Spatial Variability of Kelp Growth in the Stefansson Sound Boulder Patch

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Introduction

In the 1970s, a rare area of rocky substrate was discovered in Stefansson Sound, adjacent to Prudhoe Bay, Alaska. While the silty and muddy benthos of the surrounding Alaskan Beaufort Sea has relatively low biomass, in the 'Boulder Patch' boulders and cobbles of varying sizes and densities allow for the dense growth of sessile invertebrates and macroalgae (Dunton et al. 1982). These macroalgae provide habitat and a basal food source that support a community that is relatively productive and diverse for the area (Dunton and Schell 1987).

The Boulder Patch has an area slightly greater than $20m^2$ (Fig. 1). The boulders and cobbles are derived from the Quaternary Gubik Formation, which is found on the Alaskan arctic coastal plain. Depth over the Boulder Patch ranges from 3 to 9 m. The mouth of the Sagavanirktok River lies approximately six miles southwest. Landfast ice usually forms in October, and breaks up in late June or early July. The prevailing current is from the east and is especially strong in the summer months, but is minimal during the nine months of ice cover.

The kelp *Laminaria solidungula* makes up >90% of the macroalgal biomass in the Boulder Patch. It has adapted to the arctic environment by creating storage products from photosynthesis during the ice-free summer, then utilizing them in growth during the dark, but relatively high-nutrient winter. The annual ovate growth segments of the *L. solidungula* thallus resulting from this growth pattern allow for measurement of multiple growth years (usually 3-4) from a single time of data collection (Fig. 2).

Kelp elongation (linear growth) data has been collected at multiple permanent sites in the Boulder Patch since the 1980's (Fig. 1). At each site, kelp is collected haphazardly by SCUBA divers and measured at the surface. While these growth measurements speak to the health of the kelp population, they can also act as a proxy for other factors.

Annual elongation depends largely on the amount of light each plant is exposed to, thus the long term dataset of annual growth also documents the spatial dynamics of water quality in the Boulder Patch (Dunton et al. 2009). In the mid 1980s, two oil drilling islands and a causeway were built adjacent to the Boulder Patch (location noted on Fig. 1). While this feature altered the spatial dynamics of currents and turbidity, there are no significant resulting effects on the biological community of the Boulder Path (Martin and Gallaway 1994, Dunton et al. 2009). However, climate change and further coastal development may affect this community in ways that can only be seen through long term monitoring.

The goal of this project is to determine the spatiotemporal variability of *L. solidungula* elongation. Patterns of growth in this kelp have implications for the overall primary production of this low-biomass region, and thus have implications for carbon uptake. Kelp growth also affects higher tropic levels, which utilize kelp carbon through multiple trophic pathways (Dunton and Schell 1987). Overall, this information acts as a baseline to evaluate future change.

Methods

Data collection: *Laminaria solidungula* plants were collected in the summer at long term study sites from the 1980s-1990 and from 1996-2011. The elongation for each corresponding growth year was recorded and eventually transcribed to an Excel table (see Table 1 for number of blade segments measured per site and corresponding growth year).

GIS Data Processing and Map Projection: I displayed XY coordinate data for each of the long term sites in ArcMap using NAD83 Alaska Albers Projection, and joined it to the table of long term kelp growth data by site name. I added a shapefile of the nearby land features for visual reference. I created a single shapefile delineating the areas containing hard substrate (the Boulder Patch area) using the 'Union' and 'Dissolve' tools on four separate shapefiles which delineated areas of different categories of percent cover of hard substrate. I also created a convex polygon that contained the Boulder Patch area.

From the kelp growth data, I created separate feature classes for each year. I then used the 'Spline with Barriers' tool to interpolate the data from the yearly feature classes over the convex polygon. From the resulting rater, I used 'Extract by Mask' with the Boulder Patch area shapefile to create the final rasters of interpolated kelp elongation over the Boulder Patch area. I used the same methodology with the undivided kelp elongation data to obtain a raster of average growth over time (time-averaged). I changed the display stretch range for all rasters from their default of minimum to maximum value to 2 to55 to aid in direct visual comparison. I created a time-series group animation that displayed the yearly rasters in sequence. All rasters had the default cell size of 90.776 m^2.

To demonstrate how these rasters could be used in productivity calculations, I used 'Zonal Statistics as Table' to obtain the sum of raster cells for the time-averaged interpolation. I also used 'Raster Calculator' to convert the time-averaged raster of elongation (in centimeters) to biomass (in grams) using the relationship from Dunton et al. (2009) (Fig. 3). I calculated the sum of the cells for this raster as well.

Statistics: I compared between-site differences in kelp growth using a one-way ANOVA in R, with post hoc comparisons done using Tukey HSD (R Core Team 2013).

Results and Discussion

Sites showed variable mean annual blade elongation over time, and there were similar patterns of relative high and low growth years among sites (Fig. 4). For example, all sites saw relatively high growth in 1985 and relatively low growth in 2003. The mean raster cell value per year plotted against the mean cell value for the time-averaged raster coincides with these trends, as 1985 and 2003 were the only years to fall notably far from the mean (Fig. 5). In 1985, the mean cell value for elongation was 41.414 ± 5.669 cm (range indicates standard deviation). In 2003, the mean was 7.277 ± 1.647 cm.

These between-year trends can also be seen in the raster time series images (Fig. 6). It should be noted that some years have more reliable spatial data than others due to the number of sites sampled per year (Table 1).

These year to year differences are due to differences in the amount of photosynthetic active radiation (PAR) that penetrates to depth, allowing *Laminaria solidungula* to photosynthesize. In the Boulder Patch, this variability is directly correlated to levels of suspended sediments, which diminish the light reaching the benthos in the summer months. The extremely low values seen in 2003 are result of high storm intensity that summer (Dunton et al 2009). Depth could also affect PAR, but previous studies indicate that turbidity has a much greater impact in ultimately determining kelp production in the Boulder Patch (Aumack et al 2007, Dunton et al. 2009).

The interpolated rasters show a general trend of relative high growth farther offshore, and low growth nearshore (Fig.s 6 and 7). The time-averaged raster shows that DS-11 and W-3 tend to have the greatest annual kelp elongation (Fig. 7). This reflects the results of the one-way ANOVA and Tukey HSD: DS-11 has annual kelp elongation values that are significantly different than those of E-1, E-2, L-1 and L-2 (Fig.8, α=0.05, p<0.05); W-3 has annual kelp elongation values that are significantly different than those of E-2, L-1 and L-2 (Fig. 8, α=0.05, p<0.05). This nearshore versus offshore difference in annual elongation agrees with Aumack et al. (2007), who found higher levels of suspended solids nearer the drilling islands.

Another emergent pattern is that some years have more 'even' elongation across sites than other years. For example, elongation in 1988 and 2003 appears more even than 1999 and 2006 (Fig. 6). This may be due to the different physical forces causing turbidity over the Boulder Patch: it may be that turbidity due to resuspension causes a more spatially similar light environment than that caused by land erosion. Differences in the causes of turbidity between years may therefore lead to differences in the spatial patterns of kelp elongation, which could in turn affect local food and habitat availability.

Time-averaged total elongation over the Boulder Patch area (the sum from 'Zonal Statistics as Table) was196,709 cm, and the time-averaged total biomass gain was 29,530 g.

Conclusions and Future Work

The spatiotemporal differences shown here demonstrate the large plasticity in annual blade elongation in *Laminaria solidungula*. Although other studies have reported annual elongation over time at these sites, this is the first to spatially interpolate that data over the actual Boulder Patch area.

These data could be even more ecologically relevant with the introduction of spatial density data. Future field work will involve determining the density of *L. solidungula* at the long-term study sites. This density data could then be spatially interpolated as described above. The resulting raster (units of individuals/m^2) could then be multiplied with rasters of recent annual biomass gain (units of g/individual) derived from elongation data to obtain an estimate of the total annual biomass production of *L. solidungula* from the sum of the output raster cells (units of g/m^2). Calculating the annual production of *L. solidungula* is important for deriving the carbon budget of the region, thus determining the relative importance of the Boulder Patch to regional food webs and carbon uptake. Further monitoring of the Boulder Patch will determine whether the effects of climate change and coastal development are detrimental to the productivity of this unique ecosystem.

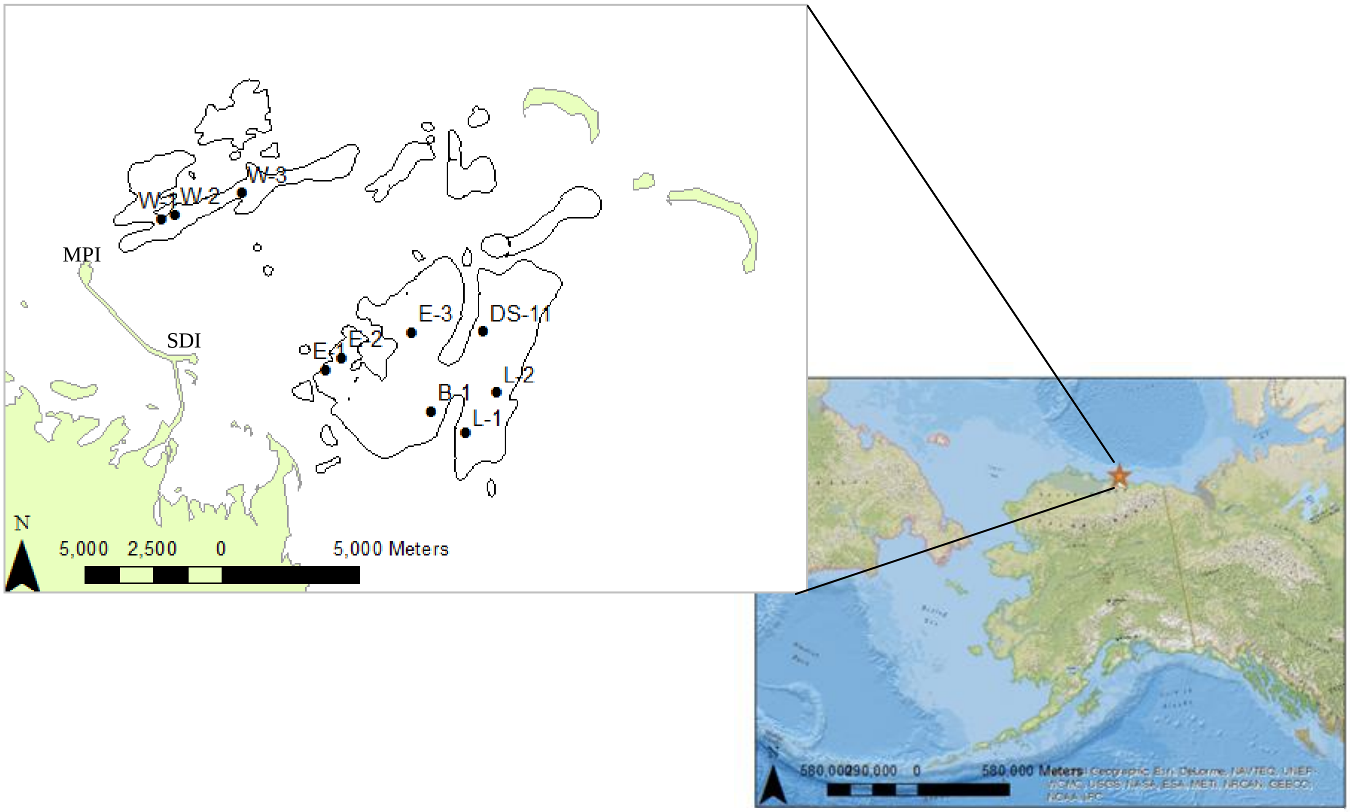


Figure 1. Location of the Boulder Patch in Alaska (black outlines), with long-term study site locations (labeled dots). MPI = Main Production Island. SDI = Satellite Drilling Island.

Figure 2. A rare *Laminaria solidungula* individual in which the oldest blade segment is still intact. The blade grows from the intersection of the stipe and the blade. Each ovate segment is a year of growth.

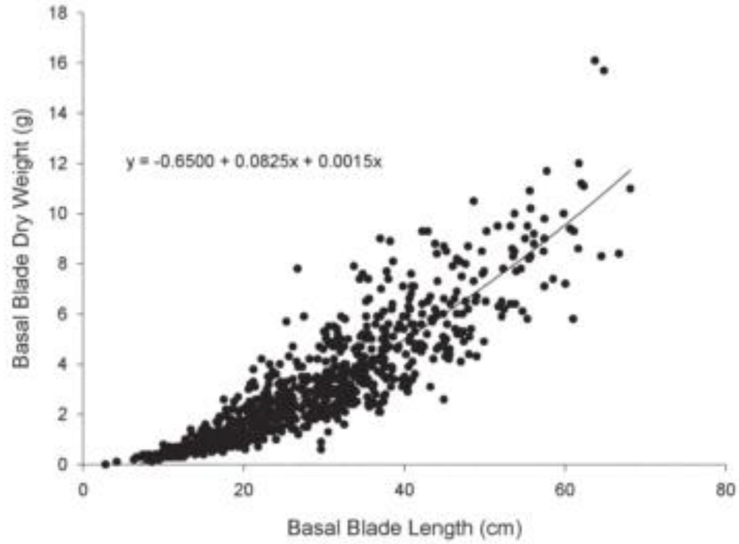


Figure 3. Relationship between *Laminaria solidungula* blade length and biomass from Dunton et al. (2009). Note that the equation should read:

$y = -0.6500 + 0.0825x + 0.0015x^2$

Table 1. Number of thallus sections measured at each site per corresponding growth year.

	W-1	W-3	E-1	E-2	E-3	DS-11	B-1	L-1	L-2
1981	52	15	55	40	31	43	-	-	-
1982	91	53	91	76	66	115	-	-	-
1983	71	57	67	85	76	99	-	-	-
1984	20	20	20	21	19	19	-	-	-
1985	40	40	40	42	38	40	-	-	-
1986	20	20	16	18	19	18	-	-	-
1987	20	18	18	18	19	17	-	-	-
1988	18	18	17	20	21	19	-	-	-
1989	18	19	20	18	20	17	-	-	-
1990	19	19	17	18	19	17	-	-	-
1996	-	-	2	6	4	2	12	8	-
1997	-	-	8	11	23	15	22	15	1
1998	-	-	19	40	41	28	36	38	19
1999	-	-	40	70	59	50	48	49	38
2000	1	1	45	80	64	61	52	57	51
2001	14	10	43	74	50	69	48	51	64
2002	73	19	70	92	64	88	93	83	73
2003	86	31	84	113	80	122	94	90	97
2004	65	38	82	88	64	90	79	74	89
2005	37	39	71	63	61	65	65	64	58
2006	-	-	39	37	40	33	32	30	35
2007	-	-	15	-	-	2	-	-	-
2008	-	-	27	-	-	9	-	-	-
2009	-	-	39	-	-	35	-	-	-
2010	-	-	50	-	-	64	-	-	-
2011	-	-	27	-	-	31	-	-	-

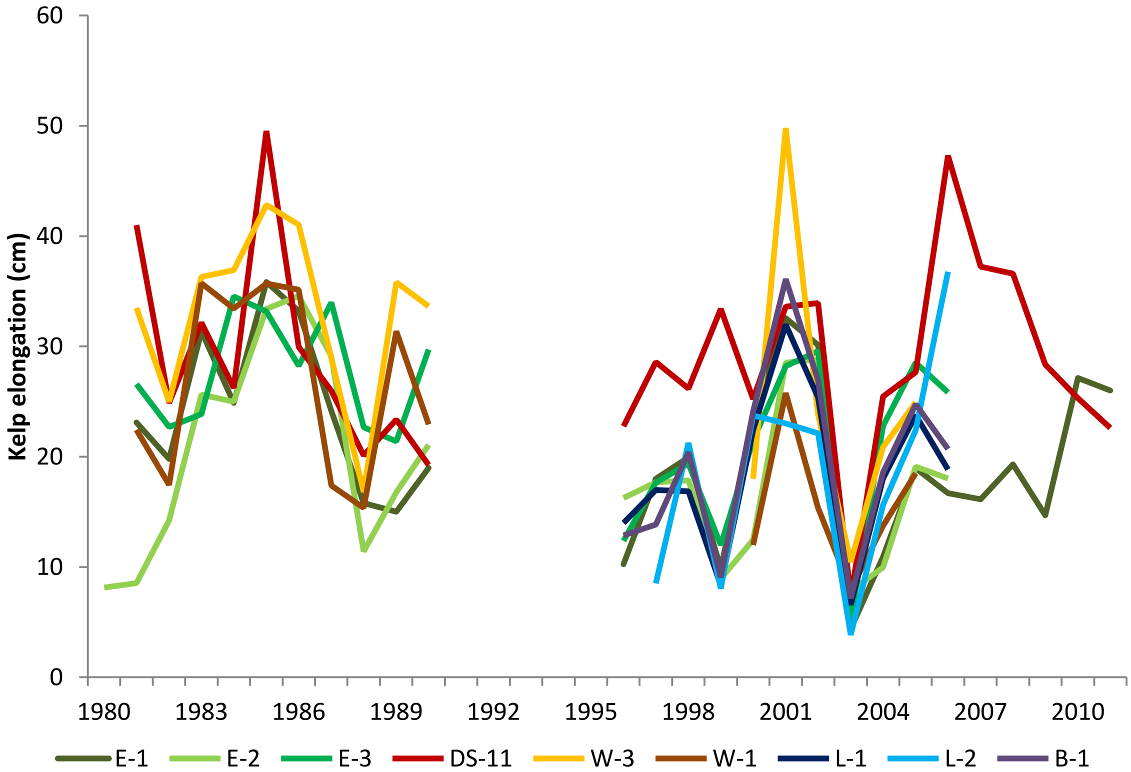


Figure 4. Kelp elongation per site over time.

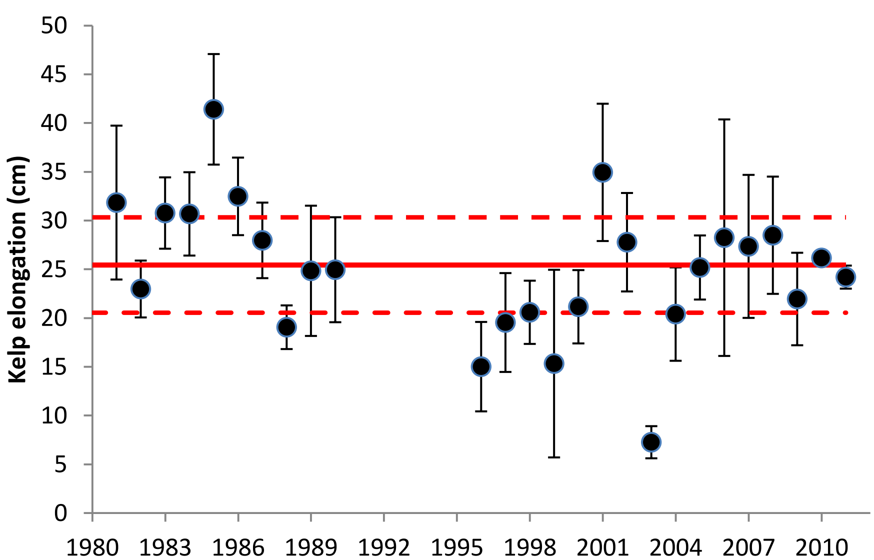
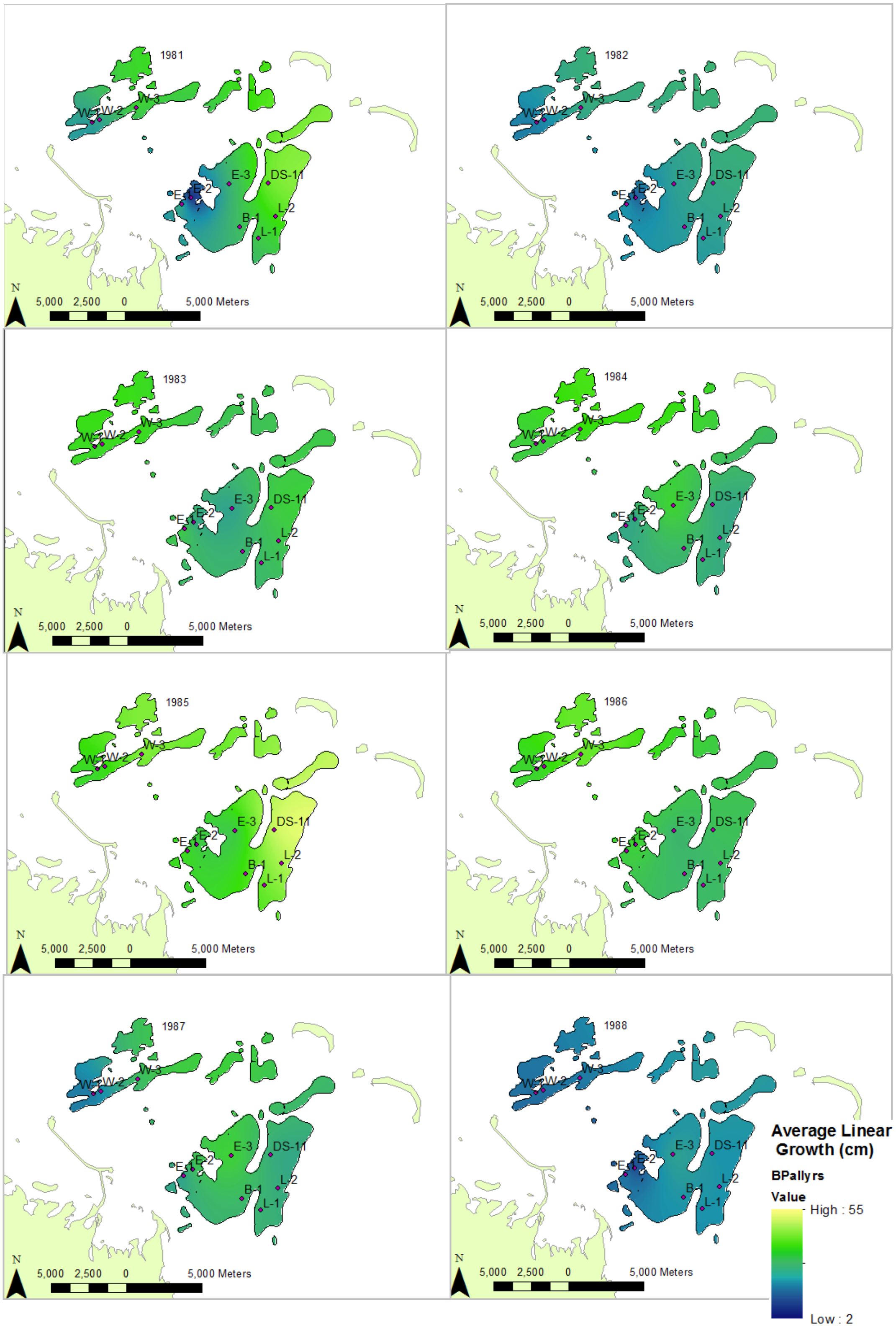
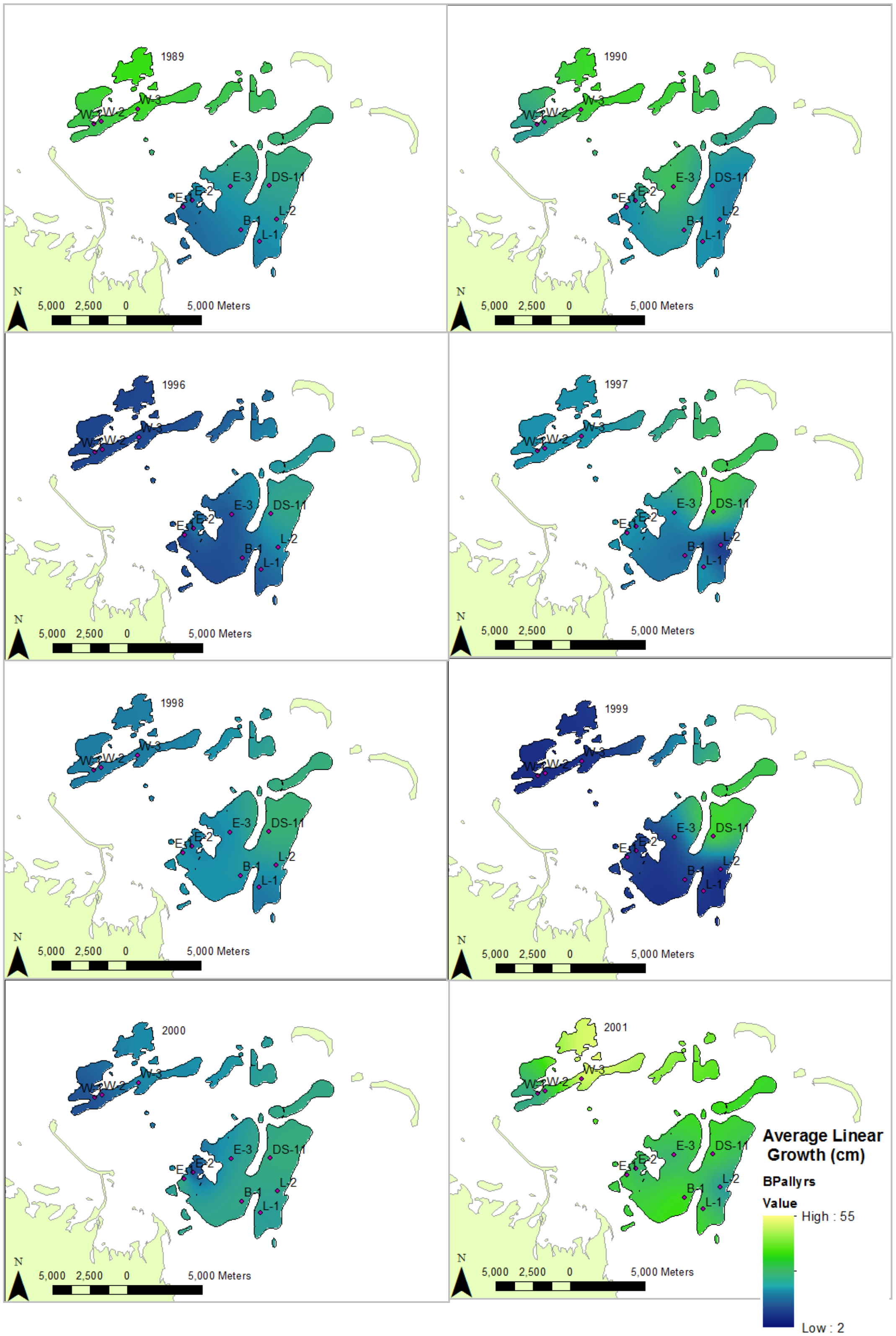


Figure 5. Mean cell value of kelp elongation raster over time (± 1 standard deviation). Solid red line is the time-averaged mean cell value. Dashed red lines are the time-averaged mean cell value ± 1 standard deviation.


1981
1982
1983
1984
1985
1986
1987
1988
W-1
W-2
W-3
E-1
E-2
E-3
DS-11
L-2
B-1
L-1
N
5,000 2,500 0 5,000 Meters
Average Linear Growth (cm)
BPallyrs
Value
High : 55
Low : 2


1989
1990
1996
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1998
1999
2000
2001
W-1
W-2
W-3
E-1
E-2
E-3
DS-11
B-1
L-1
L-2
N
5,000 2,500 0 5,000 Meters
Average Linear Growth (cm)
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Value
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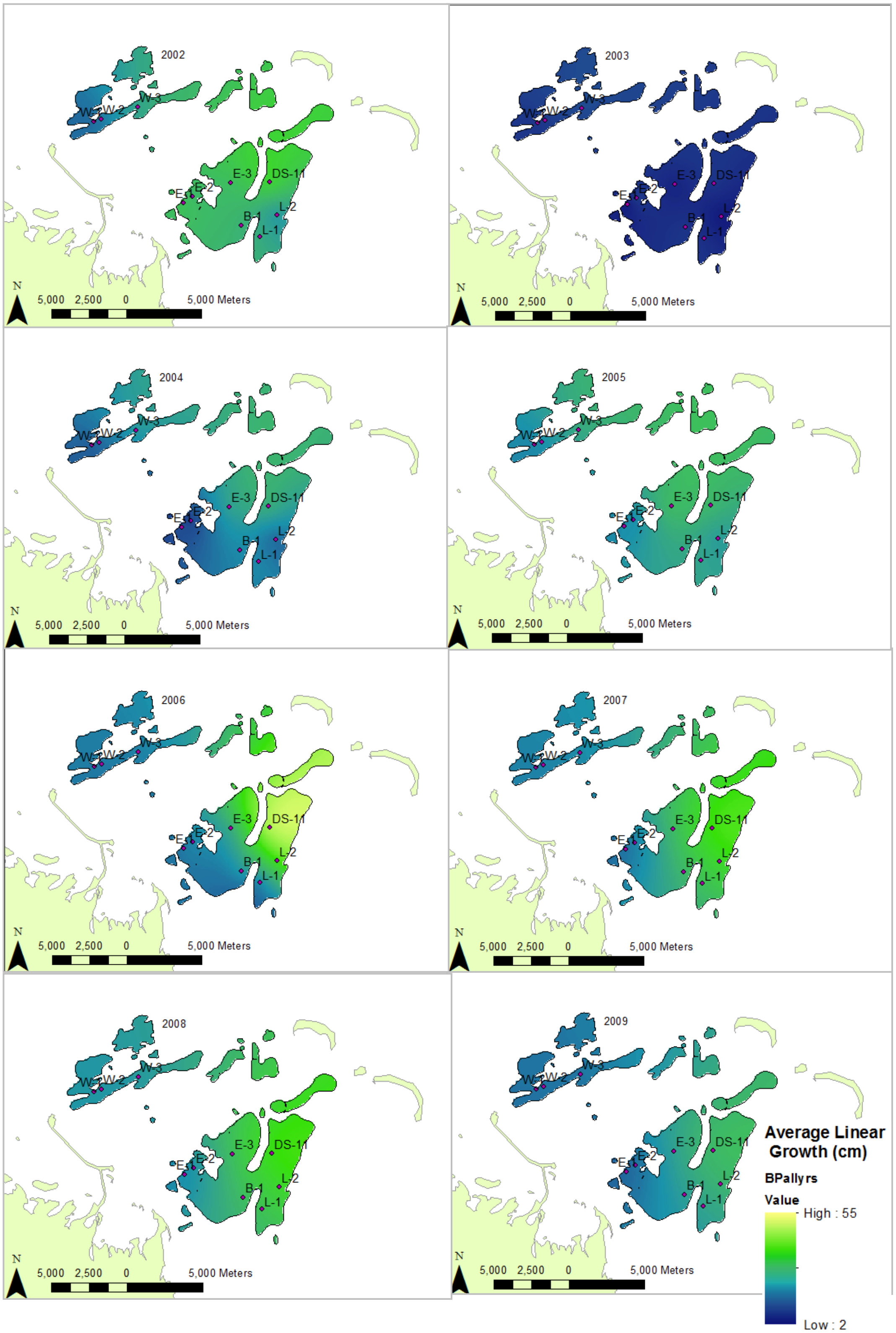
2002
2003
2004
2005
2006
2007
2008
2009
W-1
W-2
W-3
E-1
E-2
E-3
DS-11
B-1
L-1
L-2
N
5,000 2,500 0 5,000 Meters
Average Linear Growth (cm)
BPallyrs
Value
High : 55
Low : 2

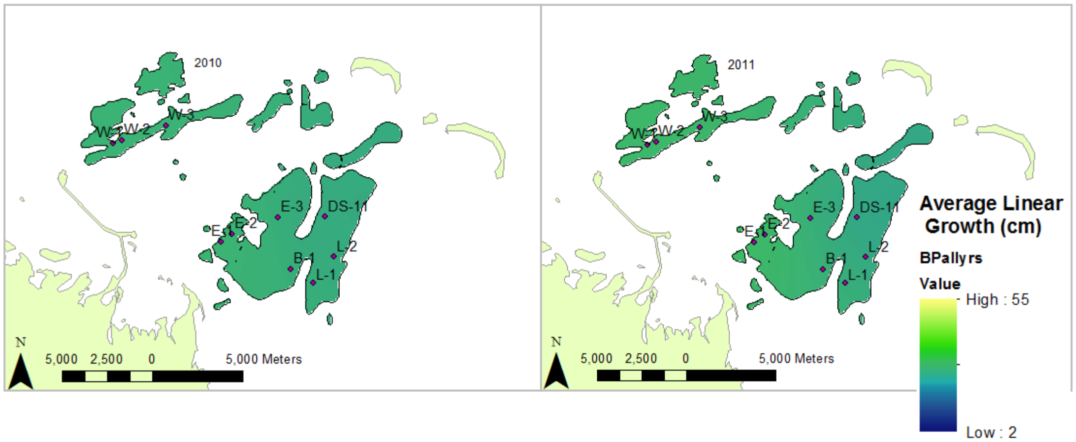

Figure 6 (also includes preceding three pages). Annual kelp elongation rasters, from spatially interpolated site data, 1981-1990 and 1996-2011. These rasters make up the time series animation.

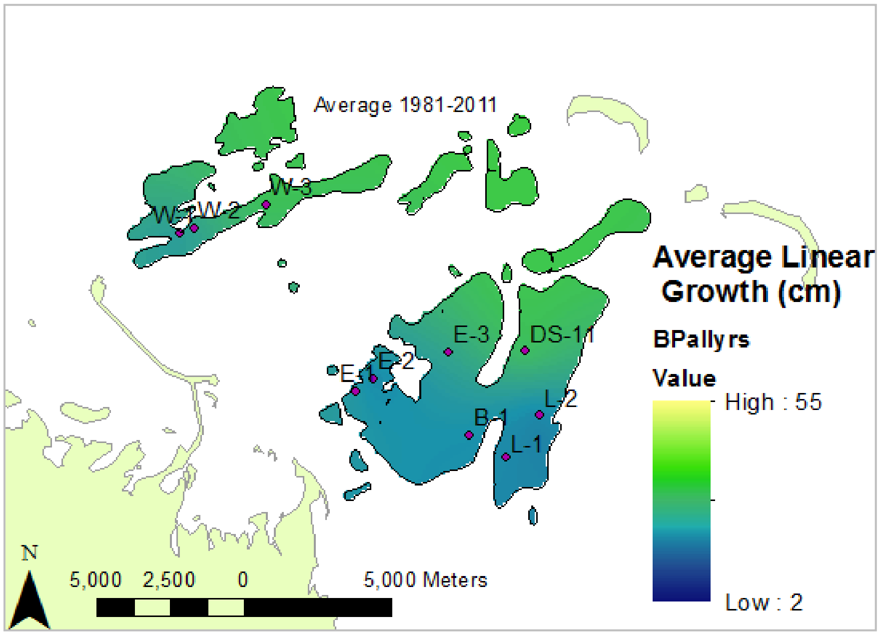

Figure 7. Time-averaged raster of kelp annual kelp elongation (linear growth).

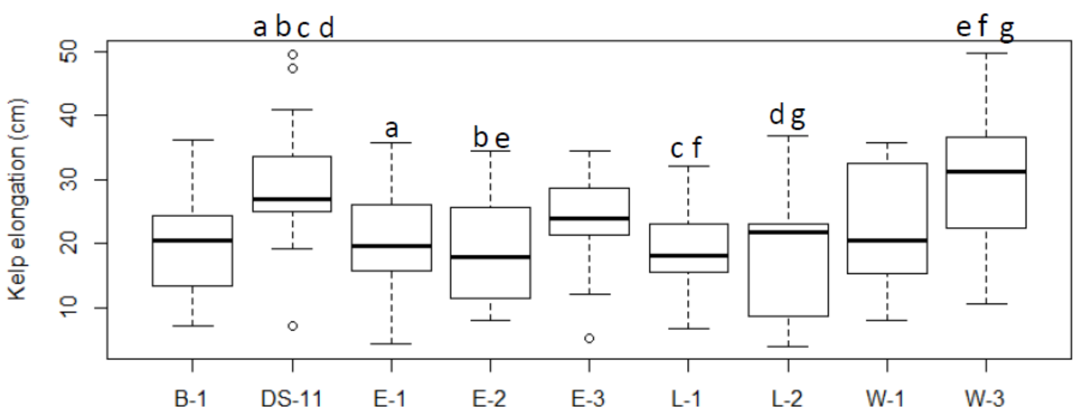

Figure 8. Boxplot comparing mean keep elongation over time between sites. Letters indicate sites that are significantly different from one another (α=0.05, *p*<0/05).

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Dunton, K. H., Reimnitz, E., & Schonberg, S. (1982). An Arctic kelp community in the Alaskan Beaufort Sea. *Arctic*. 35(4), 465-484.

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R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.