a series of pictures.

Figure 5. Weighing harvester Buckets at Libbey Beach.

Generally, one person per group was interviewed and all buckets in the group were weighed. The number of harvesters per day during low tide hours were recorded. Starting in 2018, we also examined harvested kelp to identify species and to determine where the kelp plant was cut.

DNR and the CSC developed a recreational kelp harvest brochure in English and Korean to promote best-practices (Appendix A).

2.3 Harvest Treatment Experiment

Experimental Design

We conducted a harvest treatment experiment at Libbey Beach to evaluate the impacts of two different kelp harvest blade trimming methods used by recreational harvesters. We focused on the two most commonly harvested species, *A. marginata* and *Saccharina* spp., as identified during 2015-2016 harvester surveys.

All fieldwork was completed during monthly spring and summer minus tides in 2017 and 2018. In May 2017, an 85 m transect was established at -1.5' MLLW on Libbey Beach. The tidal elevation of the transect was selected to minimize exposure impacts, optimize the survey zone for abundance of both species and maximize survey time. May was the earliest month in both 2017 and 2018 that tides were low enough to access the -1.5 MLLW transect.

We used a randomized block design with one replicate of three treatment types in each of five blocks. Due to target kelp species' patchy distribution in the study area, three 1-m^2 plots with similar target species density were selected in each block. A treatment type was randomly assigned to each plot within the block. Sand screws were installed between blocks and the location of each plot was marked with a rebar at the lower left corner.

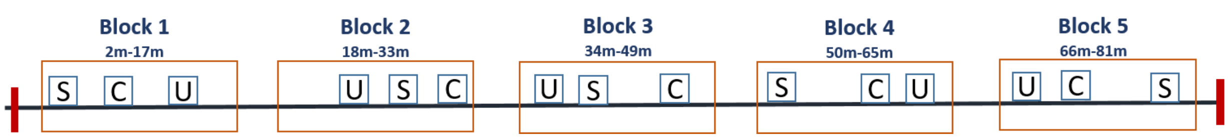

Figure 6. Transect and treatment plot layout. Horizontal line represents an 85 m transect. Blue squares represent 1-m^2 sample quadrats, labelled according to treatment (**S**ustainable, **U**nsustainable and **C**ontrol).

The treatments reproduced common recreational harvest techniques: (1) **S**ustainable harvest - trimmed blade 30 cm above holdfast, which is required in all Washington State Parks, (2) **U**nsustainable harvest - trimmed at stipe above sporopylls, which is permitted on state-owned aquatic lands and private property. **C**ontrol plots were not trimmed or manipulated (Table 1; Figure 7).

Table 1. Harvest treatment types

Treatment	Harvest method	Regulations
Sustainable	Trimmed blade 30 cm above holdfast	Required in Washington State Parks; recommended on all state-owned aquatic lands.
Unsustainable	Trimmed at stipe, above sporophylls	Allowed on state-owned aquatic lands.
Control	Not trimmed or manipulated	

Treatment Application

In May 2017, *A. marginata* and *Saccharina* spp. > 50 cm in total length were censused. Stipe and blade length, sporophyll number and length of the three longest sporophylls (for *A. marginata*), and sori presence were recorded for each sporophyte. Sporophytes > 50 cm in the sustainable and unsustainable plots were then cut (Figure 7). We focused on sporophytes > 50 cm in our methods and later in the analysis for several reasons: (1) this mimics recreational harvest preferences for longer blades, (2) McConnico and Foster found that *A. marginata* size was positively correlated to fertility and few individuals < 50 cm were fertile (2005), and (3) measuring all sporophytes was not possible due to limited low tide work window. Sporophytes in control plots were measured, but not cut. Sporophytes < 50 cm and single stipes were counted, but not measured or cut. Substrate type and macroalgae cover was also noted for each plot.

In block one, target species > 50 cm were also tagged with small plastic cable zipties and tracked by individual. Due to time constraints during the low tide fieldwork window, individuals in blocks two through five were not tagged.

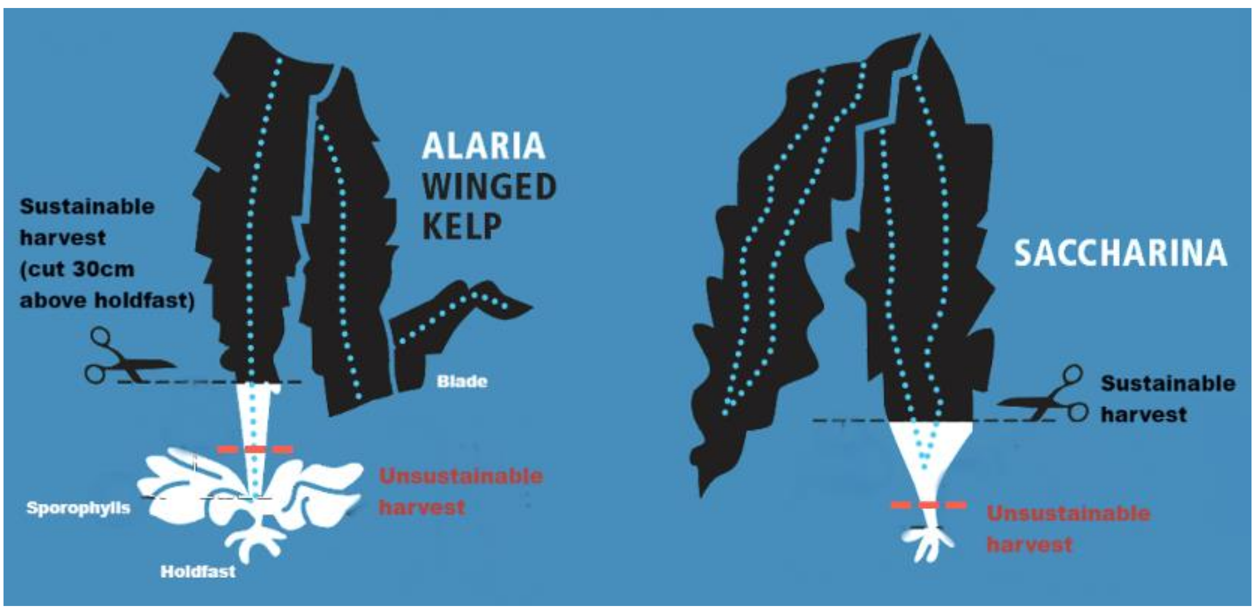

Figure 7. Sustainable and unsustainable harvest treatments, excerpted from DNR brochure (Appendix A).

Follow-up Surveys

Plots were re-surveyed during monthly minus tides in June and July 2017 and then revisited in May, June, July and August 2018 to determine differences in sporophyte density, size, growth and survivorship, and sporophyll number and size. Treatment was only applied once in May 2017. During follow-up surveys, the same parameters measured in May 2017 were repeated for all *A. marginata* and *Saccharina* spp. > 50 cm. Sporophytes < 50 cm were again counted, but not measured. In addition, all tagged individuals in block one were measured regardless of total length.

Figure 8. Study plot.

Statistical Analysis

We used linear mixed-effects analysis to examine the relationship between treatment and the response variable, density of individuals > 50 cm in total length. We analyzed each year separately. We used the model validation protocol outlined in Zuur et al. to determine the appropriate fixed, random effects and variance structure (2009). Repeated Likelihood Ratio Tests (LRT) and Akaike Information Criterion (AIC) comparisons were used to select the final model. We tested for random slopes using quadrat nested in Julian date, but removed this term due to model over specification given the small sample size. Visual inspection of residual plots were used to assess homoscedasticity and normality. To address unequal variances, we used varIdent to implement different variances per stratum of treatment in 2017 and Julian date in 2018 (Zuur et al. 2009). Minor deviations from normality were accepted (Zuur et al. 2009). Models were fit with maximum likelihood estimates (ML) using the nlme package (Pinheiro et al. 2019) in R version 3.6.0 (R Development Core Team 2019).

For 2017 data, the response variable (density of kelp >50 cm) was modelled as a function of treatment and Julian date (with an interaction term). Pre-treatment densities (May) were included in the response variable. Quadrat was used as a random effect and treatment was included with a varIdent variance structure. A *post-hoc* pairwise comparison of treatment was conducted using estimates of the slopes of the covariate (Julian date) trend with the emtrends function in the emmeans package (Lenth et al. 2019) in R.

For 2018 data, we examined the relationship between density of kelp >50 cm with treatment and Julian date as fixed effects (with an interaction term), pre-treatment density (from May 2017) as a random effect and Julien date was included with a varIdent variance structure. A *post-hoc* pairwise comparison of differences among treatment types by Julian date was conducted using least-squares means and Tukey's Honestly Significant Difference (HSD) with the emmeans package (Lenth et al. 2019) in R.

We also explored a more complex multi-year model with density modelled as a function of treatment, year, Julian date and the two-way interactions between treatment * year and Julian date * year (fixed effects). Pre-treatment density was used as a random effect and treatment was included with a varIdent variance structure. The multi-year model results were similar to the annual model results. The final annual model was preferred for simplicity.

We focused our statistical analysis on density of kelp plants > 50 cm since it was the best indicator of between-year impacts. We did not run statistical analysis on mean lengths of kelp plants > 50 cm as we would assume that lengths would decrease after harvest. We also considered kelp plant regrowth and survival in block one, but did not run statistical analysis due to small sample size.

3. Results

3.1 Harvester Practices and Interviews

From 2015 to 2018, we weighed 289 harvester buckets at the Libbey Beach public access over 20 minus low tide days. Most harvesters reported they were aware of the regulations and collected at or under the ten-pound daily limit, the bucket weights agreed with the harvester reports (84% under limit, 16 % over limit; Figure 9). All bucket weights over 15 lbs were in one group.

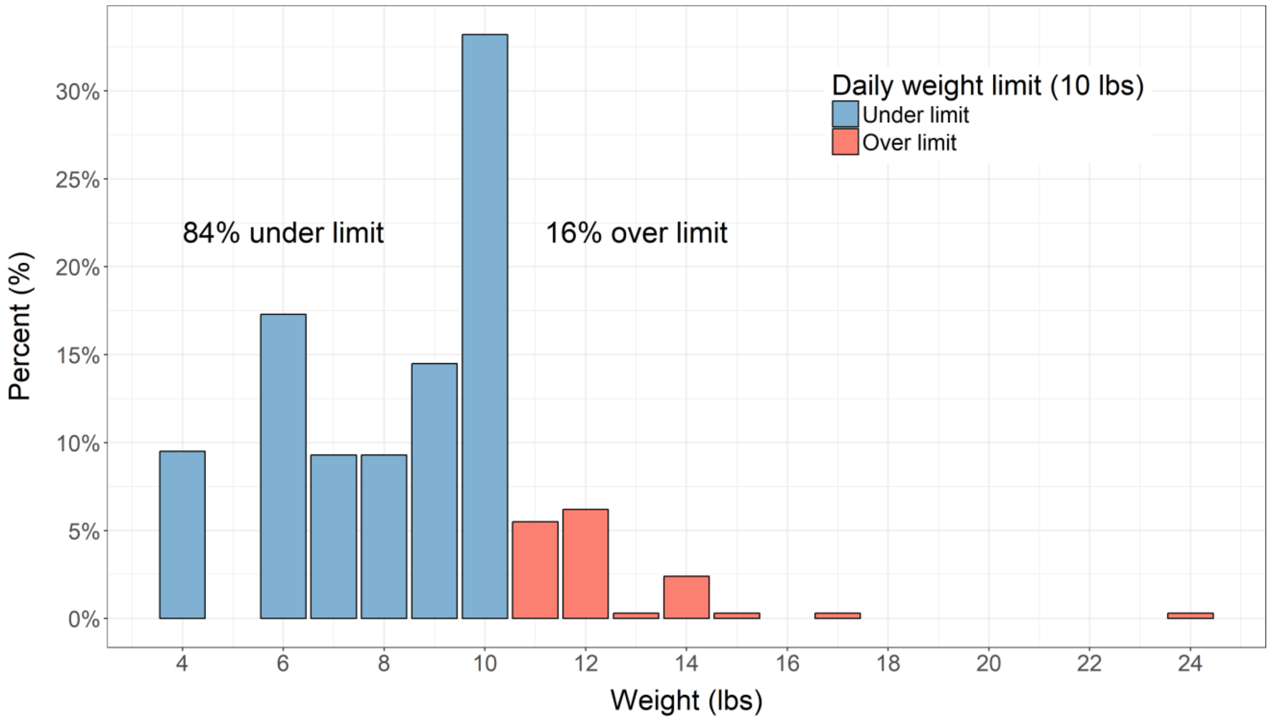

Figure 9. Wet weight of harvester buckets under and over the ten-pound daily limit (2015-2018, n = 289).

Though survey effort was not standardized across the summer, we observed peak harvest in April and May (78%), tapering into June and July (21%) (n=313). We observed that harvesters generally collected *A. marginata* either at the water line as the tide went out or while it was still slightly underwater at low tide. Harvesters reported that they were collecting kelp primarily for consumption. Reported edible uses include eating fresh in salads or as a sandwich wrap, pickling, or most commonly, drying and using in soups, broths or other dishes.

In 2017-2018, we asked a subset of harvesters what length of *A. marginata* and *Saccharina* spp. they targeted, with the majority preferring 1-3 m (50%), followed by <1 m (29%) and then all size classes (20%) (n=24). In conversation, several harvesters reported that they generally seek kelp that is relatively intact and not "bleached" from the sun (blade will take on a green color from sun exposure).

Some harvesters targeted just one species, while others collected multiple species. *A. marginata* was the primary species harvested, followed by *Saccharina* spp. (Figure 10).

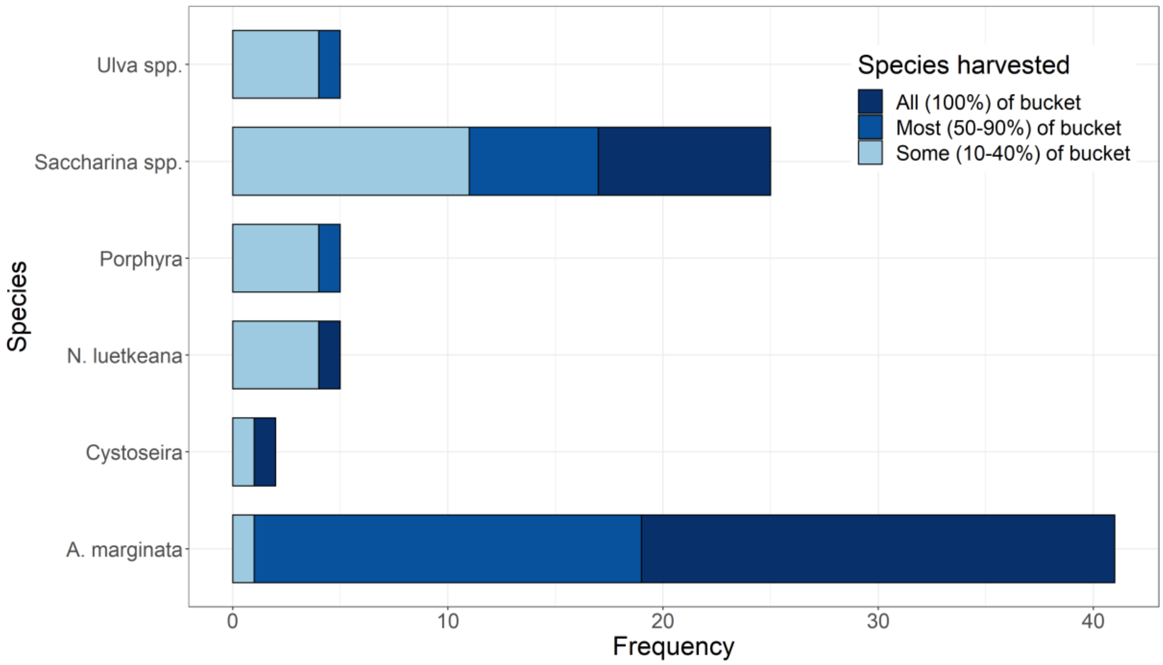

Figure 10. Recreational kelp harvest interview results, 2017-2018 (n=58). Harvesters were asked which species they harvested and approximate species composition of their buckets.

During surveys from 2015-2017, the majority of harvesters self-reported that they knew how to harvest sustainably and understood why sustainable harvest was important (Table 2). However, in 2018 we sampled a subset of kelp in harvester buckets and found 66% of the 12 harvesters surveyed both reported cutting unsustainably and had sporophytes in their buckets harvested unsustainably; cut at holdfast, at the top of the stipe or too close to the growth area, meristem, of the plant. While we do not know if all the kelp in these buckets were harvested unsustainably and the sample size is small, this does indicate that harvesters were not always aware of or were not consistently following best practices for harvesting sustainably.

Table 2. Sustainable harvest survey questions (2015-2017)

Question	Yes	No
Do you know the rules for harvesting sustainably? (n=39)	72%	28%
Do you know why it is important to harvest sustainably? (n=38)	79%	21%

3.2 Harvest Treatment Experiment

Density

Pretreatment densities

Our plots were dominated by *A. marginata* with lower densities of *Saccharina* spp. (Table 3). "Kelp" is used to refer to both target species *A. marginata* and *Saccharina* spp.

Table 3. Kelp density per quadrat (m^2) in May 2017 before treatment (mean ± SE)

	A. marginata	***Saccharina* spp.**	***A. marginata & Saccharina* spp.**
All size classes	32.7 ± 6.8	6.4 ± 2.9	39.2 ± 8.95
> 50 cm total length	14.1 ± 2.8	2.1 ± 0.8	16.3 ± 2.8

Due to patchiness, kelp density varied between plots in May 2017. Pretreatment mean density of individuals > 50 cm was highest in unsustainable plots (Figure 5).

Within year treatment effects - 2017

Treatment type significantly affected mean kelp density of individuals >50 cm over the growing season. In June and July 2017 following treatment, mean kelp density (sporophytes > 50 cm) notably decreased in unsustainable plots compared to pretreatment (June 2017: -13.5 ± 1.8 SE; July 2017: -12.8 ± 3.3 SE). Control and sustainable plot mean densities remained relatively stable throughout 2017 (Figures 11 & 12). Overall, when comparing before and after treatment, the density of sporophytes >50 cm declined significantly in the unsustainable harvested plots, but remained relatively constant in control and sustainable harvest plots. Pairwise comparison of treatment types based on the trend over the season identified significant differences between control and unsustainable and between sustainable and unsustainable plots in 2017 (Table 4).

Table 4. Pairwise comparison of trends by harvest treatment type (2017)

Treatments Compared	**Estimate**	**SE**	**DF**	**t**	**p**
C – S	0.0232	0.0516	21	0.451	0.8947
C – U	0.2477	0.0702	21	3.524	0.0055
S – U	0.2244	0.0809	21	2.773	0.0294

Between year treatment effects – 2018

In May 2018, mean kelp densities were higher for all treatment types compared to May 2017, particularly in control plots (mean difference kelp density ± SE, control: + 44.5 ± 13.3; sustainable: +19.0 ± 11.1 SE; unsustainable: +3.5 ± 12.8). Mean densities of unsustainable plots were consistently lower than sustainable and control plots throughout all post treatment surveys in 2017 and 2018 despite having the highest 2017 pretreatment mean densities (Figures 11 & 12). Pairwise comparison of treatment types by Julian date identified significant differences between treatment types for only in July and August of 2018 (Table 5). While we did not consistently see a statistical difference between treatments for all months, the plots suggest that unstainable harvest has a negative effect on the following year's population size (sporophytes > 50 cm; Figures 11 & 12).

Table 5. Pairwise comparison of harvest treatment types by month, 2018

Month (Julian date)	Treatments Compared	Estimate	SE	DF	t	p
May (137)	C – S	6.78	11.846	27	0.572	0.8359
	C – U	11.81	11.851	27	0.997	0.5853
	S – U	5.03	11.841	27	.0425	0.9057
June (164)	C – S	-6.72	9.564	27	-0.705	0.7627
	C – U	-2.94	9.540	27	-0.308	0.9491
	S – U	3.78	9.528	27	0.397	0.9171
July (192)	C – S	-1.97	0.475	27	-4.145	0.0009
	C – U	-4.44	0.582	27	-7.632	<.0001
	S – U	-2.47	0.337	27	-7.336	<.0001
August (221)	C – S	-7.72	3.412	27	-2.262	0.0788
	C – U	-9.35	3.696	27	-2.531	0.0447
	S – U	-1.64	3.665	27	-0.446	0.865

Annual variability and seasonal influences

In May 2018, mean densities were much higher in all treatments than in May 2017. We attribute this difference to year to year variation. Kelp is known to exhibit high year-to-year variation in response to climate conditions, small scale disturbances and other factors (Dayton 1985, Pfister et al. 2017). The seasonal patterns were also different between years. Mean kelp density was fairly stable post treatment in June and July, while mean density decreased linearly in 2018 for all treatment types.

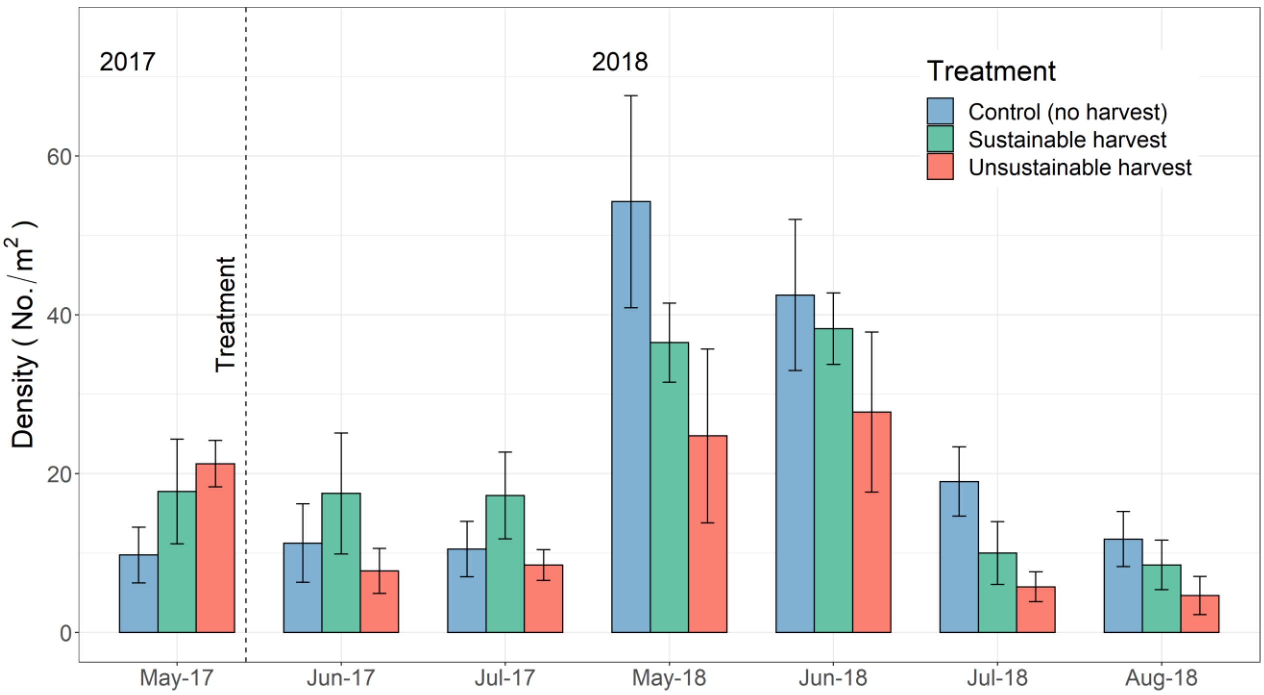

Figure 11. Density of *A. marginata* and *Saccharina* spp. > 50cm (mean ± SE) by treatment type (n = 12 plots). Pre-treatment densities are shown in May 2017.

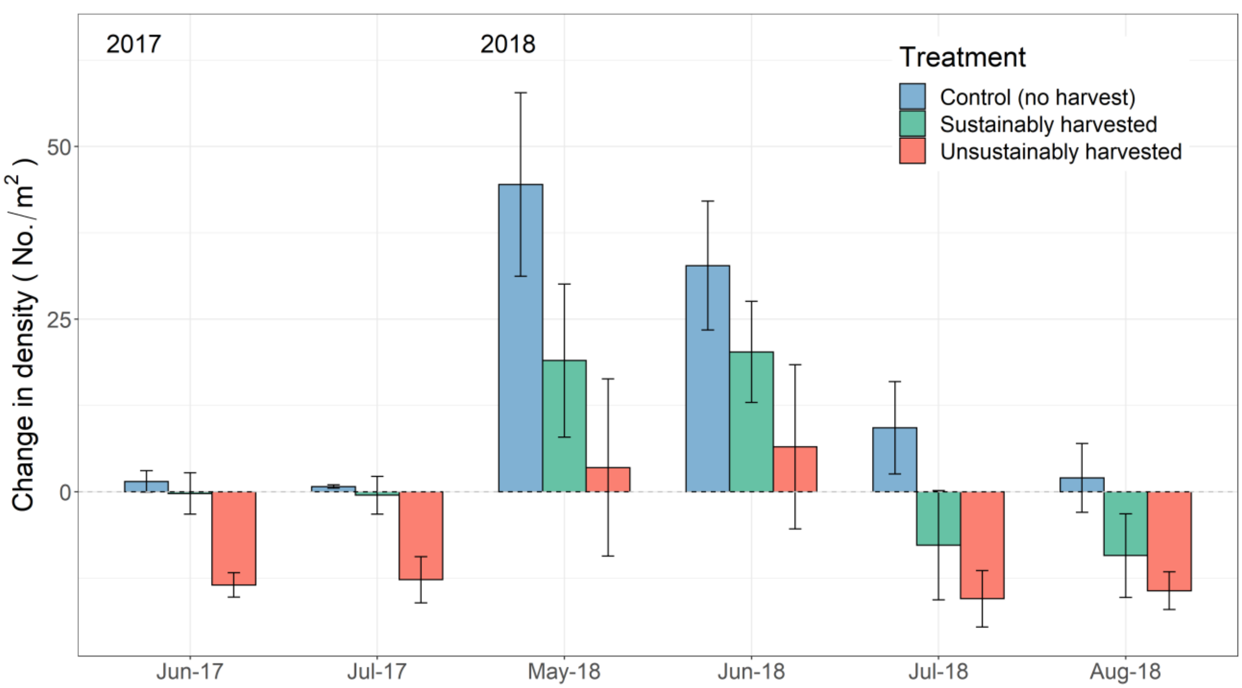

Figure 12. Change in density *A. marginata* and *Saccharina* spp. >50cm (mean ± SE) by treatment type (n = 12 plots) compared to pre-treatment densities in May 2017.

Mean Kelp Length, Survivorship and Growth

Mean kelp length (sporophytes > 50 cm total length)

In May 2017, mean sporophyte length was 134 cm for all *A. marginata* > 50 cm (±6.6 SE, 169 individuals) and 103 cm for *Saccharina* spp. > 50 cm (±7.3 SE, 25 individuals). Mean total sporophyte length in control plots peaked in July in 2017 (155 cm ± 10.9 SE, 42 individuals, Julian date=203) and in June in 2018 (161 cm ± 7.3 SE, 170 individuals, Julian date=164). Maximum *A. marginata* total length was recorded in June 2018 (542 cm) and maximum *Saccharina* spp. total length was recorded in May 2018 (206 cm; Figure 14).

Mean total length of sporophytes > 50 cm in unsustainable plots decreased substantially in June 2017 following treatment as compared to sustainable and control plots, as would be expected. Control and sustainable plot mean lengths increased compared to pretreatment lengths by July 2017, while unsustainable plot mean lengths were still less than pretreatment lengths (Figure 13). There was no discernable trend in sporophyte mean lengths between treatment types in 2018 (Figure 14). Unsustainable plots had notably fewer large sporophytes > 200 cm (generally the most fertile) by July 2017 (3 individuals), compared to control and sustainable plots (11 individuals in each; McConnico & Foster 2005). In July 2018, control plots had more large sporophytes > 200 cm (8 individuals) compared to sustainable (0 individuals) and unsustainable plots (1 individual).

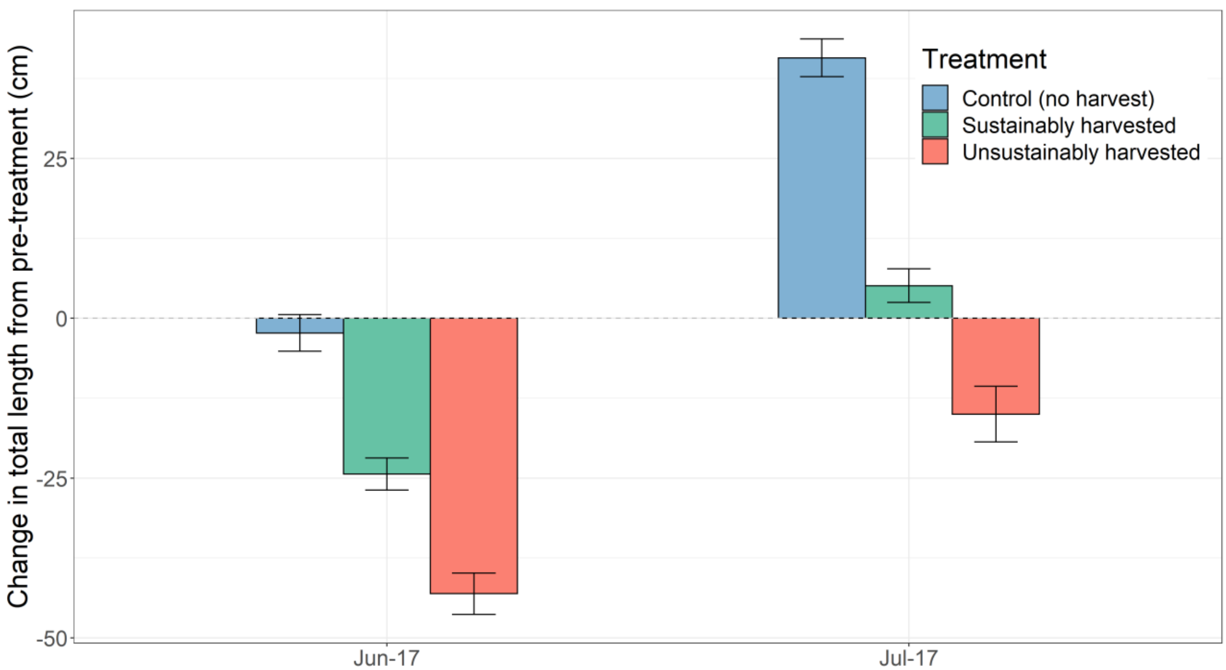

Figure 13. Change in mean total length *A. marginata* and *Saccharina* spp. >50cm (mean ± SE) by treatment type (n = 12 plots) compared to pre-treatment lengths in May 2017.

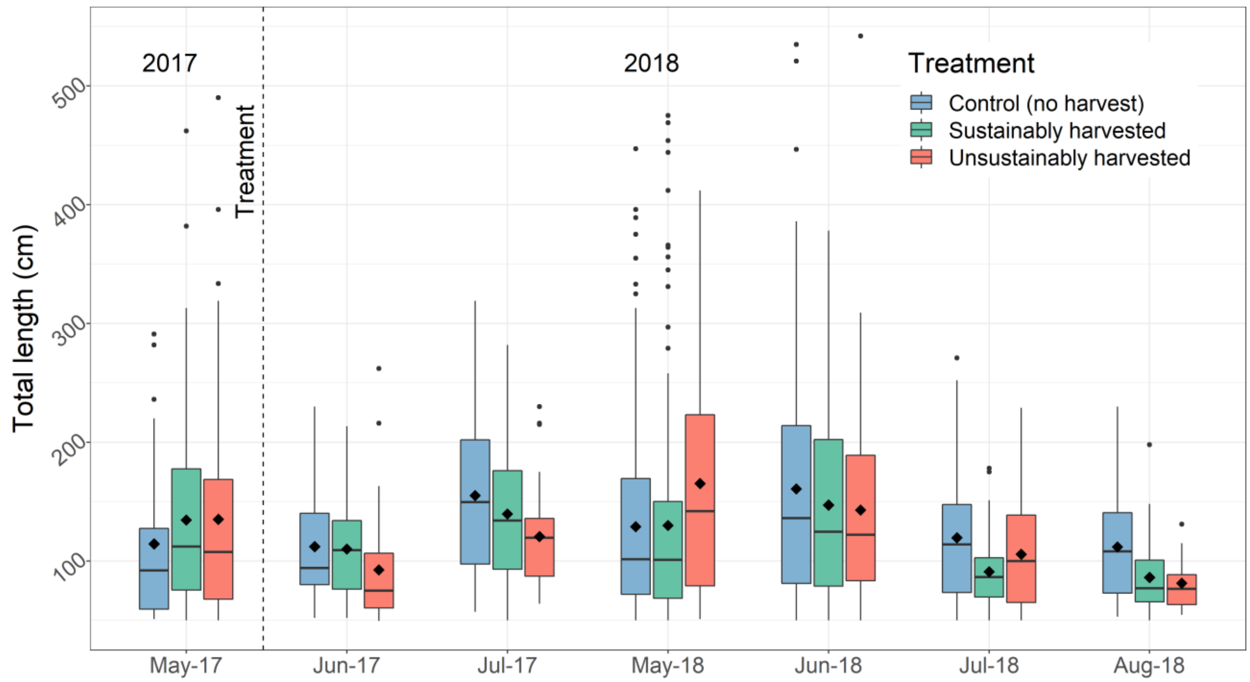

Figure 14. *A. marginata* and *Saccharina* spp. >50 cm total lengths by treatment type (n = 12 plots). Diamonds show group means. Pre-treatment lengths are shown in May 2017.

Survivorship and growth

We tagged all kelp > 50 cm in block one during May 2017 surveys to track harvested individuals that (unsustainable and sustainable plots) and individuals > 50 cm pretreatment (control plot). During June and July 2017 post treatment surveys, all individuals > 50 cm were measured and fell into two groups: 1) tagged kelp (survivorship) and, 2) untagged kelp (new growth). None of the unsustainably harvested *A. marginata* individuals recovered or continued to grow after harvest, though some of stipes persisted until the July 2017 survey (Figures 15 & 16). In addition, smaller understory kelp (<50 cm) did not survive and grow at sufficient numbers following removal of canopy (> 50 cm) kelp to replace individuals lost during the May 2017 harvest. In July 2017, kelp density (> 50 cm) was still considerably lower in the unsustainable plot compared to the control and sustainable plots (Figure 10). In contrast, sporophytes harvested sustainably survived and continued to grow. Sporophytes <50 cm in sustainable plots grew into the >50 cm size class in greater numbers than in control and unsustainable plots. In unmanipulated control plots, sporophytes > 50 cm that were tagged in May 2017 generally persisted through July and few understory sporophytes grew into the > 50 cm size class.

Seven *A. marginata* sporophytes tagged in May 2017 were still present in May 2018 and were noted to have robust, "woody" stipes compared to new recruits (proportion of sporophytes per treatment type that persisted: control:1/14 or 7%, sustainable: 5/38 or 13%, unsustainable:1/18 or 6%).

In June 2017, mean change in length of tagged sporophytes (>50 cm in May) was negative in control and unsustainable plots (- 30.15 cm and - 29.63 cm, respectively). Sustainably harvested sporophytes grew substantially longer on average in June and July 2017 (75.15 cm and 32.66 cm, respectively) compared to control and unsustainable (Figure 17).

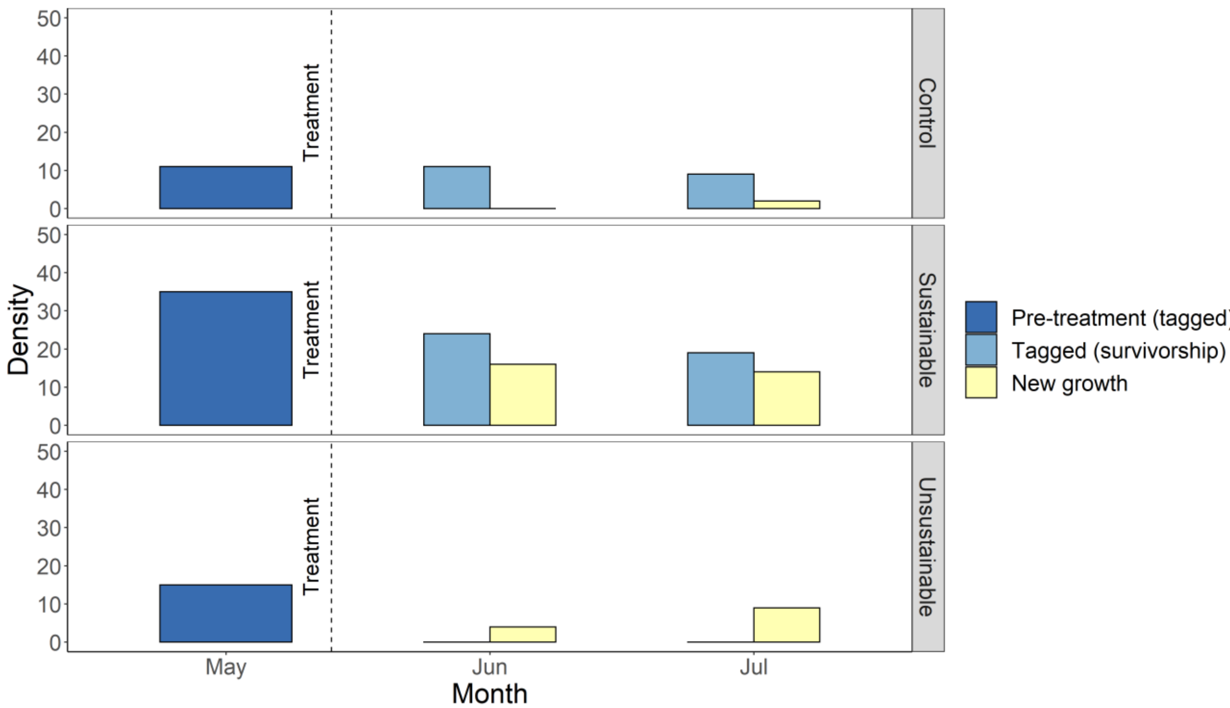

Figure 15. Density of *A. marginata* (>50 cm) by treatment type in block one, 2017 (n = 3 plots). Pre-treatment densities are shown in May 2017. Survivorship and new growth are shown in June and July.

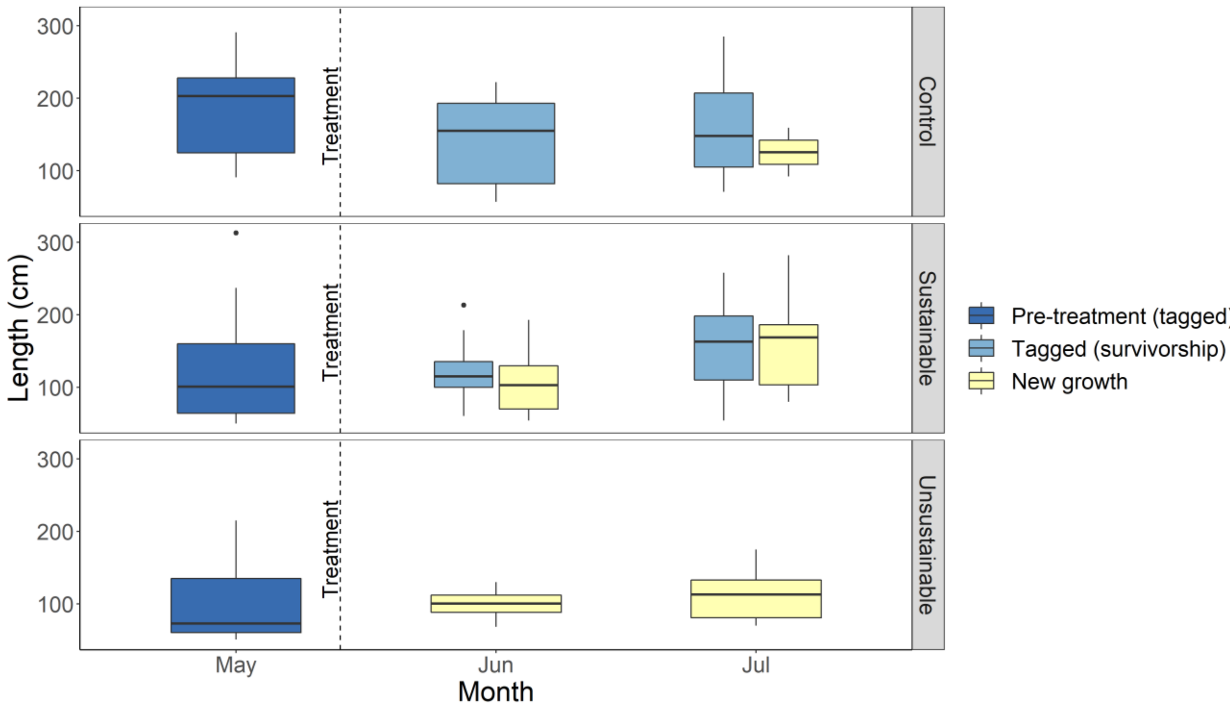

Figure 16. Length of *A. marginata* (>50 cm) by treatment type in block one, 2017 (n = 3 plots). Pre-treatment lengths are shown in May 2017. Survivorship and new growth are shown in June

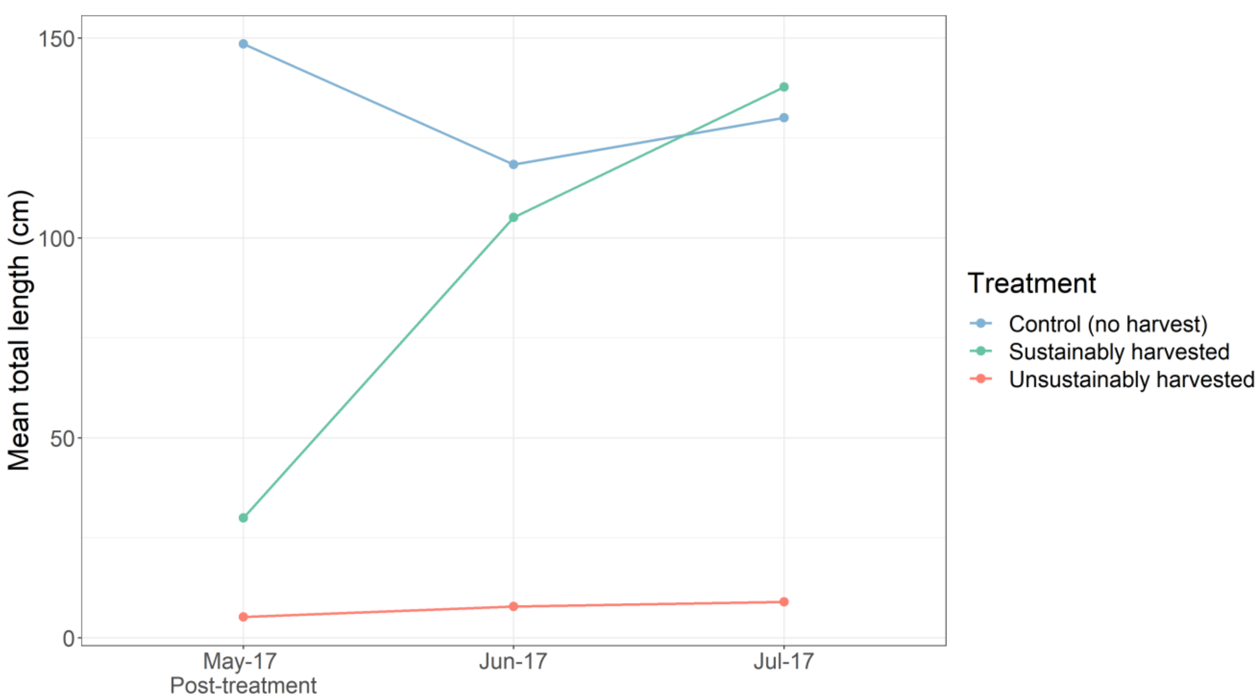

Figure 17. Mean total length of tagged *A. marginata* sporophytes in Block 1 (>50 cm in May 2017). Note that May 2017 lengths are post-treatment (n = 3 plots).

Sporophyll Development

We did not observe any significant patterns between treatment type and sporophyll number or maximum sporophyll lengths, though McConnico and Foster noted that sporophylls in canopy-cleared plots were "qualitatively smaller and less developed than those on larger sporophytes in natural stands" (2005; Figure 18 & Figure 19). Other studies reported that reproductive sporophylls with sorus area present are darker, thicker and less ruffled (McConnico & Foster 2005; Demes et al. 2012). However, we found that broad variation in the thickness, color and texture of sporophylls made it difficult to consistently identify sorus areas and reproductive sporophylls in the field with high degree of certainty.

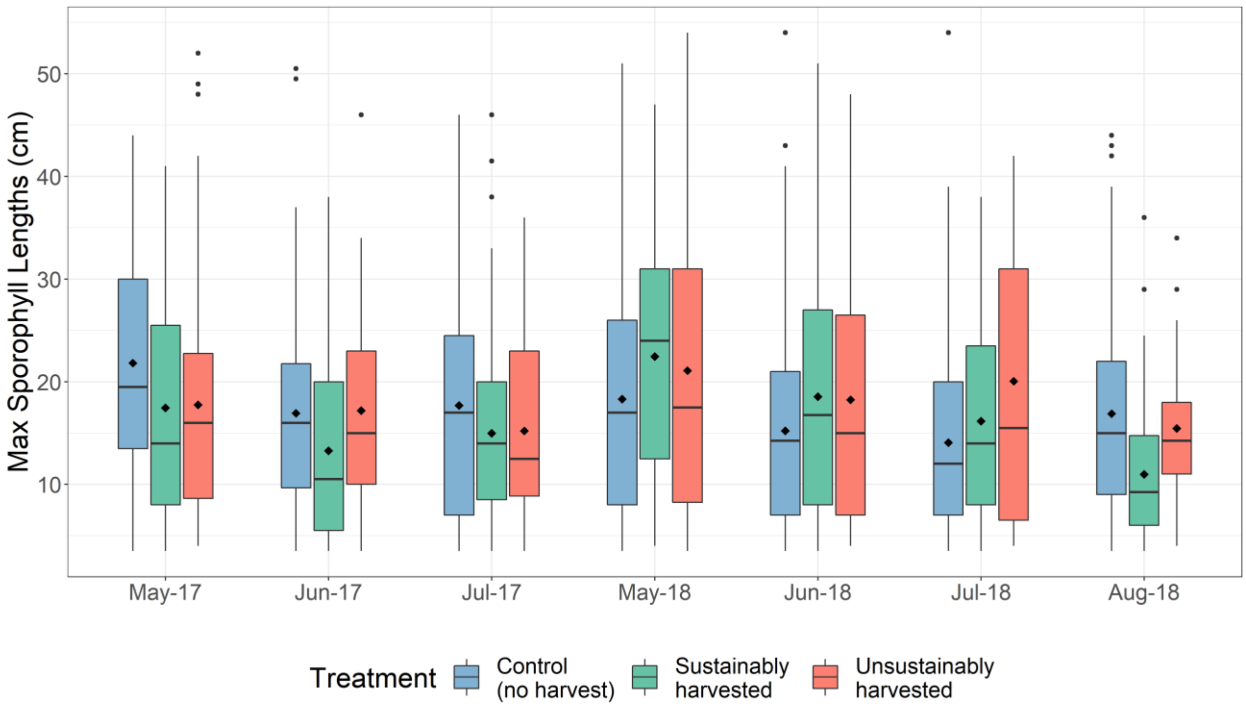

Figure 18. *A. marginata* 3 maximum sporophyll lengths per plant by treatment type (n = 12 plots). Diamonds show group means.

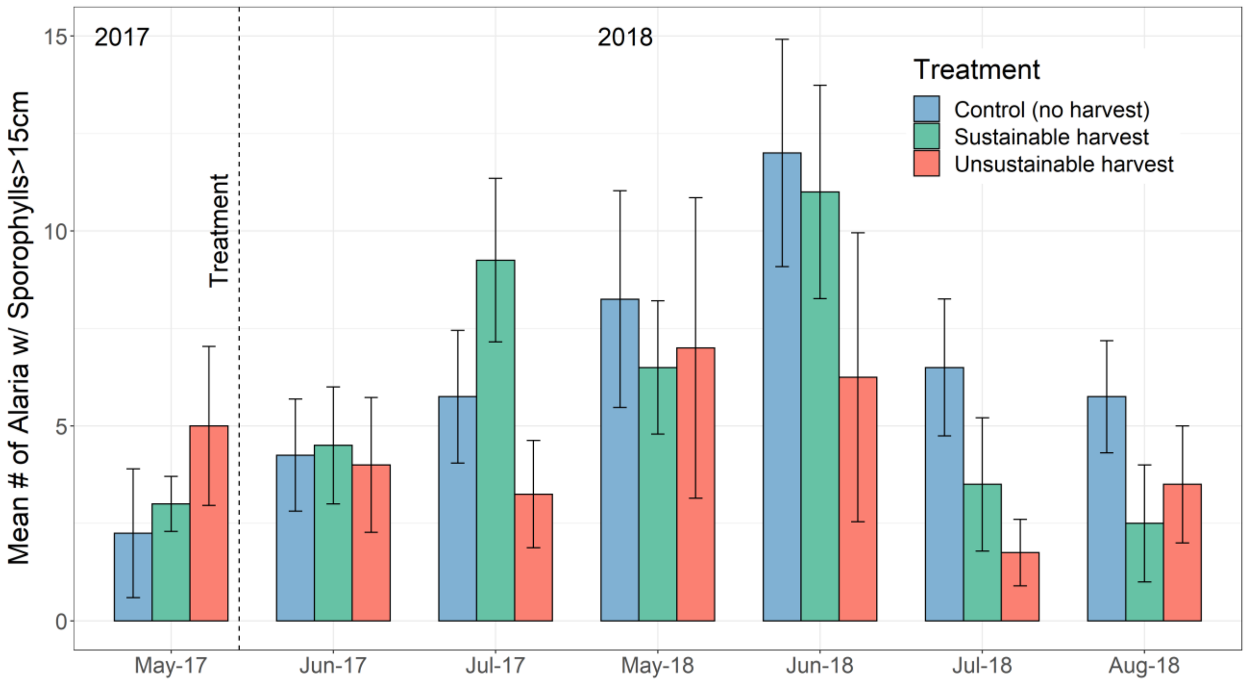

Figure 19. Mean (± SE) number of *A. marginata* with sporophylls > 15 cm by treatment type (n = 12 plots).

4. Discussion

4.1 Harvester Practices and Interviews

We found that the majority of recreational kelp harvesters stayed within the ten-pound daily harvest limit. However, there was a considerable gap between self-reported understanding of sustainable harvest practices (2015-2017) and actual harvest techniques, based on our survey of filled buckets (2018). Though our sample size was small, our 2018 surveys suggest that some harvesters may be cutting kelp unsustainably at the stipe or too close to the growth area (meristem) of the plant. Harvest progressively closer to the meristem, even at 10 cm from the base of the blade, was shown to substantially reduce regrowth rates in other kelp species (Levitt et al. 2002). This finding stresses the importance of following sustainable harvest practices and trimming at 30 cm, even if the meristem itself is left intact. In addition, we hypothesized that *Saccharina* spp. and *N. luetkeana* were the primary target species, however *A. marginata* was by far the most sought-after kelp species for consumption, followed by *Saccharina* spp.

4.2 Harvest Treatment Experiment

Our harvest treatment study results show that unsustainable harvest just once early in the growing season negatively affected kelp density (sporophytes > 50cm) within year (compared to control and sustainable harvest) and the following year (compared to control). The low amount of *A. marginata* sporophytes > 200 cm in unsustainable plots at the end of summer (compared to control plots) in both 2017 and 2018 indicates unsustainable harvest reduces the number of large individuals with the highest fecundity (McConnico & Foster 2005). In addition, smaller sporophytes in unsustainable plots did not grow into the > 50 cm size classes in sufficient numbers to replace losses following harvest. McConnico and Foster observed a similar pattern in natural versus canopy-cleared plots (2005). They speculated that larger, canopy *A. marginata* suppresses growth and recruitment of smaller sporophytes (as in the control plot), while complete removal of canopy cover exposes understory sporophytes to high solar irradiance during low tides and wave energy, ultimately stifling growth. Over time, repeated unsustainable harvest and removal of large sporophytes could affect inter-annual recruitment.

Sustainably harvested *A. marginata* survived and continued to grow following harvest in May 2017, and the effect of sustainable harvest was not significantly different than in control plots in 2017 and most of 2018. Sustainable plots were significantly different than control plots only in July 2018. In addition, sustainably harvested plots had higher kelp densities than control or unsustainable plots in June and July 2017. This may be because sporophytes both > 50 cm and < 50 cm survived and continued to grow at higher rates than other plots following harvest in May. Partial canopy-clearing may have created space for understory kelp to grow without the sudden exposure impacts observed in complete canopy-cleared unsustainable plots.

Our study also supports work showing that *A. marginata* is primarily an annual with a small percentage of sporophytes that persist year to year (McConnico & Foster 2005). We did not have enough *Saccharina* spp. in our treatment plots to compare annual and perennial kelp species response to different harvest methods.

Though dispersal distances and survival of *A. marginata* macroscopic spores have not been determined in the field, kelp species with sporophylls similarly located near the base of the plant typically have spore dispersal distances of 1-5 m, with a maximum of 10 m (McConnico & Foster 2005, Norton 1992). Due to the small size of our plots, it is likely that unharvested plants outside the study plots produced spores that recruited in our treatment plots. Given this likelihood, and high density of *A. marginata* in this area, it is especially notable that differences in treatment types were still detectable in 2018. This indicates that even spatially patchy unsustainable harvest could negatively impact kelp populations.

Our findings are limited in that they represent a relatively small sample size of two species at a single site. However, our findings agree with previous research on the impacts of unsustainable harvest in a variety of kelp species and locations (Levitt et al. 2002; Thompson et al. 2010; Borras-Chavey et al. 2012, Young 2003). These findings are also supported by widespread understanding of the basic biology of kelp –growth is halted by severing kelp below the growing center, or meristem (Abbott & Hollenberg 1976). Although we do not know if there is a longer-term impact of unsustainable kelp harvest, recreational harvest using sustainable methods requires minimal effort and allows kelp plants to survive and continue to grow.

4.3 Recommendations

Our findings confirm previous research that unsustainable harvest impacts the kelp resource by precluding regrowth. DNR's longstanding policy has been to recommend sustainable harvest and allow unsustainable harvest. We recommend that DNR consider a more precautionary management approach which requires sustainable harvest. Education would need to accompany any rule changes because harvesters generally reported that they were harvesting sustainably in 2015-2017, although we found that many were not in 2018.

Sustainable harvest techniques are only one aspect of recreational harvest management. Little is known about the scope and intensity of harvest at sites throughout Washington State. Further research is needed to determine best practices related to harvest limits, seasons, and species.

Management actions to consider include:

- Consider changing recreational harvest rules to require sustainable harvest.
- Increase education and outreach on the importance of harvesting sustainably (above the meristem at 30cm) at popular kelp harvest public access sites, targeting May and June extreme low tides when harvest peaks. Encourage recreational harvesters to follow sustainable kelp harvest practices on state-owned aquatic land.
- Conduct a more robust survey of recreational harvesters at Libbey Beach and other popular harvest sites to determine harvest timing and compliance with existing regulations. Continue sampling harvester buckets to determine whether kelp was harvested sustainably.
- Investigate potential impacts of kelp harvest timing and frequency, and effects on reproductive output and inter-annual recruitment.

- Work to improve kelp harvester education in connection to the shellfish/seaweed permit process.

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Appendix A – Kelp Harvest Brochure