Comments on the Supplemental Remedial Investigation & Feasibility Study, Volume 1: RI Report, Part 3, Environmental Setting, Section 3.1, Physical Conditions, Subsection 3.1.2, Surface Water and Circulation Patterns, prepared by The RETEC Group, Inc.

These comments were submitted previously by e-mail, but no acknowledgment was received so they are being resubmitted on paper in case the e-mail version was lost or mistakenly identified as spam.

This subsection was chosen for review because it doesn't appear to have been as carefully crafted as the rest of the RI/FS, although it contains an elaboration of a key operational assumption that informs and justifies the larger project. A statement of that assumption might be: 'We know enough about the dynamics of the bay to reliably predict where to look for the remains of Georgia Pacific's toxic waste, where it would be safe to leave some of it, how safe leaving it there would be, and how to monitor the security of what's left.'

Sediment source.

To make such an assumption we would need good estimates of the physical quantities involved. Unfortunately, one of the first quantities given, the annual discharge for the Nooksack River is ambiguous and unreferenced (1). The figure, 650,000 cubic meters of sediment discharge, is 5274 times smaller than the USGS figure for the mean water discharge for the years 1967-2000 at Ferndale: 3839 cfs (= 109 cubic meters/second => 3,430,000,000 cubic meters/year) (2). Combining the two discharges we have 1,000,000/5274 = 190 cubic centimeters of sediment in an average meter of Nooksack water. That's a little less than a cup, surprising, but reasonable. Was sediment volume measured, derived, guessed? We shouldn't have to wonder about its source, meaning, and validity. Are we be expected to search through the references listed at the start of the subsection (3) to find which document and which page contains the estimate and describes how the estimate was made?

Water exchange.

Less reasonable than the sediment volume figure is the assertion on page 3-6 that "The residence time for water in Bellingham Bay is typically four to five days, but varies between one and eleven days."

Studies of lakes and estuaries employ three measures of renewal, residence time, age, and flushing time (4).

Residence time, is the time elapsed from a water parcel's entry at a specified starting point until its departure. Age is the time elapsed since a parcel entered a water body, and the age of a water body is the average age of all water parcels. Flushing time, a more general measure, is the ratio of total volume (or mass) of water to its rate of renewal due to flow across boundaries. Flushing time is often also called residence time.

The context of RETEC's residence time assertion is a discussion of "oceanic" waters "entering" and of water "exchange", not a discussion of particular water masses or of masses from a particular source, so it seems safe to assume that flushing time or something close to it is what RETEC had in mind.

We can approximate RETEC's derivation of the residence time figure by assuming that the bay is thoroughly mixed on a time scale much smaller than the residence

time, and by assuming that water flows through the bay, not in and out of the bay. (Assume a river, not an estuary.)

The surface area of the semi-enclosed region between Samish Island and the Nooksack delta is 250,000,000 square meters; the volume of water is 5,650,000,000 cubic meters, in round figures (5). Using a tidal range of 3 meters, a tidal cycle of 24 2/3 hours, and Nooksack discharge of 9,680,000 cubic meters per tidal cycle derived from the USGS discharge figure above, we would have 3 X 250,000,000/24 2/3 = 30,400,000 cubic meters per hour moving through. It would take 5,650,000,000/(24 X 40,540,000) = 7.7 days to exchange the water in the bay at that rate, hence the "typically four to five days but varies between one and eleven days" assertion in the RI/FS, although the shorter times require more radical assumptions. A 4 meter tidal range would yield 5.8 days.

This may be a good estimate of water volumes surging back and forth past the southern end of Lummi Island, but it is not a good estimate of water exchange in the bay, that is, of residual tidal flow. The thoroughly mixed and through-flowing water assumptions are fatally unrealistic: the bay has strong vertical density stratification, and the tides flow in and out; residual tidal flow (over a cycle) is much smaller than instantaneous flow for most of the bay, approaching instantaneous flow rates only near the open boundaries.

The areas and volumes used above are taken from the model configuration for the work described in a poster at the June 4-9 2006 American Society of Limnology and Oceanography conference in Victoria. That poster described detailed computing and mapping of the flushing time of Bellingham Bay. Normal overall flushing time for the bay was determined to be 485 hours (20 days) with much longer times, an order of magnitude longer for a region of bottom waters in the northern part of the bay (5).

Sediment accumulation.

Using information in subsection 3.1.2 to estimate the sediment available for deposition.illustrates how that subsection is related to the larger remediation project. In that subsection we read that "there is a net southward flow throughout Bellingham Bay at depth, largely resulting from the lateral and vertical spreading of the Nooksack River discharge." We have read in 3.1.2 that the bay is an active water body with a residence time of a few days. 650,000 cubic meters of sediment is carried into that net southward flow. In such conditions sediments would be carried far and wide beyond the edge of the delta into the bay, sediments that would provide the natural capping of toxin containing sediments discussed in the RI/FS. (We also made the contrasting assumption that Georgia Pacific's waste settled near where it was dumped.)

How much capping we can expect? If we make the conservative assumptions that the accumulation on the tide flats at the delta does not divert a significant part of the sediment load, and that all of the sediment settles in the northern third of the bay, we can expect that 650,000 cubic meters of sediment will be spread over 250,000,000/3 square meters, which is 0.78 centimeters annual accumulation.

The empirical analysis in Section 6.2.1, Table 6-1 of the RI/FS indicates twice that rate of deposition in the inner harbor area, 1.6 centimeters per year. This discrepancy means that the estimate of the amount of sediment available is too low, or that Squalicum and Whatcom creeks supply significant sediment, or that sediment deposition is uneven and presently greater in the area of the inner harbor.

Comments provided by Bert Rubash on CD-ROM to Ecology

Table 1 – Paired Sediment and Tissue Mercury Concentration Data, Bellingham Bay and Other Puget Sound Embayments (excluding Sinclair Inlet), 1990 to 1997

Species/Tssue Type & Location	Measured Mercury Tissue Concentration in mg/kg wet wt.	Home Range Average Sediment Mercury Concentration in mg/kg dry wt.		
			slope	0.1240290
			intercept	0.0418641
Dungeness crab muscle:			deviation from fit	
Bellingham 18	0.081	0.10	0.026733	
Bellingham 18	0.027	0.10	-0.027267	
Bellingham 18	0.031	0.10	-0.023267	
Chuckanut Bay	0.060	0.12	0.003252	
Lummi Penninsula	0.090	0.20	0.023330	
Post Point	0.061	0.23	-0.009391	
Post Point	0.077	0.23	0.006609	
Central Bellingham Bay	0.126	0.37	0.038245	
Central Bellingham Bay	0.056	0.37	-0.031755	
Post Point	0.110	0.39	0.019765	
Post Point Outfall	0.080	0.39	-0.010235	
Georgia-Pacific Outfall	0.120	0.51	0.014881	
Georgia-Pacific Outfall	0.060	0.51	-0.045119	
Whatcom Waterway	0.100	0.54	-0.008840	
Whatcom Waterway	0.119	0.54	0.010160	
Whatcom Waterway	0.211	0.54	0.102160	
Whatcom Waterway	0.204	0.54	0.095160	
Whatcom Waterway	0.100	0.54	-0.008840	
Whatcom Waterway	0.108	0.54	-0.000840	
Padden Creek	0.100	0.55	-0.010080	
Boulevard Park	0.100	0.58	-0.013801	
Whatcom Waterway	0.160	0.91	0.005270	stdev
Whatcom Waterway	0.150	0.91	-0.004730	0.035038
Red Rock crab muscle:				
Port Madison	0.046	0.05		
Port Madison	0.062	0.05		
Port Madison	0.034	0.05		
Port Madison	0.069	0.05		
Port Madison	0.103	0.05		
Port Madison	0.059	0.05		
Port Madison	0.046	0.05		
Port Madison	0.223	0.05		
Port Madison	0.101	0.05		
Port Madison	0.028	0.05		
Port Madison	0.014	0.05		
Port Madison	0.074	0.05		
Port Madison	0.021	0.05		
West Eagle Harbor	0.139	0.65		
West Eagle Harbor	0.180	0.65		
West Eagle Harbor	0.062	0.65		
West Eagle Harbor	0.251	0.65		
West Eagle Harbor	0.110	0.65		
West Eagle Harbor	0.078	0.65		
West Eagle Harbor	0.046	0.65		
West Eagle Harbor	0.138	0.65		
West Eagle Harbor	0.098	0.65		
West Eagle Harbor	0.041	0.65		
West Eagle Harbor	0.032	0.65		
West Eagle Harbor	0.057	0.65		
West Eagle Harbor	0.459	5.94		
English sole muscle:				
Port Madison	0.065	0.05		
Port Madison	0.069	0.05		
Port Madison	0.065	0.05		
Vendovi Island	0.074	0.09		
Vendovi Island	0.070	0.09		
Vendovi Island	0.070	0.09		
Central Bellingham Bay	0.091	0.37		
Central Bellingham Bay	0.104	0.37		
Central Bellingham Bay	0.094	0.37		
Central Bellingham Bay	0.079	0.37		
Central Bellingham Bay	0.090	0.37		
Central Bellingham Bay	0.084	0.37		
Central Bellingham Bay	0.086	0.37		
Central Bellingham Bay	0.080	0.37		
Central Bellingham Bay	0.076	0.37		
Duwamish River	0.075	0.46		
Duwamish River	0.079	0.46		
Duwamish River	0.082	0.46		
Duwamish River	0.056	0.46		
Duwamish River	0.060	0.46		
Duwamish River	0.065	0.46		
West Eagle Harbor	0.119	0.65		
West Eagle Harbor	0.129	0.65		
West Eagle Harbor	0.142	0.65		
West Eagle Harbor	0.124	0.65		
West Eagle Harbor	0.109	0.65		
West Eagle Harbor	0.115	0.65		
Elliot Bay Waterfront	0.089	0.69		

Elliot Bay Waterfront	0.058	0.69		
Elliot Bay Waterfront	0.062	0.69		
Elliot Bay Waterfront	0.093	0.69		
Elliot Bay Waterfront	0.080	0.69		
Elliot Bay Waterfront	0.086	0.69		
Elliot Bay Waterfront	0.092	0.69		
Elliot Bay Waterfront	0.062	0.69		
Elliot Bay Waterfront	0.063	0.69		
Elliot Bay Waterfront	0.083	0.69		
Elliot Bay Waterfront	0.080	0.69		
Elliot Bay Waterfront	0.091	0.69		
Elliot Bay Waterfront	0.088	0.69		
Elliot Bay Waterfront	0.096	0.69		
Elliot Bay Waterfront	0.089	0.69		
Elliot Bay Waterfront	0.074	0.69		
Elliot Bay Waterfront	0.067	0.69	slope	0.0066588
Elliot Bay Waterfront	0.067	0.69	intercept	0.0319573
Composite hardshell clams:			deviation from fit	
Eagle Harbor	0.011	0.03	-0.021157	
Eagle Harbor	0.013	0.04	-0.019224	
Eagle Harbor	0.064	0.05	0.031710	
Eagle Harbor	0.011	0.05	-0.021290	
Eagle Harbor	0.020	0.05	-0.012290	
Eagle Harbor	0.015	0.05	-0.017290	
Eagle Harbor	0.016	0.05	-0.016290	
Eagle Harbor	0.022	0.05	-0.010290	
Eagle Harbor	0.025	0.05	-0.007290	
Eagle Harbor	0.036	0.05	0.003710	
Eagle Harbor	0.069	0.05	0.036710	
Eagle Harbor	0.031	0.05	-0.001290	
Semiahmoo	0.006	0.05	-0.026290	
Semiahmoo	0.006	0.05	-0.026290	
Semiahmoo	0.006	0.05	-0.026290	
Semiahmoo	0.006	0.05	-0.026290	
Semiahmoo	0.006	0.05	-0.026290	
Semiahmoo	0.006	0.05	-0.026290	
Sequim Bay	0.006	0.05	-0.026290	
Sequim Bay	0.006	0.05	-0.026290	
Sequim Bay	0.007	0.05	-0.025290	
Sequim Bay	0.007	0.05	-0.025290	stdev
Sequim Bay	0.006	0.05	-0.026290	0.031179
Eagle Harbor	0.015	0.08	-0.017490	
Post Point	0.019	0.39	-0.015554	
Post Point	0.020	0.39	-0.014554	
Post Point	0.020	0.39	-0.014554	
Boulevard Park	0.010	0.58	-0.025819	
Eagle Harbor	0.058	0.77	0.020915	
Eagle Harbor	0.056	0.77	0.018915	
Eagle Harbor	0.060	0.77	0.022915	
Eagle Harbor	0.081	0.77	0.043915	
Eagle Harbor	0.075	0.77	0.037915	
Eagle Harbor	0.074	0.77	0.036915	
Eagle Harbor	0.055	0.77	0.017915	
Eagle Harbor	0.159	1.30	0.118386	
Eagle Harbor	0.091	2.85	0.040065	
Eagle Harbor	0.091	12.44	-0.023793	

Bioaccumulation regression data	Number of Sample Composites	(y) y-intercept mg/kg wet	(s) slope dry/wet
Dungeness Crab	12	0.047	0.116
Red Rock Crab	3	0.060	0.067
English Sole	15	0.070	0.028
Clams and Mussels	25	0.032	0.007

w/12 clustered crab data points
0.047 0.116

w/23 crab data points
0.042 0.139

Tulalip Tribe seafood consumption (73 persons)	Consumption rate in kg/day Mean	UCL	90%-tile
Dungeness Crab	0.0120	0.0193	0.0234
Red Rock Crab	0.0001	0.0004	0.0000
English Sole	0.0023	0.0032	0.0078
Clams and Mussels	0.0144	0.0218	0.0385

Proportionality constants (Z) setting proportions of crab, fish, and shellfish in seafood diet.

1.00	1.00	1.00
0.19	0.19	0.19
1.00	1.00	1.00

Sediment Mercury Screening Levels Calculated for Different Consumption Scenarios	Sediment Screening Levels in mg/kg dry weight Mean	UCL	90%-tile
1. Crab consumption only	4.61	2.71	2.17
2. Bottomfish consumption only	107.20	76.34	29.84
3. Clam and Mussel consumption only	67.81	43.18	22.40
Total crab, bottomfish, and clams/mussels combined			
Using tissue-specific regression equations	3.74	2.09	1.29
Substituting Dungeness crab for bottomfish regression	3.33	1.85	1.28

Oral reference dose for methyl-mercury 0.0070 mg/70kg/day (for a 70 kg person)

sediment	muscle	stdev	
Dungeness			
0.10	0.0463	0.030089	65%
0.12	0.0600	0.035038	58%
0.20	0.0900	0.035038	39%
0.23	0.0690	0.011314	16%
0.37	0.0910	0.049497	54%
0.39	0.1100	0.035038	32%
0.39	0.0800	0.035038	44%
0.51	0.0900	0.042426	47%
0.54	0.1403	0.052538	37%
0.55	0.1000	0.035038	35%
0.58	0.1000	0.035038	35%
0.91	0.1550	0.007071	5%
Red Rock			
0.05	0.0677	0.054268	80%
0.65	0.1027	0.065354	64%
5.94	0.4590	0.094832	21%
Sole			
0.05	0.0663	0.002309	3%
0.09	0.0713	0.002309	3%
0.37	0.0963	0.006807	7%
0.37	0.0843	0.005508	7%
0.37	0.0807	0.005033	6%
0.46	0.0787	0.003512	4%
0.46	0.0603	0.004509	7%
0.65	0.1300	0.011533	9%
0.65	0.1160	0.007550	7%
0.69	0.0697	0.016862	24%
0.69	0.0863	0.006506	8%
0.69	0.0723	0.017039	24%
0.69	0.0847	0.005686	7%
0.69	0.0910	0.004359	5%
0.69	0.0693	0.004041	6%
Clams			
0.03	0.0110	0.031179	283%

weighted fit

a	= 0.124029	+/- 0.006785	(5.471%)
b	= 0.0418641	+/- 0.004871	(11.64%)

correlation matrix of the fit parameters:

	a	b
a	1.000	
b	-0.894	1.000

unweighted fit

a	= 0.11644	+/- 0.02093	(17.97%)
b	= 0.0468509	+/- 0.009699	(20.7%)

correlation matrix of the fit parameters:

	a	b
a	1.000	
b	-0.879	1.000

weighted fit

a	= 0.0253225	+/- 0.01089	(43.01%)
b	= 0.0673326	+/- 0.004499	(6.682%)

correlation matrix of the fit parameters:

	a	b
a	1.000	
b	-0.782	1.000

unweighted fit

a	= 0.0277407	+/- 0.02235	(80.58%)
b	= 0.0697395	+/- 0.01231	(17.64%)

correlation matrix of the fit parameters:

	a	b
a	1.000	
b	-0.922	1.000

weighted fit

#129-E

0.04	0.0130	0.031179	240%
0.05	0.0640	0.031179	49%
0.05	0.0110	0.031179	283%
0.05	0.0200	0.031179	156%
0.05	0.0150	0.031179	208%
0.05	0.0160	0.031179	195%
0.05	0.0220	0.031179	142%
0.05	0.0250	0.031179	125%
0.05	0.0360	0.031179	87%
0.05	0.0690	0.031179	45%
0.05	0.0310	0.031179	101%
0.05	0.0060	0.032565	543%
0.05	0.0060	0.032565	543%
0.05	0.0060	0.031850	531%
0.05	0.0067	0.032565	488%
0.08	0.0150	0.031179	208%
0.39	0.0197	0.032565	166%
0.58	0.0100	0.031179	312%
0.77	0.0580	0.032565	56%
0.77	0.0767	0.032565	42%
0.77	0.0550	0.031179	57%
1.30	0.1590	0.031179	20%
2.85	0.0910	0.031179	34%
12.44	0.0910	0.031179	34%

a	= 0.0066588	+/- 0.002779	(41.74%)
b	= 0.0319573	+/- 0.007258	(22.71%)

correlation matrix of the fit parameters:

	a	b
a	1.000	
b	-0.322	1.000

unweighted fit

a	= 0.00670003	+/- 0.002798	(41.76%)
b	= 0.031771	+/- 0.007228	(22.75%)

correlation matrix of the fit parameters:

	a	b
a	1.000	
b	-0.321	1.000

Note: The estimates of sample variance above are based on the scatter of data points; laboratory estimates of variation were not available.

For 95% joint slope and intercept probability that a fit to a parent distribution would fall below an upper margin to the fit to a sample, the margin would be defined by a slope and intercept as follows:

The distribution of a sample mean is Gaussian, so we are looking for the integral of a joint, two tail probability of 90% (which gives us a single tail probability of 95% since we are only concerned with the upper bound). Individual 94.87% probability integrals would work. (sqrt(0.90)) The corresponding integration limits for Gaussian probability are -1.95 X stdev. and +1.95 X stdev.

Now let's revisit the statistical conclusions on page 6 of Appendix E

First is a recomputation of the results in the box containing the conclusions using slope and intercept from weighted fitting.

Sediment Screening Levels	Sediment Screening Levels in mg/kg dry weight		
	Mean	UCL	90%-tile
1. Crab only	4.37	2.59	2.07
2. Bottomfish only	117.53	83.73	32.78
3. Clam and Mussel only	68.20	43.42	22.51
Total combined tissue-specific	3.58	2.02	1.27
Substituting crab	3.18	1.78	**1.24**

(y) y-intercept mg/kg wet	(s) slope dry/wet
0.042	0.124
0.060	0.067
0.067	0.025
0.032	0.007

With weighted fitting using sample variance, screening levels are lower for crab and higher for bottomfish and shellfish

Finally, let's account for the liklihood that our fitting of samples matches the underlying distributions of sediment and muscle concentrations.

z = 1.95

Sediment Screening Levels	Sediment Screening Levels in mg/kg dry weight		
	Mean	UCL	90%-tile
1. Crab only	3.88	2.27	1.81
2. Bottomfish only	63.73	45.35	17.64
3. Clam and Mussel only	36.43	22.77	11.24
Total combined tissue-specific	2.88	1.55	0.85
Substituting crab	2.62	1.41	**0.88**

(y) y-intercept mg/kg wet	(s) slope dry/wet
0.051	0.137
0.060	0.067
0.076	0.047
0.046	0.012

intercept sigma	slope sigma
0.004871	0.006785
0.004499	0.010890
0.007258	0.002779

We see that accounting for variance in the fitting procedure results in significantly lower screening levels for sediment. Note that weighted fitting has much lower slope and intercept variances than unweighted fitting; i.e. accounting for variance in the fitting procedure used in Appendix E would result in even lower screening levels.

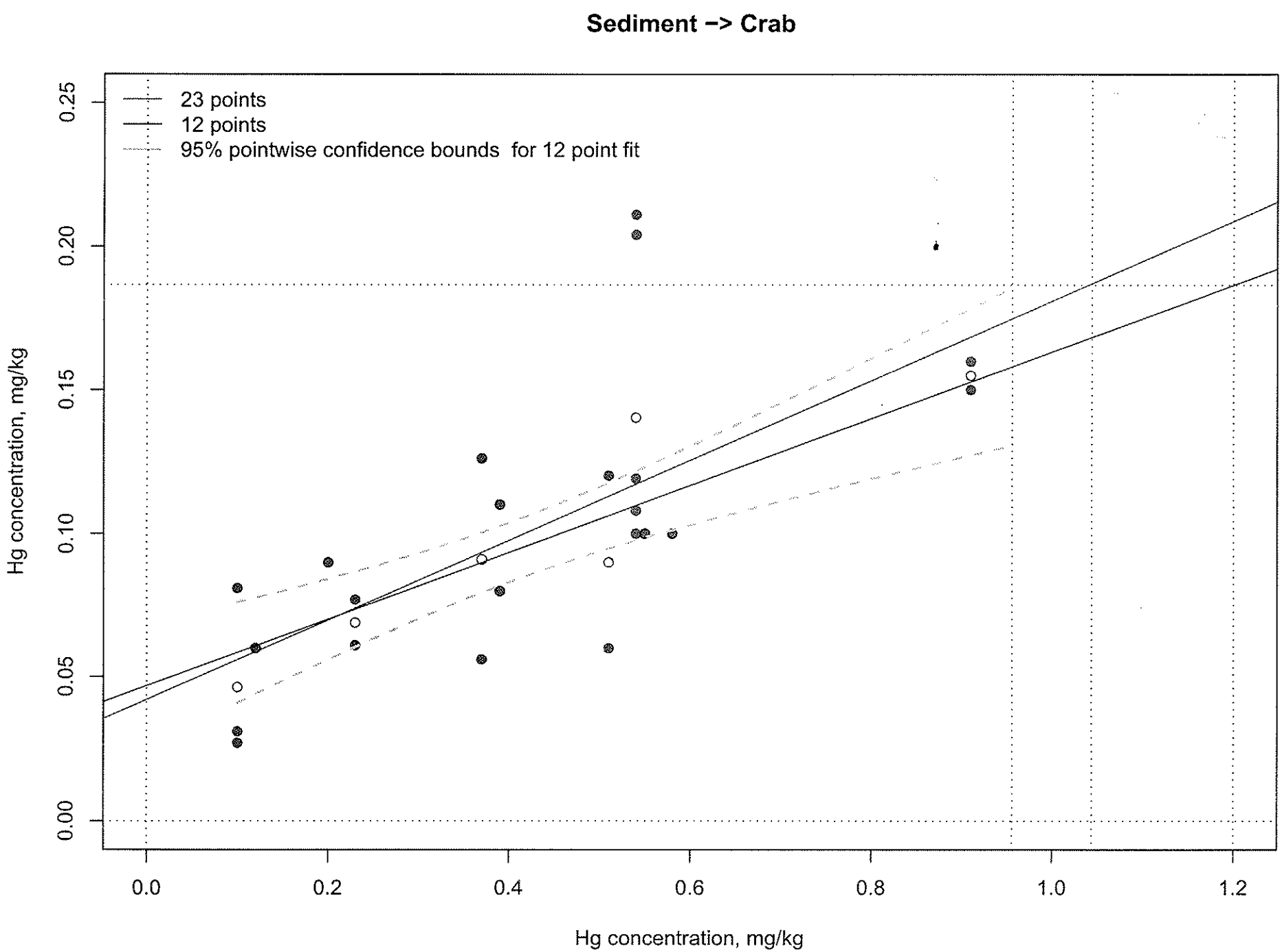
sediment	crab	deviation
0.1	0.0463	0.030089
0.12	0.06	0.035038
0.2	0.09	0.035038
0.23	0.069	0.011314
0.37	0.091	0.049497
0.39	0.11	0.035038
0.39	0.08	0.035038
0.51	0.09	0.042426
0.54	0.1403	0.052538
0.55	0.1	0.035038
0.58	0.1	0.035038
0.91	0.155	0.007071

sedim	ent crab	deviation
0.1	0.081	0.026733
0.1	0.027	-0.027267
0.1	0.031	-0.023267
0.12	0.06	0.003252
0.2	0.09	0.02333
0.23	0.061	-0.009391
0.23	0.077	0.006609
0.37	0.126	0.038245
0.37	0.056	-0.031755
0.39	0.11	0.019765
0.39	0.08	-0.010235
0.51	0.12	0.014881
0.51	0.06	-0.045119
0.54	0.1	-0.00884
0.54	0.119	0.01016
0.54	0.211	0.10216
0.54	0.204	0.09516
0.54	0.1	-0.00884
0.54	0.108	-0.00084
0.55	0.1	-0.01008
0.58	0.1	-0.013801
0.91	0.16	0.00527
0.91	0.15	-0.00473

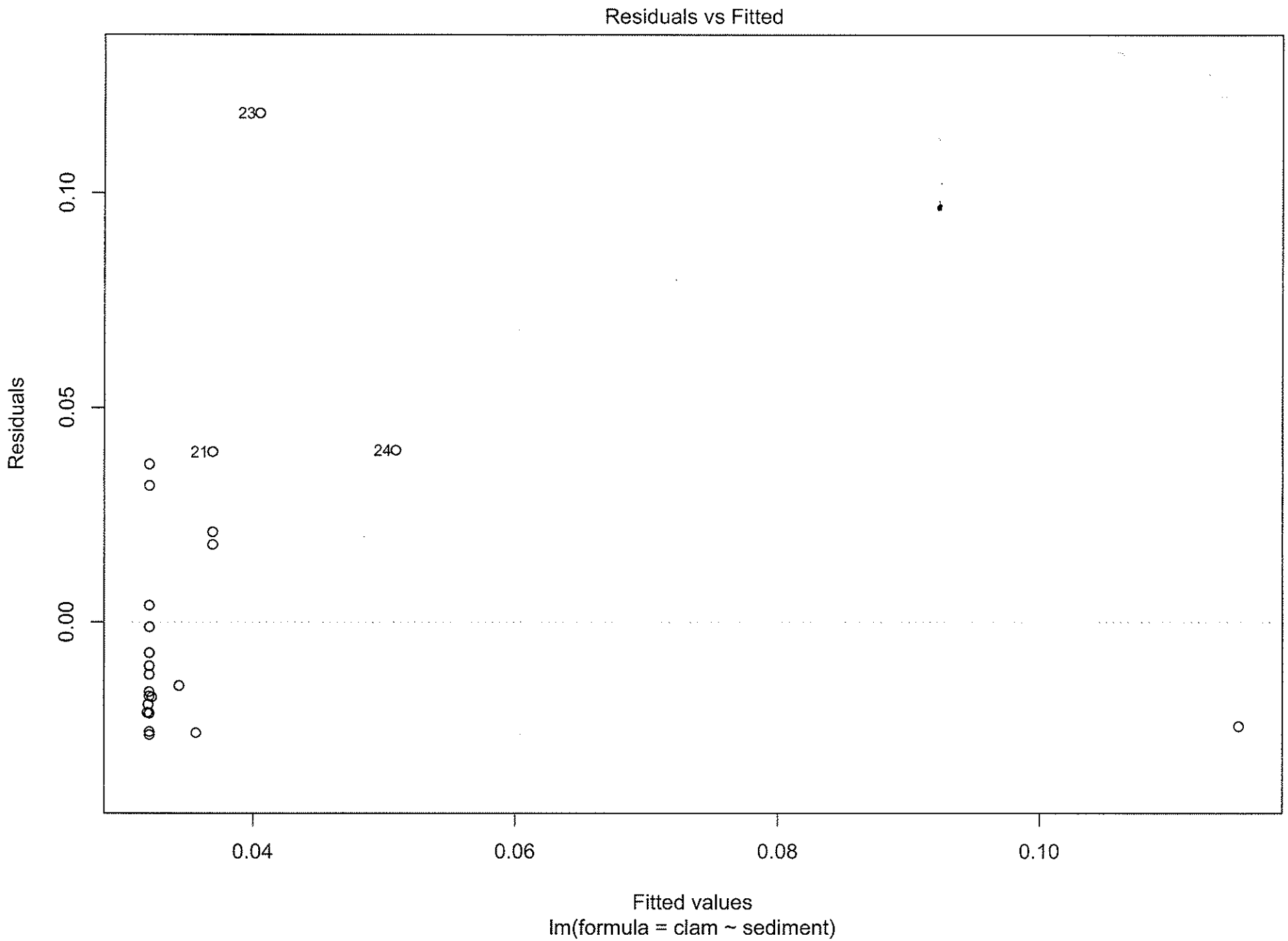
sediment clam

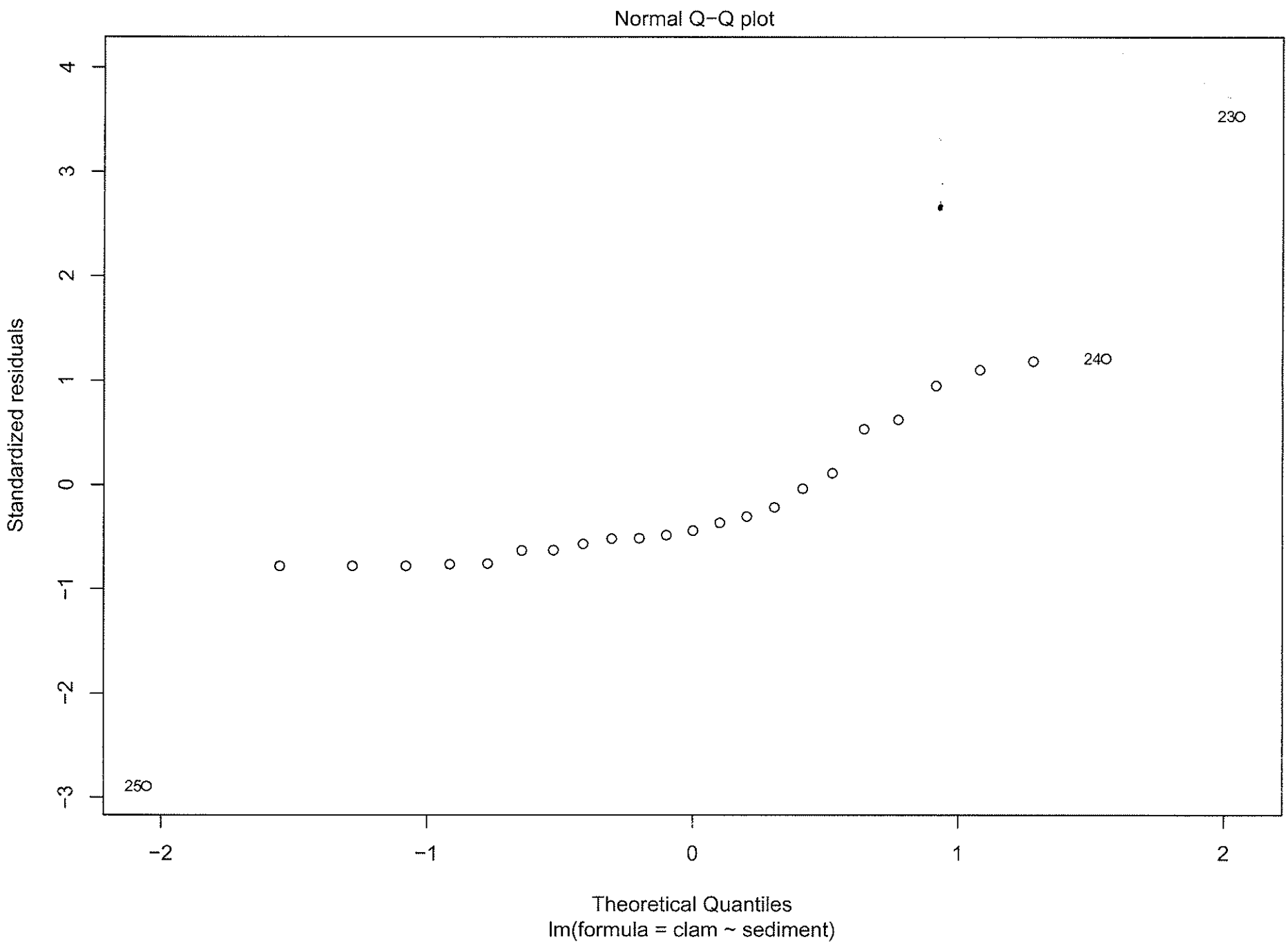
0.03	0.011
0.04	0.013
0.05	0.064
0.05	0.011
0.05	0.02
0.05	0.015
0.05	0.016
0.05	0.022
0.05	0.025
0.05	0.036
0.05	0.069
0.05	0.031
0.05	0.006
0.05	0.006
0.05	0.006
0.05	0.006
0.05	0.006
0.05	0.006
0.05	0.006
0.05	0.006
0.05	0.007
0.05	0.007
0.05	0.006
0.08	0.015
0.39	0.019
0.39	0.02
0.39	0.02
0.58	0.01
0.77	0.058
0.77	0.056
0.77	0.06
0.77	0.081
0.77	0.075
0.77	0.074
0.77	0.055
1.3	0.159
2.85	0.091
12.44	0.091

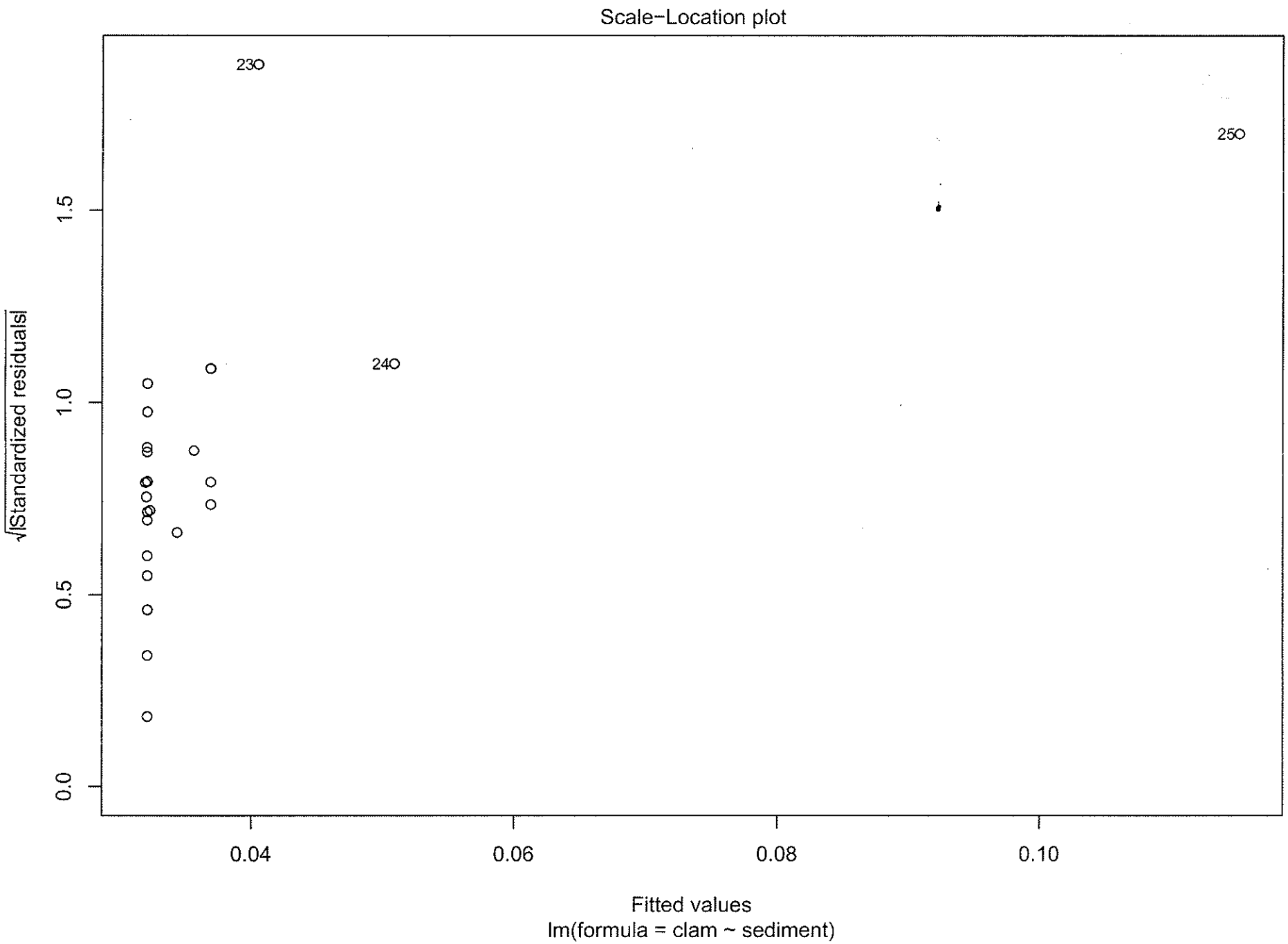
sediment	clam	deviation
0.03	0.011	0.031174
0.04	0.013	0.031174
0.05	0.064	0.031174
0.05	0.011	0.031174
0.05	0.02	0.031174
0.05	0.015	0.031174
0.05	0.016	0.031174
0.05	0.022	0.031174
0.05	0.025	0.031174
0.05	0.036	0.031174
0.05	0.069	0.031174
0.05	0.031	0.031174
0.05	0.006	0.03256
0.05	0.006	0.03256
0.05	0.006	0.031845
0.05	0.0067	0.03256
0.08	0.015	0.031174
0.39	0.0197	0.03256
0.58	0.01	0.031174
0.77	0.058	0.03256
0.77	0.0767	0.03256
0.77	0.055	0.031174
1.3	0.159	0.031174
2.85	0.091	0.031174
12.44	0.091	0.031174

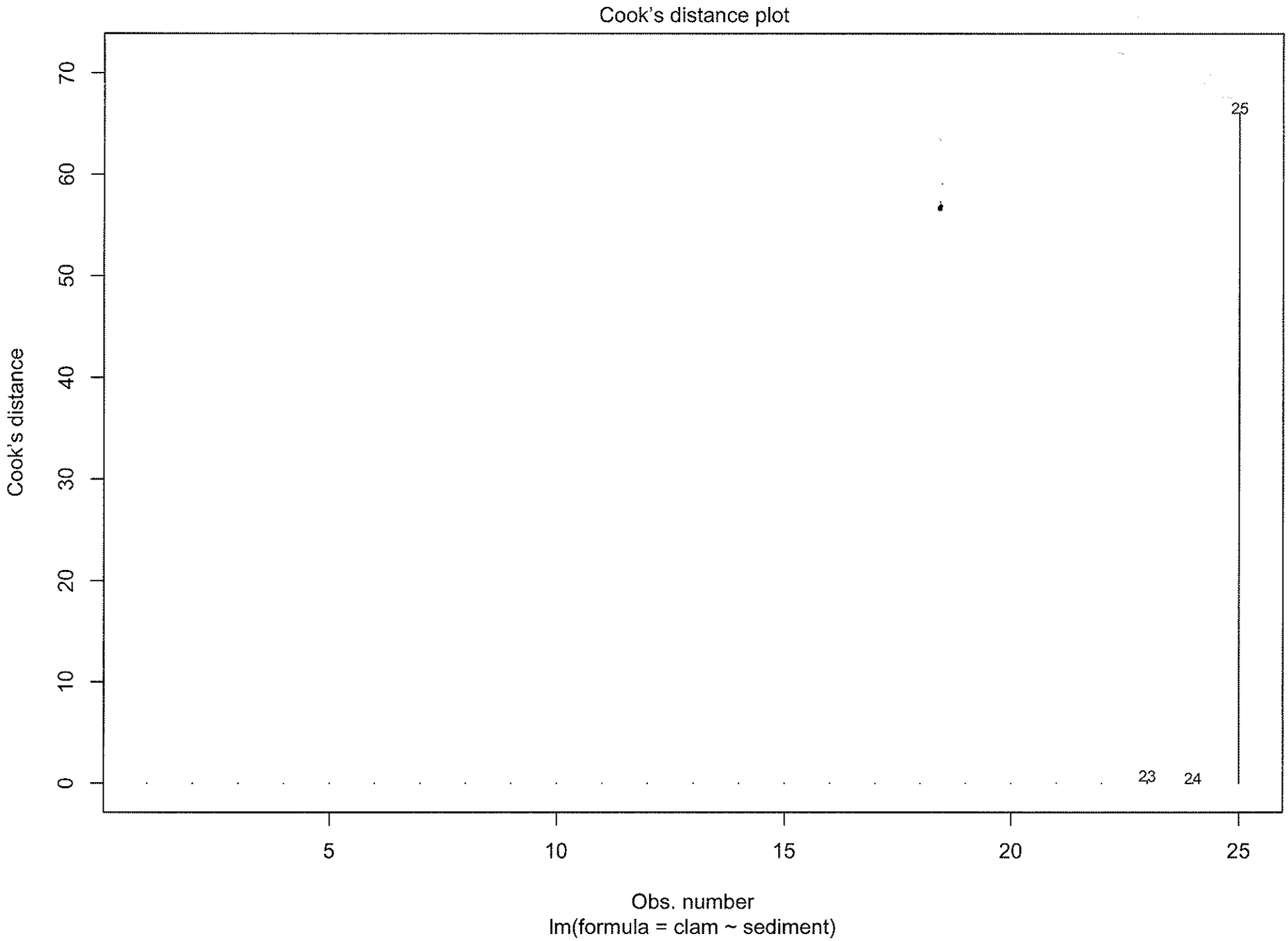

Sediment -> Crab
23 points
12 points
95% pointwise confidence bounds for 12 point fit
Hg concentration, mg/kg
0.00
0.05
0.10
0.15
0.20
0.25
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Hg concentration, mg/kg

#129-F


Residuals vs Fitted
Residuals
0.00
0.05
0.10
230
210
240
0.04
0.06
0.08
0.10
Fitted values
lm(formula = clam ~ sediment)


Normal Q−Q plot
Standardized residuals
Theoretical Quantiles
lm(formula = clam ~ sediment)
230
240
250
4
3
2
1
0
−1
−2
−3
−2
−1
0
1
2


Scale−Location plot
230
250
240
1.5
1.0
0.5
0.0
√|Standardized residuals|
0.04
0.06
0.08
0.10
Fitted values
lm(formula = clam ~ sediment)


Cook's distance plot
Cook's distance
0
10
20
30
40
50
60
70
5
10
15
20
25
23
24
25
Obs. number
lm(formula = clam ~ sediment)