ELKHORN SLOUGH BANK EROSION MONITORING

Synthesis of results by Kerstin Wasson, October 2013

An ESNERR & MBNMS team visits about 30 permanent sites in the Slough to assess bank erosion rates. This monitoring has occurred since 2001.

We assess

- Distance from permanent stakes to bank
- Distance from permanent stake to vegetation edge
- Vegetation type and cover
- Cliff height
- Maximum Undercutting of cliff
- Hole density (small i.e. isopods; large i.e. crabs)

Highlights:

Bank erosion and landward vegetation movement continue to occur at high rates in the main channel and Parsons Slough entrance channel.

Things seem to have gotten a bit better overall since the early 1990s when Malzone monitored the banks.

There's been a lot of interannual variation in the past 12 yrs of monitoring, but few directional trends.

Vegetation is quite far back from bank edges at many sites, esp. in upper Slough. Vegetation movement and bank erosion don't seem as tightly coupled as we expected.

Crab holes don't seem to correlate with erosion or vegetation retreat.

ELKHORN SLOUGH
Rapid Biological Assessments

We also do a quick survey of what is living on the mudflats in front of the banks. Occasionally we conduct a formal community analysis of these data. For this year, a few highlights from quick perusal of the data will have to suffice:

FEWER SHELLS

We found unusually few shells in 2013 vs. earlier years. This could be due to lower abundance of bivalves, or lower otter consumption rates, or a hydrodynamic fluke (recent strong tides washed shells away). For example, here are total shells found for diff. spp:

	2011	**2013**
Butter clams	124	50
Gaper clams	45	15
Jackknife clams	419	17
Macoma spp	308	84

LESS CAULACANTHUS

We detected this invasive red turf alga at fewer sites in 2013 than previous years. Good news?

ELKHORN SLOUGH
Rapid Biological Assessments

INVADER NOT EXTINCT!

Susie found a Mya arenaria (soft-shell clam) shell at Long Valley that looked like it had been quite recently alive. This is our first confirmation that this invasive species, which I'd reported previously as locally extinct, is still alive and kicking, albeit in very low numbers. We had found it sporadically in earlier years, but thought they were old shells.

NEW SPECIES FOR SLOUGH!

Susie also found a new native snail species never reported from the Slough at Long Valley, Melampus olivaceus! Cool!

ALGAL IDS

Brent and Susie helped us ID some of our common fuzzy red and brown algae. They include the brown Ectocarpus and the reds Ceramium (distinctive banding, dichotomous branching) and Polysiphonia (no banding, irregular branching).

We'll keep lumping them disrespectfully as "fuzzy red-brown algae" though, because our rapid assessments in the field are too fast to allow for IDs at this fine scale.

TEMPORAL TRENDS: 2001-2013

Question:

Is bank erosion and vegetation retreat increasing, decreasing, or remaining steady over the decade that we have been conducting this monitoring? How are other bank attributes changing?

Approach:

Repeated measures ANOVA of annualized data. Since repeated measures only works if there are no blanks, I filled in missing years with average of years on either side.

Examined all 27 sites (including restricted, artificial berms, etc.) to get Sloughwide assessment, and also looked at just those 9 sites in the main channel with natural banks (this is probably what we're really interested in, excluding the berms, the Parsons complex, etc.).

Answer:

Bank erosion and vegetation movement are still very much happening in the Slough, around 30 cm/yr of loss.

Very few obvious directional trends over time in any of the measured parameters, though there is quite a bit of interannual variation. This might be useful for looking for correlations with annually varying factors, such as otter numbers, storminess, or algal cover.

2013 had more crab holes and lower cliffs than earlier years.

Note that data labels are for measurement years, but the rates apply to the previous period.

So erosion rate listed for 2009 is really the rate for the period spanning 2007-2009.

In most cases we had 2 yr intervals between sampling, but rates shown are all annualized to make for consistent comparisons.

Measurement	**period**
2002	2001-2002
2004	2002-2004
2005	2004-2005
2007	2005-2007
2009	2009-2011
2011	2009-2011
2013	2011-2013

In the text notes under graphs, if I refer to erosion being high in 2009, you need to keep in mind that this really means it was high 2007-2009.

BANK EROSION OVER TIME
at all sites

(This is change in distance from marker to bank edge, negative numbers are erosion)

No obvious directional trends over time.

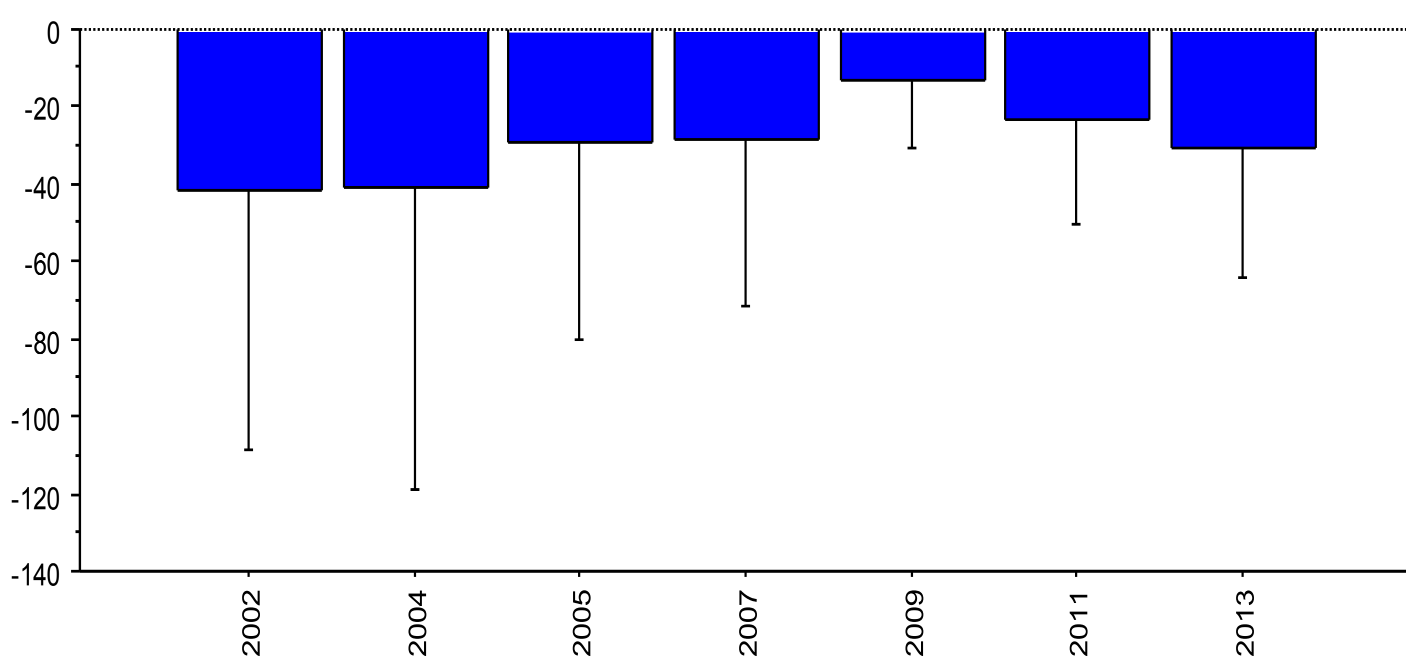
Erosion rates particularly high in early monitoring years, and particularly low in 2009.

Definitely still have very significant erosion rates, around 30 cm yr.

No observed benefit to Parsons sill (no decrease in last yrs)

ANOVA Table for bank erosion rate

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	26	182211.676	7008.141				
Category for bank erosion rate	6	15597.906	2599.651	1.516	.1763	9.094	.569
Category for bank erosion rate * Subject	156	267561.966	1715.141				



BANK EROSION OVER TIME
at 9 natural main channel sites

(This is change in distance from marker to bank edge, negative numbers are erosion)

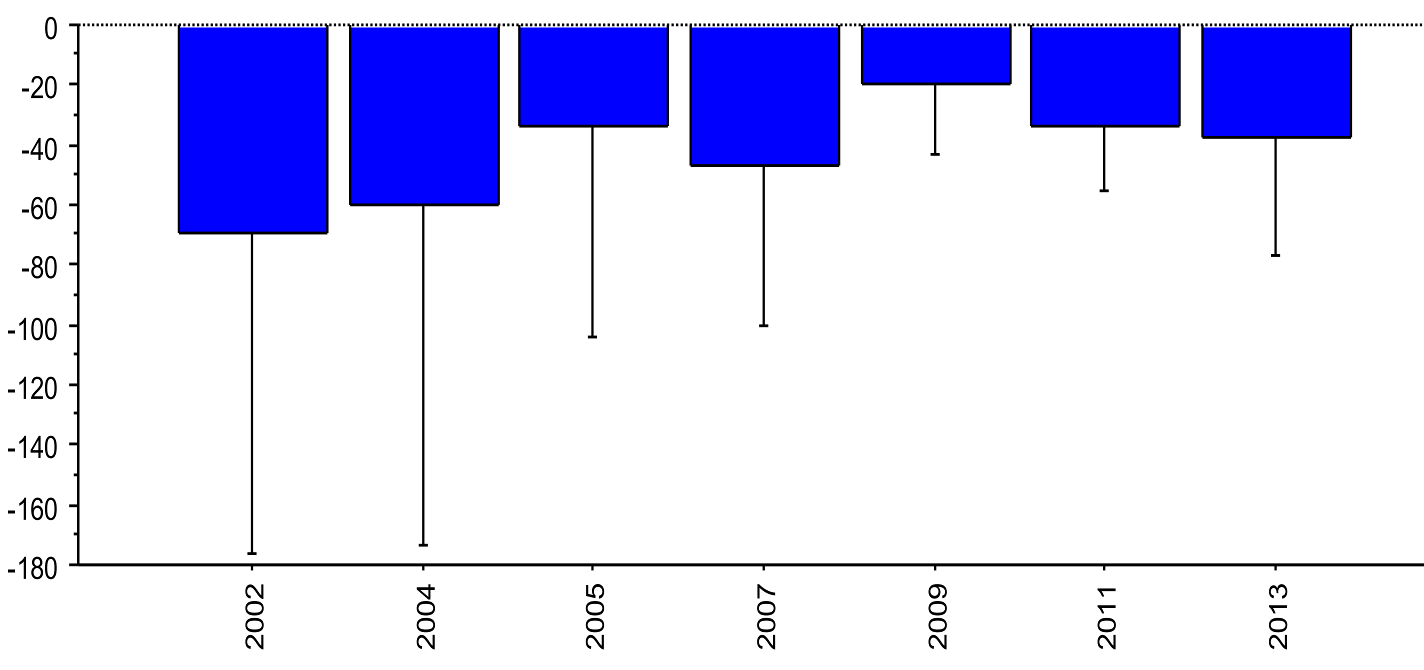
No obvious directional trends over time.

Erosion rates particularly high in early monitoring years, and particularly low in 2009.

Definitely still have very significant erosion rates, around 40 cm yr.

ANOVA Table for bank erosion rate
Row exclusion: repeated measures (imported)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	8	109819.896	13727.487				
Category for bank erosion rate	6	15799.360	2633.227	.757	.6072	4.541	.266
Category for bank erosion rate * Subject	48	167010.722	3479.390				



VEGETATION MOVEMENT RATE at all sites

(This is change in distance from marker to last live plant, negative numbers are landward movement)

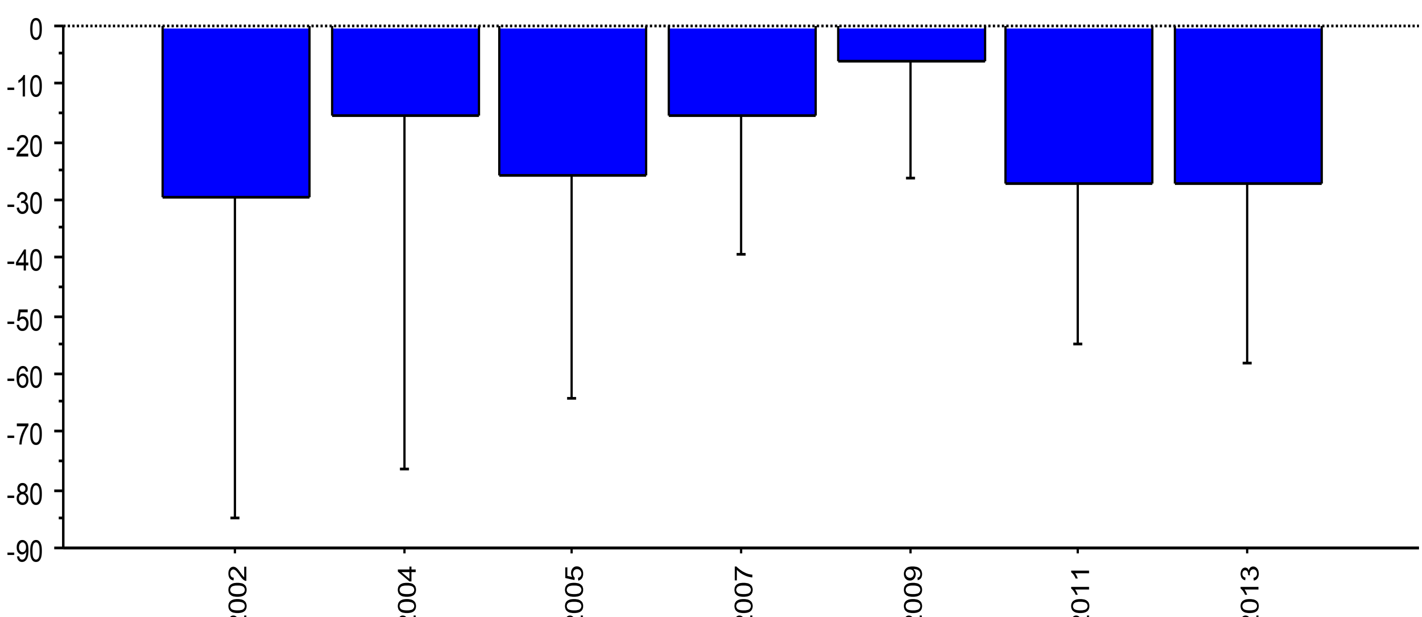
Fairly similar patterns to bank erosion, with 2009 having lowest rate of loss, and early and late years having higher rates.

No directional trends over time.

Definitely significant rates at which vegetation is being lost by moving backward from channels, around 30 cm/ yr.

ANOVA Table for vegetation loss rate

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	26	63628.514	2447.251				
Category for vegetation retreat rate	6	12245.967	2040.994	1.447	.2002	8.680	.545
Category for vegetation retreat rate * Su...	156	220095.530	1410.869				



VEGETATION MOVEMENT RATE
at 9 natural main channel sites

(This is change in distance from marker to last live plant, negative numbers are landward movement)

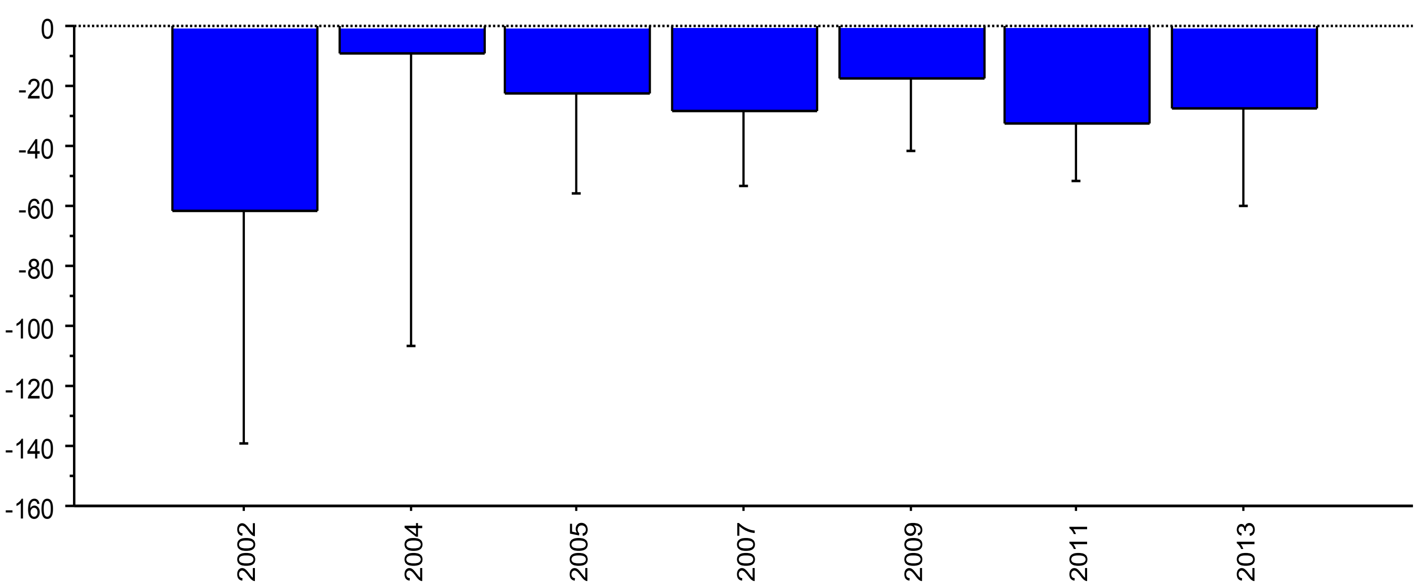
No directional trends over time.

Both 2004 and 2009 had low rates (former is diff than pattern for banks).

Definitely significant rates at which vegetation is being lost by moving backward from channels, around 30 cm/yr.

ANOVA Table for vegetation loss rate
Row exclusion: repeated measures (imported)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	8	25482.730	3185.341				
Category for vegetation retreat rate	6	14821.051	2470.175	.927	.4840	5.565	.325
Category for vegetation retreat rate * Su...	48	127846.875	2663.477				



DISTANCE BETWEEN BANK EDGE AND VEGETATION EDGE
at all sites

(This distance between vegetation edge and bank edge, positive numbers represent vegetation edge that is landward of bank edge)

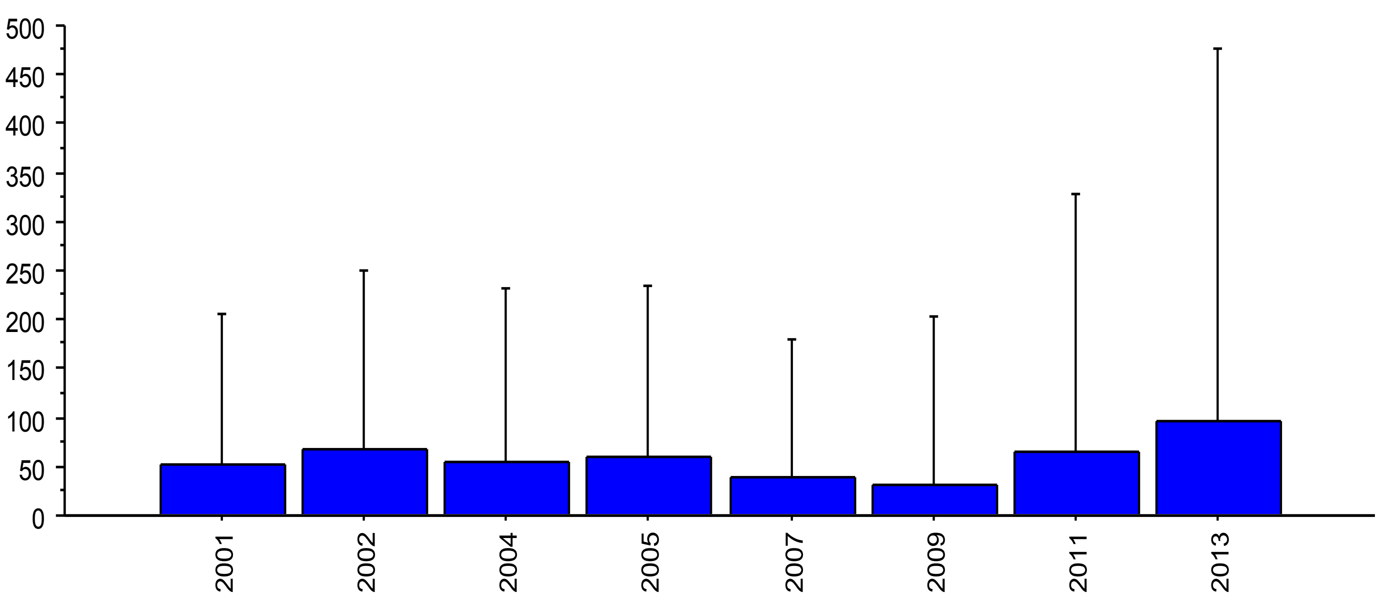
No directional trends over time.

On average, veg is back 50 cm or so from bank edge.

Distance was least in 2009, when bank erosion rates were lowest, maybe suggestive that bank erosion is hastened in years of high veg retreat (for instance due to high algal cover?)

ANOVA Table for distance from bank edge to veg edge

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	26	7307377.484	281052.980				
Category for distance from bank edge to...	7	70018.703	10002.672	.702	.6701	4.916	.293
Category for distance from bank edge to...	182	2592093.316	14242.271				



DISTANCE BETWEEN BANK EDGE AND VEGETATION EDGE

at 9 natural main channel sites

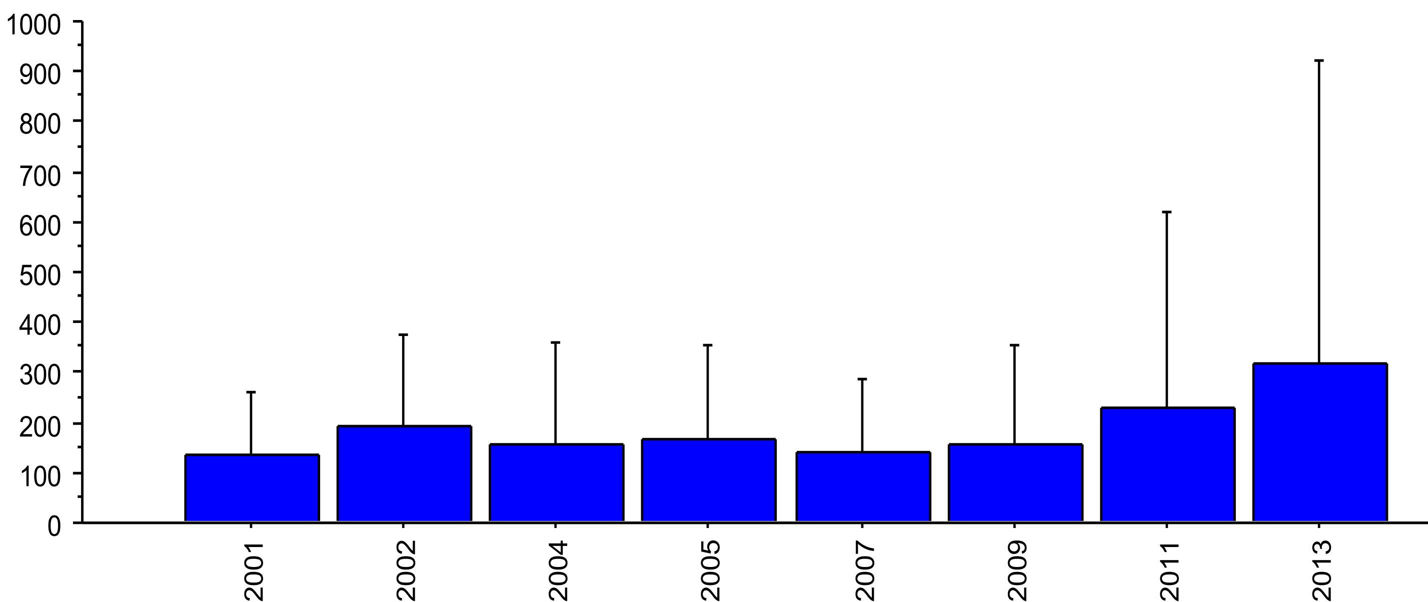
(This distance between vegetation edge and bank edge, positive numbers represent vegetation edge that is landward of bank edge)

No directional trends over time, but last two years had highest values on record, so perhaps distance is increasing?

Veg is back further from the edge at these site than average for all 27 sites: > 1 m

ANOVA Table for distance from bank edge to veg edge
Row exclusion: repeated measures (imported)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Pov
Subject	8	3448433.205	431054.151				
Category for distance from bank edge to...	7	234890.062	33555.723	.866	.5390	6.061	.
Category for distance from bank edge to...	56	2170245.712	38754.388				



VEGETATION RETREAT RATE
at all sites

(This is change in distance between vegetation edge and bank edge, positive numbers represent increases in this distance, negative numbers represent decreases.)

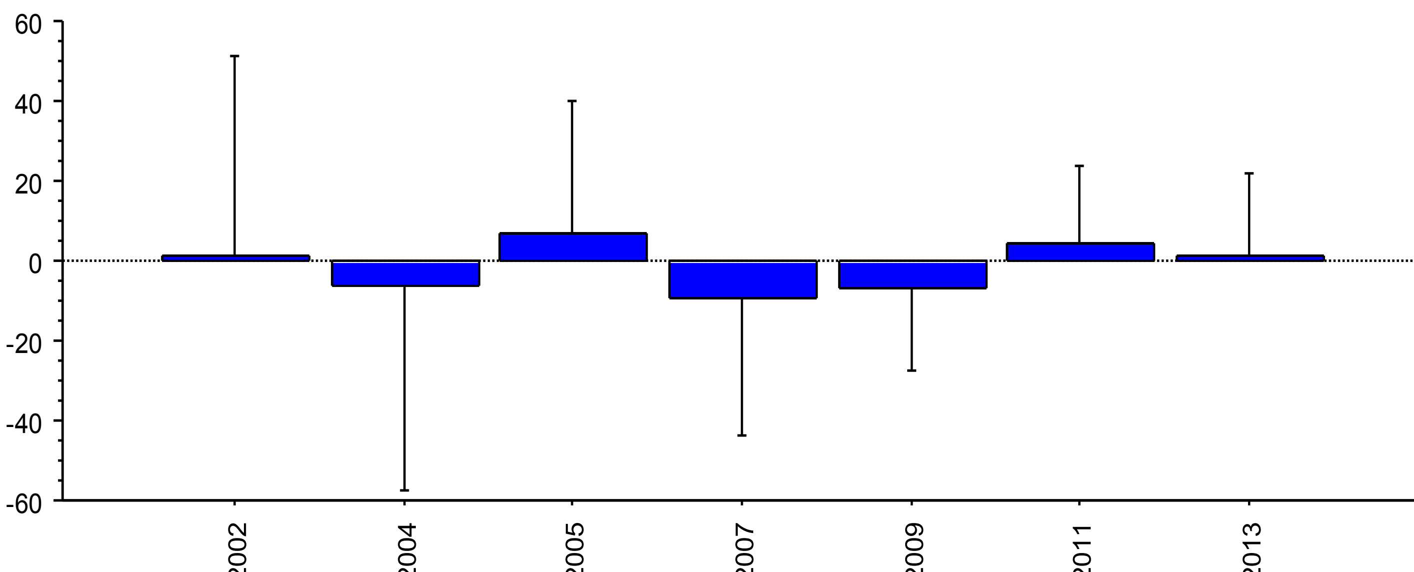
No directional trends over time.

Varies from slightly positive to slightly negative: can rule out trend of vegetation retreating faster from bank over time

Rates were particularly low in 2007-2009, when bank erosion rates were low, maybe suggestive that bank erosion is hastened in years of high veg retreat (for instance due to high algal cover?)

ANOVA Table for vegetation retreat from bank

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Powe
Subject	25	18485.640	739.426				
Category for vegetation retreat from bank	6	5844.022	974.004	.736	.6212	4.417	.28
Category for vegetation retreat from ban...	150	198440.791	1322.939				



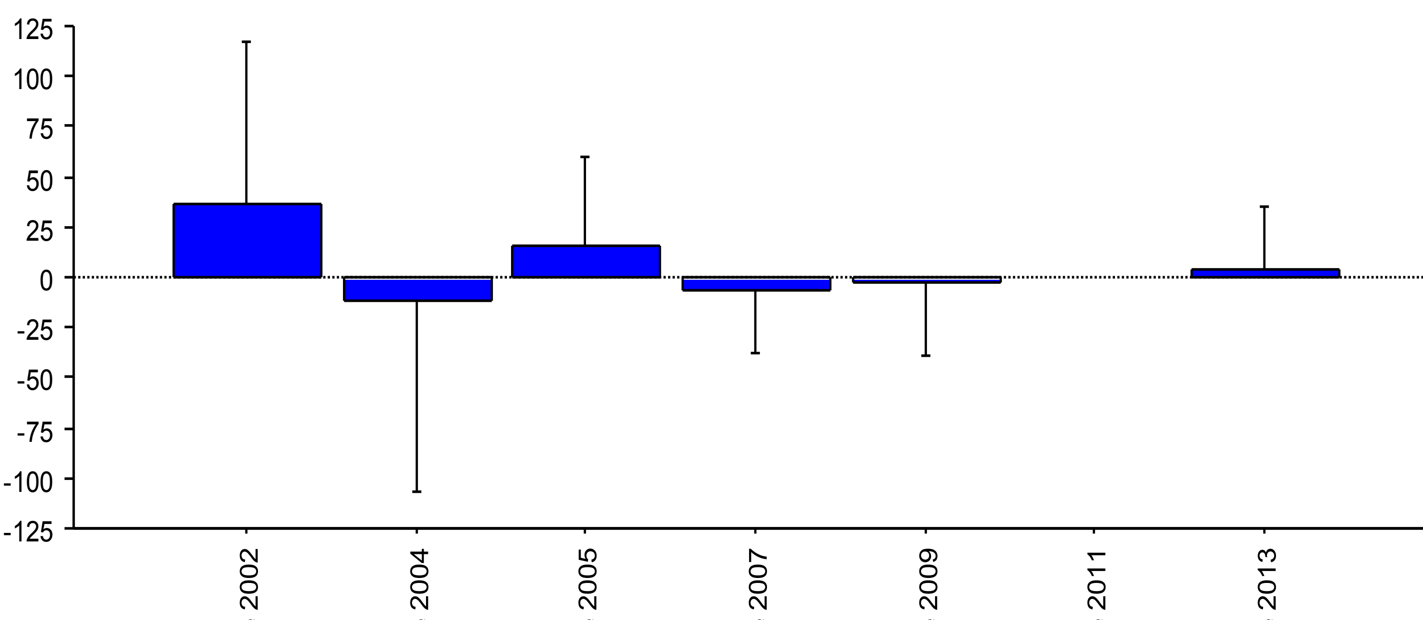
VEGETATION RETREAT RATE
at 9 natural main channel sites

(This is change in distance between vegetation edge and bank edge, positive numbers represent increases in this distance, negative numbers represent decreases.)

No directional trends over time.

ANOVA Table for vegetation retreat from bank
Row exclusion: repeated measures (imported)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Pow er
Subject	7	9438.881	1348.412				
Category for vegetation retreat from bank	6	12682.366	2113.728	.646	.6931	3.875	.225
Category for vegetation retreat from ban...	42	137475.181	3273.219				

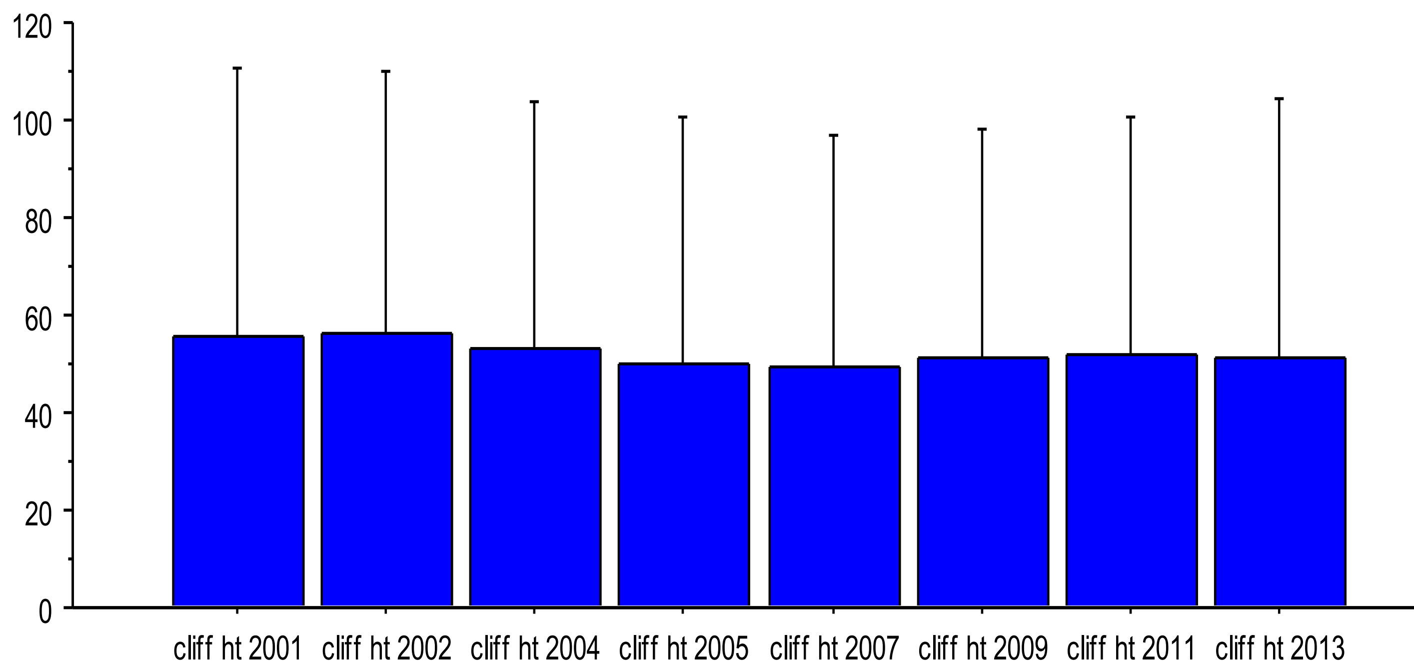


CLIFF HEIGHT
at all sites

No directional trends over time.

ANOVA Table for cliff height

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	26	505750.448	19451.940				
Category for cliff height	7	1193.023	170.432	.983	.4449	6.883	.411
Category for cliff height * Subject	182	31546.751	173.334				

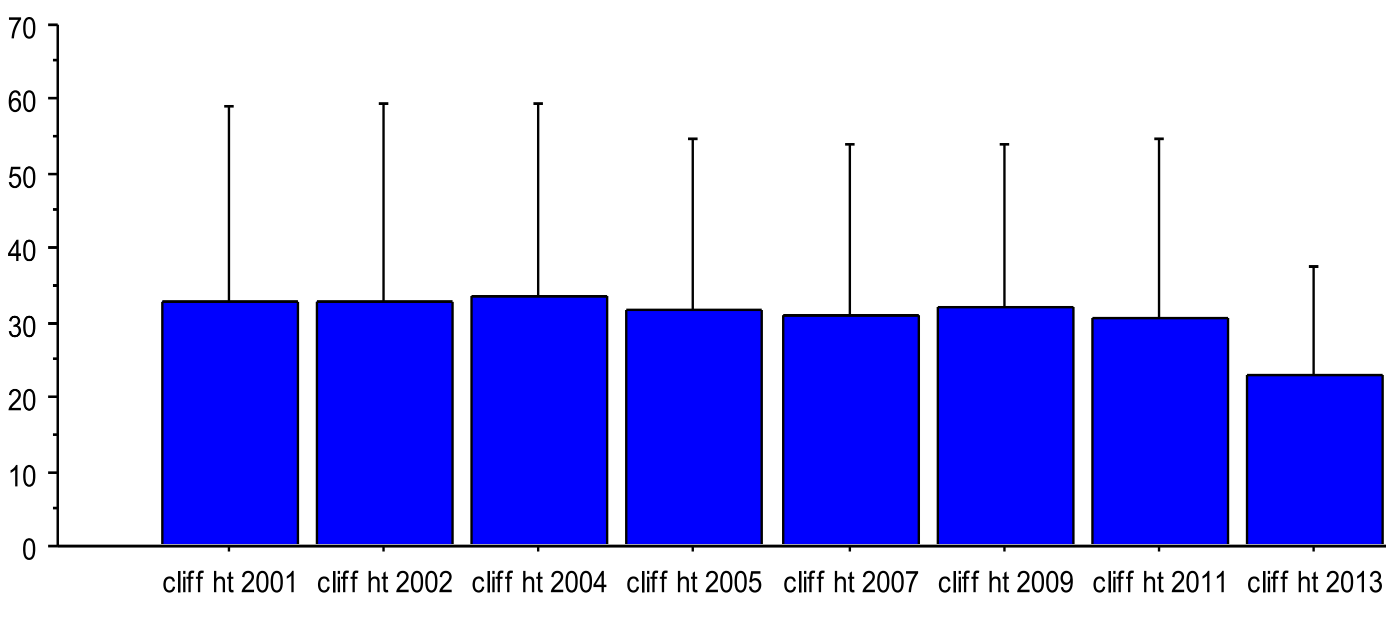


CLIFF HEIGHT
at 9 natural main channel sites

No directional trends over time, except for odd pattern of decrease in 2013. What's up with that?

ANOVA Table for cliff height
Row exclusion: repeated measures (imported)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	8	31940.750	3992.594				
Category for cliff height	7	702.500	100.357	1.787	.1081	12.508	.666
Category for cliff height * Subject	56	3145.250	56.165				

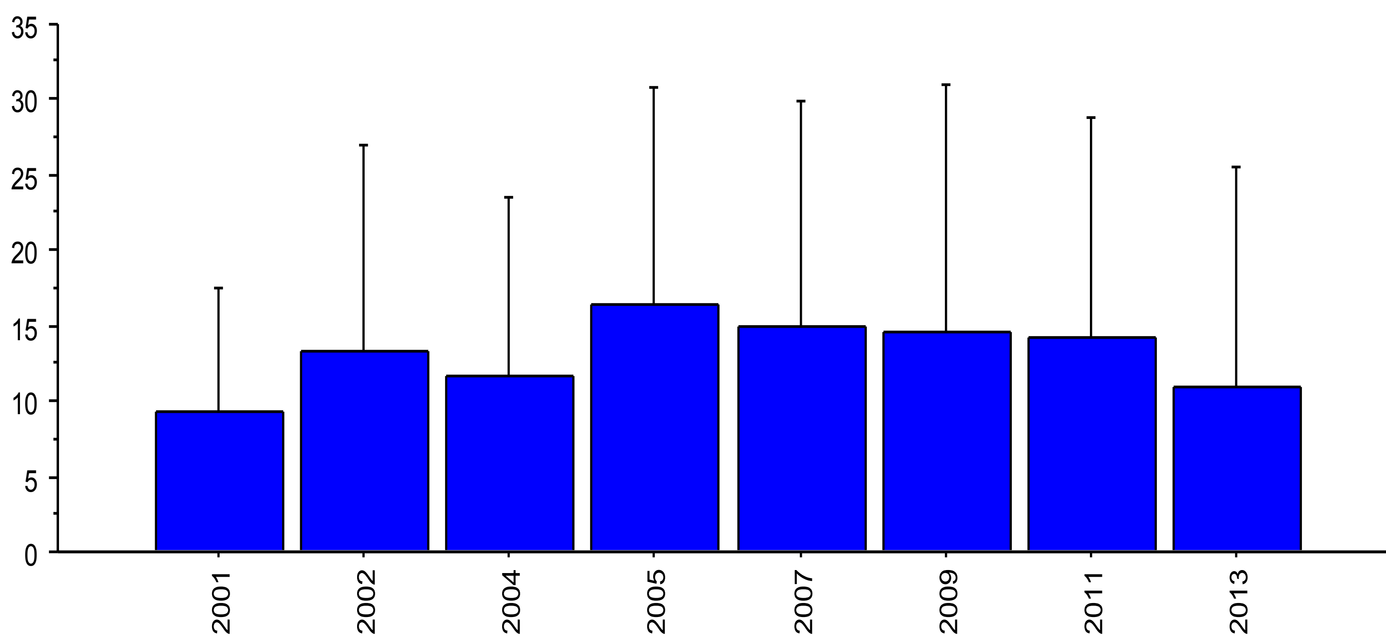


UNDERCUT
at all sites

No directional trends over time.

ANOVA Table for undercut

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Pow er
Subject	26	23347.329	897.974				
Category for undercut	7	1049.352	149.907	1.710	.1091	11.970	.687
Category for undercut * Subject	182	15954.523	87.662				



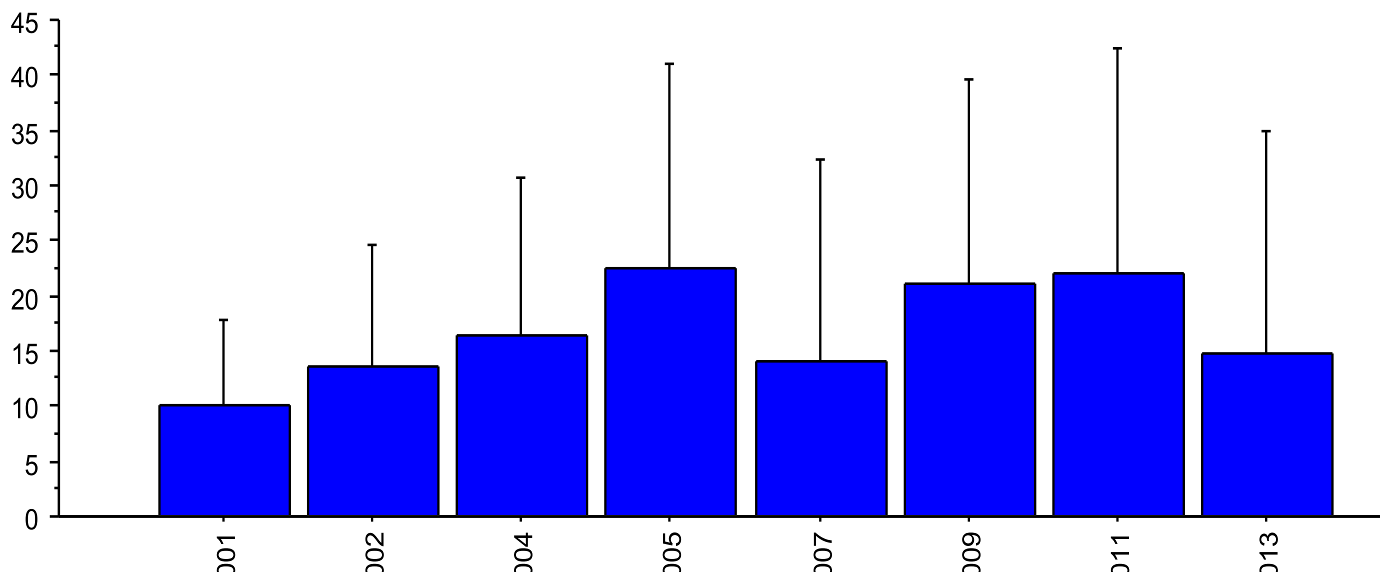
UNDERCUT
at 9 natural main channel sites

No directional trends over time.

Years with worst erosion are definitely not ones with highest undercut.

ANOVA Table for undercut
Row exclusion: repeated measures (imported)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	8	11319.278	1414.910				
Category for undercut	7	1307.778	186.825	1.612	.1512	11.281	.610
Category for undercut * Subject	56	6492.222	115.933				



SMALL HOLES
at all sites

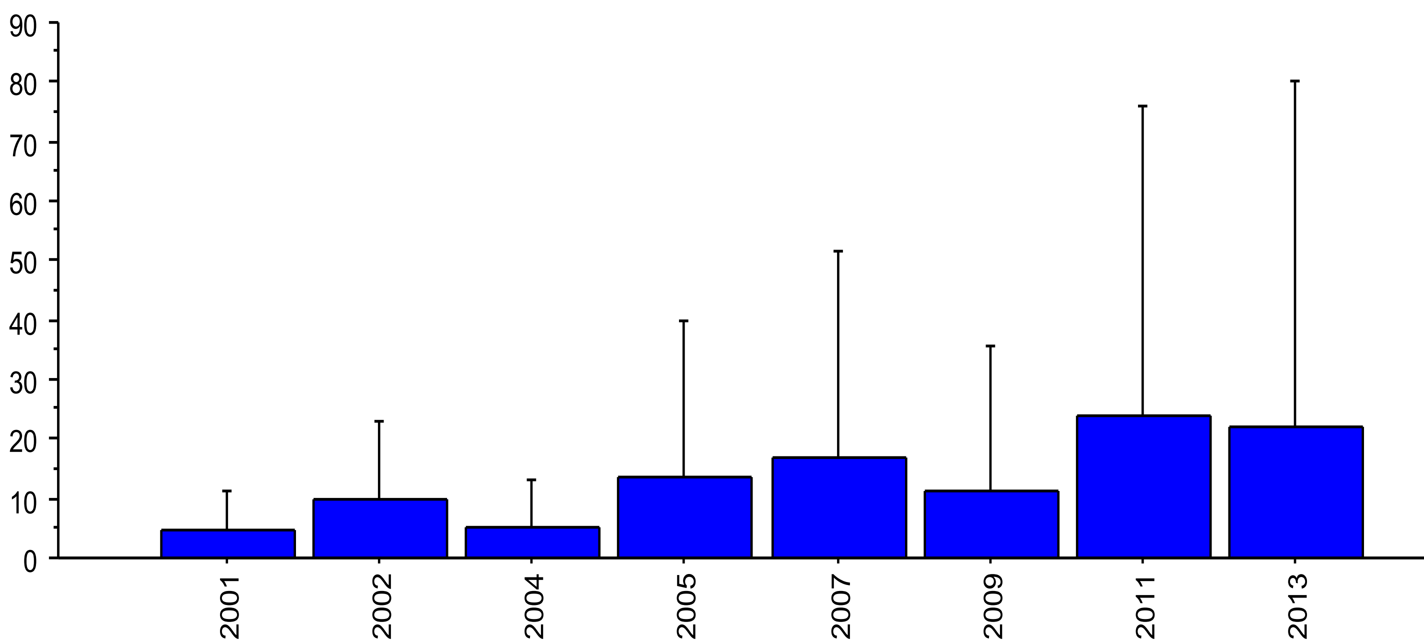
(Holes 1 cm or less, likely to be Spheroma, though maybe includes some tiny crabs?)

Increase over time, but high variance.

Some early years sig. lower than some late years.

ANOVA Table for small holes

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	26	113492.426	4365.093				
Category for small holes	7	9625.091	1375.013	2.156	.0401	15.091	.808
Category for small holes * Subject	182	116080.315	637.804				



SMALL HOLES
at 9 natural main channel sites

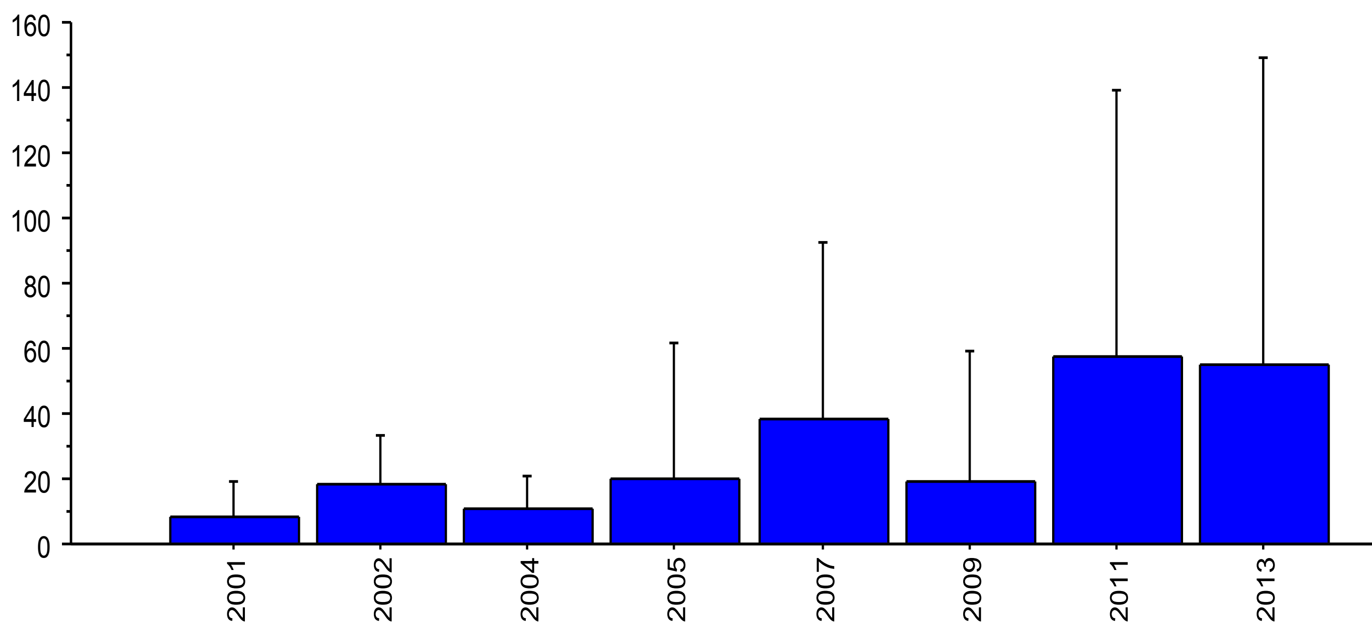
(Holes 1 cm or less, likely to be Spheroma, though maybe includes some tiny crabs?)

Increase over time, but high variance.

Some early years sig. lower than some late years.

ANOVA Table for small holes
Row exclusion: repeated measures (imported)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	8	83824.674	10478.084				
Category for small holes	7	23276.108	3325.158	1.933	.0812	13.532	.708
Category for small holes * Subject	56	96322.549	1720.046				



LARGE HOLES
at all sites

(Holes > 1cm, likely to be grapsid crabs)

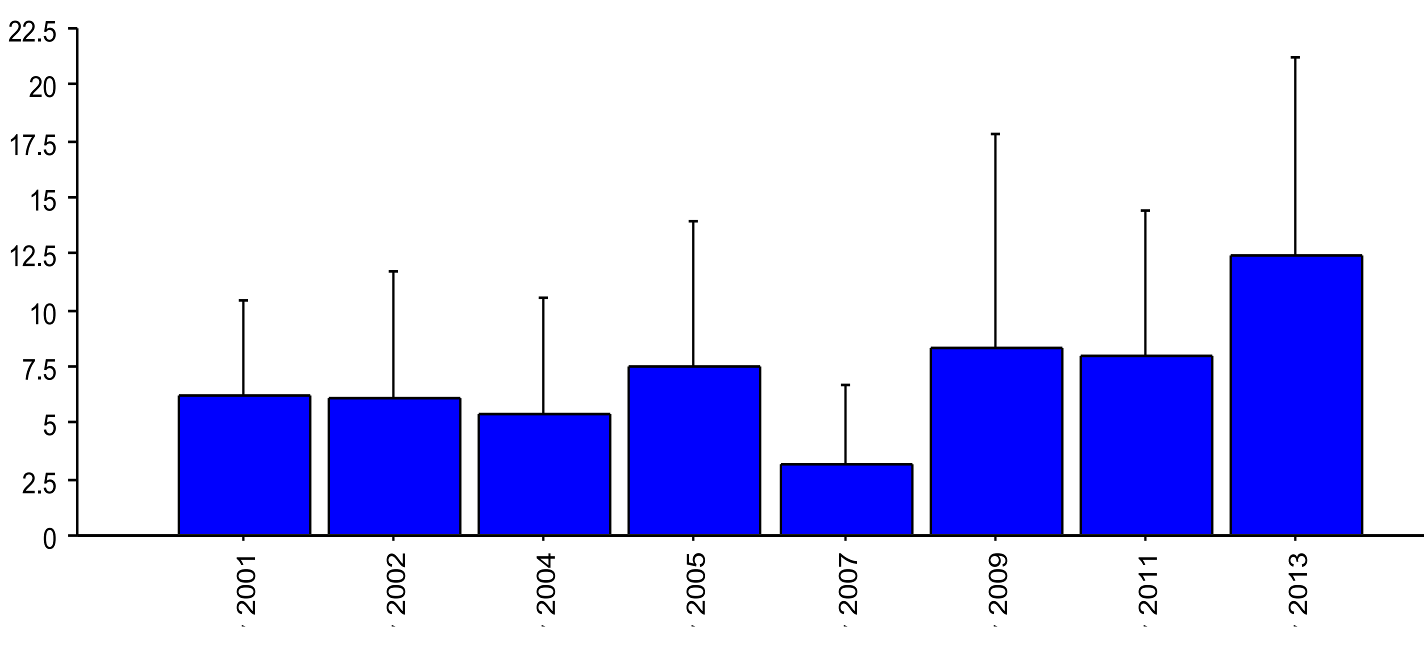
Particularly high in 2013, particularly low in 2007.

Lots of variance, so hard to say if there is a directional trend over time, but last 3 periods have been highest, so looks like a trend towards increase.

No clear correlation with otter numbers in estuary or with rates of bank erosion.

ANOVA Table for large holes

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	26	5038.502	193.789				
Category for large holes	7	1374.073	196.296	9.396	<.0001	65.774	1.000
Category for large holes * Subject	182	3802.146	20.891				



LARGE HOLES
at 9 natural main channel sites

(Holes > 1cm, likely to be grapsid crabs)

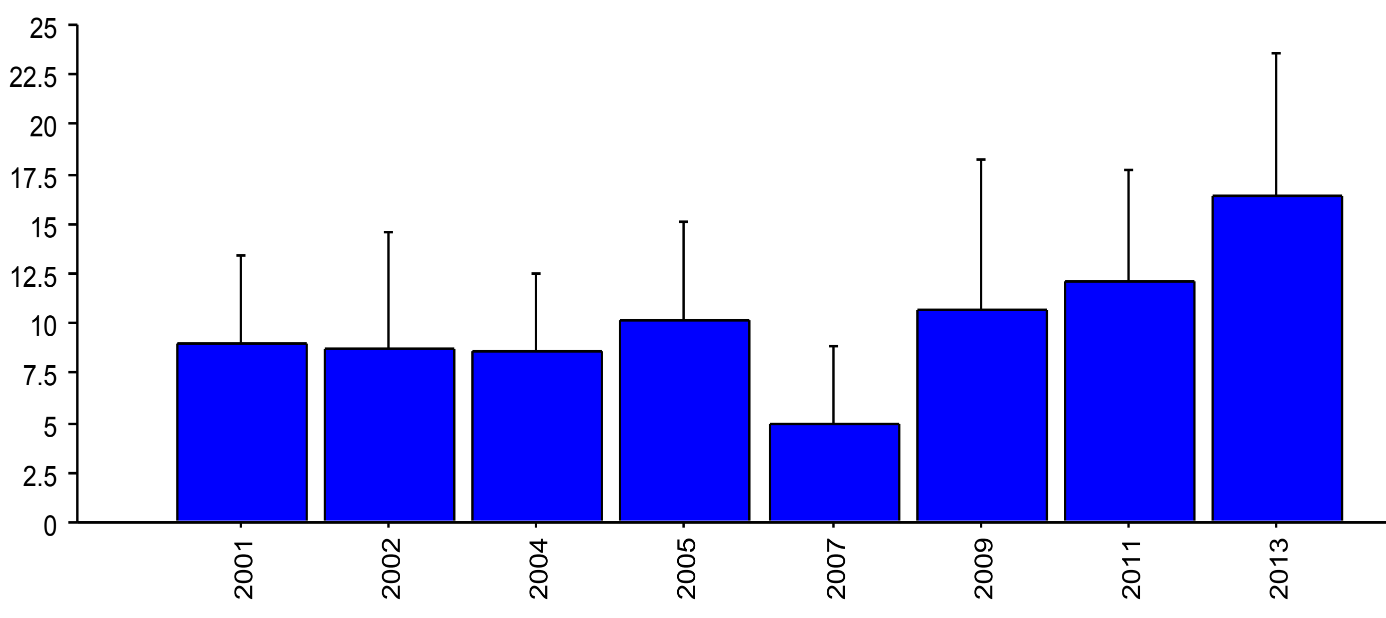
Particularly high in 2013, particularly low in 2007.

Lots of variance, so hard to say if there is a directional trend over time, but last 3 periods have been highest, so looks like a trend towards increase.

No clear correlation with otter numbers in estuary or with rates of bank erosion.

ANOVA Table for large holes
Row exclusion: repeated measures (imported)

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Subject	8	550.778	68.847				
Category for large holes	7	682.944	97.563	3.723	.0022	26.060	.966
Category for large holes * Subject	56	1467.556	26.206				



REGIONAL TRENDS

Question:

Is bank erosion and vegetation loss faster in some regions of the Slough than others? How do other bank attributes differ across Slough regions? Do temporal trends differ by Slough region?

Approach:

- Bank erosion and veg loss rate was graphed (no stats) by site, using the average across all years.
- Conducted normal one-way ANOVA on averaged bank erosion rate across all years (2001-2013), with region as factor.
- Conducted repeated measures ANOVA as described in previous section, but separated data by Slough region.

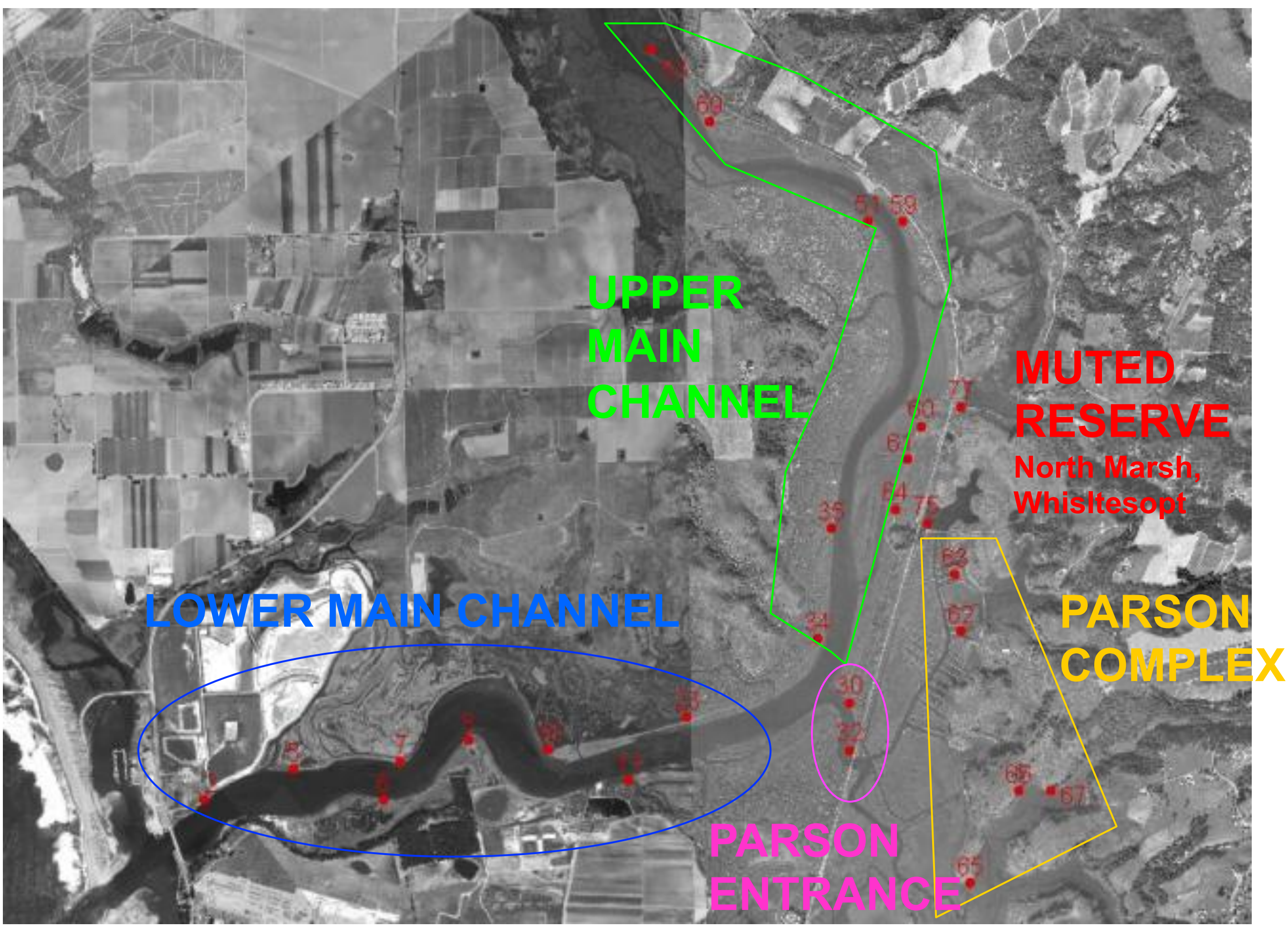
Answer:

Yes, there are strong spatial patterns: really high bank erosion and vegetation loss rates in Parson's entrance, moderate in main channel, and low in Parsons complex and muted sites. Vegetation is further landward from bank edge in upper Slough. Cliffs are high and burrow holes are more common in Parsons entrance and upper Slough. Parsons entrance is most undercut region.

Temporal trends are also different across Slough regions.Rapid erosion rates at Parsons seem to be slowing (on this northern bank where we monitor, at least). Vegetation seems to be moving further landward from bank edge in upper Slough over time. Burrow holes are increasing in most Slough regions, but particularly upper.

REGION

I divided sites up as shown below, to look for differences by region.

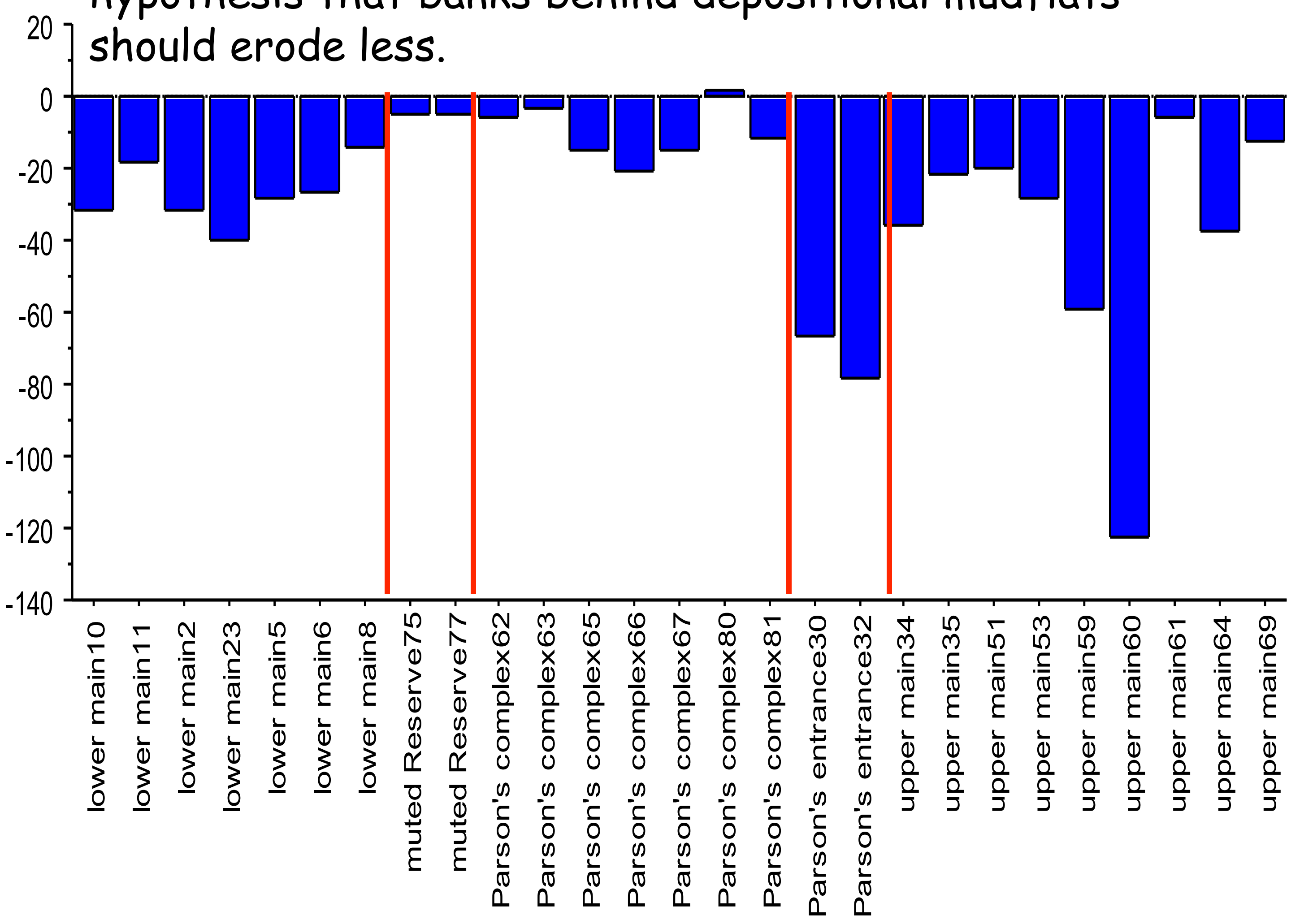


BANK EROSION BY SITE

Quite a bit of variability among sites within a region, even using average of 2001-2013 data, which should decrease the role of single calving events.

Site 60, the record breaking site averaging 1.2 m of bank erosion per year, is the one on Coyote Peninsula that Steve Lonhart has been checking for the past years. Site 59 is the next closest site, south of Kirby Dock area, and also has a very high erosion rate,

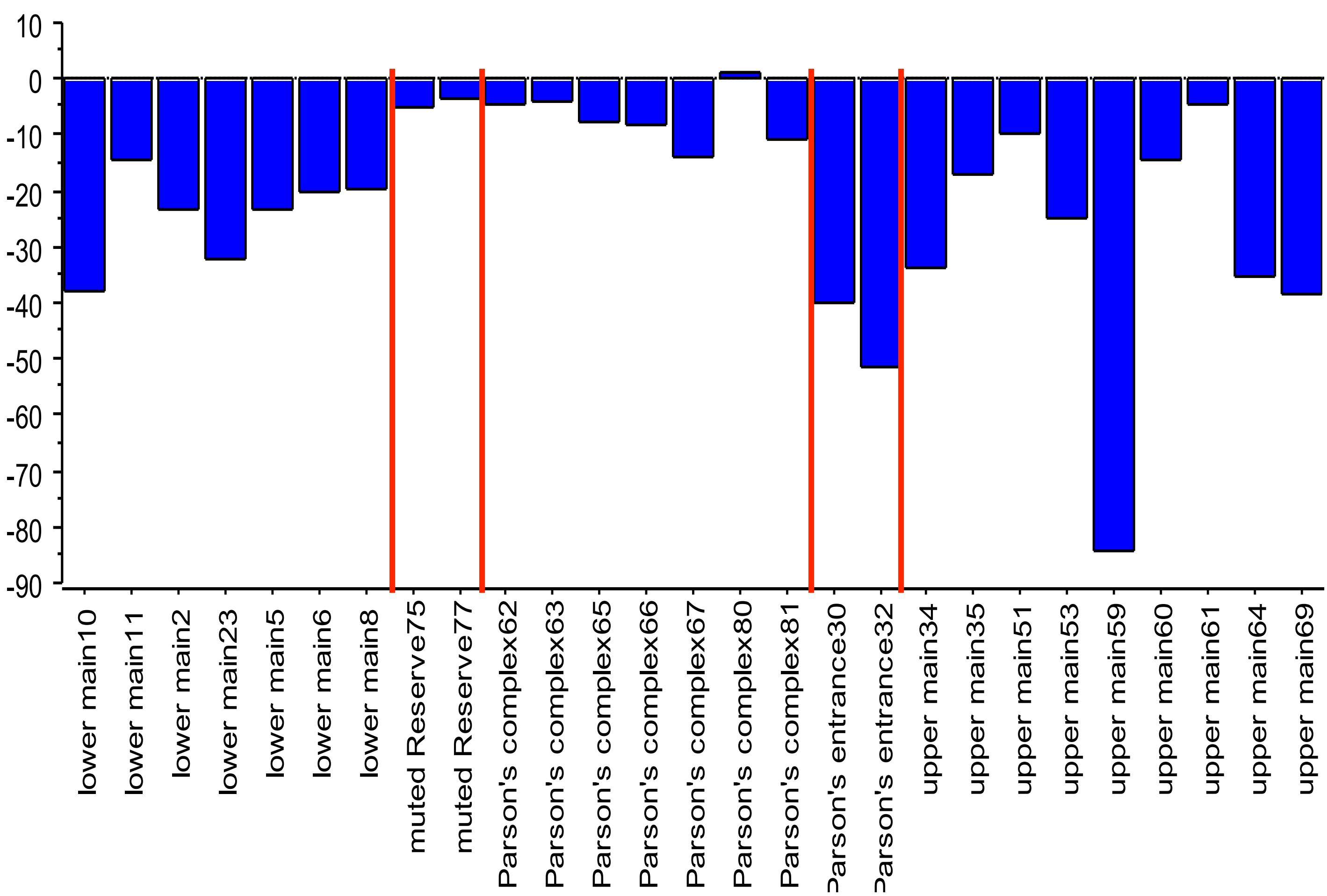
Site 23 in lower Slough is one with a huge fluffy mudflat in front of it, so that doesn't support my hypothesis that banks behind depositional mudflats should erode less.



VEGETATION MOVEMENT BY SITE

Fairly similar to patterns of bank erosion.

In this case however Site 59 (south of Kirby) is the big loser, with an average of over 80 cm/yr of vegetation migration landward. Site 69 north of Kirby also has high rate of veg movement, but not as high rate of bank erosion.



BANK EROSION BY REGION

Highest in Parsons entrance channel;

next highest in main channel esp. upper;

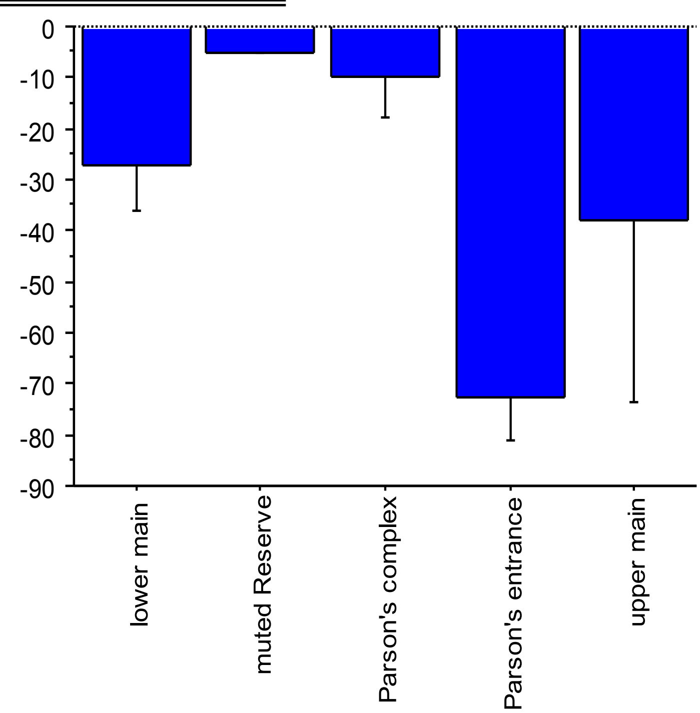
low in Parsons complex and muted sites

ANOVA Table for ann. change in d to edge 2002-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Pow er
region	4	8221.954	2055.488	4.160	.0117	16.642	.855
Residual	22	10869.159	494.053				

Means Table for ann. change in d to edge 2002-2013
Effect: region
Row exclusion: erosion 2013 stats regression reg anova.svd

	Count	Mean	Std. Dev.	Std. Err.
low er main	7	-27.227	8.723	3.297
muted Reserve	2	-5.066	.153	.108
Parson's complex	7	-10.021	7.913	2.991
Parson's entrance	2	-72.595	8.564	6.055
upper main	9	-38.144	35.291	11.764



BANK EROSION BY REGION OVER TIME

Lower main: no clear temporal trends, but highest 2013

Muted Reserve: no clear temporal trends

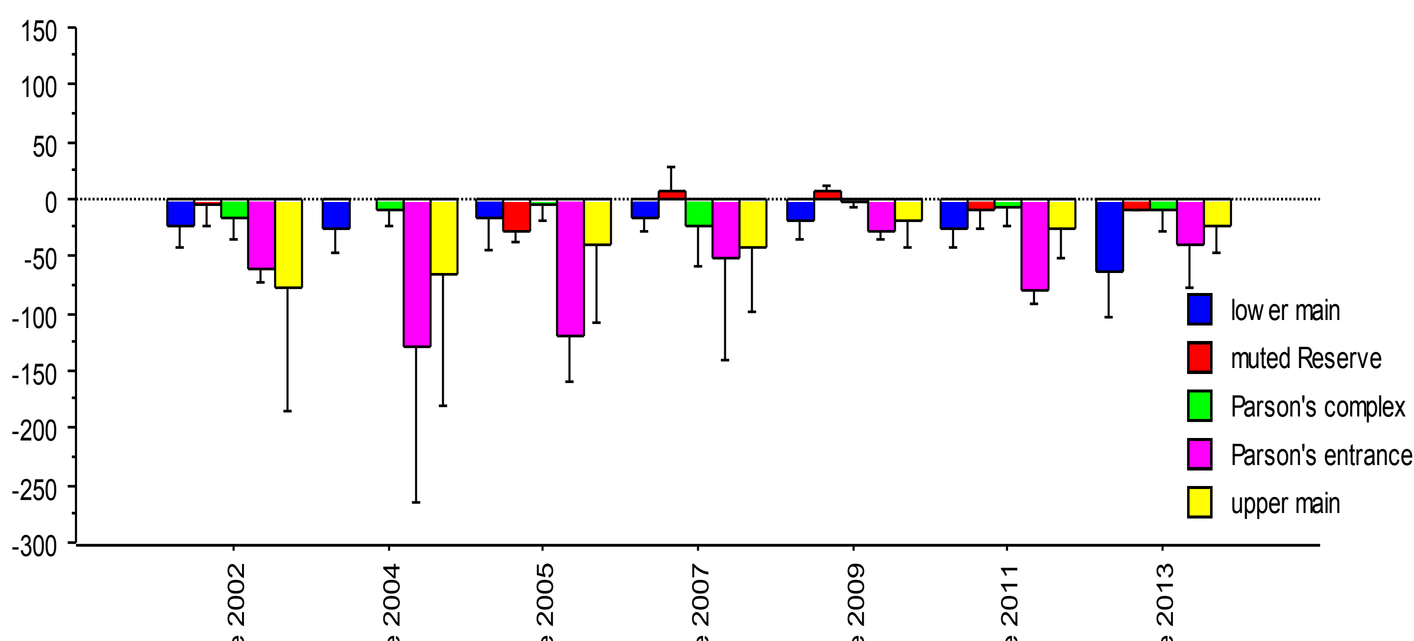
Parsons complex: no clear temporal trends, highest in 2007

Parsons entrance channel: extremely high rates 2004-5, likely related to bridge replacement; again higher 2011, perhaps related to Parsons sill, now a bit lower again in 2013

Upper main: no clear temporal patterns, but highest in early yrs

ANOVA Table for bank erosion rate

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	62085.527	15521.382	2.843	.0486	11.370	.673
Subject(Group)	22	120126.149	5460.280				
Category for bank erosion rate	6	13568.976	2261.496	1.343	.2426	8.058	.505
Category for bank erosion rate * region	24	45284.414	1886.851	1.121	.3306	26.892	.826
Category for bank erosion rate * Subject...	132	222277.552	1683.921				



VEGETATION MOVEMENT BY REGION

Same patterns as for bank erosion:

Highest in Parsons entrance channel;

next highest in main channel esp. upper;

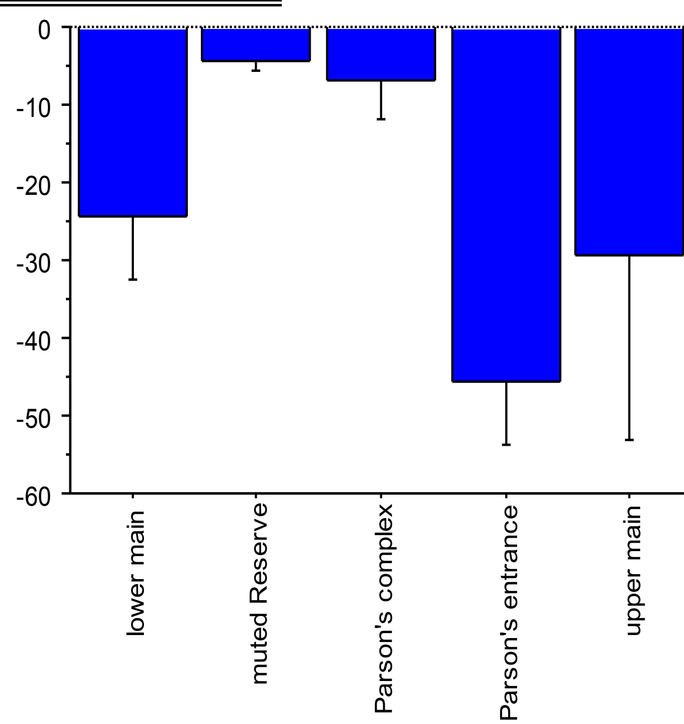
low in Parsons complex and muted sites

ANOVA Table for ann. change in d to veg 2002-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	3840.575	960.144	4.095	.0125	16.379	.849
Residual	22	5158.526	234.478				

Means Table for ann. change in d to veg 2002-2013
Effect: region
Row exclusion: erosion 2013 stats regression reg anova.svd

	Count	Mean	Std. Dev.	Std. Err.
lower main	7	-24.493	7.944	3.003
muted Reserve	2	-4.284	1.259	.890
Parson's complex	7	-6.966	5.023	1.899
Parson's entrance	2	-45.666	8.008	5.663
upper main	9	-29.237	23.882	7.961



VEGETATION MOVEMENT BY REGION OVER TIME

similar trends as for bank erosion

Lower main: no clear temporal trends, but highest 2013

Muted Reserve: no clear temporal trends

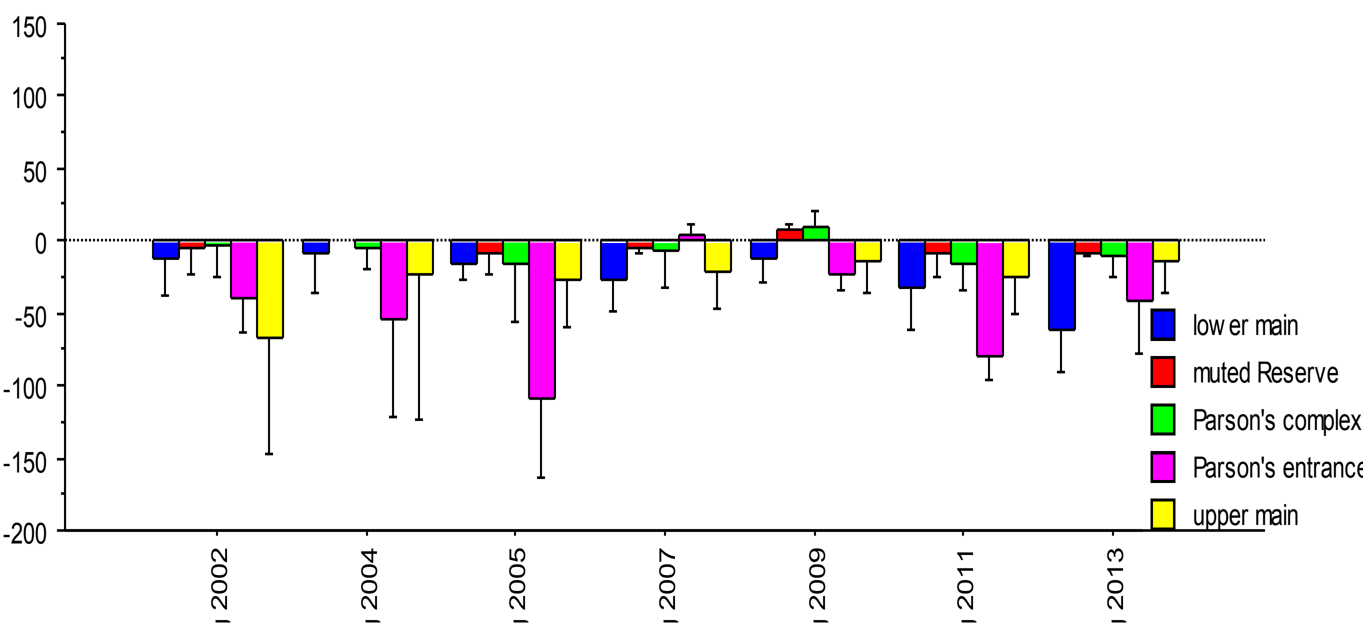
Parsons complex: no clear temporal trends, highest in 2005

Parsons entrance channel: extremely high rates in 2005, likely related to bridge replacement; again higher 2011, perhaps related to Parsons sill, now a bit lower again in 2013

Upper main: no clear temporal patterns, but highest in early yrs

ANOVA Table for vegetation loss rate

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	28253.001	7063.250	4.393	.0092	17.571	.876
Subject(Group)	22	35375.512	1607.978				
Category for vegetation retreat rate	6	12614.935	2102.489	1.548	.1675	9.288	.576
Category for vegetation retreat rate * reg...	24	40811.845	1700.494	1.252	.2107	30.048	.879
Category for vegetation retreat rate * Su...	132	179283.686	1358.210				



DISTANCE BETWEEN VEG EDGE AND BANK EDGE, BY REGION

In main channel and Parsons entrance, vegetation is landward of bank edge – particularly far in upper main channel and Parsons entrance

Within Parsons complex, vegetation hangs a bit seaward of bank edge

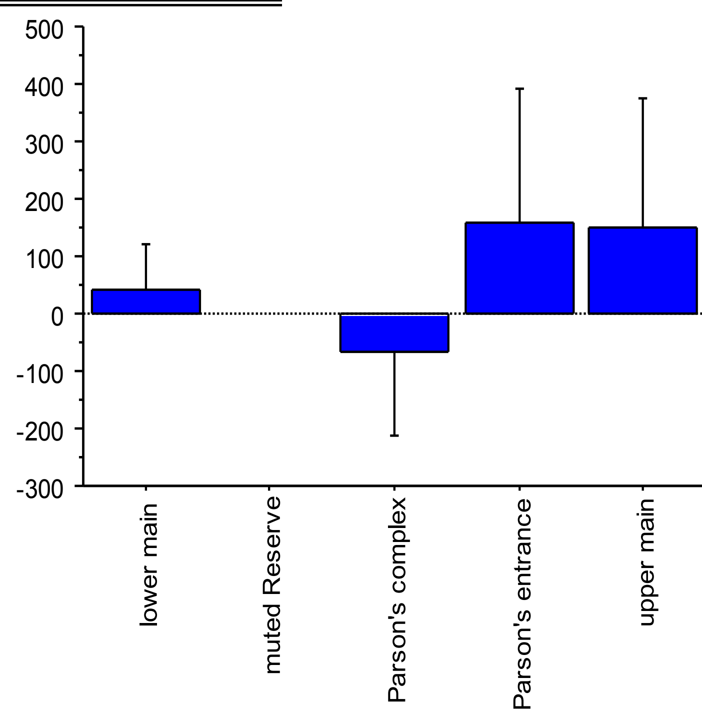
At muted sites, veg edge and bank edge are same

ANOVA Table for d from edge to veg 2001- 2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	219025.301	54756.325	1.967	.1349	7.870	.492
Residual	22	612297.205	27831.691				

Means Table for d from edge to veg 2001- 2013
Effect: region
Row exclusion: erosion 2013 stats regression reg anova.svd

	Count	Mean	Std. Dev.	Std. Err.
lower main	7	43.438	76.126	28.773
muted Reserve	2	-1.250	1.768	1.250
Parson's complex	7	-68.327	144.692	54.689
Parson's entrance	2	159.625	233.168	164.875
upper main	9	151.272	222.918	74.306



DISTANCE BETWEEN VEG AND EDGE OVER TIME

Lower main: veg small distance behind bank, no temporal trends

Muted Reserve: veg and bank edge same, no temporal trend

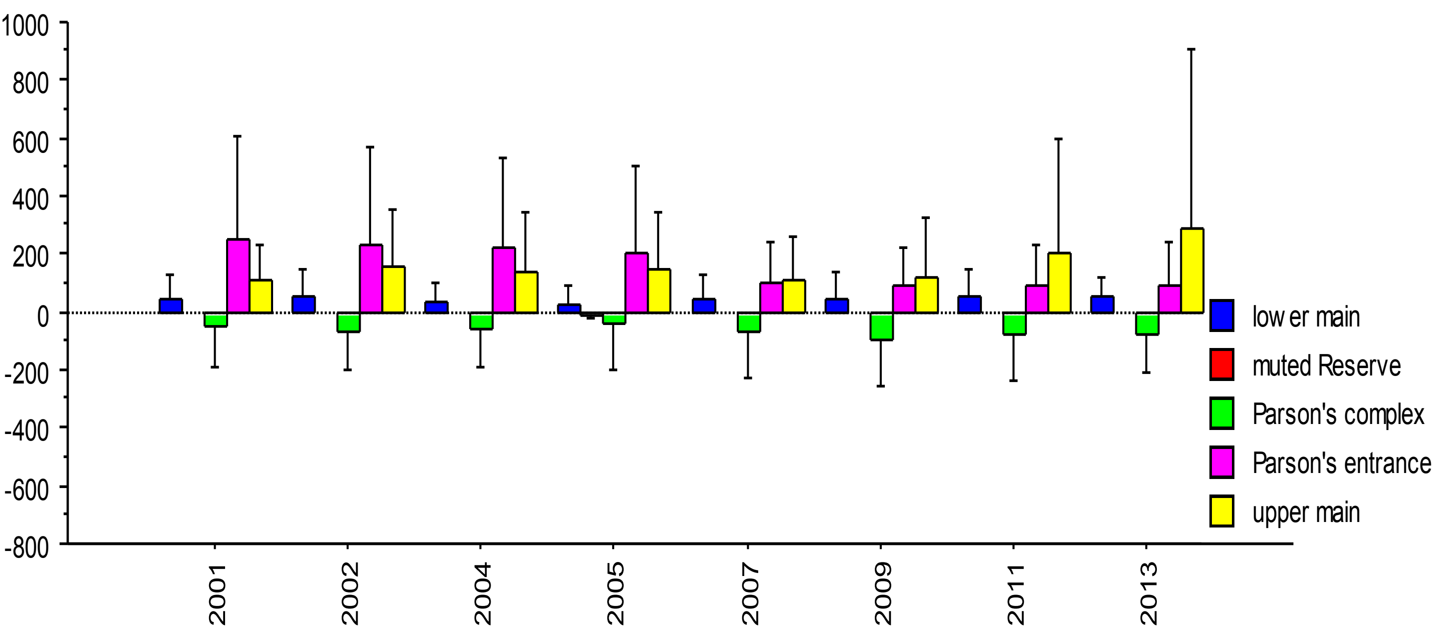
Parsons complex: veg here typically overhangs, is seaward of bank; no clear temporal trends

Parsons entrance channel: vegetation close to bank edge in late vs. early years, quite a bit seaward in all cases

Upper main: vegetation has moved landward relative to bank edge in recent years, and is now a few meters back on average

ANOVA Table for distance from bank edge to veg edge

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	1852043.334	463010.834	1.867	.1521	7.469	.468
Subject(Group)	22	5455334.149	247969.734				
Category for distance from bank edge to...	7	34906.446	4986.635	.328	.9403	2.297	.147
Category for distance from bank edge to...	28	251470.412	8981.086	.591	.9484	16.545	.515
Category for distance from bank edge to...	154	2340622.904	15198.850				



CLIFF HEIGHT BY REGION

Cliffs are higher in lower main channel and Parsons complex, probably because these include artificial berms

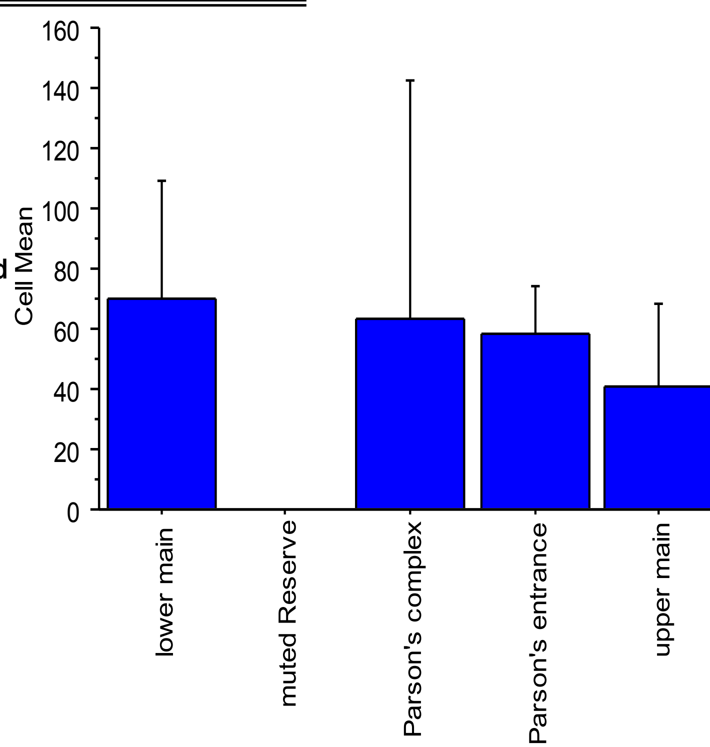
No cliffs at muted sites

ANOVA Table for cliff ht average 2001-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	9708.629	2427.157	.988	.4345	3.953	.256
Residual	22	54038.017	2456.274				

Means Table for cliff ht average 2001-2013
Effect: region
Row exclusion: erosion 2013 stats regression reg anova.svd

	Count	Mean	Std. Dev.	Std. Err.
lower main	7	69.759	39.785	15.037
muted Reserve	2	0.000	0.000	0.000
Parson's complex	7	63.155	79.670	30.112
Parson's entrance	2	58.531	15.512	10.969
upper main	9	40.743	27.876	9.292

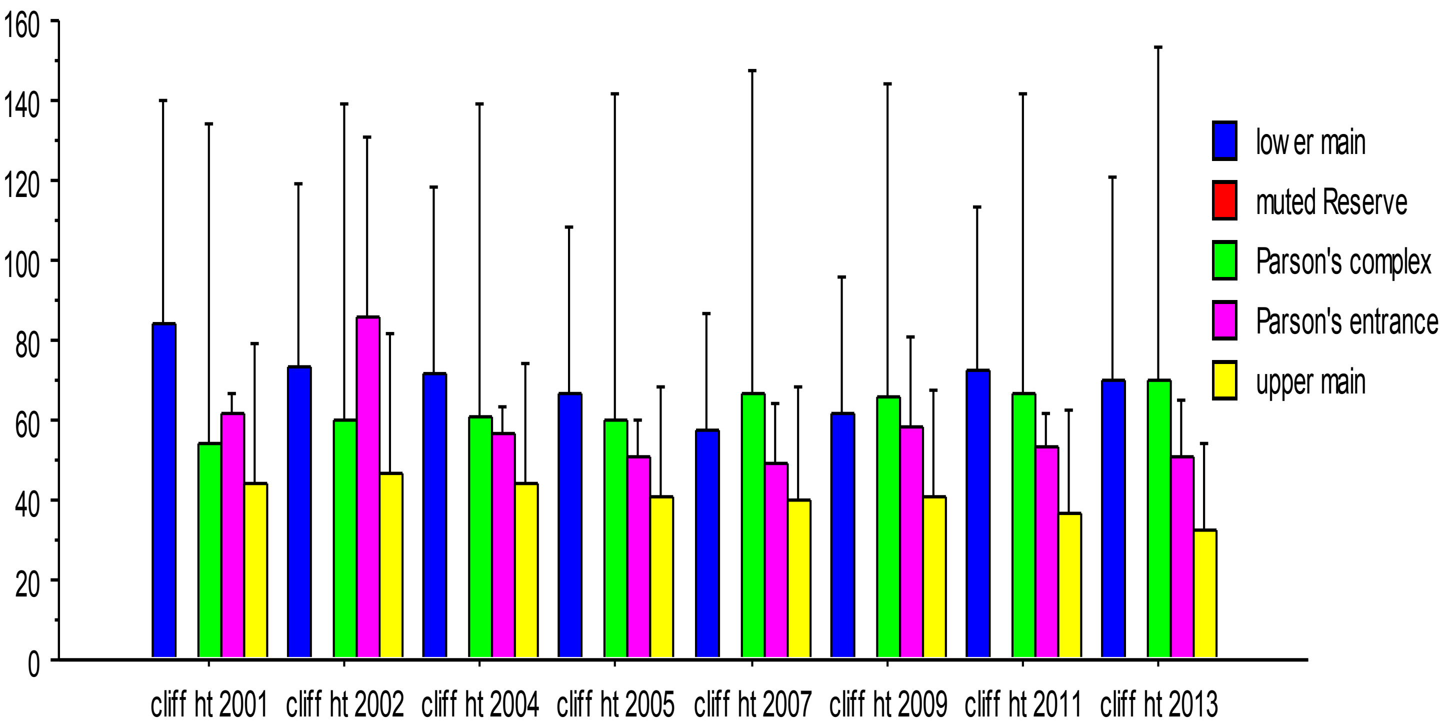


CLIFF HEIGHT OVER TIME

No obvious patterns, but cliff height decreased in upper main channel in 2011-2013

ANOVA Table for cliff height

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	77499.193	19374.798	.995	.4309	3.981	.258
Subject(Group)	22	428251.255	19465.966				
Category for cliff height	7	1389.597	198.514	1.223	.2932	8.563	.507
Category for cliff height * region	28	6556.649	234.166	1.443	.0841	40.405	.959
Category for cliff height * Subject(Group)	154	24990.102	162.273				



UNDERCUT BY REGION

Cliffs are most undercut in Parsons entrance channel and upper main channel

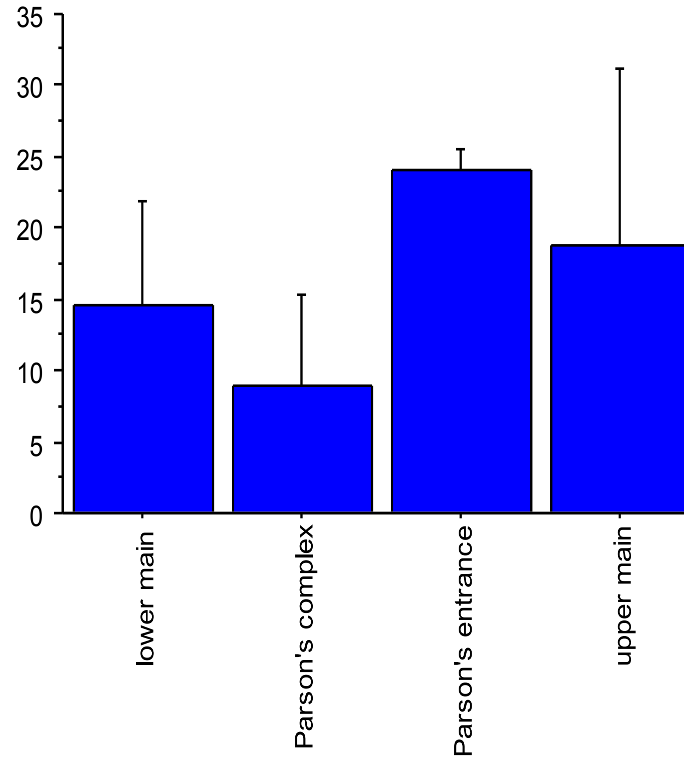
Signature of crab burrowing and/or high currents?

ANOVA Table for undercut 2001-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Pow er
region	3	544.397	181.466	2.085	.1327	6.256	.449
Residual	21	1827.516	87.025				

Means Table for undercut 2001-2013
Effect: region
Row exclusion: erosion 2013 stats regression reg anova.svd

	Count	Mean	Std. Dev.	Std. Err.
low er main	7	14.509	7.456	2.818
Parson's complex	7	8.980	6.417	2.425
Parson's entrance	2	24.094	1.458	1.031
upper main	9	18.730	12.474	4.158



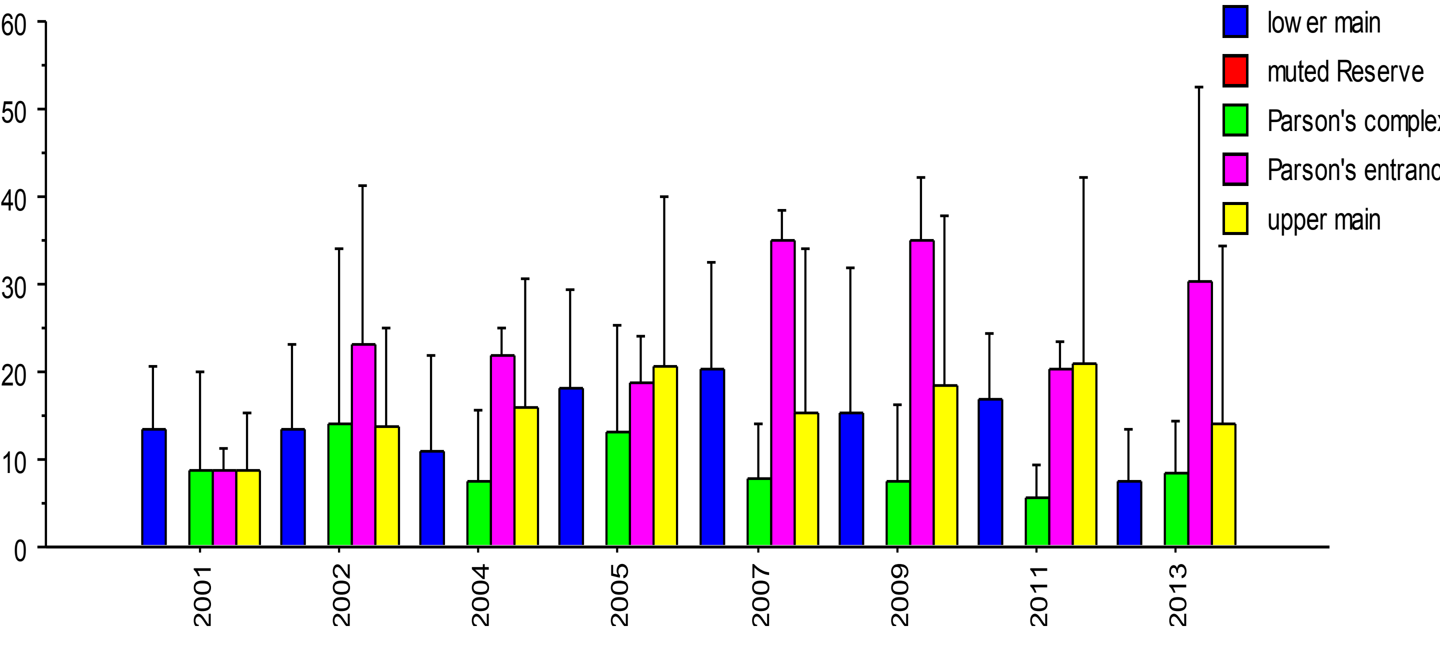
UNDERCUT OVER TIME

Parsons entrance has deepest undercut

No clear temporal trends anywhere

ANOVA Table for undercut

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	6245.190	1561.298	2.008	.1284	8.034	.501
Subject(Group)	22	17102.139	777.370				
Category for undercut	7	766.892	109.556	1.241	.2837	8.687	.514
Category for undercut * region	28	2358.823	84.244	.954	.5369	26.719	.793
Category for undercut * Subject(Group)	154	13595.701	88.284				



SMALL HOLES BY REGION

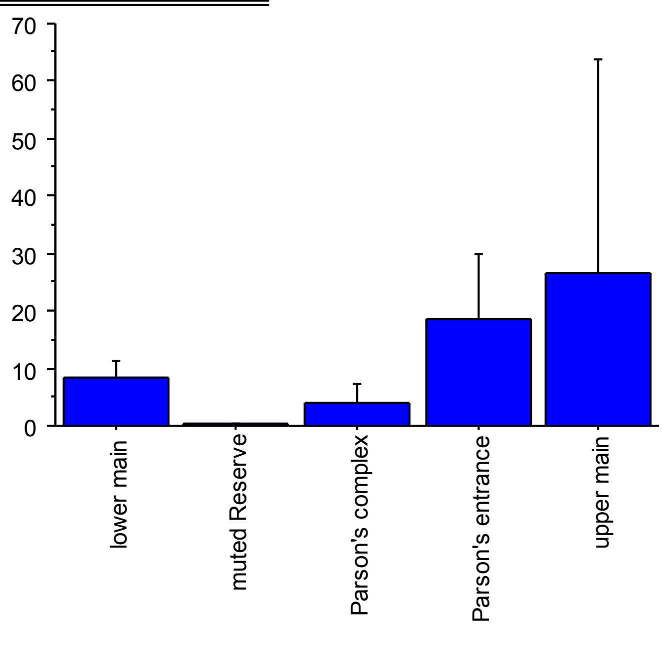
Most small holes in Parsons and upper main channel

ANOVA Table for Sphaeroma density 2001-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	2753.199	688.300	1.326	.2916	5.303	.338
Residual	22	11422.978	519.226				

Means Table for Sphaeroma density 2001-2013
Effect: region
Row exclusion: erosion 2013 stats regression reg anova.svd

	Count	Mean	Std. Dev.	Std. Err.
lower main	7	8.339	3.141	1.187
muted Reserve	2	.262	.135	.095
Parson's complex	7	3.982	3.218	1.216
Parson's entrance	2	18.563	11.402	8.063
upper main	9	26.543	37.369	12.456



SMALL HOLES OVER TIME

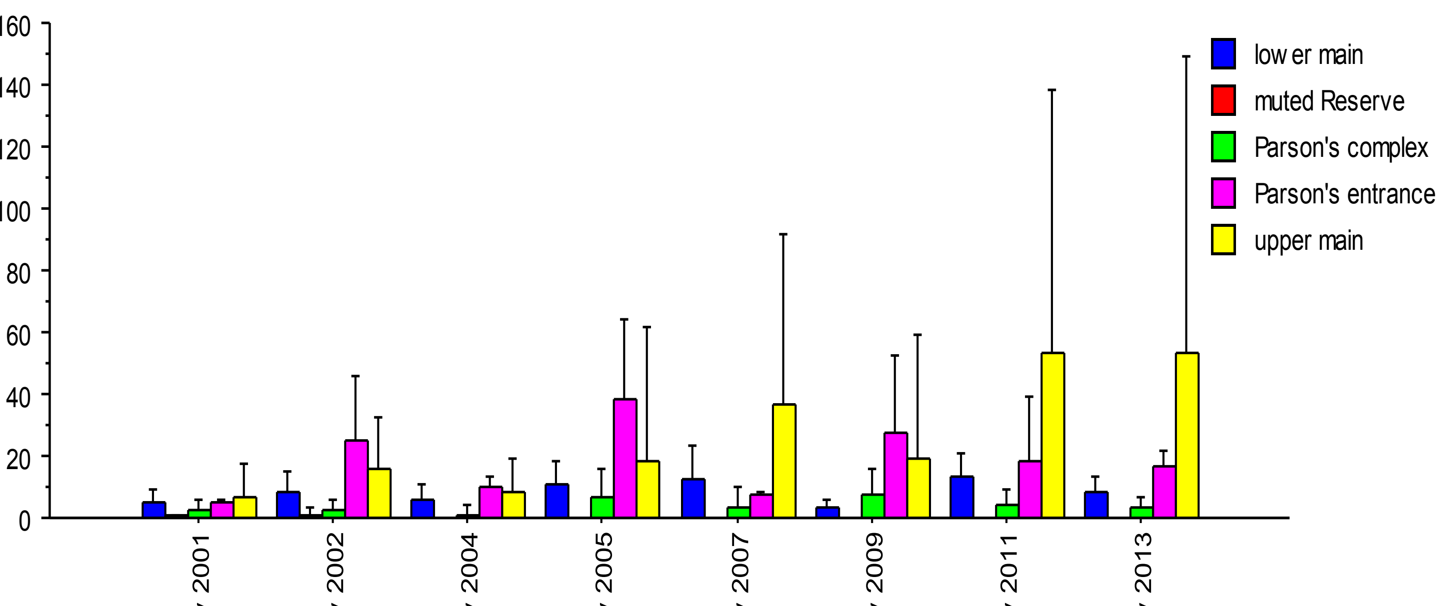
Low everywhere in 2001

High sometimes at Parsons entrance

Increase in upper main channel (a few sites with 100s of holes per quadrat account for this)

ANOVA Table for small holes

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	21963.375	5490.844	1.320	.2937	5.279	.336
Subject(Group)	22	91529.051	4160.411				
Category for small holes	7	3153.364	450.481	.691	.6795	4.838	.287
Category for small holes * region	28	15697.400	560.621	.860	.6703	24.082	.734
Category for small holes * Subject(Group)	154	100382.915	651.837				



LARGE HOLES BY REGION

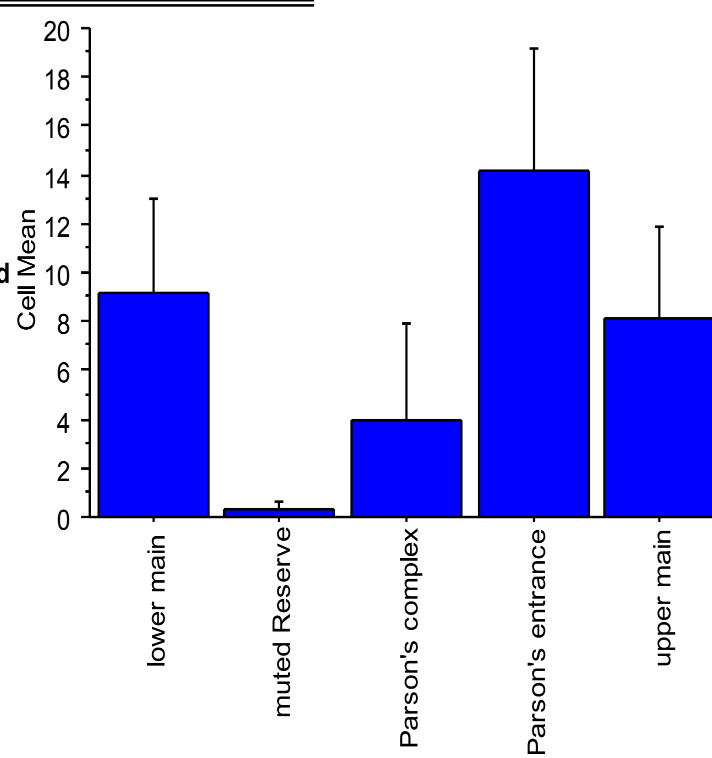
Most crab holes in Parsons entrance; unlike small holes, they are second most common in lower main channel

ANOVA Table for crab density 2001-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Pow er
region	4	300.184	75.046	5.098	.0046	20.390	.926
Residual	22	323.882	14.722				

Means Table for crab density 2001-2013
Effect: region
Row exclusion: erosion 2013 stats regression reg anova.svd

	Count	Mean	Std. Dev.	Std. Err.
low er main	7	9.134	3.859	1.459
muted Reserve	2	.321	.253	.179
Parson's complex	7	3.955	3.981	1.505
Parson's entrance	2	14.219	4.906	3.469
upper main	9	8.093	3.796	1.265



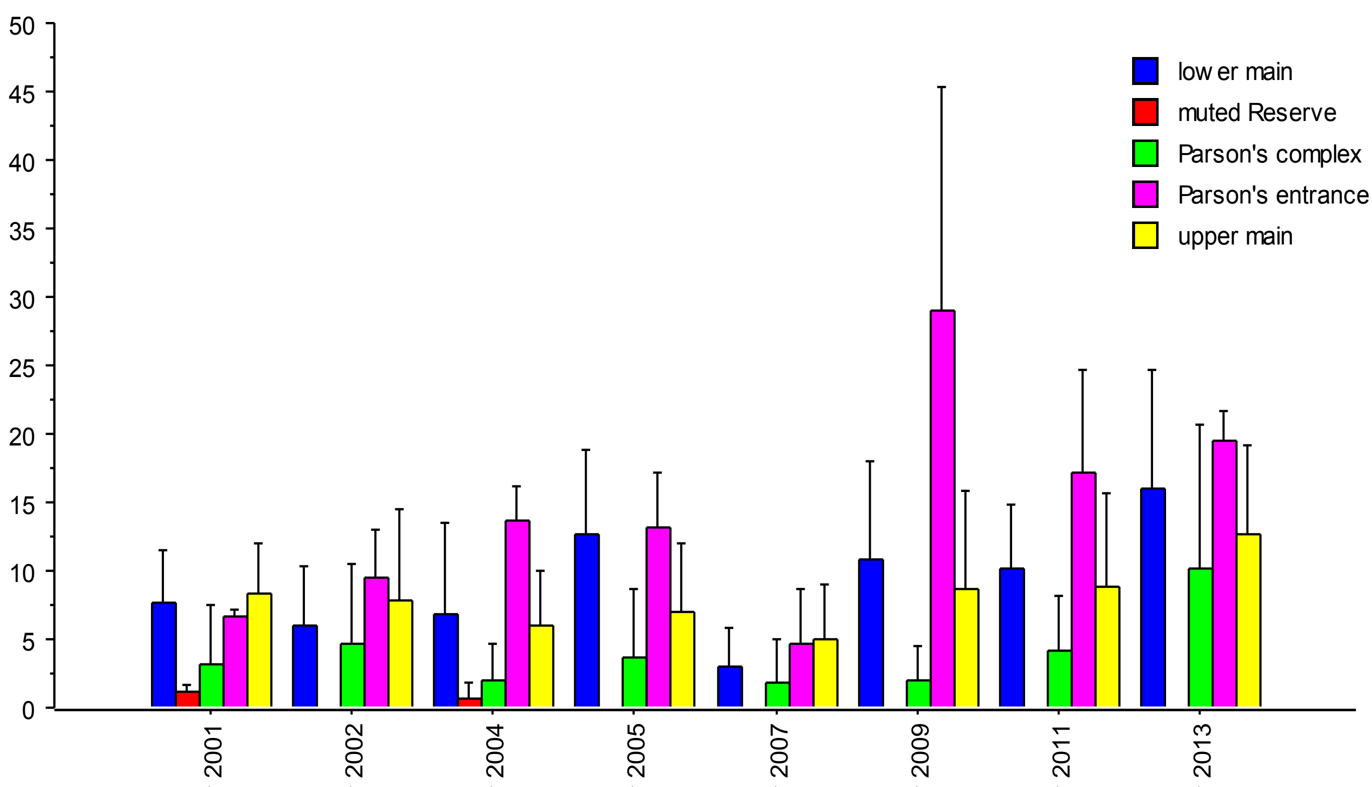
LARGE HOLES OVER TIME

Increasing over time in most Slough regions.

Highest in Parson's entrance, which is also fastest eroding area, but temporal patterns don't seem to correspond well to erosion rates

ANOVA Table for large holes

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
region	4	2410.933	602.733	5.047	.0049	20.186	.923
Subject(Group)	22	2627.569	119.435				
Category for large holes	7	984.905	140.701	7.780	<.0001	54.461	1.000
Category for large holes * region	28	1017.110	36.325	2.009	.0040	56.242	.996
Category for large holes * Subject(Group)	154	2785.036	18.085				



TEMPORAL TRENDS: LONG-TERM

Question:

Are bank erosion rates increasing or decreasing over the longer term?

Approach:

Used Malzone's data for the 13 stations of his that our team has re-occupied (he had many more stations up tidal creeks that we didn't re-occupy, and we have new stations in the upper Slough and Parsons, so only these 13 are the same). Malzone's data is average for 1994-1996; our data is average of 2001-2013.

Answer:

Overall, erosion seems fairly similar 20 years later, so we can probably rule out a nightmarish scenario of ever worsening erosion and feedback loops.

At 6 main channel sites with natural banks, erosion rates have decreased at 4, increased at 2. The rates of decrease seem more pronounced than the rates of increase, esp. for two stations up near Kirby.

No obvious spatial patterns – some increase and some decrease in upper and lower estuary.

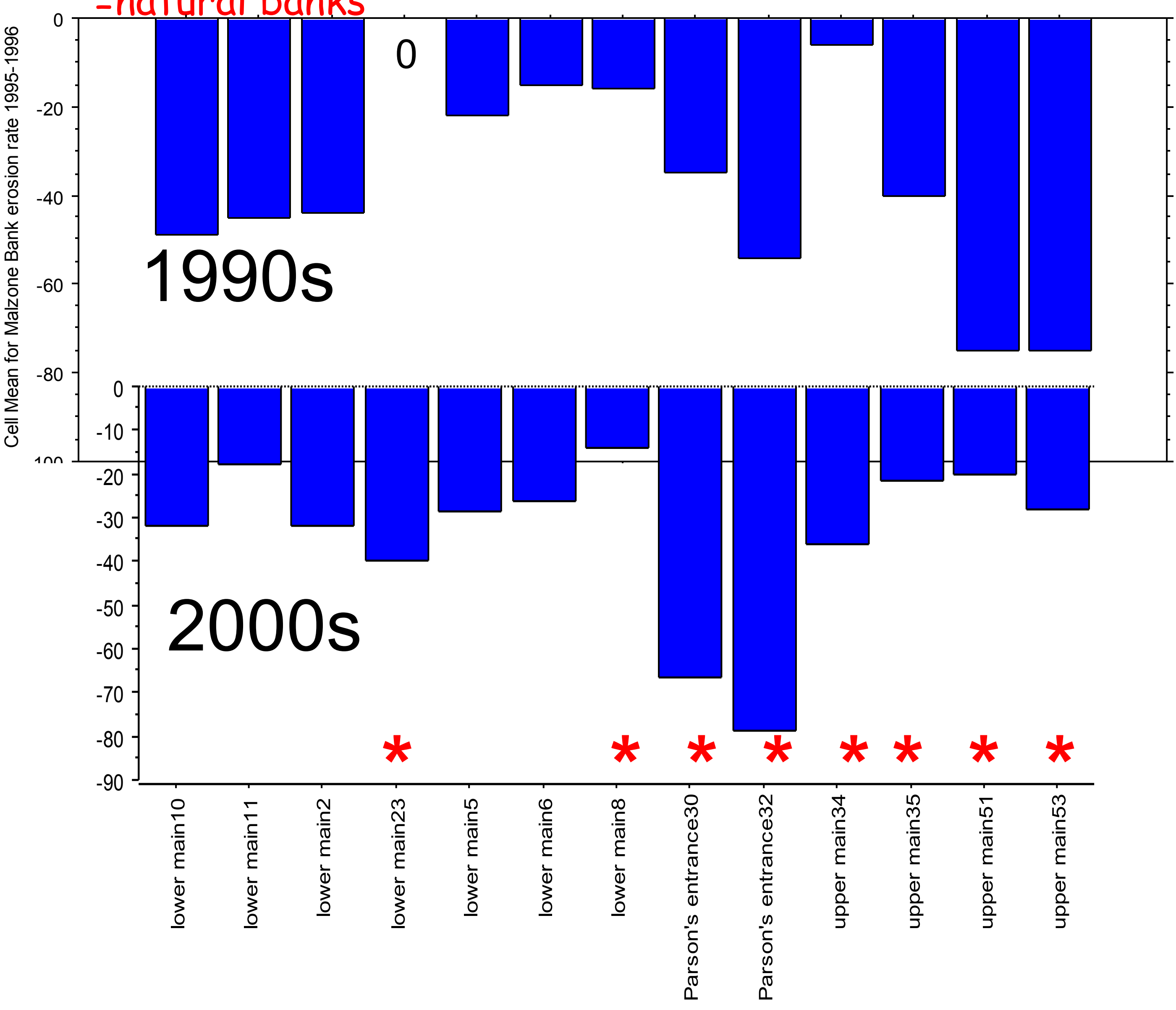
(Parsons channel has seen increase, but that seems likely to be result of local not estuary-wide processes: bridge replacement and sill.)

BANK EROSION OVER TIME BY SITE
Malzone 1990s vs. our 2000s data

Overall, things look better now than then. Many sites have lower annual erosion rates now than they did when he was monitoring.

Exceptions are sites 5 and 6 in lower main channel (both on artificial berms that eroded badly in last years), sites 30 and 32 in the Parsons entrance channel (due to bridge replacement and sill), and sites 23 in the lower and 34 in the upper main channel.

*=natural banks



BANK TYPE

Question:
Is bank erosion faster in natural vs. artificial banks? How do other attributes of natural vs. artificial banks differ?

Approach:
ANOVA on data averaged across all periods from natural vs. artificial banks in main channel (omitted Parsons complex and entrance channel and muted sites).

Unfortunately this is a bit confounded by region: we have 7 artificial banks, 5 of which are in the lower slough, and 9 natural banks, 7 of which are in the upper slough.

Answer:
Natural banks have higher erosion and vegetation loss rates on average, but due to high variation, this is not significant.

Artificial banks are higher, and have vegetation closer to the bank edge (perhaps because algae doesn't drift up and kill it).

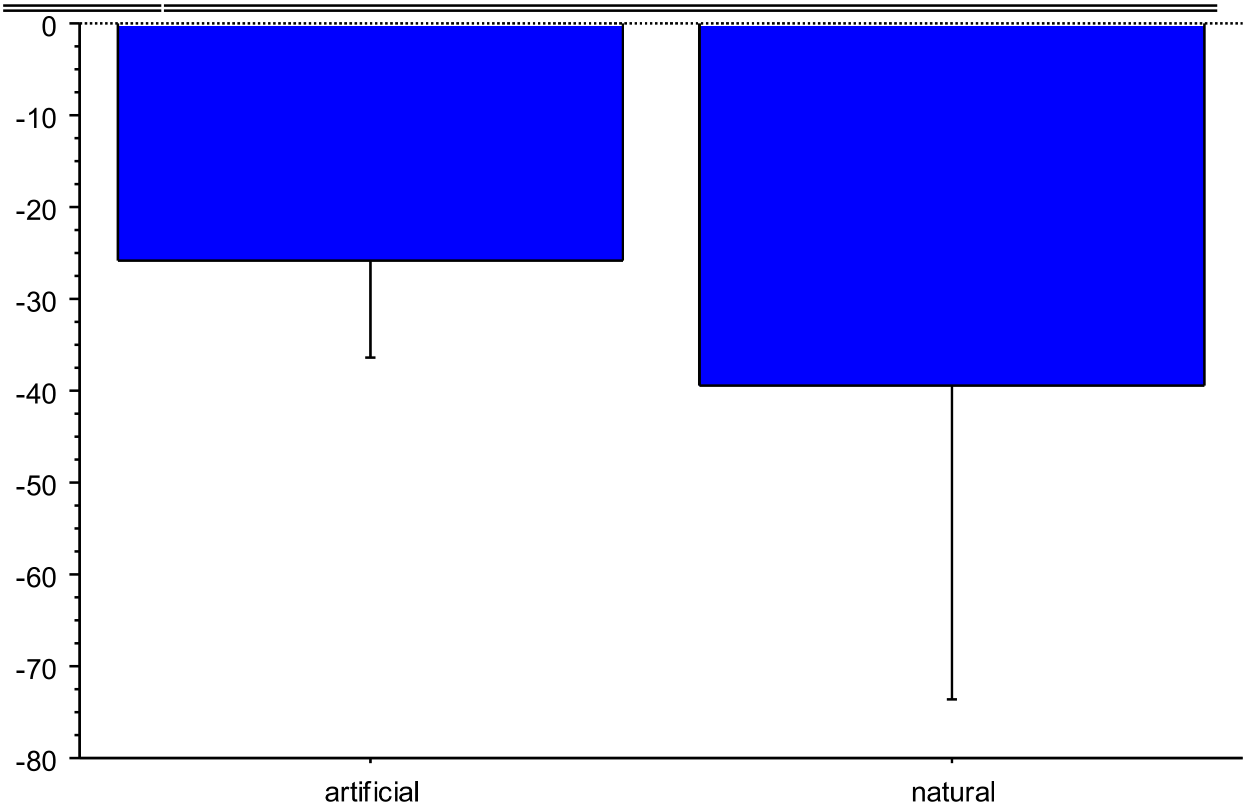
Artificial banks have fewer burrow holes.

BANK EROSION BY BANK TYPE

No significant difference in erosion rate of artificial vs. natural banks, though higher in latter

ANOVA Table for ann. change in d to edge 2002-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
bank type	1	728.147	728.147	1.003	.3335	1.003	.148
Residual	14	10161.263	725.804				

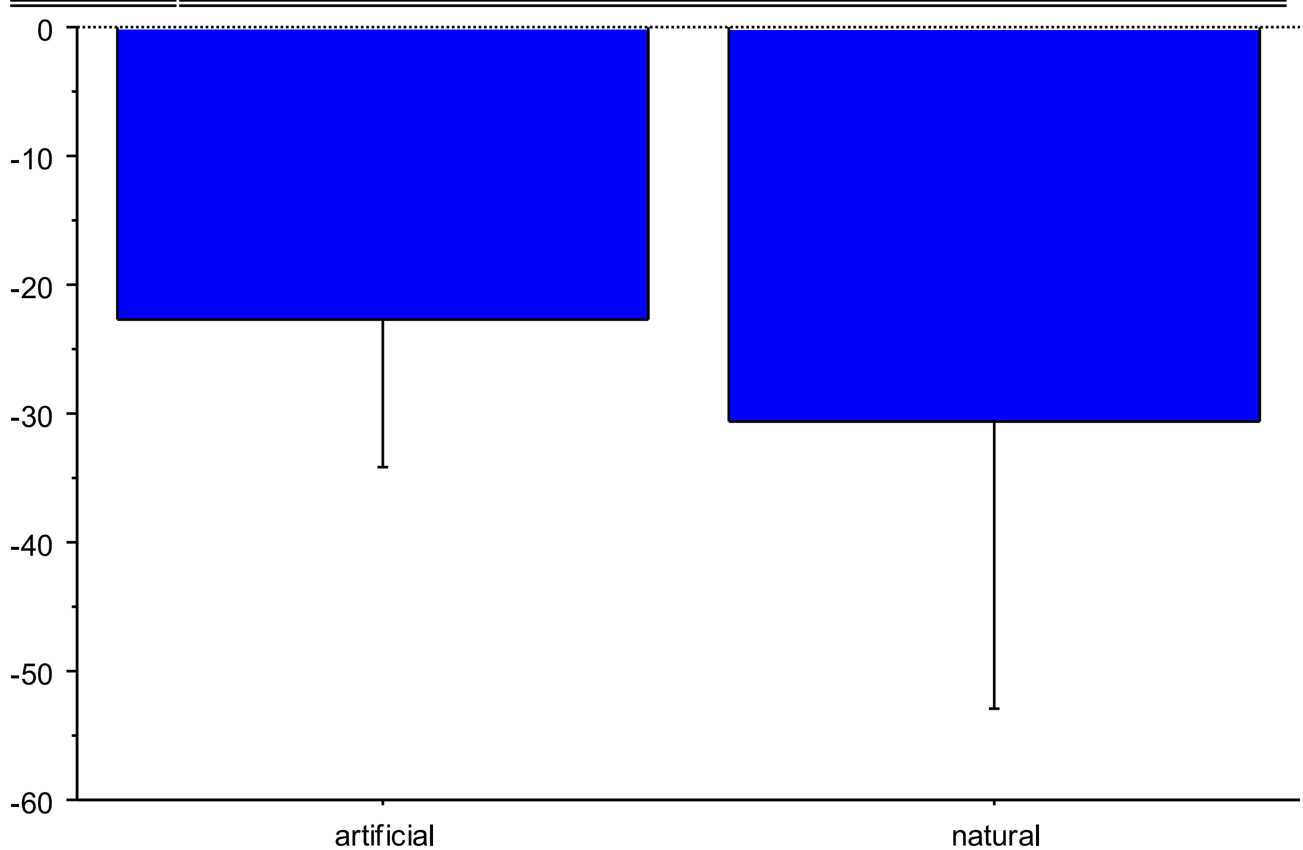


VEGETATION MOVEMENT BY BANK TYPE

Vegetation edge migration also not significant between artificial vs. natural banks, though higher in latter

ANOVA Table for ann. change in d to veg 2002-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
bank type	1	241.582	241.582	.706	.4148	.706	.119
Residual	14	4788.456	342.033				

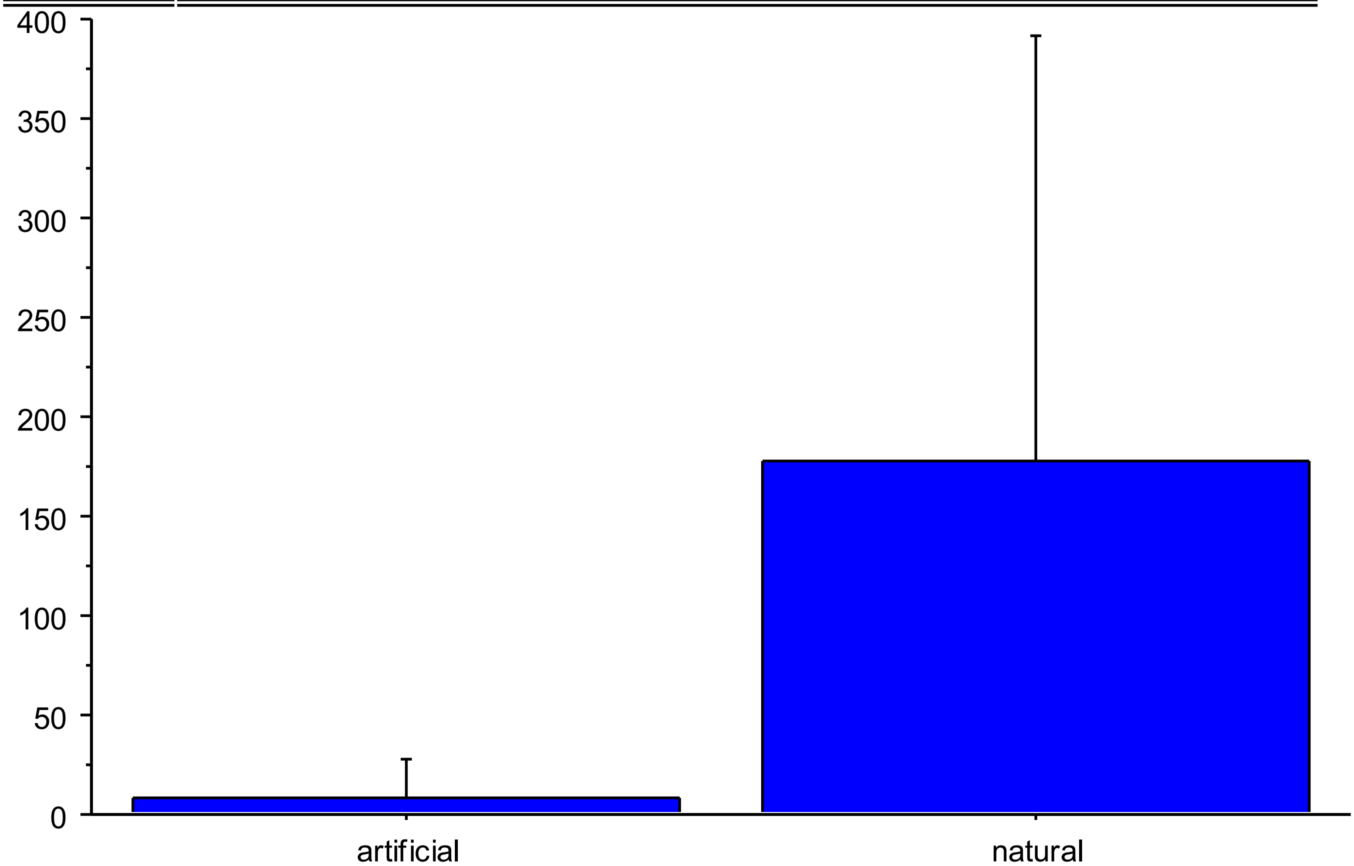


DISTANCE BETWEEN VEGETATION AND BANK EDGES BY BANK TYPE

Vegetation is much farther landward of bank edge on natural banks, maybe because they are lower?

ANOVA Table for d from edge to veg 2001- 2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Pow er
bank type	1	113720.715	113720.715	4.369	.0553	4.369	.485
Residual	14	364377.027	26026.930				



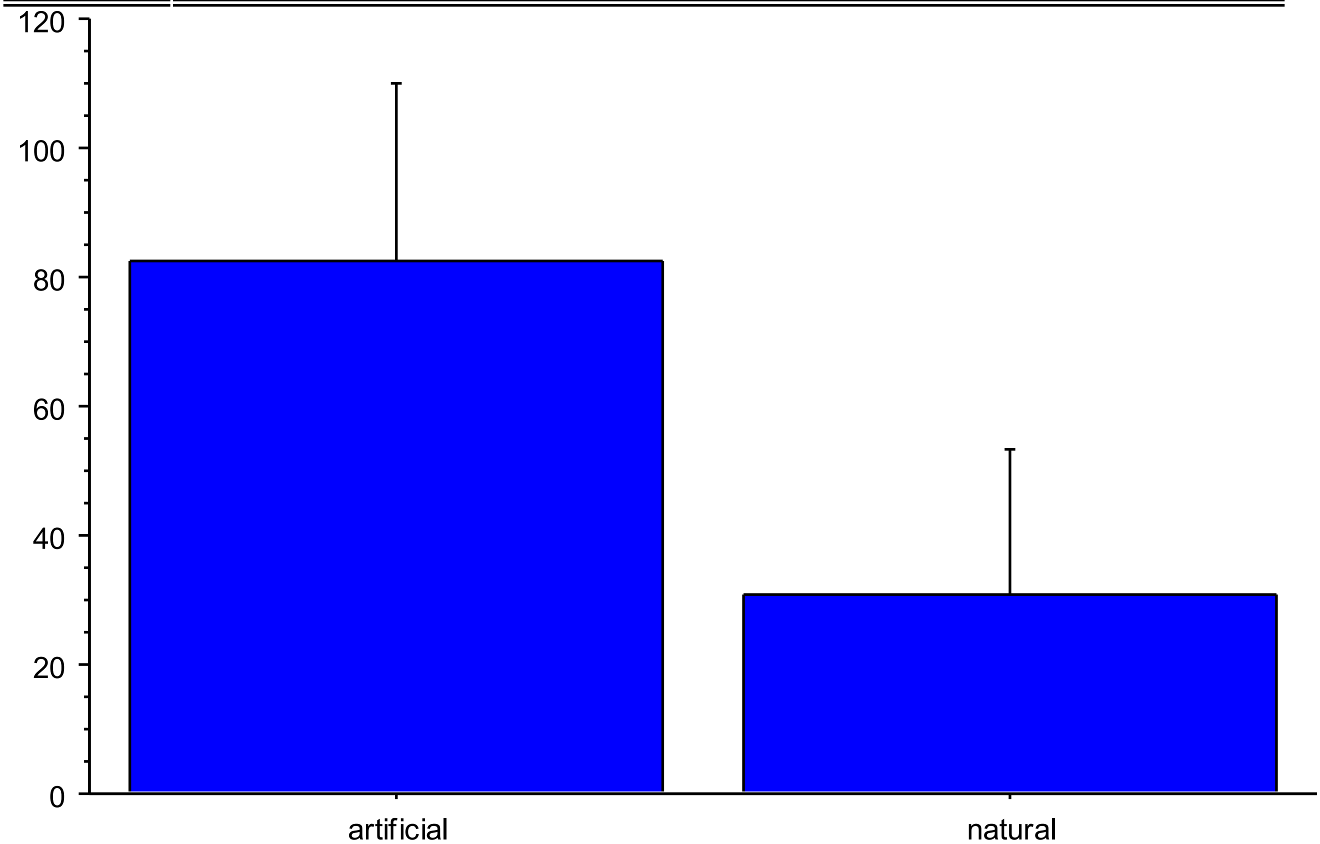
CLIFF HEIGHT BY BANK TYPE

Yes, artificial banks are definitely higher – more than twice as high on average

Thus they don't get covered by algae, and don't have vegetation retreat?

ANOVA Table for cliff ht average 2001-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
bank type	1	10433.580	10433.580	16.994	.0010	16.994	.979
Residual	14	8595.318	613.951				

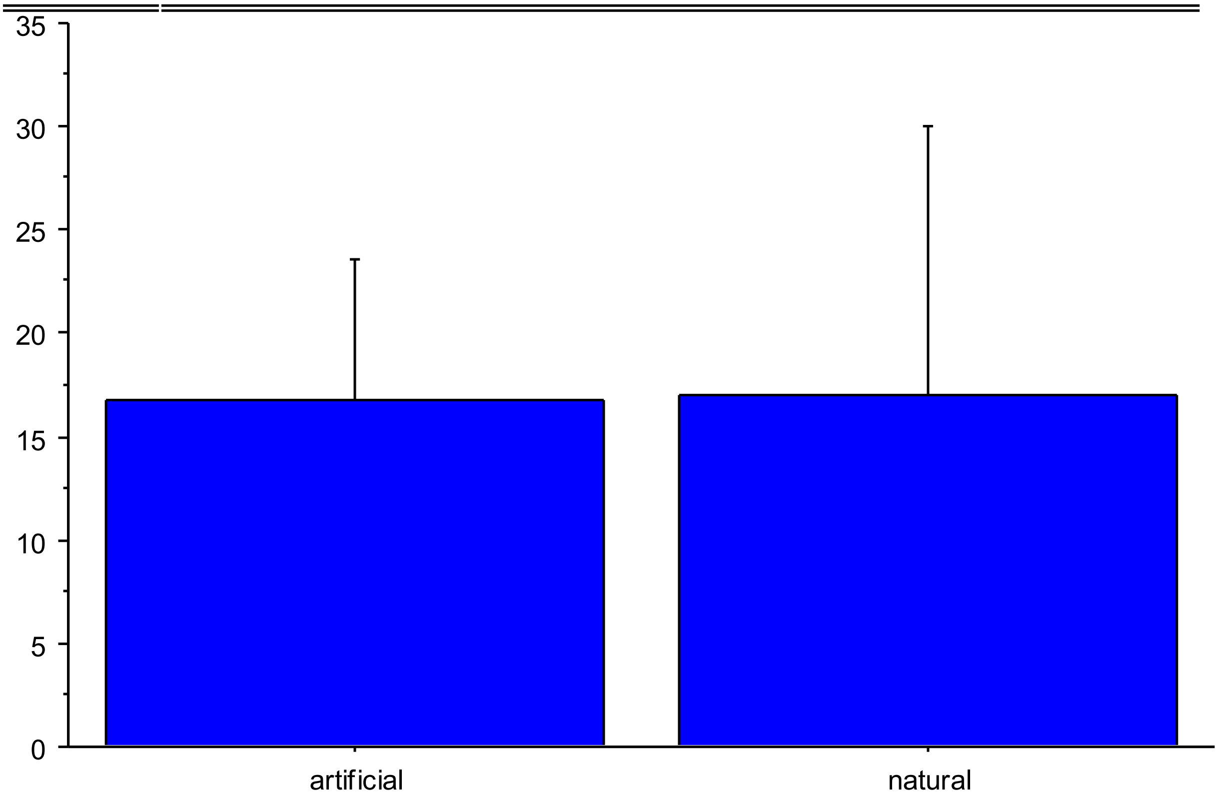


UNDERCUT BY BANK TYPE

Artificial banks just as undercut – not sure I would have expected that – thought they might be stronger?

ANOVA Table for undercut 2001-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
bank type	1	.165	.165	.001	.9706	.001	.050
Residual	14	1648.320	117.737				

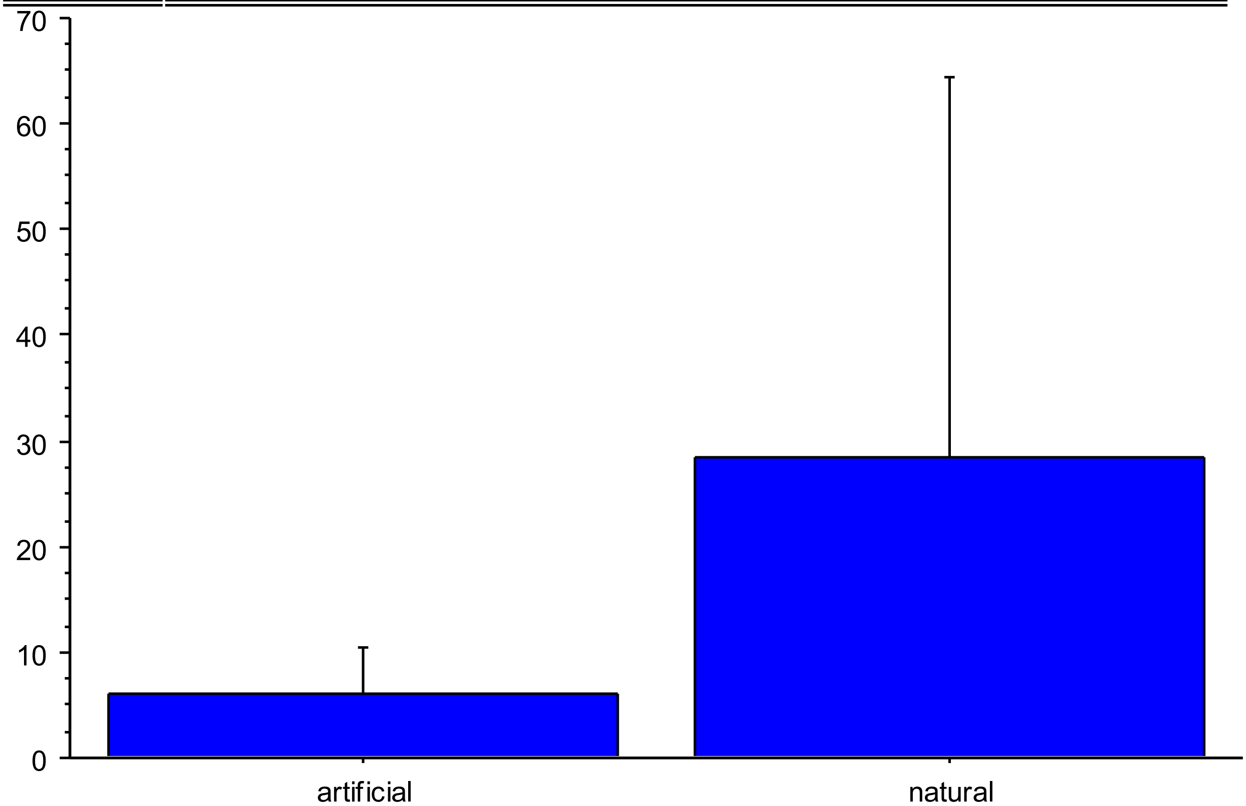


SMALL HOLES BY BANK TYPE

Many more small holes in natural banks….but perhaps this is confounded by region, since Spheroma seems abundant only in upper Slough where there are no artificial banks?

ANOVA Table for Sphaeroma density 2001-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
bank type	1	1960.624	1960.624	2.596	.1295	2.596	.310
Residual	14	10574.939	755.353				

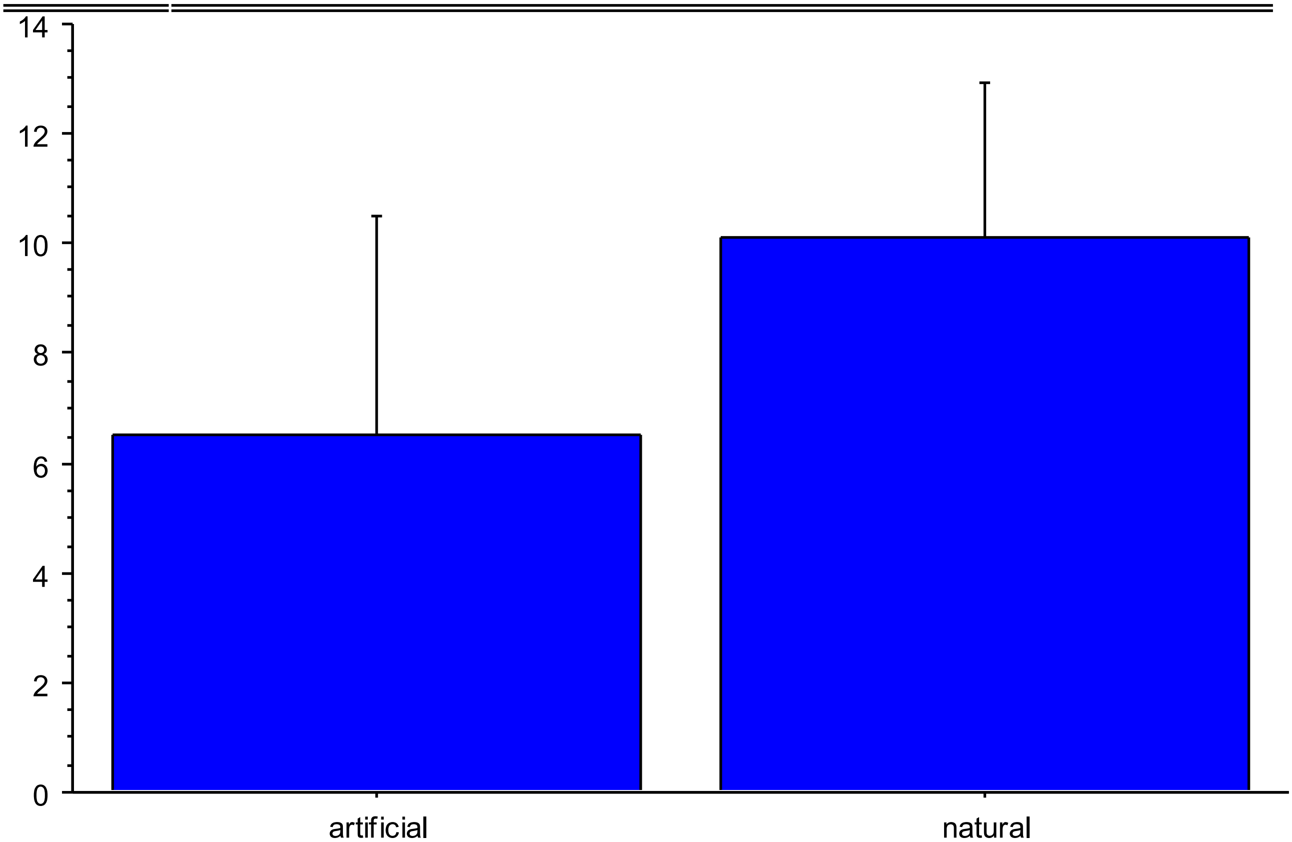


LARGE HOLES BY BANK TYPE

More crab holes in natural banks – this makes sense

ANOVA Table for crab density 2001-2013
Row exclusion: erosion 2013 stats regression reg anova.svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Pow er
bank type	1	51.317	51.317	4.558	.0509	4.558	.502
Residual	14	157.609	11.258				



CORRELATIONS

Question:

What are relationships between measured variables? Is erosion faster in areas where vegetation is far back from bank, or where there are lots of crab holes?

Approach:

- Simple regressions between different measured variables.
- Used data only from natural banks in main channel, to avoid confounding factors from artificial banks, tidally muted sites, and anomalous fast erosion in Parsons entrance due to local hydrodynamic changes there.
- Used individual stake (not site) as rep, because this seemed fair for regressions; would need to re-consider that before publication; quick comparisons suggest we'd get similar results if using average of two stakes per site as rep
- Used data from different time periods to look for averaged long-term trends vs. current patterns.

Answers:

Surprising lack of relationship between variables we expected to be linked.

Bank erosion rates and vegetation movement rates seem quite uncoupled. That's a problem for all our scenarios involving algae or crabs killing vegetation, and then banks eroding.

The distance between veg edge and bank edge decreases in areas of fast erosion or fast landward migration of vegetation. This direction of causality isn't so interesting: increasing distance is response not driver as we'd thought?

CORRELATIONS cont'd

The distance itself, between veg and edge, doesn't seem to predict erosion or vegetation movement rates. That's weird: we expected broad deader zones at the bank to have faster erosion rates. That would fit our model of algae or crabs contributing to erosion by increasing the size of the dead zone. Doesn't seem to be the case at these sites.

However, we did find that sites where bank edge and veg edge are very close to other (distances near zero) had lowest erosion rates though, so at least this is predictive. Maybe the mechanism is occurring, but only at this low end of the spectrum: a factor that makes the distance increase from 0 to 50 cm might increase erosion rates, but what happens to increases above 50 no longer matters. Something to think about for exps.

Undercutting correlated positively with bank erosion. However cliff height didn't, nor did higher cliffs seem to protect vegetation from retreat as we'd expected.

Small hole density seemed to correlate with bank erosion, but one site is driving the pattern, and the timing is wrong for our proposed mechanism (the holes came after the period of high erosion).

Small holes actually seemed to slow landward vegetation movement, the opposite effect we'd expect.

Large holes correlated with nothing, sadly.

Potential driver: VEGETATION EDGE MOVEMENT RATE

Rationale:

Rate of marsh edge movement could influence rate of bank erosion (or vice versa), or the two could be responding to similar processes. In all of these cases, you'd expect a strong correlation between rate of vegetation movement and bank erosion – both moving landward from the permanent marker at similar rates.

Results:

Surprisingly weak relationship between rate of vegetation movement and bank loss.

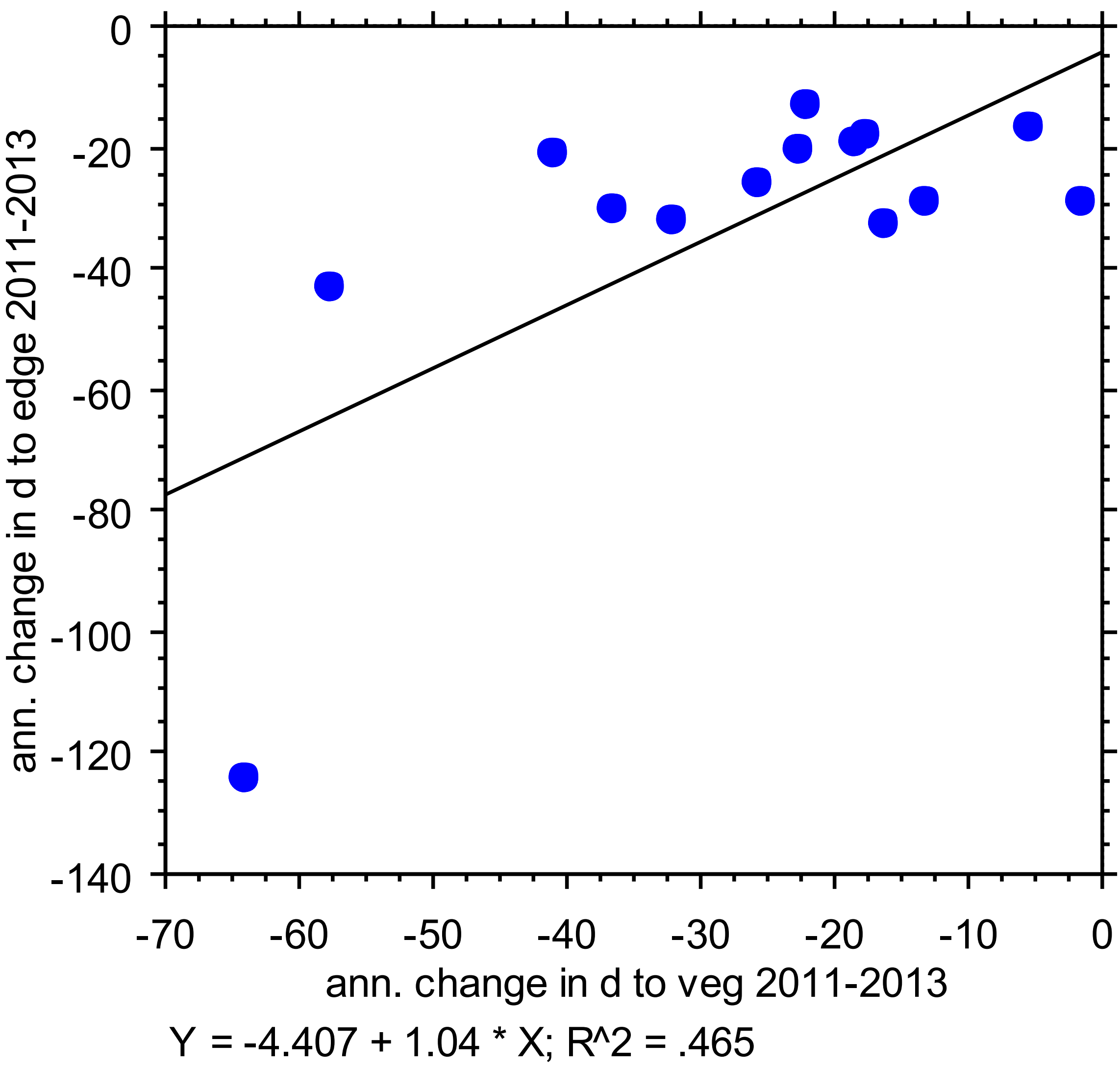
Suggests perhaps that there are separate processes affecting vegetation movement, such as subsidence, which are not directly influencing bank erosion rates?

Seems to suggest that death of pickleweed at edge does not result in increased bank erosion, or you'd see a stronger correlation? Does this change our paradigms?

VEGETATION MOVEMENT vs. BANK EROSION

Significant relationship (p=0.007), but seems driven by outlier. Visually if you ignore that point, not really a good relationship at all.

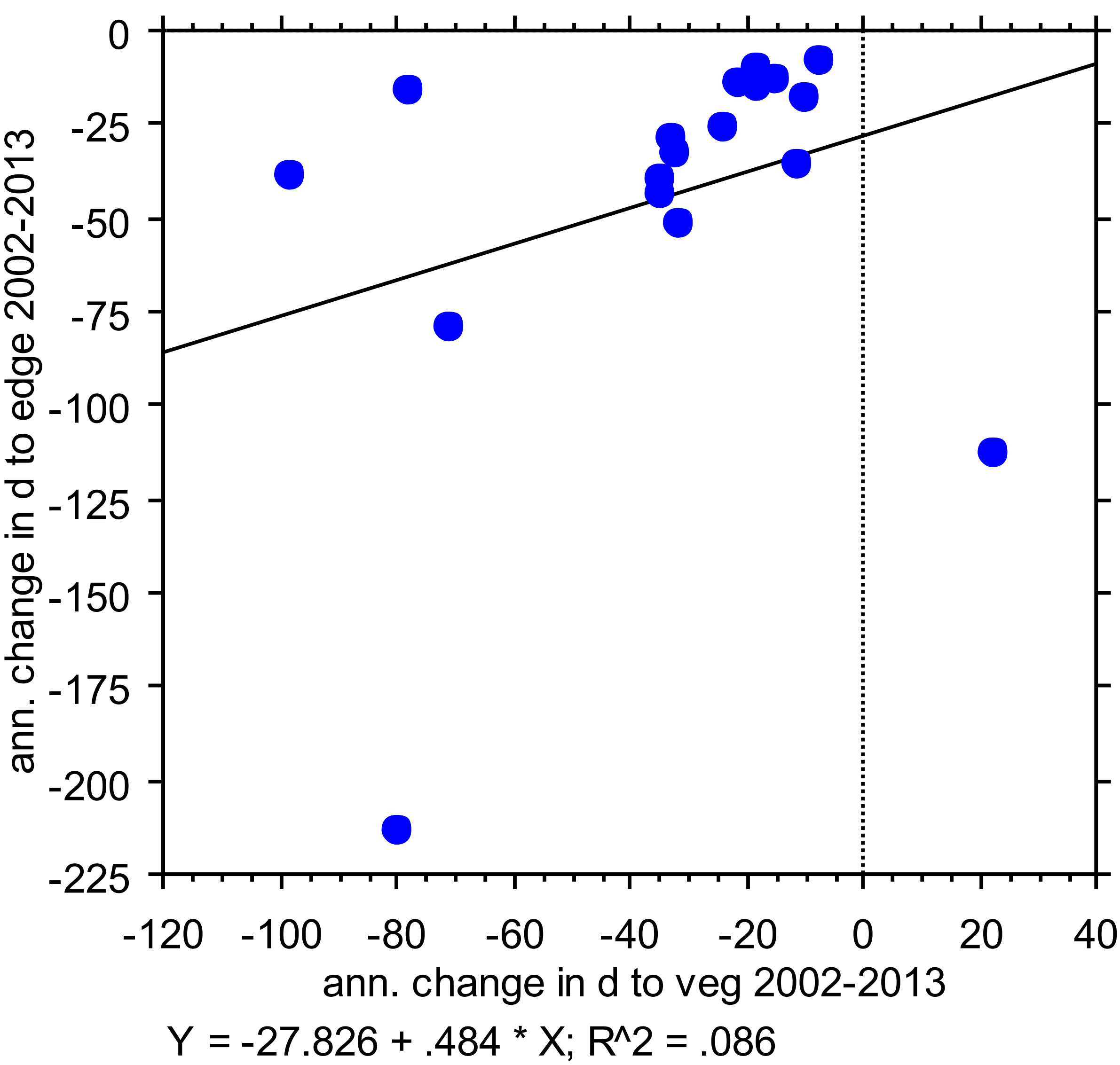
(2011 & 2013 data averaged)



VEGETATION MOVEMENT vs. BANK EROSION

Relationship not significant (p=0.2) over entire monitoring period.

(2001-2013 data averaged)



Potential driver: VEGETATION RETREAT

Rationale:

The rate at which the distance between marsh and bank edges are changing could affect bank erosion rates: areas with rapid vegetation retreat could have destabilized banks more prone to erosion. Or both could be responding to similar processes. Either way, you'd expect a correlation between rate at which bank and veg edge are moving apart and bank erosion rate.

Results:

There was a significant correlation, but not in the expected direction: sites where distance between bank edge and veg edge DECREASED had the highest bank erosion rates.

This could happen if rate of bank erosion outstrips rate of vegetation migration at rapidly eroding sites – rapid bank erosion is narrowing the distance.

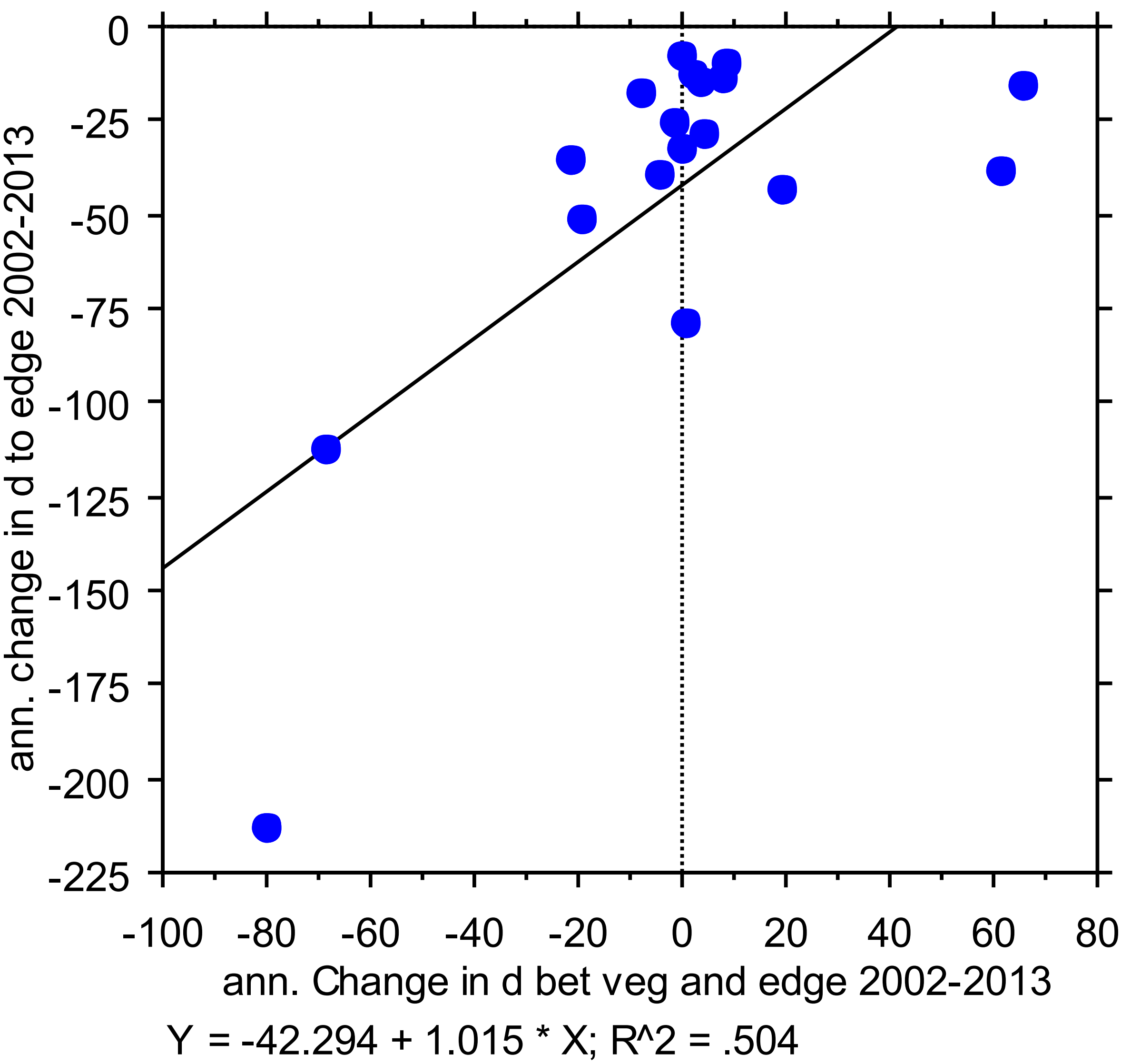
Conversely, there was a marginally significant correlation in the expected direction between vegetation retreat rate and vegetation movement rate: sites where vegetation is moving landward most quickly have greater increase in distance between veg and edge.

So, I had causality backwards, seems like vegetation retreat (increase in distance between bank edge and veg edge) should be the dependent variable, and it can be decreased by fast bank erosion, or increased by fast landward migration of vegetation.

VEGETATION RETREAT RATE vs. BANK EROSION RATE

Significant relationship (p=0.001) in opposite direction as expected: stakes where distance between bank edge and veg edge has increased have LOWER erosion rates!

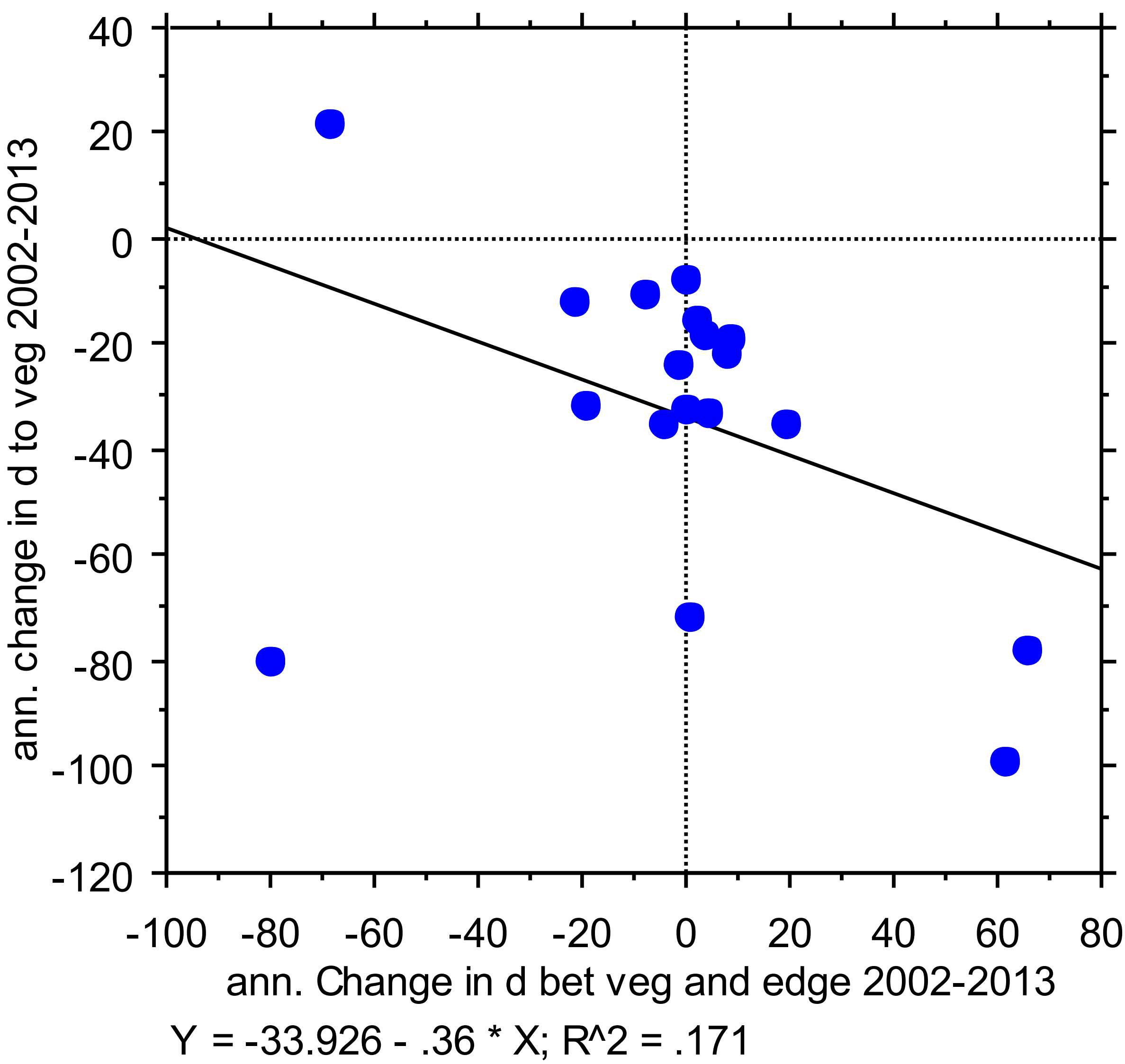
(graph below is from 2001-2013 data averaged, using just last years is also significant, but a bit less so)



VEGETATION RETREAT RATE vs. VEGETATION MOVEMENT RATE

Relationship marginally significant (p=0.09) over entire monitoring period, but OPPOSITE from previous slide. Sites with increases in distance between veg and bank edges had faster vegetation migration rates.

(2001-2013 data averaged)



Potential driver: DISTANCE BETWEEN BANK AND VEGETATION EDGE

Rationale:

If marsh loss near edge is important driver of bank erosion, you'd expect sites with vegetation far from bank edge to have faster erosion rates.

For instance, if algae or crabs kill pickleweed, and then the bank becomes destabilized, you'd expect a bare zone to precede bank loss.

Results:

No such clear relationship.

It does seem that sites where the vegetation is very close to the bank edge have lower bank erosion and vegetation retreat rates.

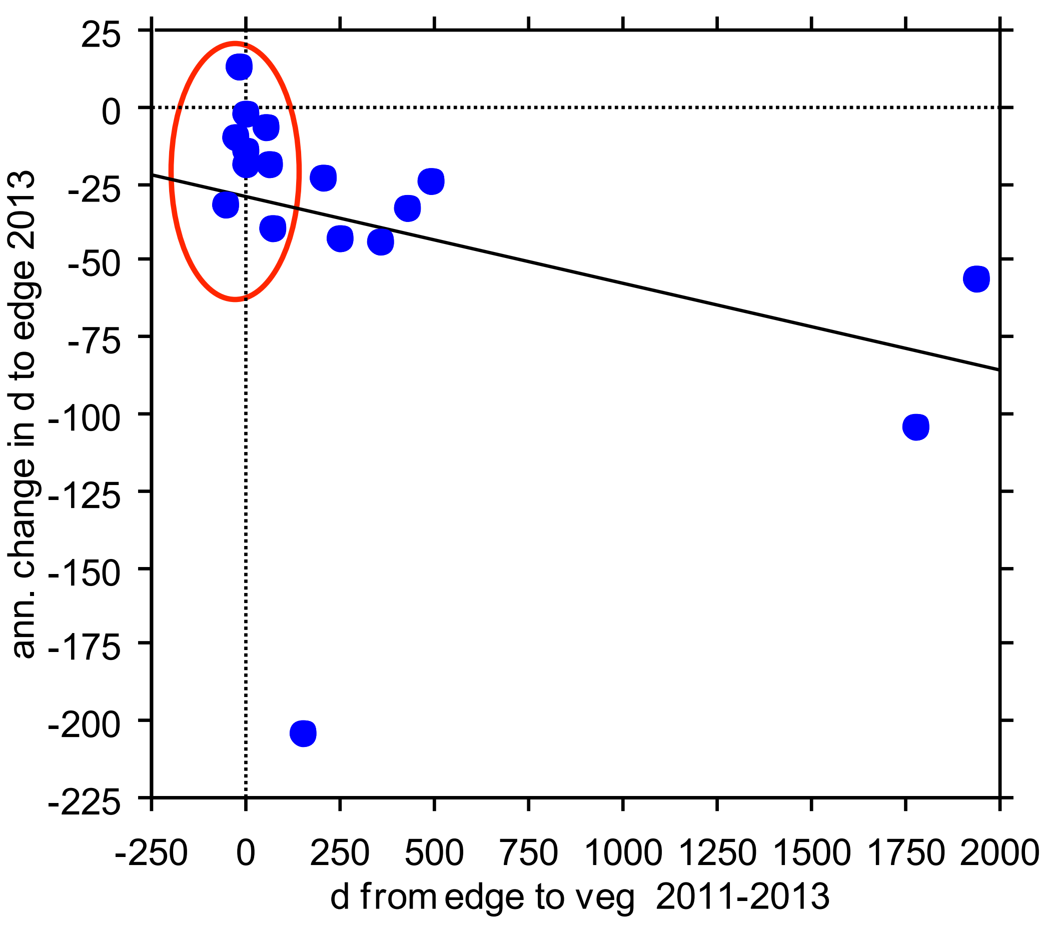
But among sites where the vegetation is far back, there is high variance in erosion and vegetation movement rates.

DISTANCE BETWEEN BANK AND VEGETATION EDGE vs. BANK EROSION

No sig. relationship (p=0.2). I'd expected sites with veg farther from bank edge to erode faster, but that's not the case.

However, all sites where veg edge was right near bank edge (circled) did have pretty low erosion rates, so at least maybe that's predictive.

(plotted below is erosion measured in 2013 (which represents 2011-2013 erosion) vs. average distance from bank to edge in 2011 and 2013 averaged; also didn't get any stronger pattern using just one year of data or entire 12 yr average)



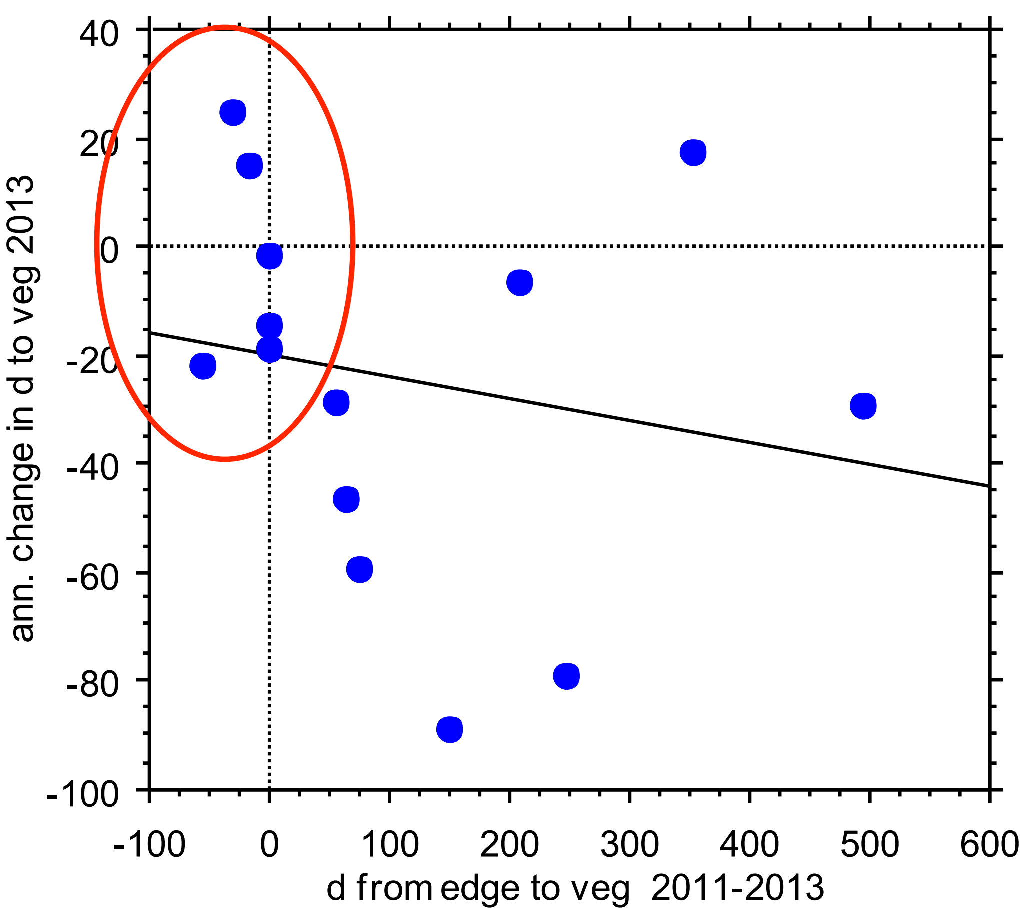
Y = -29.561 - .028 * X; R^2 = .116

DISTANCE BETWEEN BANK AND VEGETATION EDGE vs. VEGETATION MOVEMENT RATE

No sig. relationship (p=0.5). Sites with veg far from edge can have both high and low rates of vegetation retreat.

However, all sites where veg edge was right near bank edge (circled) did have pretty low veg retreat rates, so at least maybe that's predictive.

(plotted below is veg movement measured in 2013 (which represents 2011-2013) vs. average distance from bank to edge in 2011 and 2013 averaged; also didn't get any stronger pattern using just one year of data or entire 12 yr average)

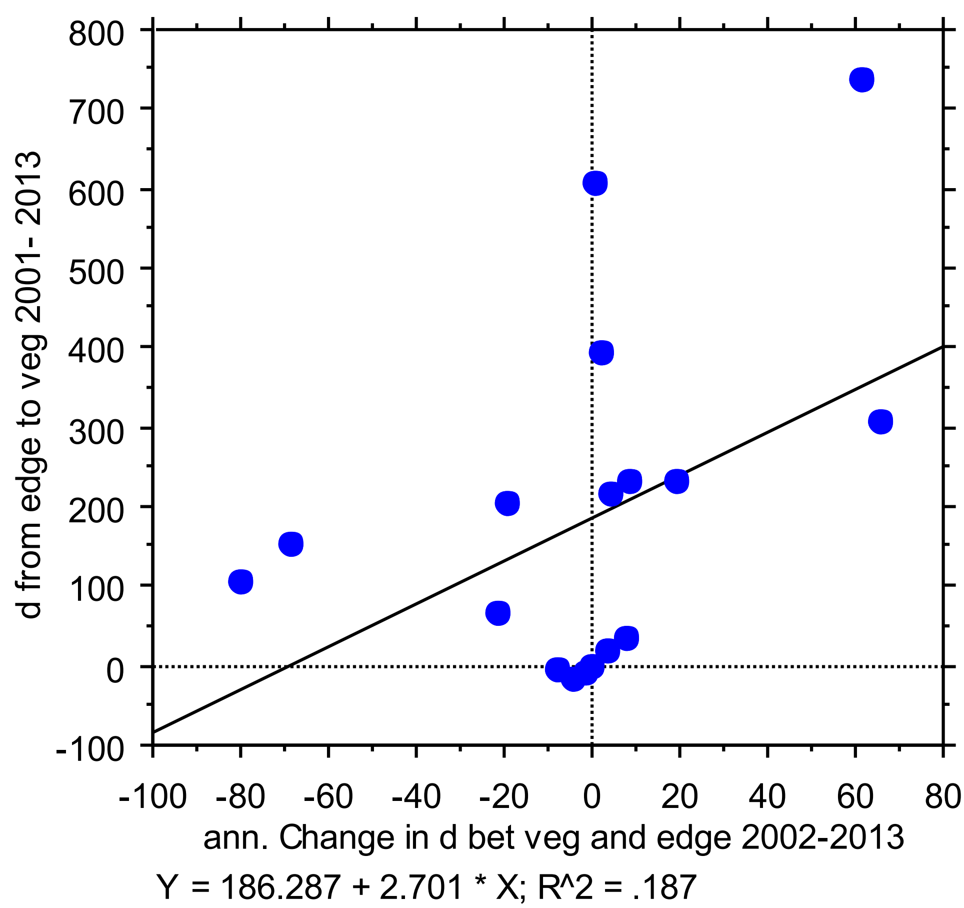


Y = -19.795 - .04 * X; R^2 = .036

DISTANCE BETWEEN BANK AND VEGETATION EDGE vs. VEGETATION RETREAT RATE

Marginally significant (p=0.07). Sites with veg far from edge tend to have greater increases in this distance.

(plotted below is 2001-2013 average; results for just recent years are not sig. at all)



Potential driver: CLIFF HEIGHT AND UNDERCUT

Rationale:

Predict that higher banks should resist erosion and have less landward vegetation movement than lower banks.

Also expect that undercutting hastens rate of bank erosion.

Results:

Cliff height had opposite effect than predicted : lowest cliffs have lower rates of bank erosion. But relationship between cliff height and bank erosion is weak.

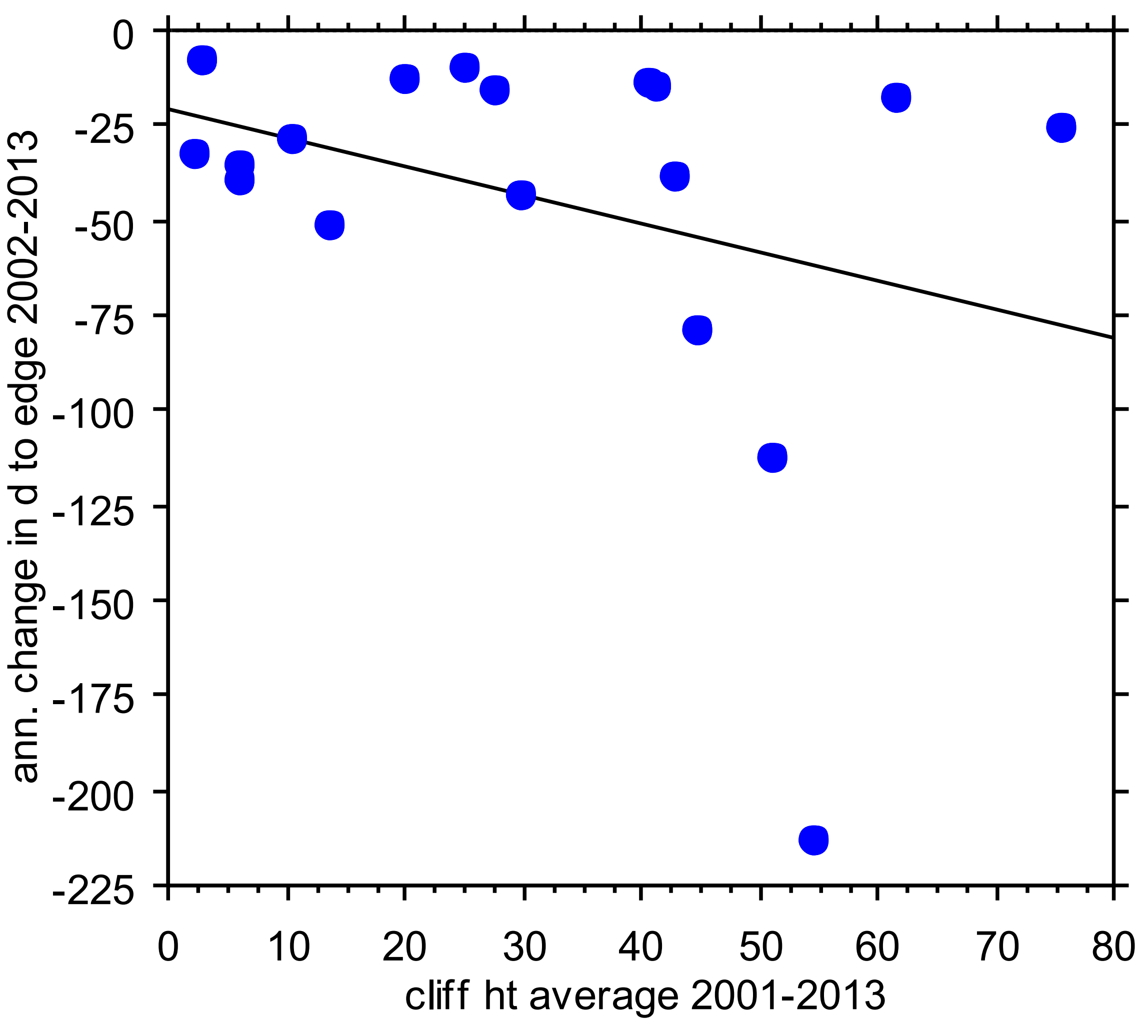
No significant relationship between cliff height and vegetation movement – surprising that higher cliffs didn't protect vegetation from algal mats, for instance, and thus slow rates of landward migration.

Undercutting does correlate significantly with bank erosion rate, as predicted (and has no effect on vegetation migration).

CLIFF HEIGHT VS. BANK EROSION RATE

Slight negative relationship, but not significant (p=0.2).
None of lowest cliffs (<20 cm) have high rates of erosion.

(plotted below is 2001-2013 average)



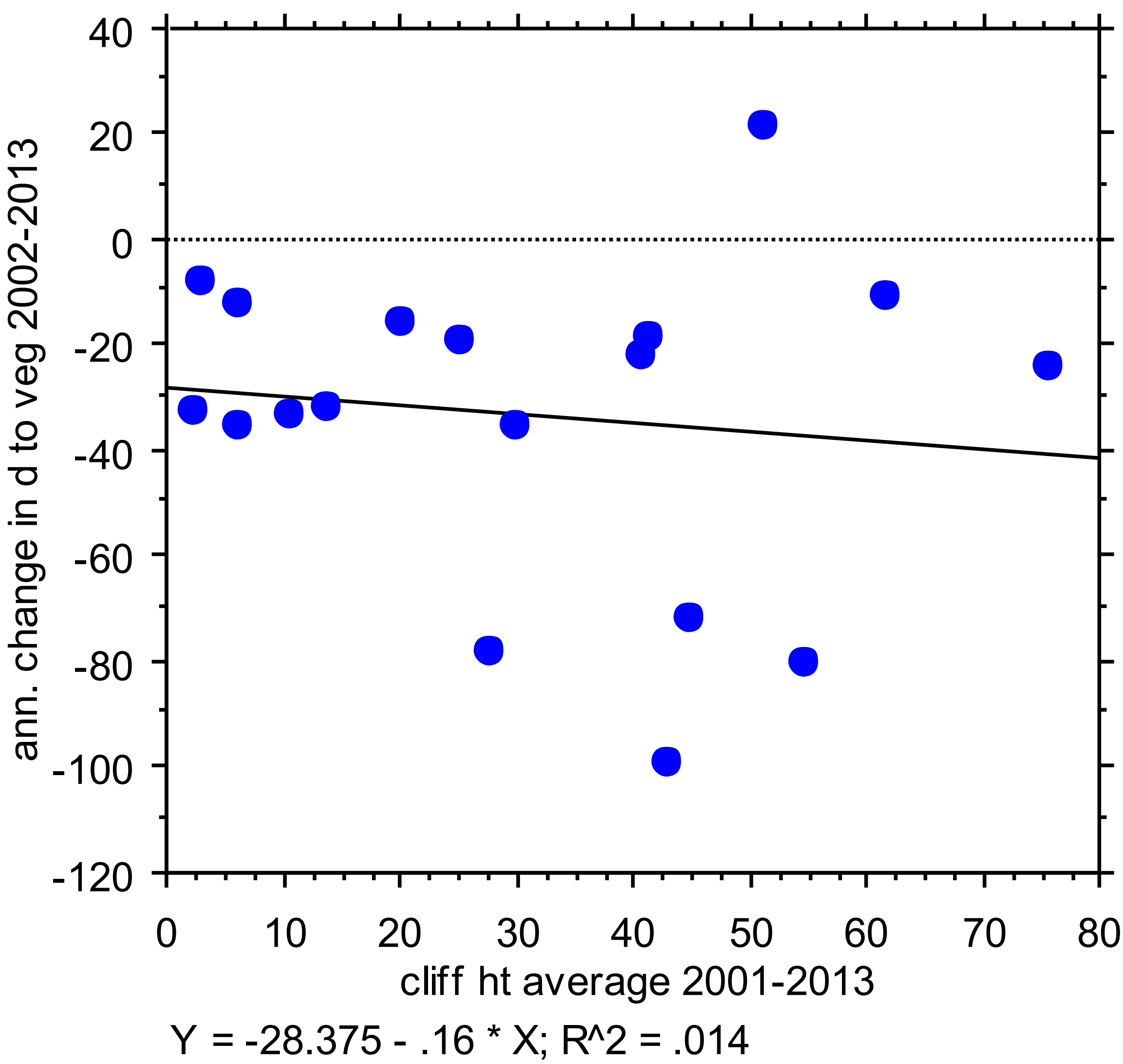
Y = -20.919 - .745 * X; R^2 = .108

CLIFF HEIGHT VS. VEGETATION MOVEMENT RATE

No relationship (p=0.6).

Counter to expectation that high banks might protect vegetation from algal mats and thus slow rates of movement.

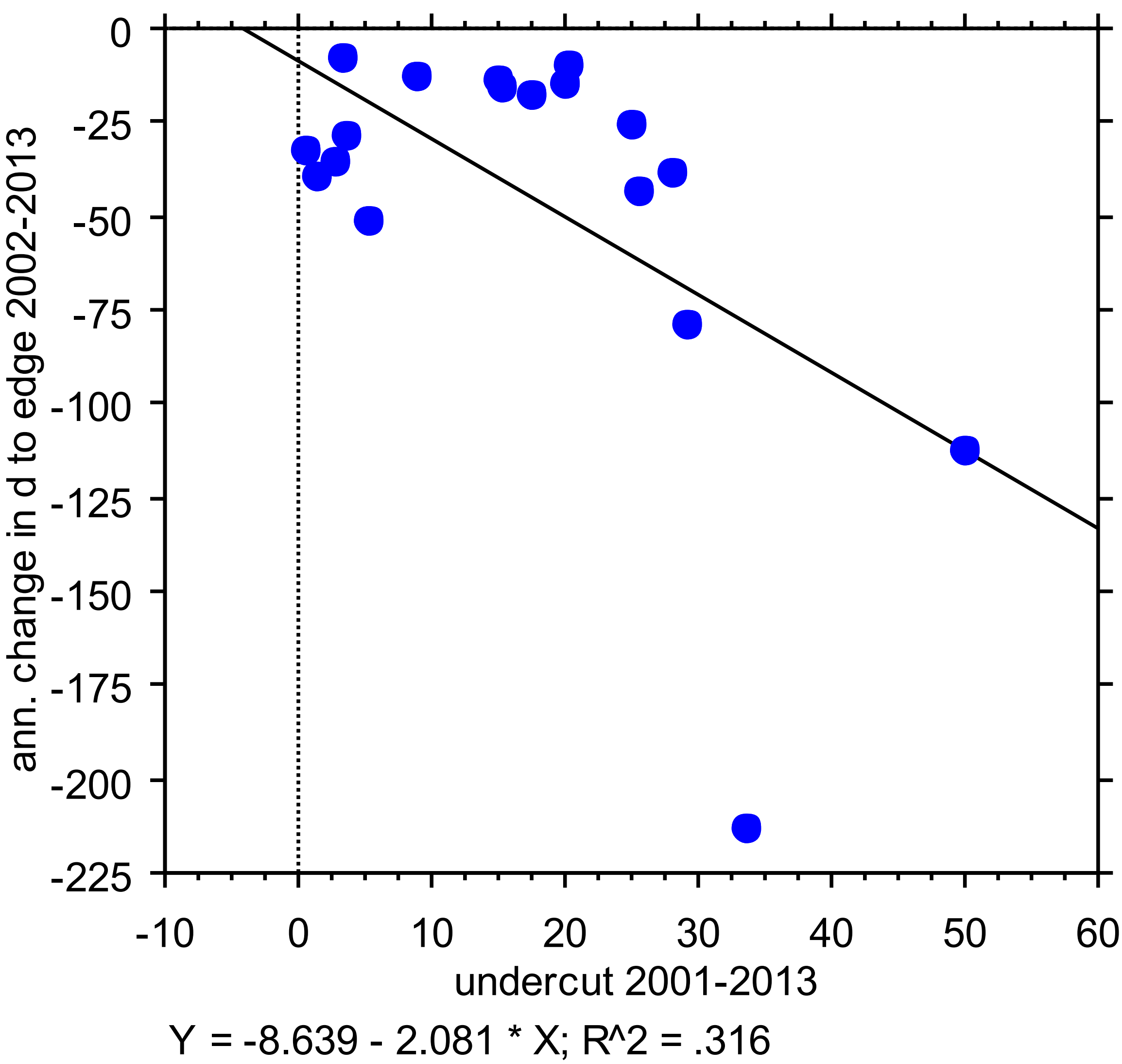
(plotted below is 2001-2013 average)



UNDERCUT VS. BANK EROSION RATE

Significant positive relationship (p=0.02): higher bank erosion in areas with greater undercutting. Makes sense!

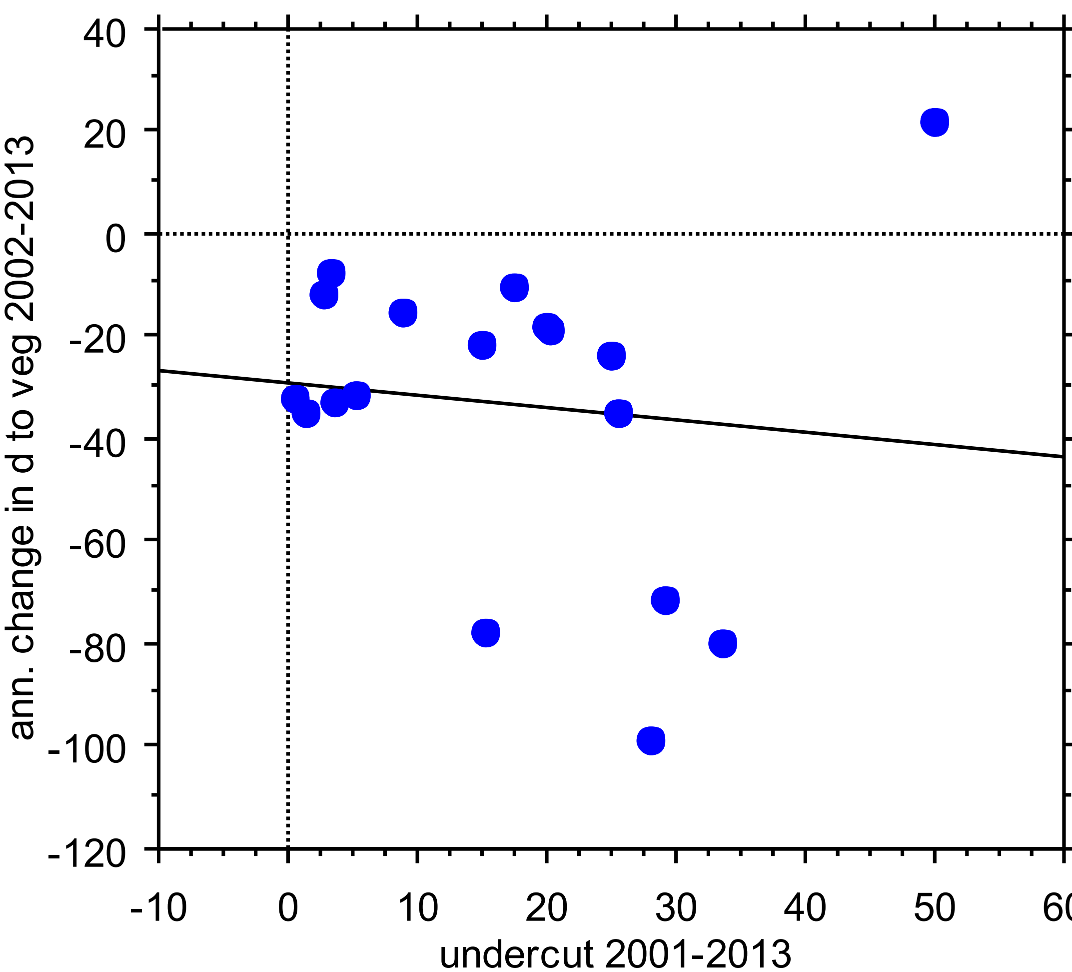
(plotted below is 2001-2013 average)



UNDERCUT VS. VEGETATION MOVEMENT RATE

No relationship (p=0.7).

(plotted below is 2001-2013 average)



Y = -29.287 - .239 * X; R^2 = .011

Potential driver: BURROW HOLES

Rationale:

Rate of bank erosion could be hastened due to weakening of bank by burrow holes. Rate of vegetation movement could also be hastened if burrowing damages roots, for instance.

Results:

Density of large holes of the sort definitely made by crabs don't correlate with any of our response variables (not bank erosion, movement of veg edge, distance between veg and bank edge, or change in that distance).

Density of small holes (which could be made by the burrowing isopod Spheroma or by tiny crabs) seemed to show a negative correlation with bank erosion rate. However when I examined this more closely, it seemed suspect: temporally, the pattern was that bank erosion in early years correlated with holes in later years, not vice versa, which doesn't fit our model for causality. Also, a single station, (Coyote, 60) is responsible for the significance of the pattern. Weirdly, density of small holes seems to have a positive relationship on vegetation (it moves less landward with more holes).

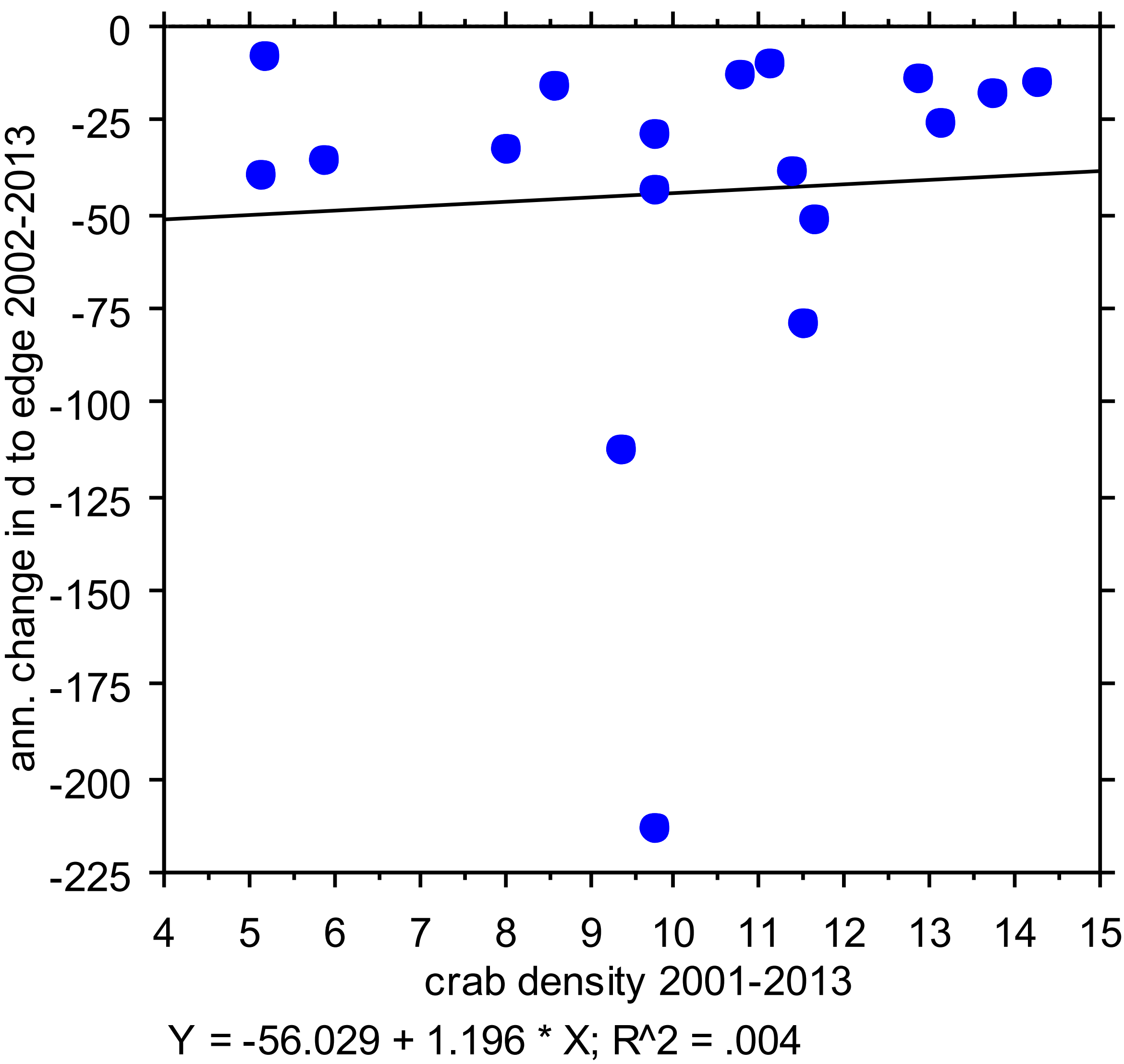
Density of total holes wasn't useful to look at either: it's driven by the more abundant small holes and closely resembles patterns for small holes, but less significant.

CRAB HOLES vs. BANK EROSION

No relationship (p=0.8) with holes and erosion rates averaged over all monitoring years (for each stake).

(2001-2013 averaged; also tried 2011 holes vs. 2013 erosion, 2011-2013 holes vs. 2011-2013 erosion, and got nothing better.

Note that "crab hole" = holes > 1 cm)

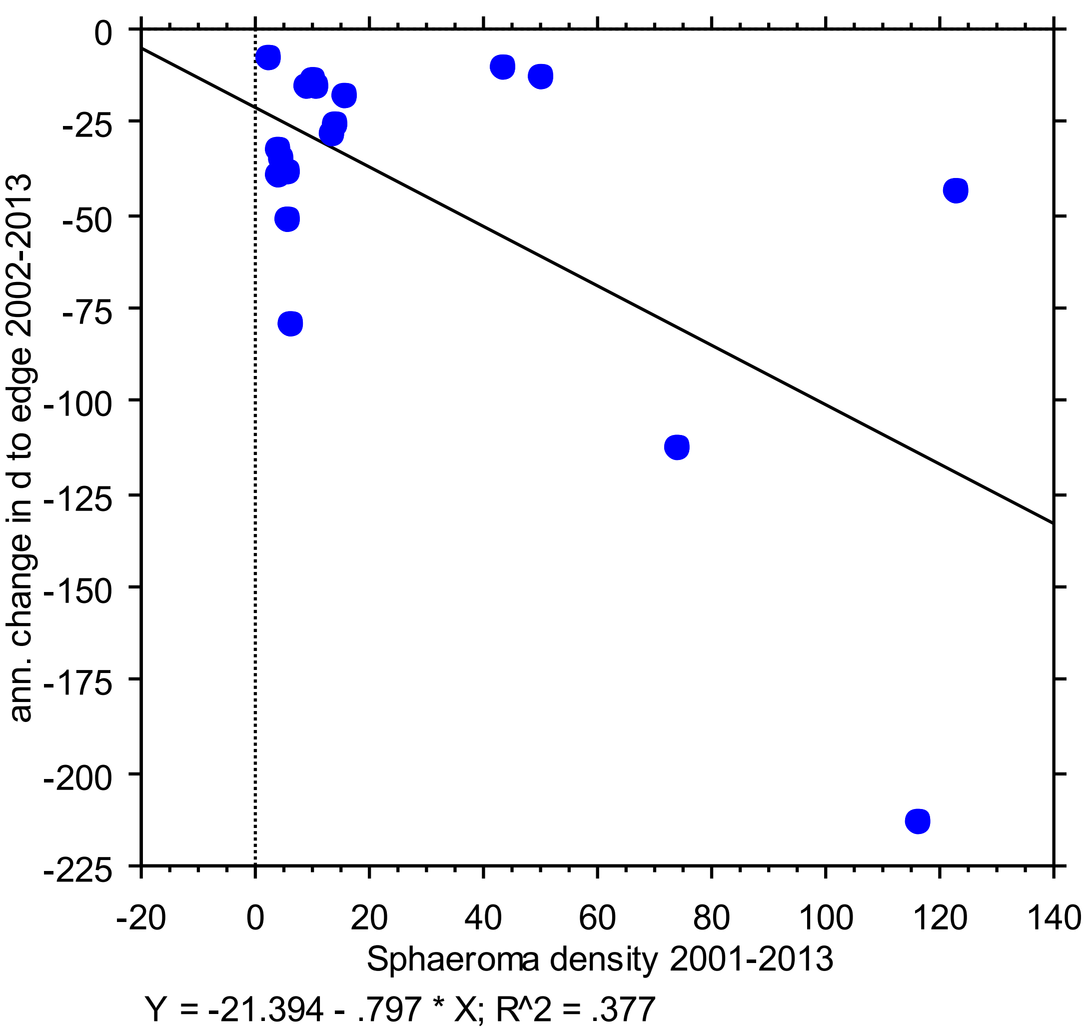


SPHEROMA HOLES vs. BANK EROSION

Significant relationship (p=0.008) with Spheroma holes and erosion rates averaged over all monitoring years (for each stake).

(2001-2013 averaged;

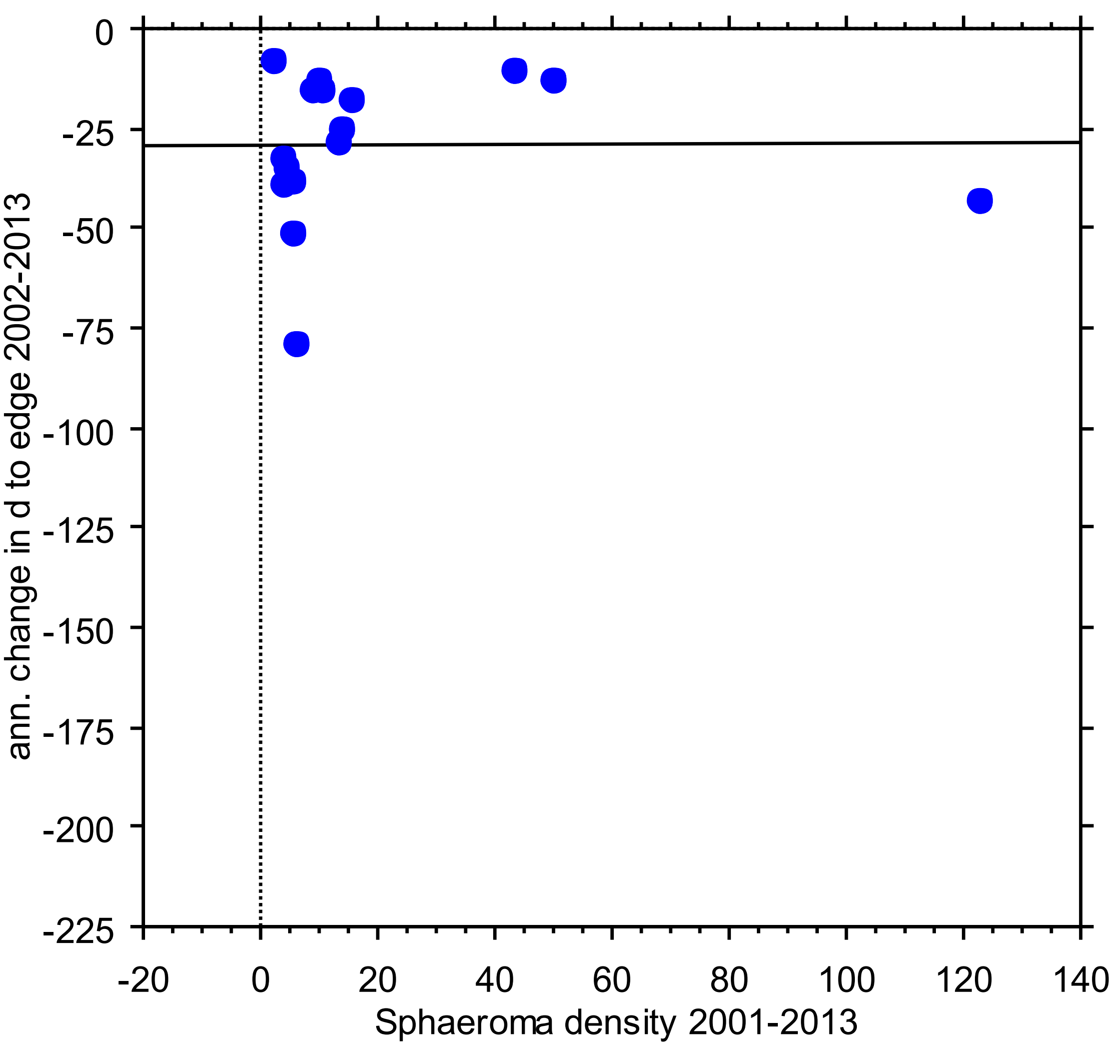
Note that "Spheroma hole" = holes 1 cm or less)



SPHEROMA HOLES vs. BANK EROSION

Oops, but if I redo the same analysis on the last page without data from station 60, Coyote peninsula, the significance disappears entirely.

Suggests the pattern is not very robust……



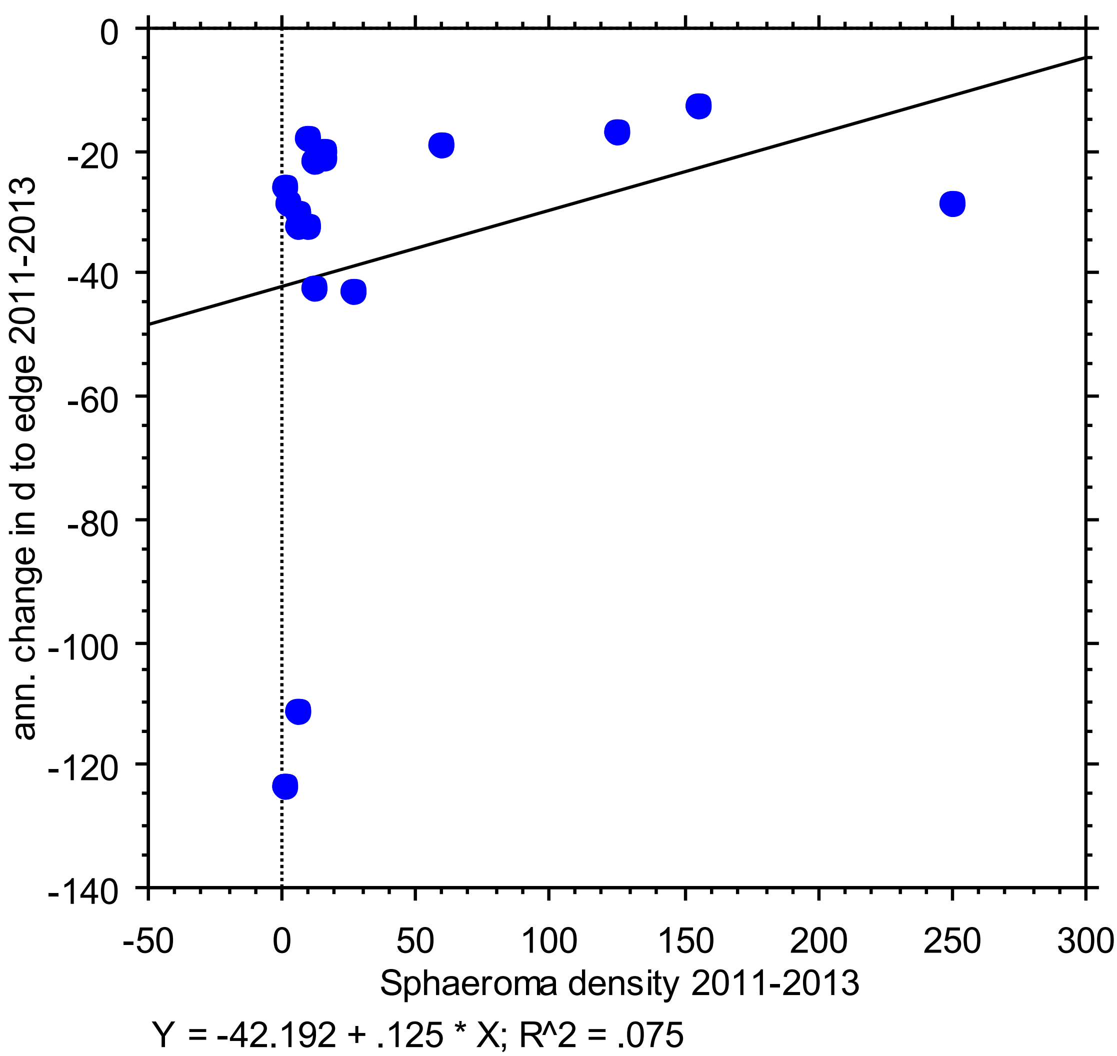
Y = -29.176 + .004 * X; R^2 = 3.778E-5

SPHEROMA HOLES vs. BANK EROSION

No sig relationship (p=0.3) with Spheroma holes and erosion rates when looking just at last few years.

(2011 & 2013 data averaged)

Note that "Spheroma hole" = holes 1 cm or less)

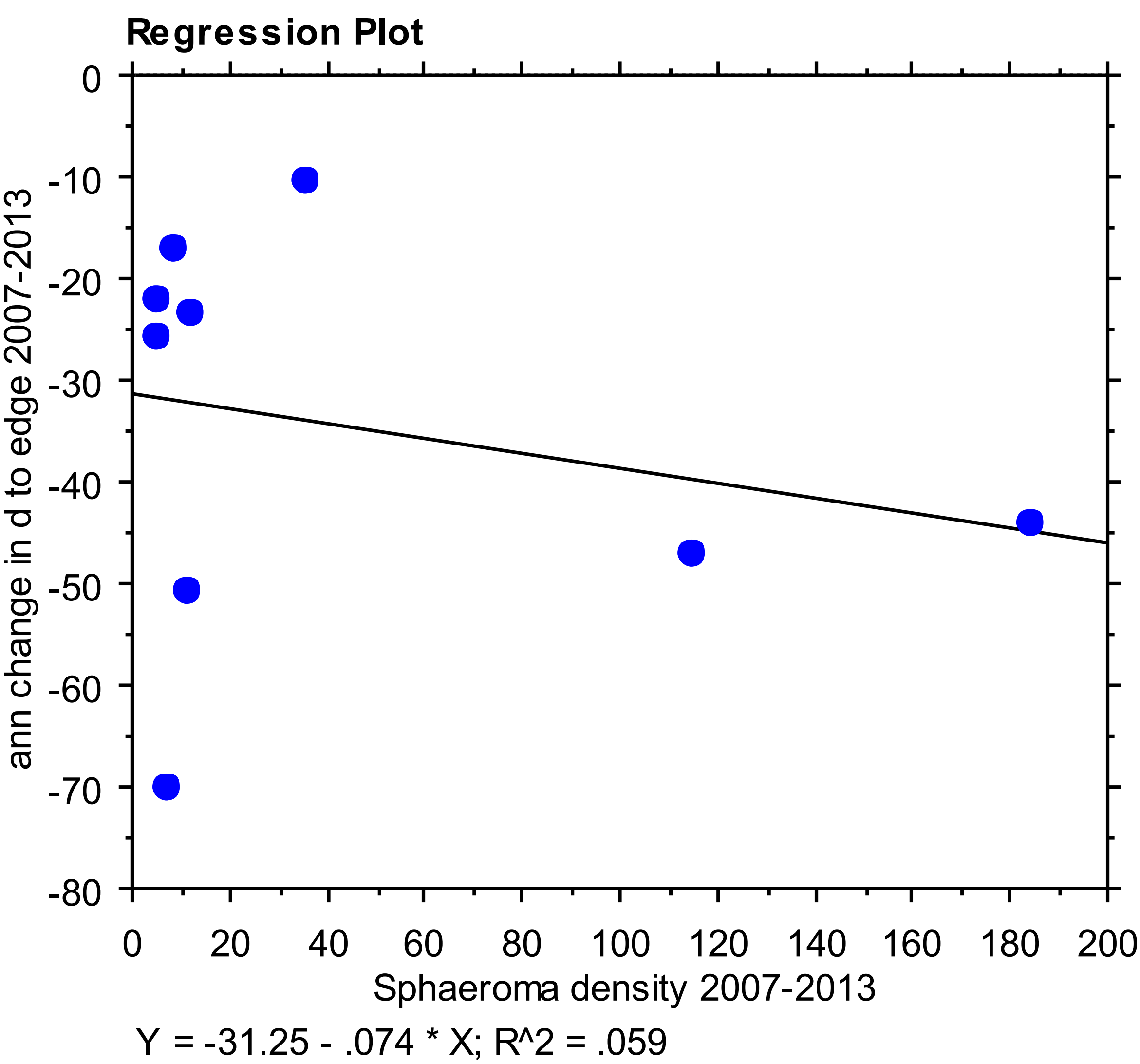


SPHEROMA HOLES vs. BANK EROSION

Hmm, examining time periods further, no sig relationship ($p=0.5$) with Spheroma holes and erosion rates for 2007-2013.

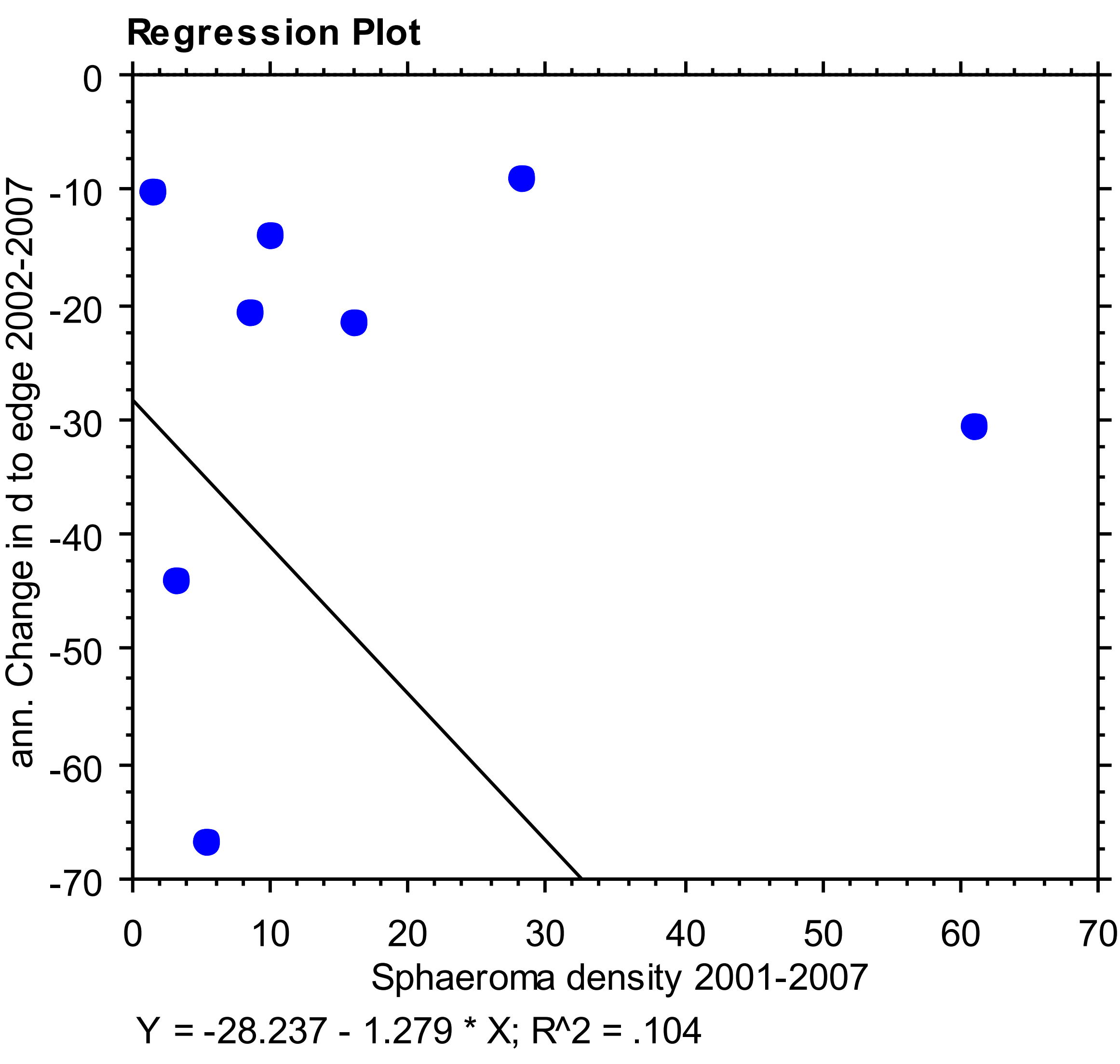
(2007-2013 averaged, using average of both stakes as rep, because it was what I had handy; decreased replication lowers sig. of these analyses but R2 is similar, for those analyses where I compared the methods)

Note that "Spheroma hole" = holes 1 cm or less)



SPHEROMA HOLES vs. BANK EROSION

Nothing significant (p=0.4) for early period, 2002-2007 either. What's going on?

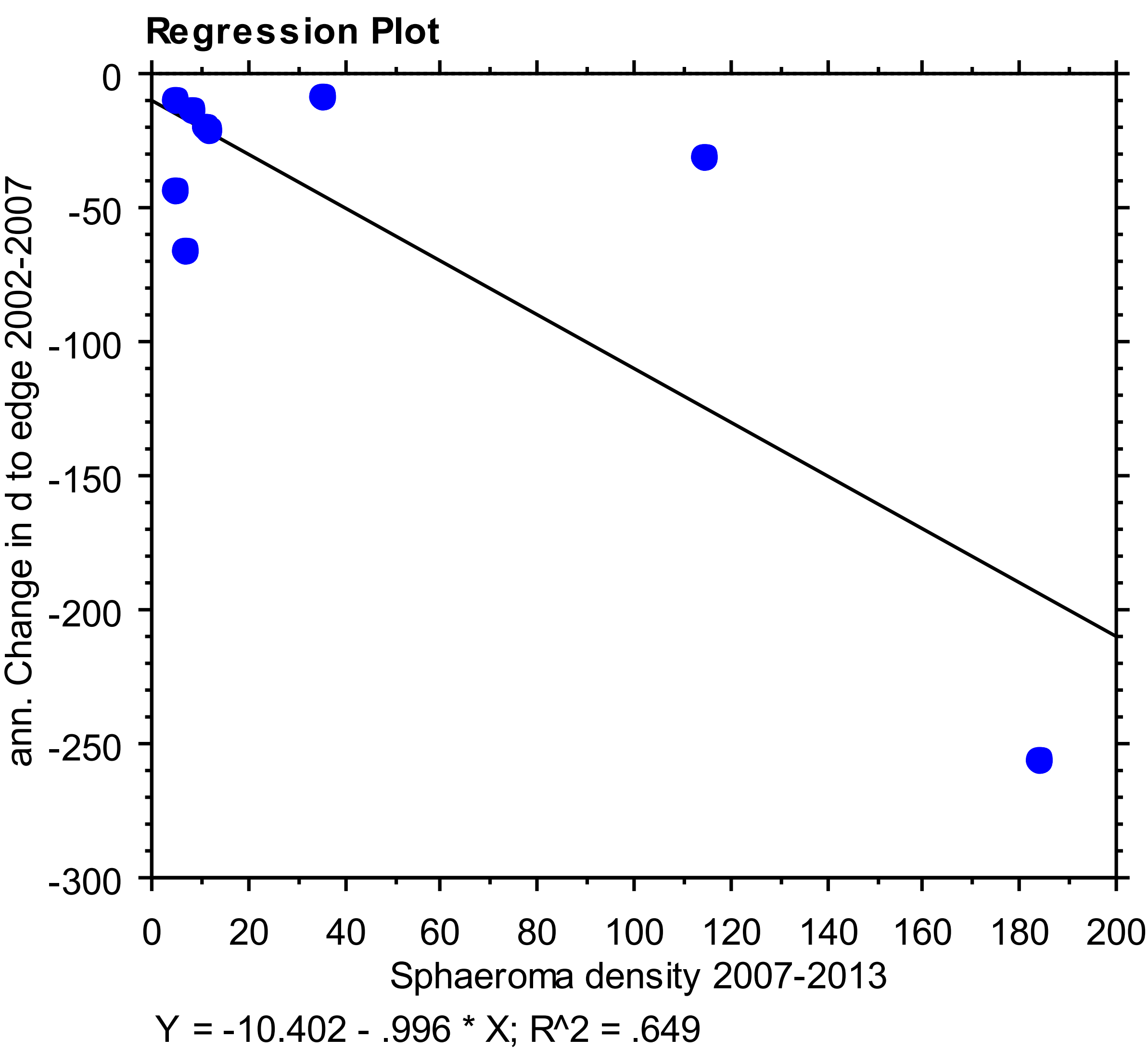


SPHEROMA HOLES vs. BANK EROSION

Here's the smoking gun! Significant relationship (p=0.009) despite this analysis being with half the reps as I was using originally.

Erosion in the early period correlates with small holes in the later period! However if I remove that one outlier, (station 60, Coyote, with 180 small holes on average), the pattern falls apart completely....

Doesn't look like we can do much here....

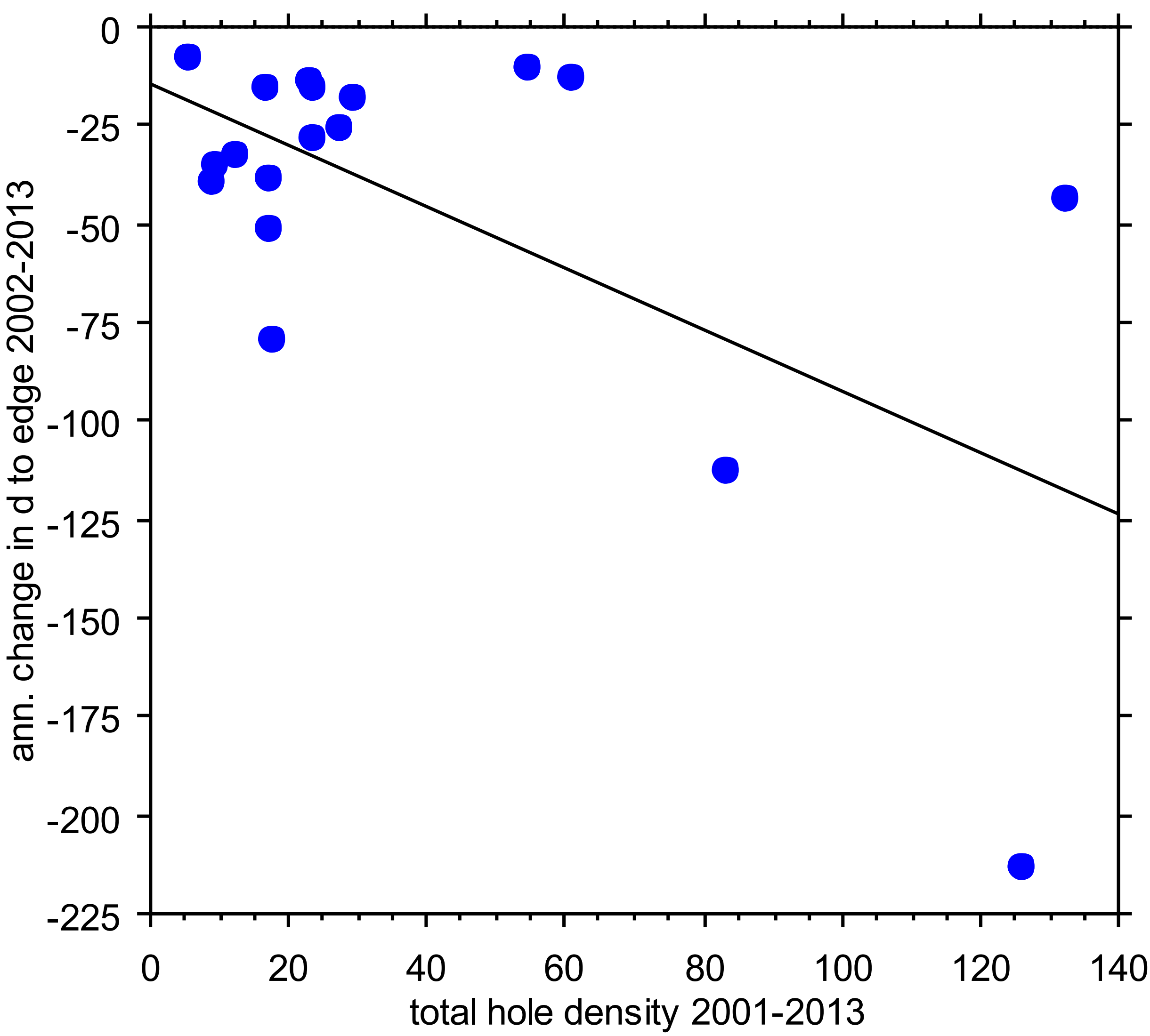


TOTAL HOLES vs. BANK EROSION

Strong relationship (p=0.007) over total monitoring period. This is clearly driven by the small holes, since pattern looks much like the Spheroma hole graph for all periods.

(2001-2013 averaged)

Note that "total holes+=small + large)



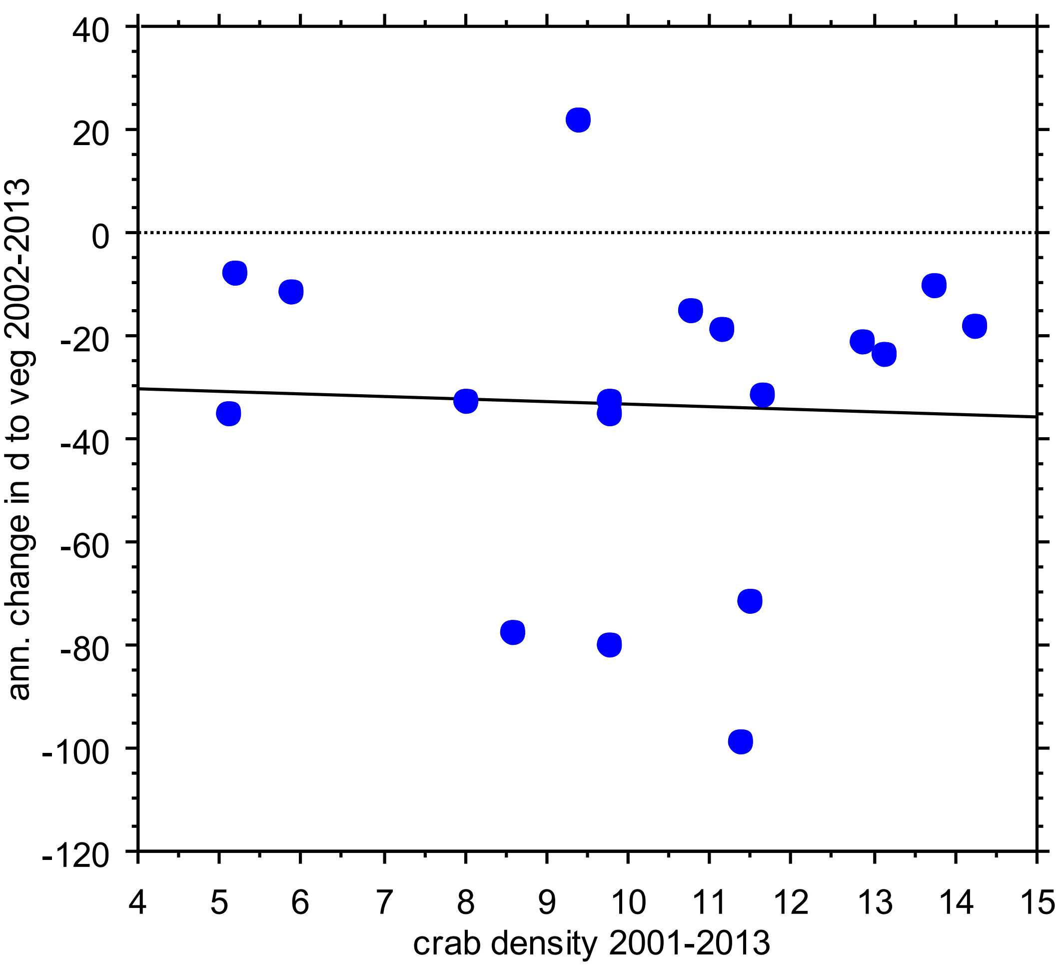
Y = -14.221 - .781 * X; R^2 = .369

CRAB HOLES vs. VEGETATION MOVEMENT

No relationship (p=0.9) with holes and vegetation movement rates averaged over all monitoring years (for each stake).

(2001-2013 averaged; also tried 2011 holes vs. 2013 veg movement, 2011-2013 holes vs. 2011-2013 veg movement, latter was a bit better but still not sig

Note that "crab hole" = holes > 1 cm)



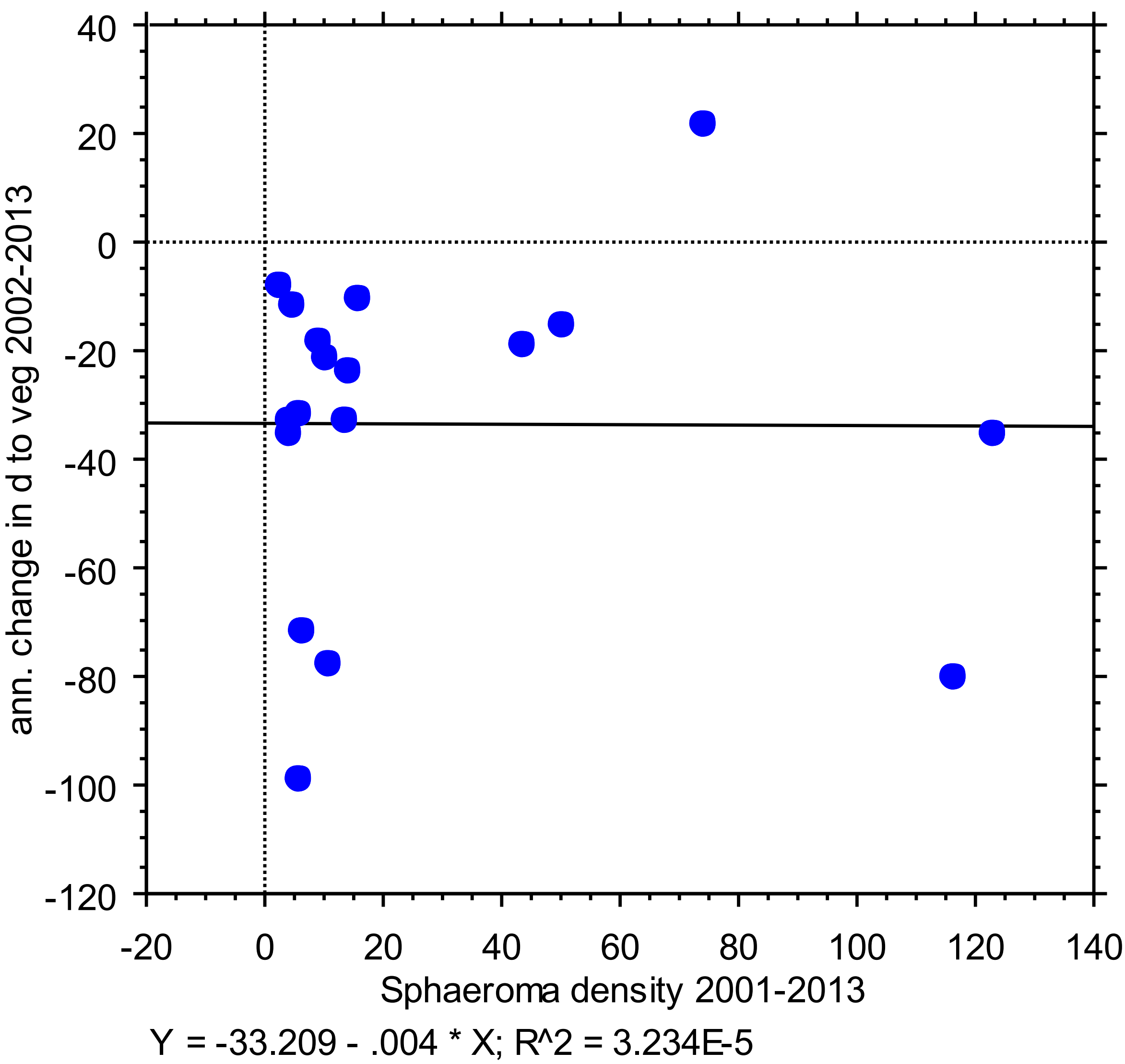
Y = -28.317 - .497 * X; R^2 = .002

SPHEROMA HOLES vs. VEGETATION MOVEMENT

No relationship (p=0.9).

(2001-2013 data averaged)

Note that "Spheroma hole" = holes 1 cm or less)



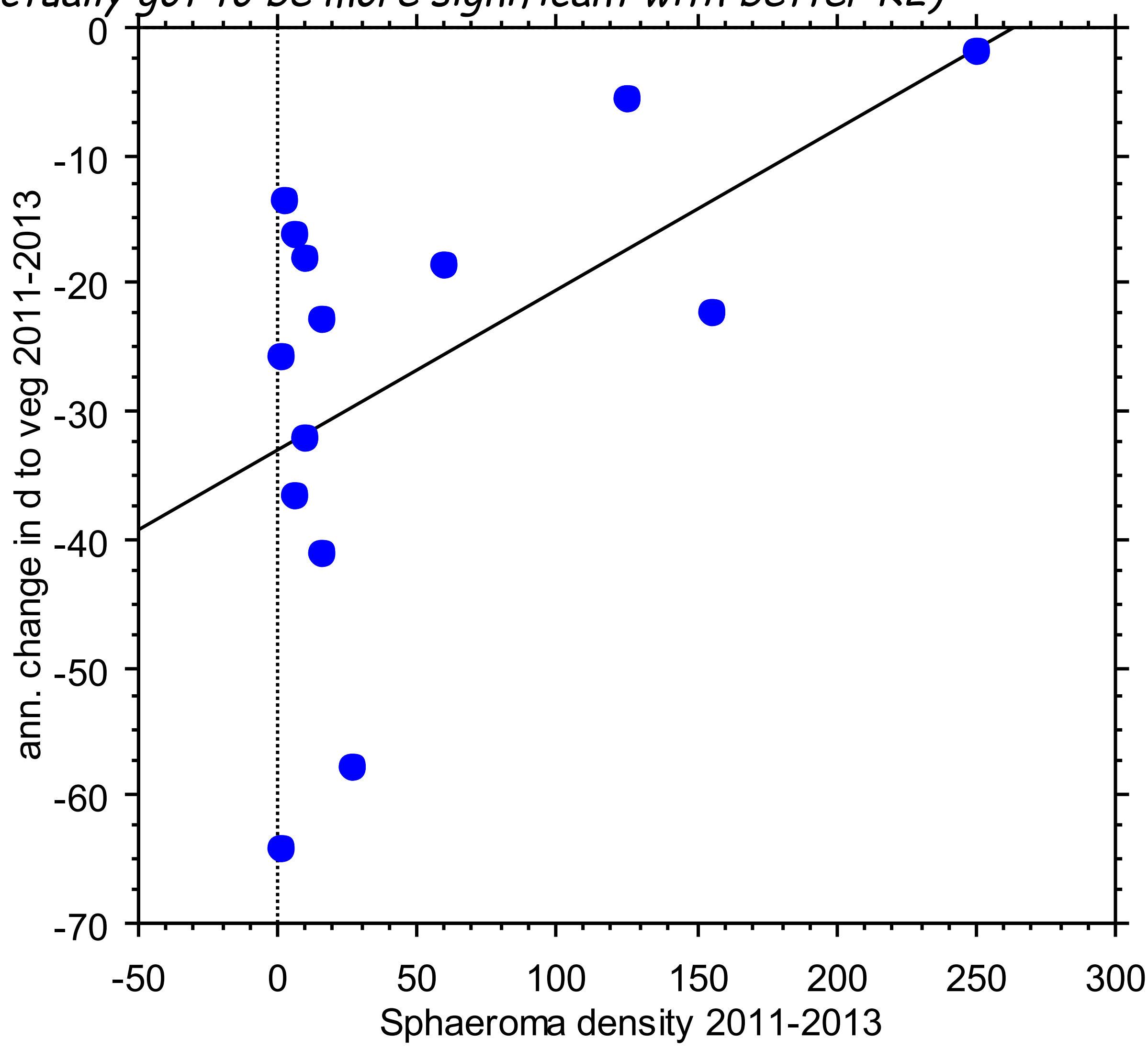
SPHEROMA HOLES vs. VEGETATION MOVEMENT

Marginally significant positive relationship (p=0.05). The more Spheroma holes, the less landward retreat of vegetation???

(2011 & 2013 data averaged)

Note that "Spheroma hole" = holes 1 cm or less)

(I removed station 60 to see if it was driving pattern, and it actually got to be more significant with better R2)

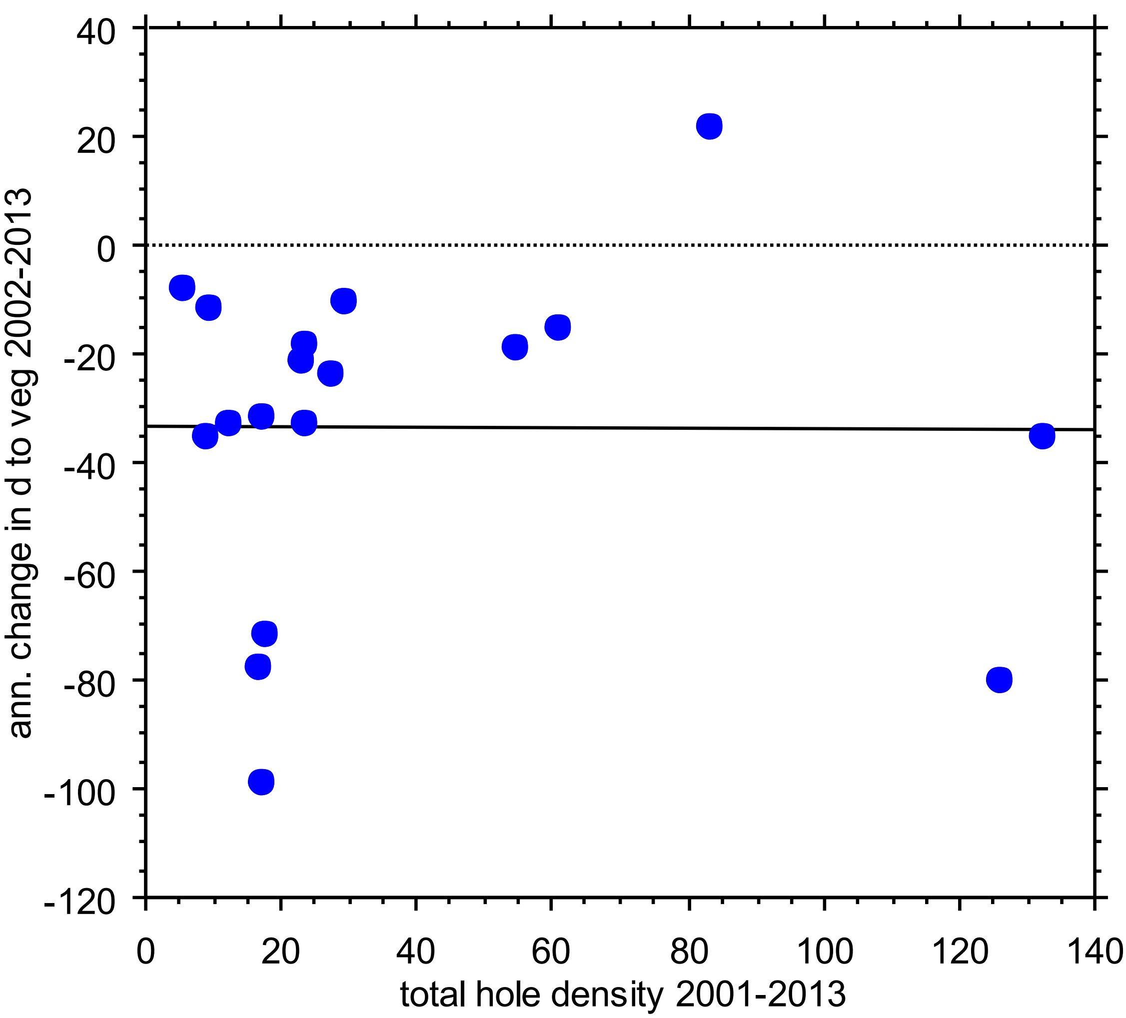


Y = -32.956 + .125 * X; R^2 = .272

TOTAL HOLES vs. VEGETATION MOVEMENT

No relationship (p=0.9).

(2001-2013 average)

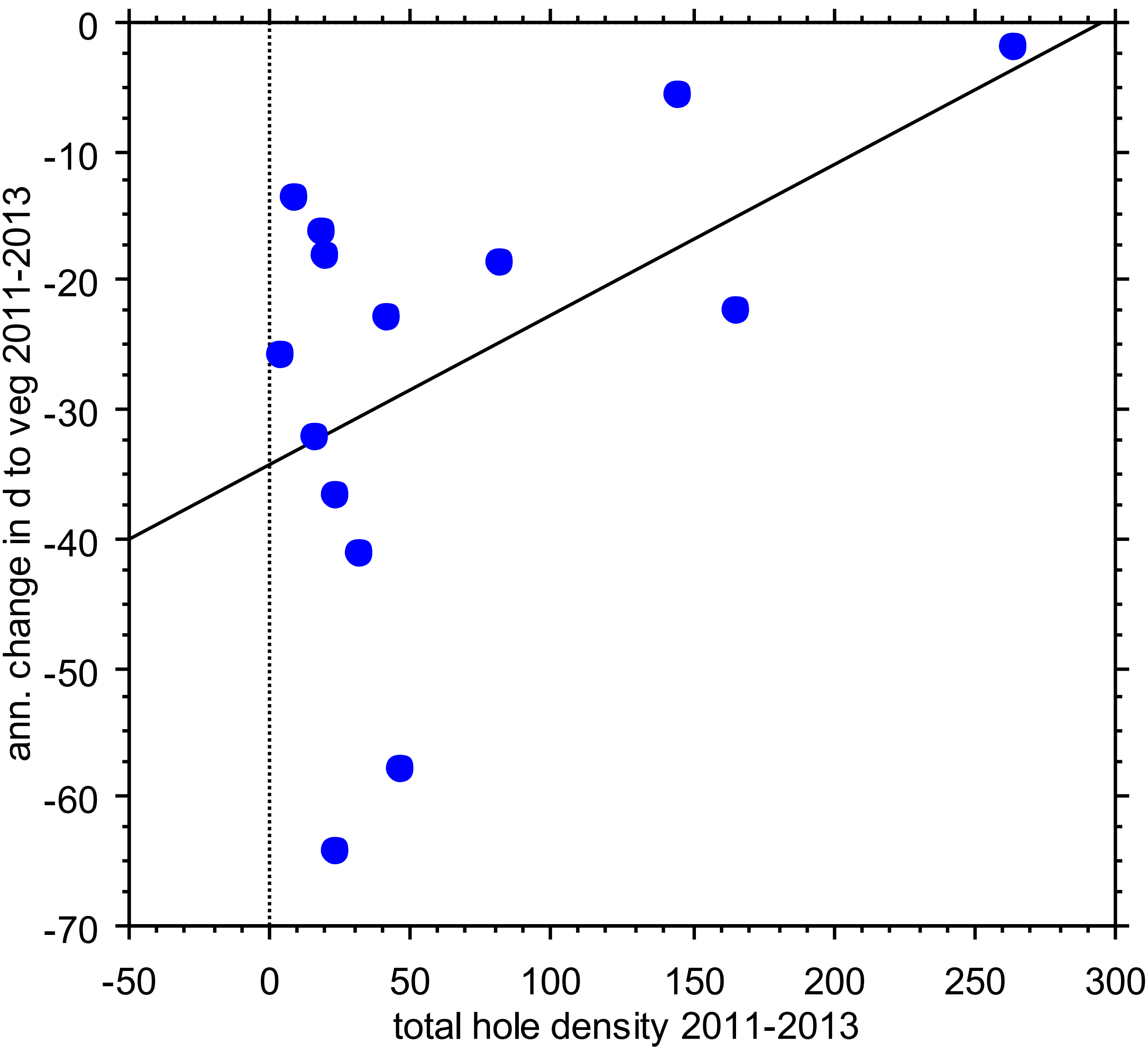


Y = -33.121 - .006 * X; R^2 = 5.247E-5

TOTAL HOLES vs. VEGETATION MOVEMENT

Marginally significant positive relationship (p=0.07). The more Spheroma holes, the less landward retreat of vegetation???

This is of course driven by Spheroma holes; weaker with crab holes added in
(2001-2013 average)



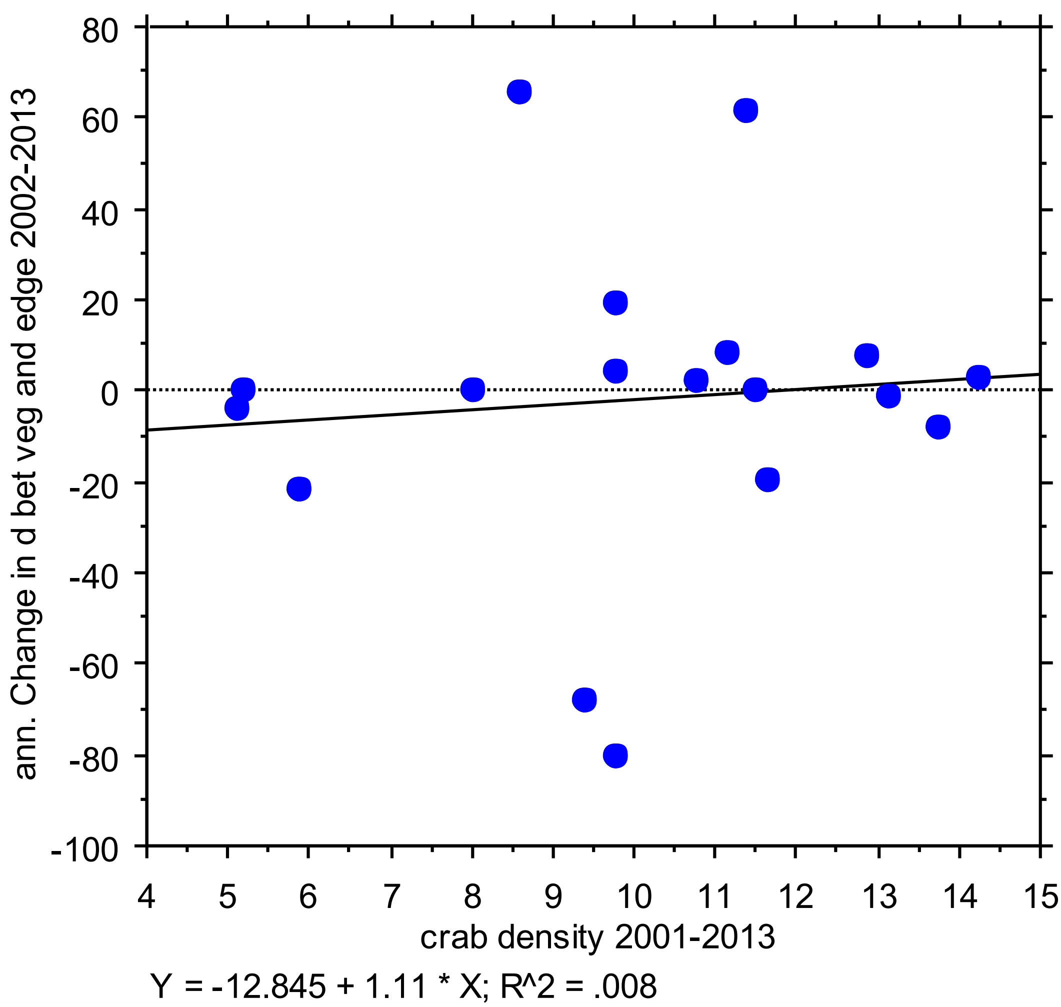
Y = -34.165 + .116 * X; R^2 = .237

CRAB HOLES vs. VEGETATION RETREAT

No relationship ($p=0.7$) with holes and vegetation retreat rates averaged over all monitoring years (for each stake).

(2001-2013 averaged; also tried 2011 holes vs. 2013 veg retreat, 2011-2013 holes vs. 2011-2013 veg retreat, latter was a bit better but still not sig

Note that "crab hole" = holes > 1 cm)



SPHEROMA HOLES vs. VEGETATION RETREAT

Marginally significant relationship (p=0.07).
Lots of Spheroma holes in places where distance between bank and edge has decreased.

(2001-2013 data averaged)

Note that "Spheroma hole" = holes 1 cm or less)

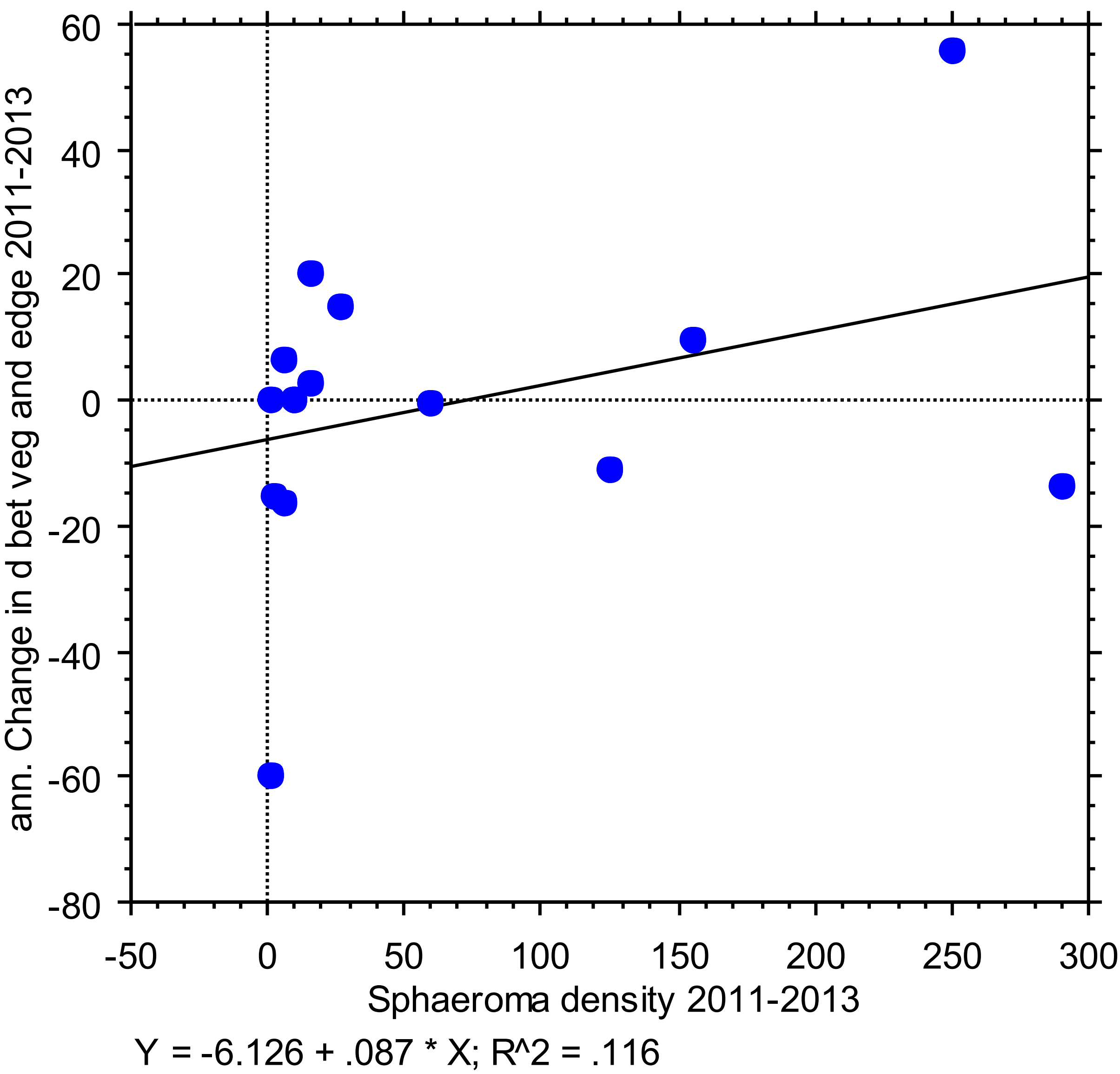
The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

SPHEROMA HOLES vs. VEGETATION RETREAT

No relationship ($p=0.2$) in past years.

(2011 & 2013 data averaged)

Note that "Spheroma hole" = holes 1 cm or less)

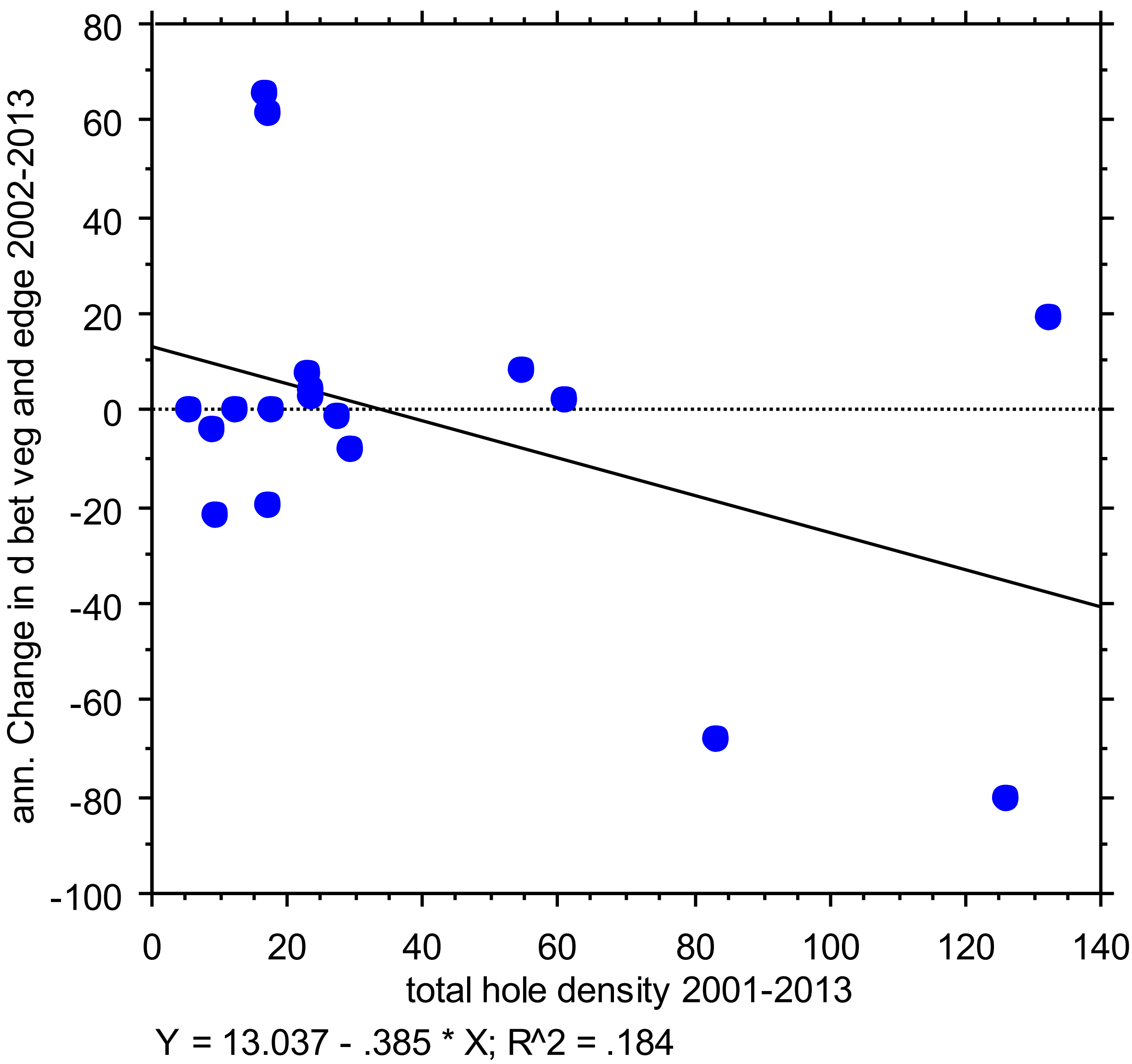


TOTAL HOLES vs. VEGETATION RETREAT

Marginally significant relationship (p=0.08).
Lots of holes in places where distance between bank and edge has decreased.

A bit weaker than Spheroma holes alone showed

(2001-2013 data averaged)

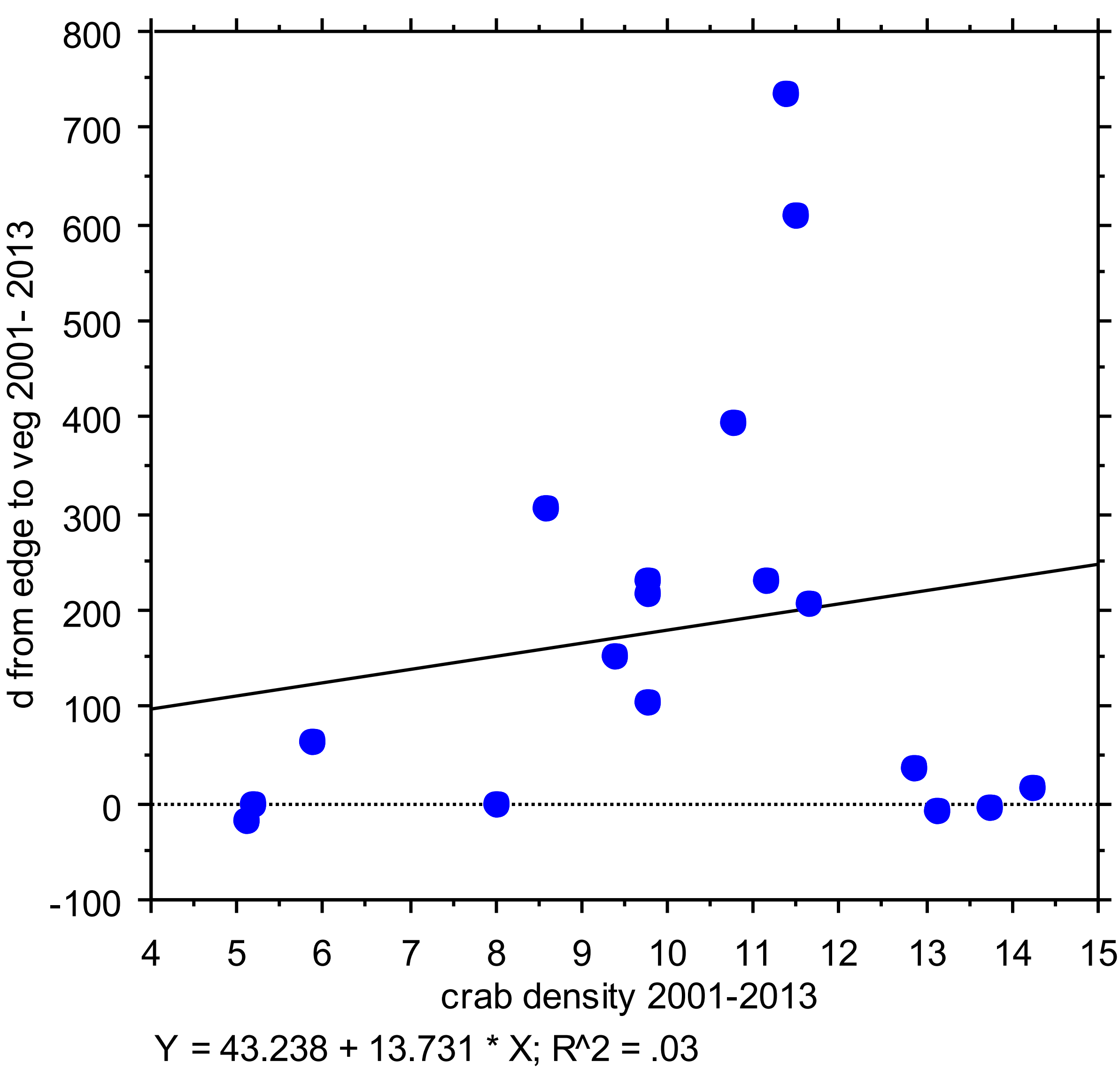


CRAB HOLES vs. DISTANCE BETWEEN VEG AND BANK EDGE

No relationship (p=0.5).

(2001-2013 averaged; also tried 2011 holes vs. 2013 veg retreat, 2011-2013 holes vs. 2011-2013 veg retreat, latter was a bit better but still not sig

Note that "crab hole" = holes > 1 cm)

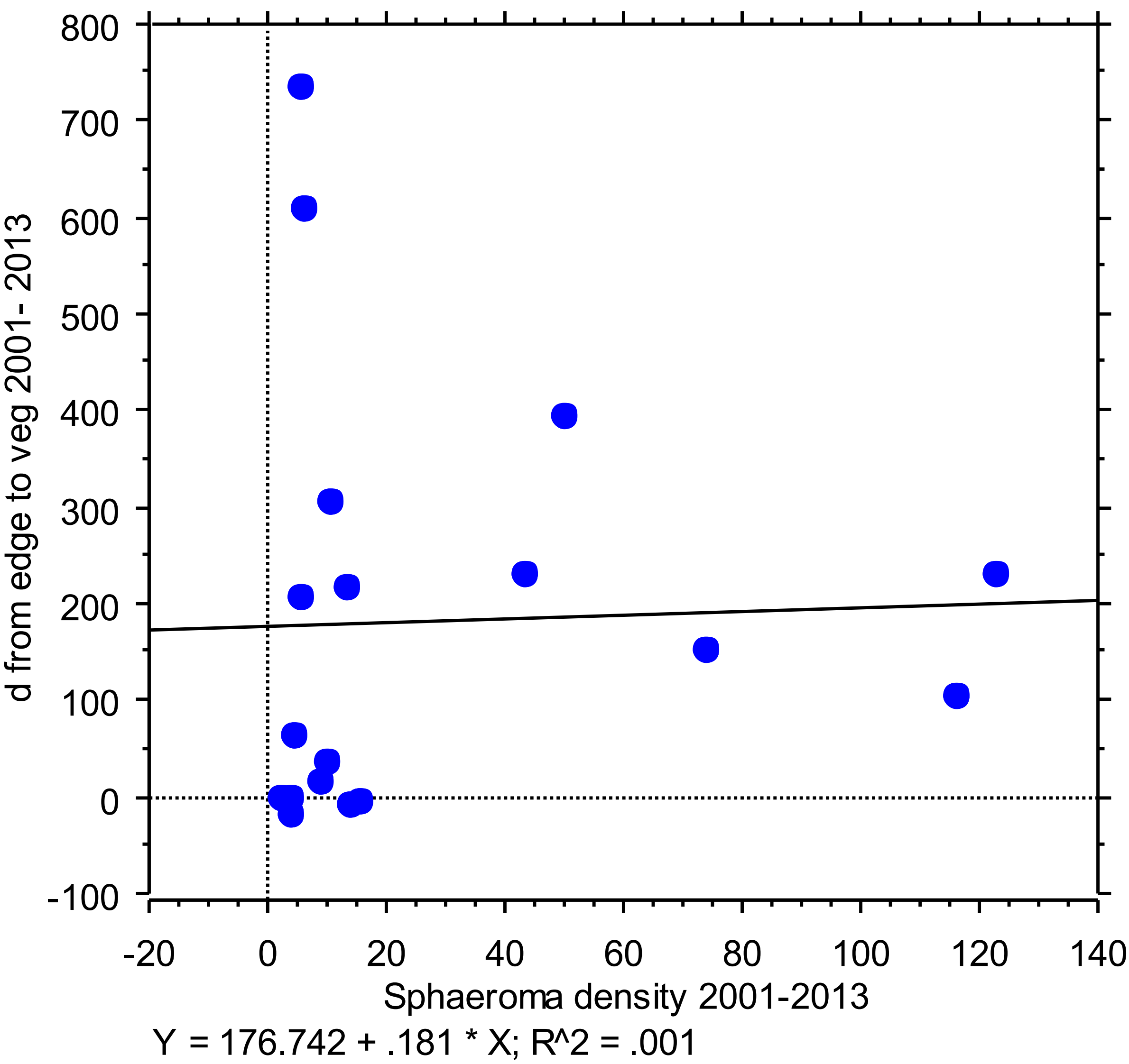


SPHEROMA HOLES vs. DISTANCE BETWEEN VEG AND BANK EDGE

No relationship (p=0.9).

(2001-2013 data averaged, also checked 2011-2013 and found nothing)

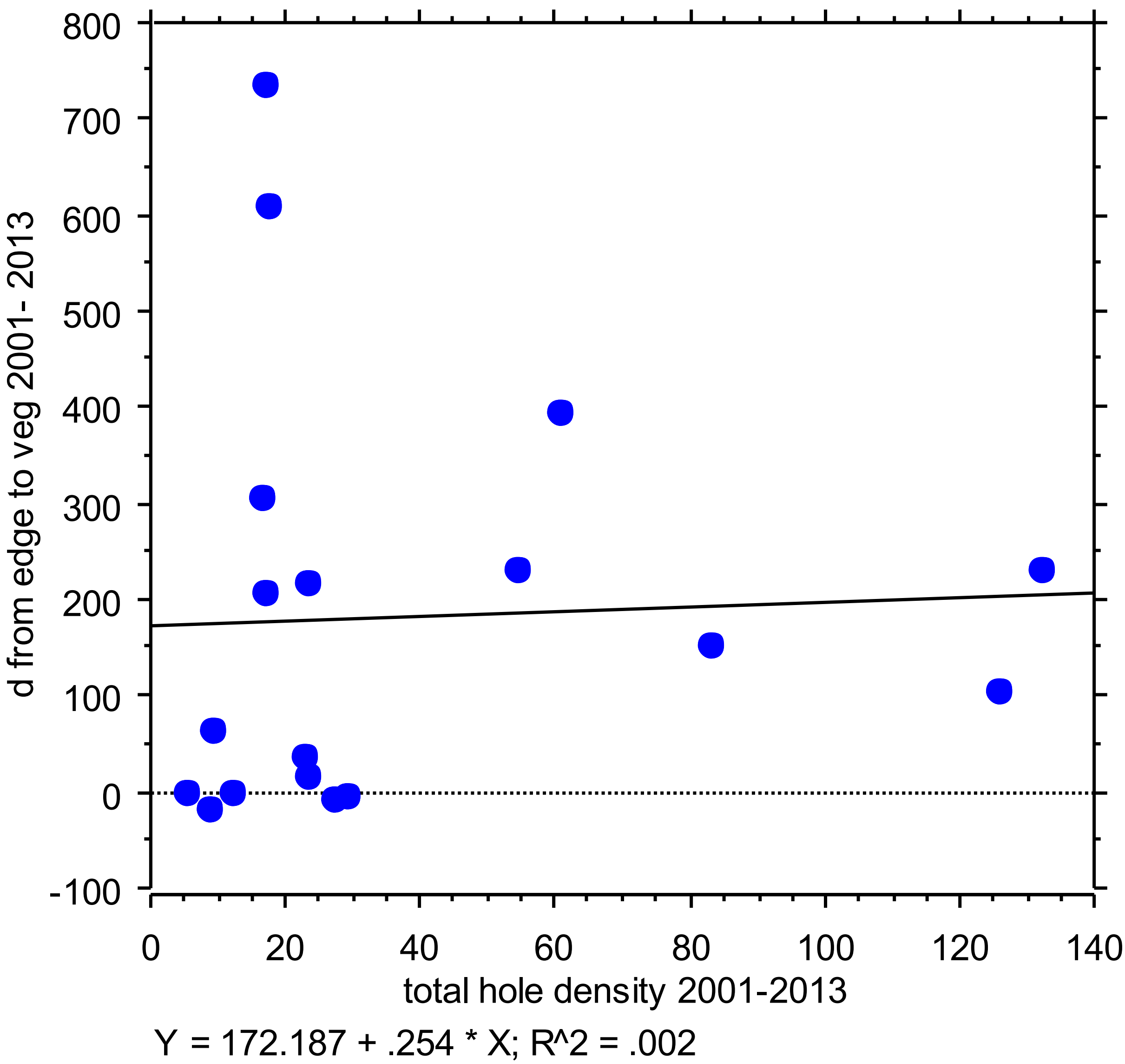
Note that "Spheroma hole" = holes 1 cm or less)



TOTAL HOLES vs. DISTANCE BETWEEN VEG AND BANK EDGE

No relationship (p=0.9).

(2001-2013 data averaged, also checked 2011-2013 and found nothing)



MECHANISMS OF BANK EROSION

This year in the field we started paying attention to different visual characteristics of bank loss

There is a lot of spatial variation in appearance of banks, even within small areas (either side of a point, for instance)

It seems likely that mechanism of bank erosion is at least in part a result of physical factors, in particular currents and eddies resulting in undercutting in some places, deposition in others, etc.

But this may interact with biological factors: crabs burrowing may be more likely to result in undercutting, while wrack in vegetation retreat from edge.

Following photos are fodder for further thoughts and analyses…

VEG NEAR EDGE
At some banks, veg edge is very close to bank edge.
These areas have low rates of erosion and veg migration.

VEG NEAR EDGE
Often these banks with veg near edge seem to be ones in more depositional channel areas, with mudflat in front of bank

VEG NEAR EDGE

Here is one very extensive and depositional mudflat in front of a bank where veg is near edge

However, this station (I think it's 23) had pretty high rates of erosion despite this deposition.

VEG OVERHANGING EDGE
At quite a few stations, we have live plants extending seaward of the bank edge.
In this case, the overhang is on a point (near Moonglow), so it may be formed due to currents.
However overhanging banks in general seem like they might be the signature of weakening due to crab burrowing.

We did find that undercutting correlates with bank erosion rates…

VEG BACK FROM EDGE

In many places along the main channel, vegetation is a few feet back from the bank edge.

Often, there is wrack around, suggesting that wrack smothered and killed the vegetation near the edge.

Maybe crab burrowing killing pickleweed roots could also result in this look? Seems less likely, but possible.

(This is near Moonglow).

VEG BACK FROM EDGE
Similar area as last photo, but dramatic backlighting shows vegetation retreat.

VEG BACK FROM EDGE

I can't believe I'd never noticed the role of wrack before – this is a photo from 2011 with that signature look of wrack causing vegetation retreat….

Guess it's possible that erosion first lowers bank edges, and then wrack becomes a problem (rather than wrack being initial driver of bank loss, it's a consequence of it and then leads to further loss in a positive feedback loop?)

Certainly areas with high banks would not be as prone to having wrack drift up on them……maybe still another way to look at the problem of low banks is sediment starvation?

VEG BACK FROM EDGE
Upper Slough also has similar banks (this is off Coyote peninsula, a picture from many years ago)

Understanding what leads to this initial retreat of vegetation from the bank edge may be key to understanding erosion? Or correlations didn't reveal anything, but we didn't have many examples of veg moving from near 0 to 50 cm back, which might be critical period?

Yes, on that last point – I just checked the data to see whether we had any natural banks where distance between veg and edge changed from near 0 to near 50 cm, and there was just one single station, 8 in the lower estuary. Veg in early years averaged 7.6 cm from edge, in later years 47 cm. Total holes went from 21 to 23 on average, and bank erosion rate from 14 cm/yr to 16 cm yr. So nothing to striking going on here.

But would be nice to take a closer look at causes and consequences of initial landward migration of vegetation from bank – should maybe try algal addition exp. on banks where veg is at edge, and force it to retreat, and then monitor erosion rate relative to controls?

VEG BACK FROM EDGE
At Parsons channel, where we know currents have been unusually fast in past years due to bridge replacement and sill, you also see this look of vegetation retreat.

So here's a spot where we know physical drivers are likely cause, but still have wrack on banks and vegetation retreat – maybe the two do interact.

This site had series of banks, like steps, which we also see at some other sites, though not usually so steep.

VEG BACK FROM EDGE
Here is a different look for veg back from edge, in this case in an artificial borrow ditch at Minhoto. Is this what our banks should look like?

HOLES

They certainly do seem like they are contributing to weakness of bank. There are tiny, dense holes made by Spheroma, such as those shown here at Kirby, where we did confirm the burrowing isopod was in them. Only a few parts of upper Slough and Parsons entrance have dense small holes like this. Some small holes could presumably also be made by tiny crabs?

Most places have some larger holes that must be due to crabs, such as shown by red arrow above.