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Short Communication

Bed-scale rockweed harvest findings are not altered by study critiques, a response to Seeley *et al.*

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ABSTRACT

Seeley et al., 2024 (Comment: A reexamination of Johnston et al., 2023, bed-scale impact and recovery of a commercially important intertidal seaweed. J. Exp. Mar. Biol. Ecol. 574) describe a number of reasons that they believe our study's experimental design was flawed and our inferential conclusions were incorrect. We believe that these claims are the result of misunderstandings of the objectives behind our sampling design and statistical analyses. Throughout this response to Seeley et al., we reiterate key objectives of our study design: examining rockweed harvest at a whole-bed scale, realistically capturing the effects of current commercial rockweed harvest methods in Maine, and using coastwide site averages to estimate effect sizes of rockweed harvest. The first claim by Seeley et al. that our study design severely undersampled rockweed beds ignores established sampling methodologies in rockweed research. The suggestion that our sampling design resulted in impact sites that were *de facto* control sites is not supported by our analyses that showed greater declines in mean rockweed height and biomass at impact sites relative to control sites. In response to their second claim that rockweed companies had control of key elements of our study design and execution, we detail our specific approaches to lessen any possibility for such conflicts to bias our findings. In the final section of our response, we present power analyses in support of our Before-After Control-Impact study design and we highlight the statistically significant effects of treatment on rockweed biomass that contradict Seeley et al.'s claim that we drew conclusions about biomass recovery based solely on large *p*-values.

1. Introduction

In Johnston et al., 2023 (hereafter Johnston et al.), we presented the results of a rockweed (*Ascophyllum nodosum*) harvest study that quantified the effects of commercial rockweed harvest on mean rockweed height and biomass at the whole-bed scale. Seeley et al., 2024 (hereafter Seeley et al.) described a number of reasons they believe our study and conclusions are unsuitable for use in resource management policy. We thank them for their comment and the opportunity to provide further clarity on a number of points.

2. Response to claims of study flaws

2.1. Study design

Seeley et al. suggest that we severely undersampled rockweed beds due to the fact that we “sampled only two 10 m^2 [sic] transects out of 100 possible 10m^2 [sic] transects.” The comment authors ignore established sampling methodologies in rockweed research that are used to estimate mean bed biomass. When designing the rockweed sampling methodology for our experiment, we consulted Appendix A (Biomass Assessment Methodology) in the Maine Department of Marine Resource's Rockweed Fishery Management Plan (Rockweed Plan Development Team et al., 2014). For each rockweed bed, “one to three transects per bed should be sufficient […] Ten quadrats should be sampled along each 30-meter transect. The sampling unit used for the

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assessment shall be a 0.25 m^2 (50 x 50 cm) quadrat." This would result in 2.5 m^2 to 7.5 m^2 of sampled area per rockweed bed (our study = 2.5 m^2). We also referenced other studies that had assessed the impact of rockweed harvest at the bed scale, such as Kay, 2015 (ten 0.25 m^2 quadrats = 2.5 m^2) and Trott and Larsen, 2012 (twelve 0.0625 m^2 quadrats = 0.75 m^2).

Seeley et al. go on to question changes in our study design since public presentations by Johnston et al. authors during our initial stakeholder engagement and design phase of the study. The comment authors first point out that the number of sites included in our study changed from 54 to 38. During the first year of the study (2018), we established 54 research sites that were all accessible by foot with coastal landowner permissions. At the time, rockweed in the intertidal zone was held in public trust by the state of Maine, and harvest of the resource did not require landowner permission. This changed in 2019 when Maine's Supreme Judicial Court ruled that rockweed located within the intertidal zone is the private property of the adjacent upland property owner. Fourteen research sites were subsequently removed from the study due to landowner denials of harvest permission and/or foot access to the intertidal. Two sites were removed from statistical analyses in our study due to outlier sampling values, which we detailed in the methods section and visualized in the supplementary data (Johnston et al., Fig. S1). We maintain this choice was statistically sound, but nothing is missing to prevent readers from reviewing the data and making their own conclusions.

The comment next notes that our rockweed sampling methodology was initially a three-transect design (high, middle, low) that changed to a two-transect design (middle, middle). We used the three-transect design at the first twelve sites we surveyed during the before harvest time period. After this initial sampling, Johnston et al. recognized that a reduced sampling design was necessary to successfully complete all rockweed surveys within tidal and fieldwork schedules. Our decision to place the two transects in the middle intertidal zone was informed by both a) previous studies that used a similar sampling approach (Ugarte et al., 2006; Kay, 2015) and b) conversations with a harvest company representative which indicated that harvesting more often includes the middle than the high or low intertidal zones (A. Feibel, personal communication). We wanted to ensure that this change did not bias our findings, however, and thus to test the comparability of two- and three-transect sampling designs, we surveyed nine sites with four 10-m transects (high, middle, middle, low) and compared mean rockweed height and biomass at each site under the different sampling designs (Fig. 1). Across sampling designs, there was no statistically significant difference between estimates of mean rockweed height ($F_{2,\,16} = 0.68$, $p = 0.52$) or biomass ($F_{2,\,16} = 0.14$, $p = 0.87$). As a result, we retained the initial high-middle-low estimates for 12 initial site surveys (10.5% of 114 site surveys) and we used middle-middle estimates for the remainder of our sampling.

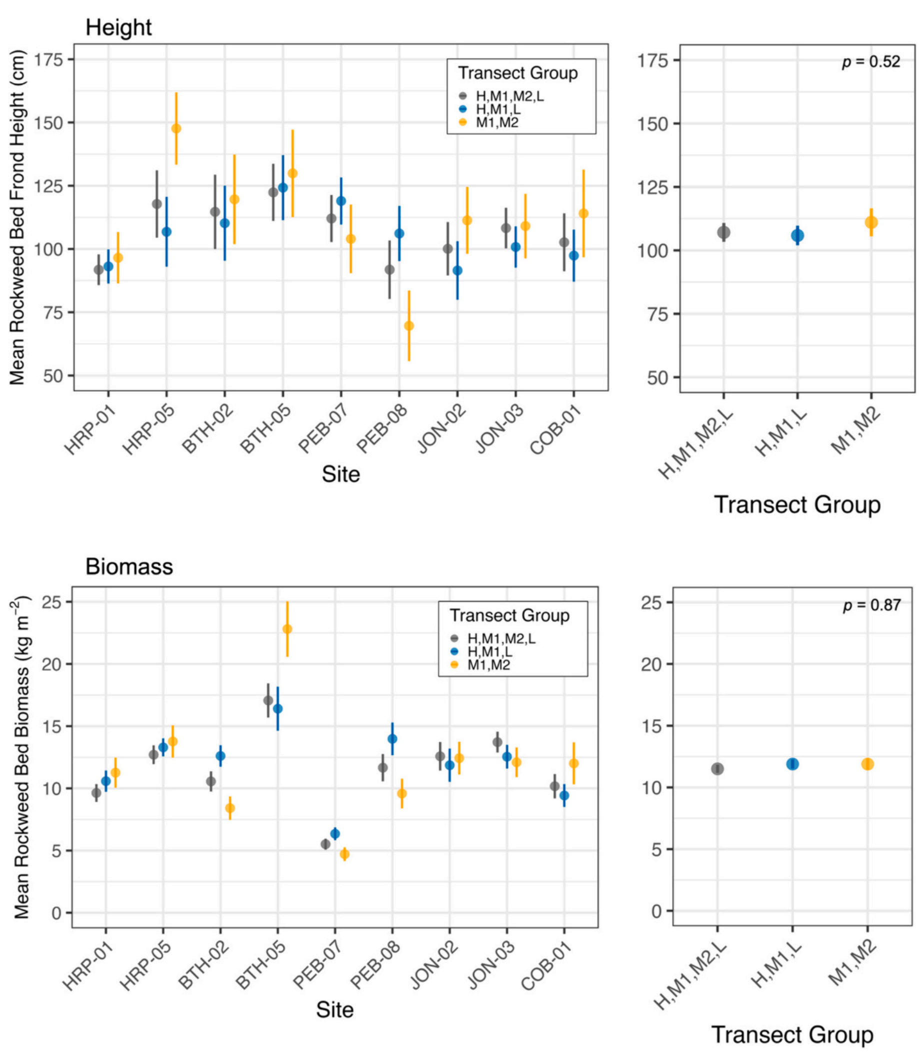

Fig. 1. Comparison of mean rockweed height and biomass across four-, three-, and two-transect sampling approaches. Along each transect, five 0.25 m^2 quadrats were sampled. Grand means are displayed in the right-side panels. Error bars represent 95% confidence intervals.

2.2. The role of commercial rockweed companies in the design and execution of the study

Seeley et al. state that "[r]ockweed companies with financial interests in the outcome of the study were key players in this study. These companies controlled key elements of the design and the execution of this study." One of the main objectives of our study was to conduct harvest in a manner representative of commercial practices in our region. This objective—along with the large site sizes in our experiment—necessitated working with rockweed harvest companies. We clearly detailed in the methods section of Johnston et al. to what extent harvesters were involved in planning and executing the study. Our study would not have captured the realistic effects of commercial harvest if we, as researchers, had prescribed the precise locations of harvest. We are not professional harvesters, and we would not make the same decisions as a harvester would, thus preventing us from capturing realistic impacts of actual harvest practices. We recognized from the start that we were working with for-profit companies with vested financial interests in the outcome of our study, and we executed our experimental design accordingly. For example, we used methodological safeguards (harvest companies did not know the location of sampling transects) and preliminary analyses (χ^2 tests of transect data; Johnston et al., Table 1) to independently assess whether there was a signal of harvest at impact sites relative to control sites. Further, although the companies involved measured the size of their harvest for their own uses, we did not use those estimates in this study. We independently estimated the magnitude of harvest at each site without any input from the harvesters themselves, to prevent any conflict of interest from biasing those estimates.

Despite study design considerations and harvest company assurances, we acknowledge that our data cannot confirm whether the intensity of harvest observed in our study is equal to that of typical commercial operations. However, we provide comprehensive quantitative data on the size of harvest impacts at each site that can be used to contextualize our study. To repeat the point made in the Johnston et al. discussion section, our results are only applicable to the range of harvest impacts we documented, and we report that range so that our results can be appropriately applied to management. Furthermore, in Table 3 of Johnston et al. we reviewed published rockweed harvest studies and calculated standardized effect sizes when sufficient data were provided. Despite claims by Seeley et al. that our results are an outlier in comparison to other studies, the effect sizes observed in our study were similar to those in another bed-scale study (Kay, 2015) and smaller than those observed in studies that conducted harvests at smaller spatial scales (Kelly et al., 2001; Ugarte et al., 2006; Walder, 2015). We welcome future research on commercial rockweed harvest at the bed scale that further contextualizes our study and either supports or contradicts our conclusions.

Last, we would like to note that we convened a stakeholder meeting in 2018 to receive input on our study design and sampling methodology, not just from the rockweed harvest industry, but from many rockweed stakeholders in Maine. These stakeholders included representatives from federal and state agencies (National Park Service, U.S. Fish and Wildlife Service, Maine Department of Marine Resources, Maine Department of Inland Fisheries and Wildlife), conservation non-profits and land trusts (The Nature Conservancy, Maine Audubon Society, Frenchman Bay Partners, Maine Coast Heritage Trust), rockweed harvest and processing businesses (PhycoLife, North American Kelp, Acadian Seaplants, Ocean Organics, Source Inc.), and facilitators from Maine Sea Grant. We presented our study design to the stakeholder group and held small-group discussions, during which we received study feedback from each stakeholder group. Therefore, in addition to the sound scientific design of our study, we have confidence that the broader rockweed stakeholder group in Maine, including regulatory and management agencies, supported the design and execution of our study.

2.3. Inferential conclusions

Seeley et al. repeatedly claim that our sampling transects were unlikely to have fully overlapped with the areas of harvest at each of our impact sites, resulting in site assignments (control and impact) that were functionally the same. The comment authors misunderstand several key components of our experimental design. First, we reiterate that our study examines the bed-scale effects of rockweed harvest. If our sampling completely overlapped with harvest at all sites and $< 100\%$ of the site areas were harvested, as is typical at commercially harvested sites (Sharp, 1987), reported effect sizes would overestimate the true mean impact of harvest on the bed. We anticipated that there would be a range of overlap between our sampling quadrats and harvest locations across the 19 impact sites, and that the mean effect size of harvest across all sites would thus be an informative index of bed-scale effects across Maine's coast.

However, we recognize that there was uncertainty in this outcome, and any sampling scheme has a small probability of rare events, such as sampling and harvest locations that did not overlap across all of our impact sites. Before we presented any analyses about the effects of

Table 1
Dates of rockweed harvest and post-harvest sampling at impact sites (all in 2019). Signs of harvest were assessed by visually searching quadrats for bluntly cut fronds consistent with commercial harvest. These quadrats ($0.0625\ m^2$) were sampled for a related study on invertebrates (Mittelstaedt, 2023) conducted in different quadrats than those in Johnston et al., but in the same beds and during the same post-harvest time period.

Site	Harvest Date(s)	Date of After Survey	Signs of Harvest (% of quadrats)
BTH-04	June 20, July 6	August 6	50
BTH-01	June 27	August 1	50
BTH-06	June 27	August 13	100
HRP-04	July 11, 16	August 28	100
HRP-03	July 17, 18, 22, 23	August 28	100
HRP-02	July 24, 29, 30, 31 August 1	August 27	75
JON-02	August 16	September 11	50
JON-03	August 16	September 11	0
JON-08	August 27	September 6	0
PEB-08	October 11	October 12	50
PEB-09	October 11	October 12	50
PEB-10	October 11	October 12	25
COB-12	October 17	November 23	50
COB-01	October 24	November 23	0
COB-09	October 31	November 2	50
COB-10	October 31	November 2	0
PEB-03	November 14	November 15	0
PEB-04	November 14	November 15	50
PEB-05	November 14	November 15	75

harvest in Johnston et al., we assessed whether our sampling methodology was able to detect a signal of harvest at impact sites relative to control sites. We showed that we successfully detected impacts of harvest and documented declines in mean rockweed height and biomass between the before and after harvest periods at impact sites that were greater on average than at control sites (Johnston et al., Table 1 and Fig. 3). It is not possible that our impact sites were *de facto* control sites. Furthermore, harvest dates at all sites were known, which ensured that sampling during the after time period occurred post-harvest (Table 1).

To further assess whether harvest occurred at our sites, we visually recorded signs of rockweed harvest (bluntly cut fronds) during sampling for a related study on invertebrates conducted in different quadrats, but in the same beds and during the same post-harvest time period as Johnston et al. (Table 1). Using a smaller total sampling area (four 0.0625 m^2 quadrats) at each site than we used in this study, zero out of 14 control sites and 14 out of 19 impact sites (74%) showed physical evidence of harvesting in at least one mid-intertidal quadrat (Mittelstaedt, 2023).

Much of the comment's section on inferential conclusions focuses on the claim that we "drew conclusions, based on a large *p*-value, regarding the truth of the null hypothesis of 'no harvest treatment effect.' " However, we found a statistically significant effect of treatment on rockweed biomass during both the harvest ($t_{1,\ 72} = -2.21$, $p = 0.03$) and regrowth ($t_{1,\ 72} = 2.21$, $p = 0.03$) time intervals, which resulted in no statistically significant effect of treatment at the conclusion of our study ($t_{1,\ 72} = -0.003$, $p > 0.99$). From a power perspective, this is very different than statistically non-significant differences across each time interval that result in a non-significant difference at the final time step. We do agree with Seeley et al. that greater illustration of our study's power would be helpful in understanding the minimum detectable effect sizes (MDES), especially given the marginally non-significant decline in mean rockweed height between the before and after time periods ($t_{1,\ 72} = -1.91$, $p = 0.06$). Using our before harvest data as pilot data ($N = 38$ sites), our study had 80% power to detect an effect of treatment on changes in biomass and height at -2.9 kg m^{-2} and $-$ 18 cm, respectively (Fig. 2). These MDES are smaller than most of the rockweed harvest effect sizes reported in the literature (Johnston et al., Table 3). We performed the power analysis with the simr package in R version 4.3.1.

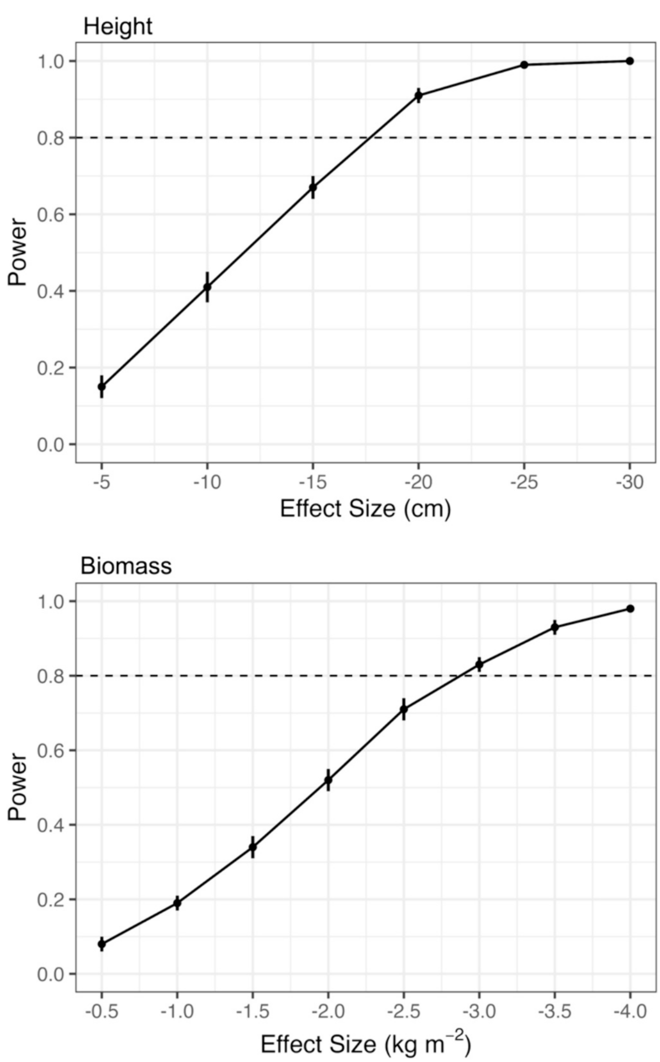

Fig. 2. Retrospective power analyses using before time period data as pilot data ($N = 19$ control sites and 19 impact sites). Point estimates and 95% confidence intervals were calculated using the simr package in program R.

Finally, we would like to clarify our assessment of regional differences in rockweed harvest and recovery dynamics. Given the design of our study, it would be inappropriate to make inferences about the impact of harvest based on any single site. Bed-scale averages for rockweed height and biomass are most robust at large site sample sizes (*e.g.*, N = 38 in our study). In Johnston et al., we explored regional trends to highlight variation across different areas of the Maine coast, but we should have been more explicit in stating that these assessments should not form the basis of policy. The relatively small sample sizes within each region reduced the statistical power to test harvest impacts and decreased the probability of achieving a mix of sites that over- and under-represent bed-scale harvest impacts. There is certainly variation in rockweed harvest and recovery across regions, harvest methods, and harvest companies, but our study was not designed to test these interactions. The sampled rockweed population that we were making inferences about—beds available to harvesters with three quarters harvested by the largest operator—was appropriately represented in our coastwide study.

3. Conclusion

The critiques of our study in Seeley et al. are largely the result of misunderstandings of our statistical objectives and experimental design. Rockweed harvest has been studied for many decades and will continue to generate further research moving forward. The comment authors' assertion that our research creates "a false foundation for marine policy" misses the extent to which we integrated our results with the rockweed harvest literature and added to this discussion by measuring harvest impacts at scales that are more directly applicable to current industry practices. In our paper, we compiled the first review of rockweed harvest effect sizes, contextualized our results within the literature, and suggested specific research that would further inform the interpretation of our results.

CRediT authorship contribution statement

Elliot M. Johnston: Writing – original draft, Visualization, Formal analysis, Conceptualization. **Hannah N. Mittelstaedt:** Writing – review & editing, Conceptualization. **Laura A. Braun:** Writing – review & editing, Conceptualization. **Jessica F. Muhlin:** Writing – review & editing, Conceptualization. **Brian J. Olsen:** Writing – review & editing, Conceptualization. **Hannah M. Webber:** Writing – review & editing, Conceptualization. **Amanda J. Klemmer:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The datasets and code supporting this manuscript are available from the corresponding author on reasonable request.

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