Tampa Bay Estuary Program Technical Memorandum

Tampa Bay Sediment Quality Targets Physical Parameters Assessment

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Tampa Bay Sediment Quality Targets
Physical Parameters Assessment

The Tampa Bay Estuary Program and its partners have identified the protection of uncontaminated sediments in Tampa Bay and the reduction in the level of contamination of contaminated sediments as important, broad goals for the Comprehensive Conservation and Management of the bay's environment (TBNEP CCMP, 1996). The TBEP has been working for more than six years to develop an empirically based, objective process for establishing specific sediment quality targets to meet these broad goals.

Recently, the TBEP work to develop sediment quality targets has focused on quantifying empirical relationships between observed responses in benthic organisms and measured levels of sediment contamination. The benthic organism responses included incidence of acute toxicity, chronic toxicity, and benthic community impairment (Shannon-Weiner Diversity Index). The results of this work were reported recently in MacDonald et al., In Review, and they were discussed in depth at a March 5, 2002 TBEP Sediment Quality Target Workshop. Among other interests, the participants of the March 5 workshop expressed an interest in reviewing the relative contributions of physical parameters such as sediment grain size and salinity to explaining the distribution of benthic organisms.

The purpose of this technical memorandum is to support the ongoing target setting process by providing a review of the observed relative contributions of physical parameters to the explanation of benthic organism distributions, and to present recent relevant observations from the ongoing Tampa Bay Benthic Program.

Objectives

The specific objectives of this technical memorandum are:

- to present recent relevant observations from the Tampa Bay Benthic Program, and

- to estimate the relative importance of salinity and sediment size in determining benthic health in Tampa Bay.

Data Sources

The physical parameter data (e.g., salinity, dissolved oxygen concentration, percent silt/clay), benthic organism data, and sediment contamination data were reported for past and recent data for the TBEP Benthic Database for Tampa Bay (pers. comm. Stephen Grabe and Susan Janicki).

The Threshold Effect Level (TEL) and Probable Effect Level (PEL) were identified and developed by MacDonald and others (cited In Review, may be final at publication of this memo).

Approach

The overall approach of this work was to search for readily apparent relationships in the observed data. Relatively strong relationships in the observed data would be best applicable to the development of empirically based sediment quality targets, and would help to support the ongoing sediment quality target development process.

The approach to meet the first objective of presenting recent relevant benthic observations was to prepare maps and tables summarizing individual samples for the parameters of interest.

The approach to meet the second objective of estimating the relative importance physical parameters was to apply stepwise multivariate regression techniques to model the distribution of benthic organisms as a function of several measured independent variables. The independent variables included physical parameters, concentrations of sediment contaminants, and indices of sediment contamination (described below). Several candidate functional forms of the independent variables were compared including X^n, ln(X), and X, where candidate values of n ranged from 0.35 to 2. The intent was to determine which of these parameters best explained the distribution of benthic organisms as observed by the number of taxa, the Shannon-Weiner Index, and the Tampa Bay Benthic Index.

In order to increase the possibility of finding a signal in the observations, three metrics of sediment contamination were included as separate independent variables in the regression analyses.

- Concentrations of individual contaminants (e.g., arsenic, copper, Lindane).

- Probable Effect Level Quotients (PELQ) as developed by MacDonald and others (In Review):

$$\text{PELQ} = \frac{\sum_{i=1}^{I}\left[\frac{C_i}{PEL_i}\right]}{I}$$

where Ci = the concentration of the ith contaminant,
PELi = the PEL value of the ith contaminant, and
I = the number of contaminants in a particular PELQ group (i.e., metals, PAHs, PCBs, all measured toxins).

- TEL/PEL distance as developed for this technical memorandum following a general Mahalanobis Distance type of approach:

$$\text{TEL/PEL distance} = \sqrt{\sum_{i=1}^{I}\left[\frac{(C_i - TEL_i)}{(PEL_i - TEL_i)}\right]^2}$$

where Ci = the concentration of the ith contaminant,
TELi = the TEL value of the ith contaminant,
PELi = the PEL value for the ith contaminant, and
I = the number of contaminants in a particular TEL/PEL distance group (i.e., metals, PAHs, all measured toxins).

This TEL./PEL distance explanatory variable was added to allow for the possibility that a high level of concentration for one or more contaminants could be diluted by averaging with low levels of other contaminants. Such a possibility could obscure a potential relationship in the observed data. The TEL/PEL distance rescales all of the contaminant concentrations as the proportion of the distance from the TEL to the PEL value, and then combines all of the contaminant values to measure how far away a particular sample is from a no-biological-effects condition in multiple dimensions. The TEL/PEL distance was also calculated for several groups of contaminants (i.e., metals, PAHs, all measured toxins).

Results of Recent Observations

Sediment Contaminants

The levels of sediment contaminants for each individual sample reported in the recent Tampa Bay Benthic Database are mapped in Figure 1. The samples (N=1396) were classified as those with no TEL or PEL value exceeded (n=643), those with up to 3 TEL values exceeded but no PEL value exceeded (n=477), those with more than 3 TEL values exceeded but no PEL value exceeded (n=175), and those with one or more PEL values exceeded (n=101). Of the last group, 42 samples had only 1 PEL value exceeded, and 23 samples had 10 or more PEL values exceeded. Almost all areas of Tampa Bay were reported to have both samples with no TEL values exceeded and samples with a few (<3) TEL values exceeded. Groups of contaminated sediment samples were primarily reported for Northern Hillsborough Bay and its tributaries.

Table 1 presents a detailed summary of the sources of contaminants reported for the red dots (i.e., PEL values exceeded) mapped in Figure 1. The contaminants are tabulated by benthic sampling stratum.

Sediment Grain Size (% Silt/Clay)

The sediment grain size observations are mapped in Figure 2 for each individual sample, and they are classified by percentage of slit/clay. Fine grain sediments, which are often associated with contaminants in Tampa Bay, were reported primarily in Hillsborough Bay, northern Boca Ciega Bay, and the tributaries to Tampa Bay.

To further define the general co-location of contaminants and fine grain sediments in Tampa Bay, the distribution of silt/clay reported for each of the contaminant classes mapped in Figure 1 was as follows:

Mapped Contamination Category	Percent Silt/Clay Percentiles						
	0th	5th	25th	50th	75th	95th	100th
No TEL Exceeded No PEL Exceeded	0.3	1.2	2.2	3.7	8.5	36.9	85.9
<4 TEL Exceeded No PEL Exceeded	0.5	1.4	2.9	5.1	8.7	31.8	82.2
>=4 TEL Exceeded No PEL Exceeded	0.5	1.2	2.1	4.7	17.0	49.6	88.6
>=1 PEL Exceeded	0.2	1.4	5.4	12.1	38.9	69.7	96.6

Near-Bottom Water Salinity

The bottom salinity values are mapped in Figure 3 for each individual sample represented in the Tampa Bay Benthic Database. Bottom salinities follow the expected gradient of increasing salinity from the tributaries to the bay mouth, and the bottom waters of Boca Ciega Bay were reported to be relatively more lagoonal in nature.

Near-Bottom Dissolved Oxygen

The bottom dissolved oxygen concentrations are mapped in Figure 4 for each individual sample. Low bottom dissolved oxygen concentrations were reported for Northern Hillsborough Bay, the tributaries to Hillsborough Bay, and sporadically in the southern portions of Tampa Bay.

Tampa Bay Benthic Index

The Tampa Bay Benthic Index values are mapped in Figure 5 for each individual sample represented in the Tampa Bay Benthic Database (n = 856). The Benthic Index values were classified as degraded, marginal, or healthy following the classification system reported by Grabe (1998). As discussed at the March 5, 2002 workshop, the Benthic Index was developed to be closely related to the Shannon-Wiener Index and hence the number of taxa (for additional discussion see also Coastal Environmental, 1995).

Results of Regression Analyses

As discussed previously, the overall approach of this work was to search for readily apparent relationships in the individual samples of the observed data mapped in Figures 1 through 5.

Stepwise multiple regressions of the number of taxa, Shannon-Wiener Index and Tampa Bay Benthic Index as functions of physical parameters, concentrations of sediment contaminants, and indices of sediment contamination yielded the following best models:

Number of Taxa	$= a + B_1(DO^{0.45}) + B_2(\text{Silt Clay}^{0.45}) + B_3(\text{Salinity})$	$N = 373$	$R^2 = 0.52$
Shannon-Wiener	$= a + B_1(DO^{0.30}) + B_2(\text{Silt Clay}^{0.60}) + B_3(\text{Salinity}^{0.80})$	$N = 373$	$R^2 = 0.49$
TB Benthic Index	$= a + B_1(DO^{0.30}) + B_2(\text{Silt Clay}^{0.30}) + B_3(\text{Salinity}^{0.75})$	$N = 373$	$R^2 = 0.45$

Each of these models was highly significant ($P > F < 0.0001$). The concentrations of sediment contaminants, and the two indices of sediment contamination did not explain any important additional variation in the response variables.

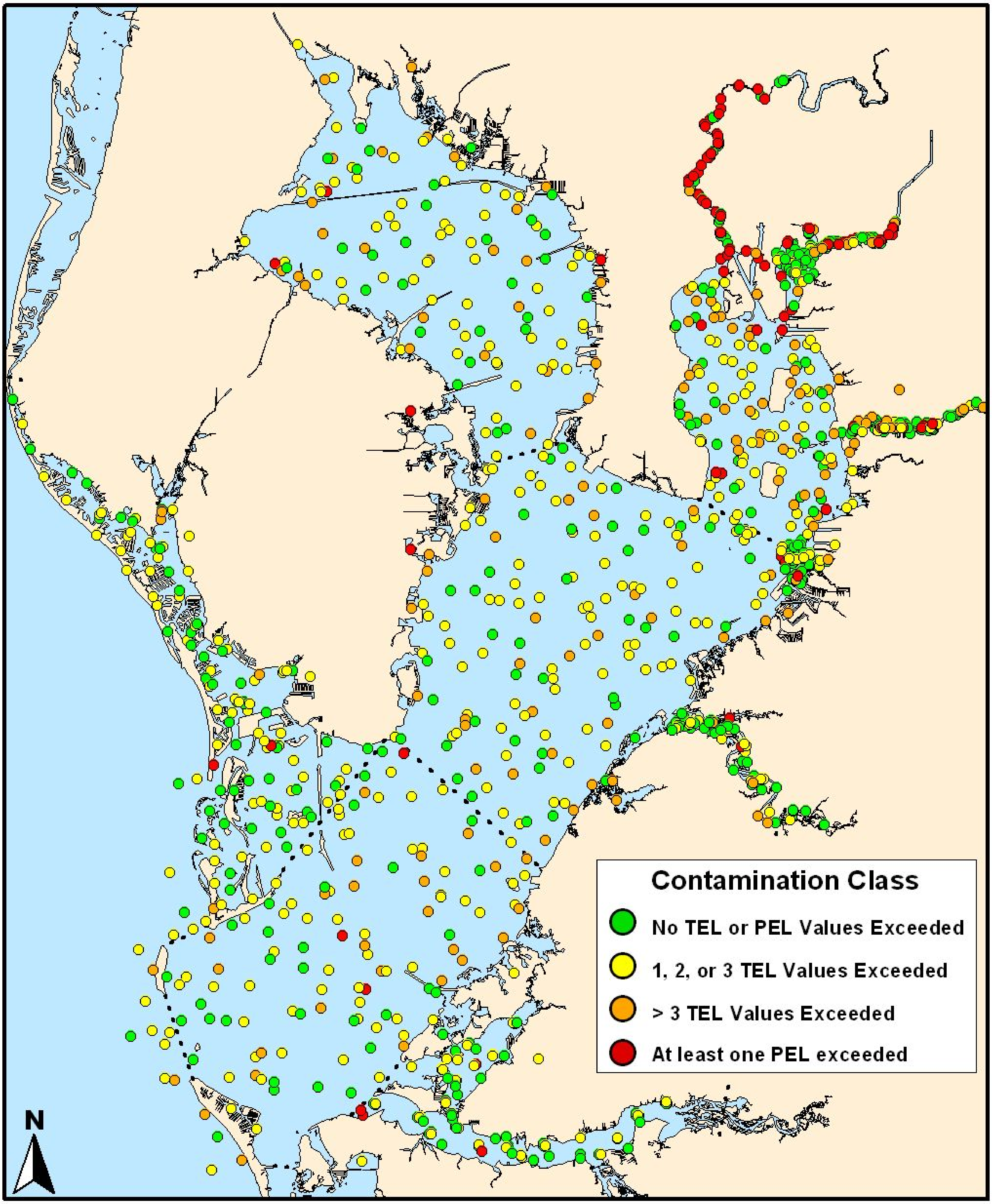
The question was then posed, "Is there a possibility that a readily apparent relationship between the benthic organisms and sediment contamination levels existed that was not being detected by the multiple regression model (e.g., a different curve form than the candidates curve forms tested)"? The question was investigated by plotting the residuals of a basic physical model against the contaminant variables. Dissolved oxygen was operationally defined as an anthropogenic impact and included as an independent variable for these plots. The basic physical model was fit by regression ($P > F < 0.0001$) as:

Number of Taxa	$= a + B_1(\text{Silt Clay}^{0.45}) + B_2(\text{Salinity})$	$N = 703$	$R^2 = 0.44$

The plots of the residuals (Figures 6 and 7) indicate that there is a moderate degree of variability in the number of species predicted by silt clay and salinity that is unexplained, but the plots (Figures 8 through 15) do not indicate a readily apparent relationship between the number of taxa expected based on silt clay and salinity and the level of sediment contamination. There is an apparent relationship for dissolved oxygen (Figure 8). More taxa are predicted to occur than were observed for low dissolved oxygen levels. The dissolved oxygen relationship was also identified above by the initial stepwise regression results. There may be more subtle relationships visible in the plots such as the consistency of less taxa observed than expected for the highest levels of PELQ values for PCBs in Figure 11.

Figure 12 maps the basic physical model residuals for each sample. There appear to be groups of samples visible that were reported to have fewer taxa than expected in particular areas (i.e., the red dots). This may be visually biased in some instances due to greater concentrations of samples.

Benthic Contamination Class by Sample
Tampa Bay



Janicki Environmental, Inc.
Map Series No. A0252901

Figure 1

Sediment Grain Size Class by Sample
Tampa Bay

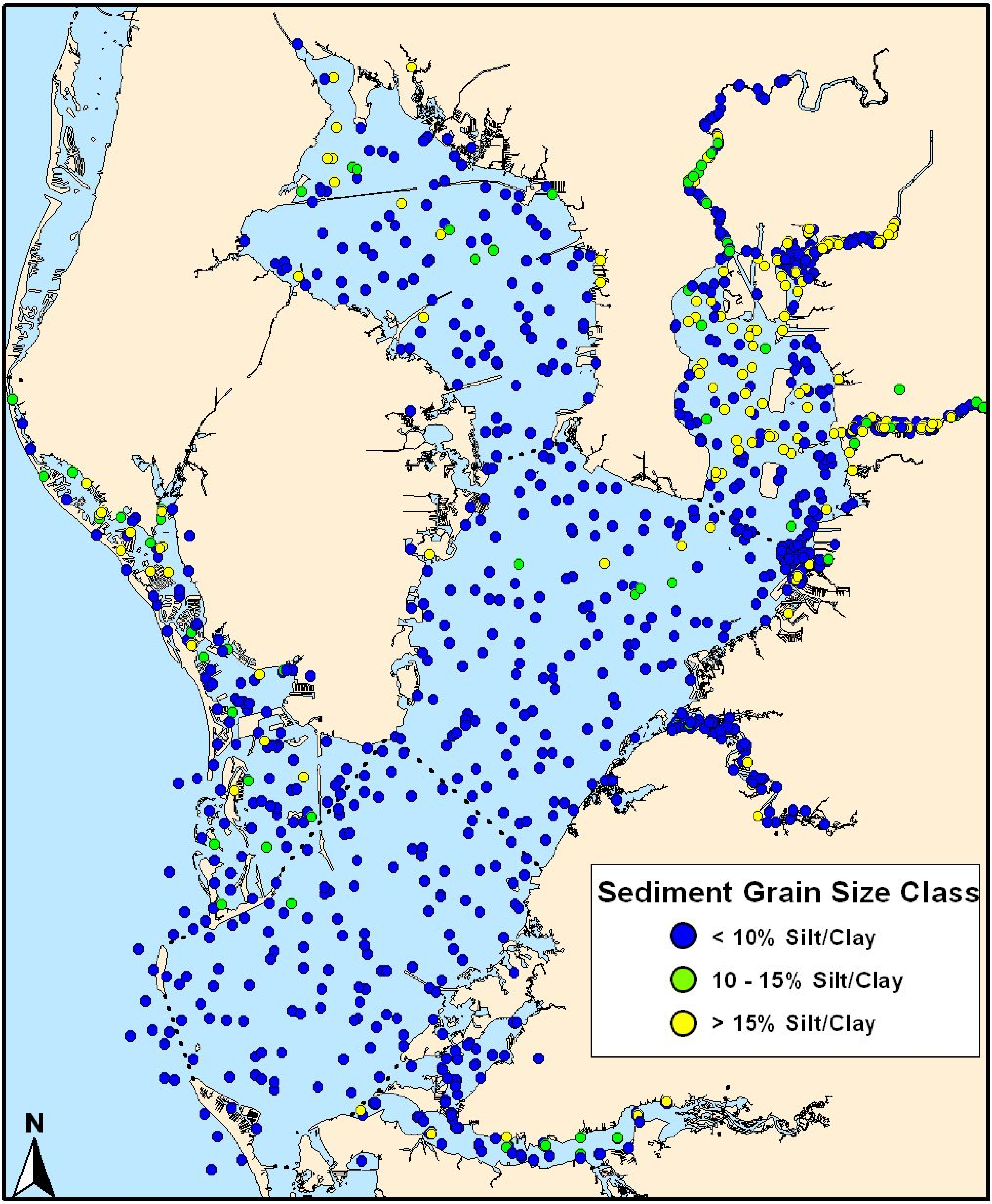


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Figure 2

Salinity Class by Sample
Tampa Bay

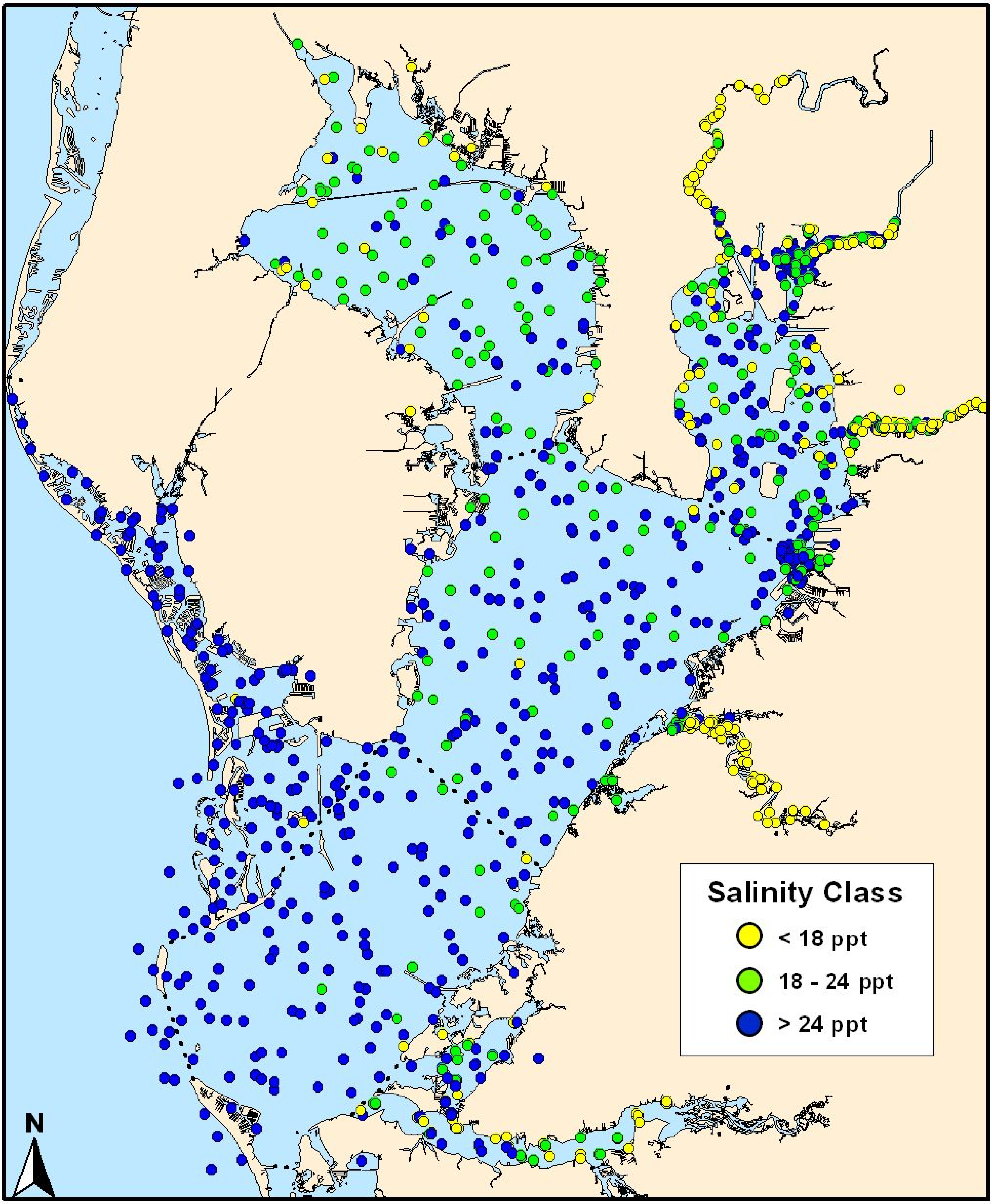

Figure 3

Dissolved Oxygen Class by Sample
Tampa Bay

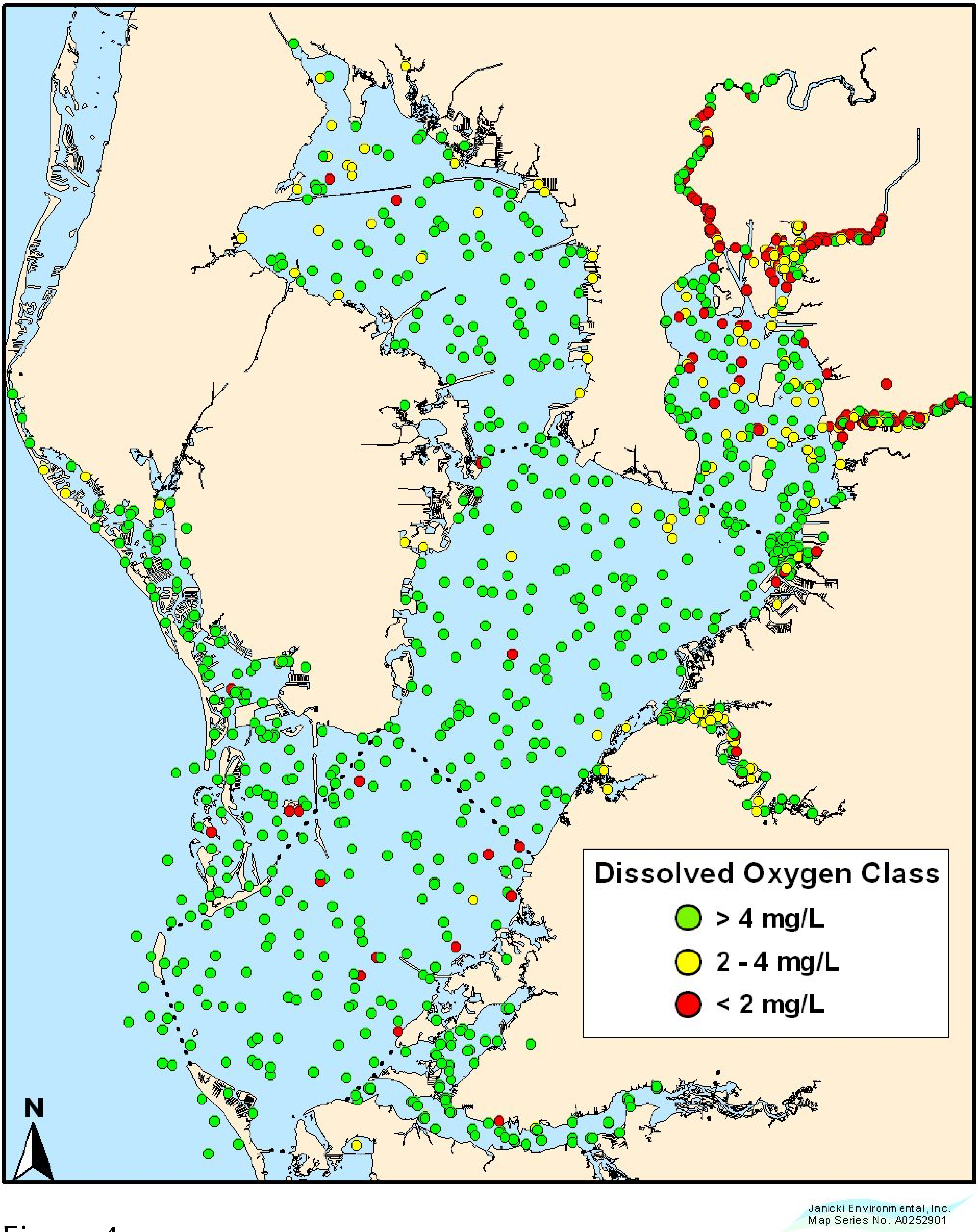

Figure 4

Tampa Bay Benthic Index Class by Sample
Tampa Bay

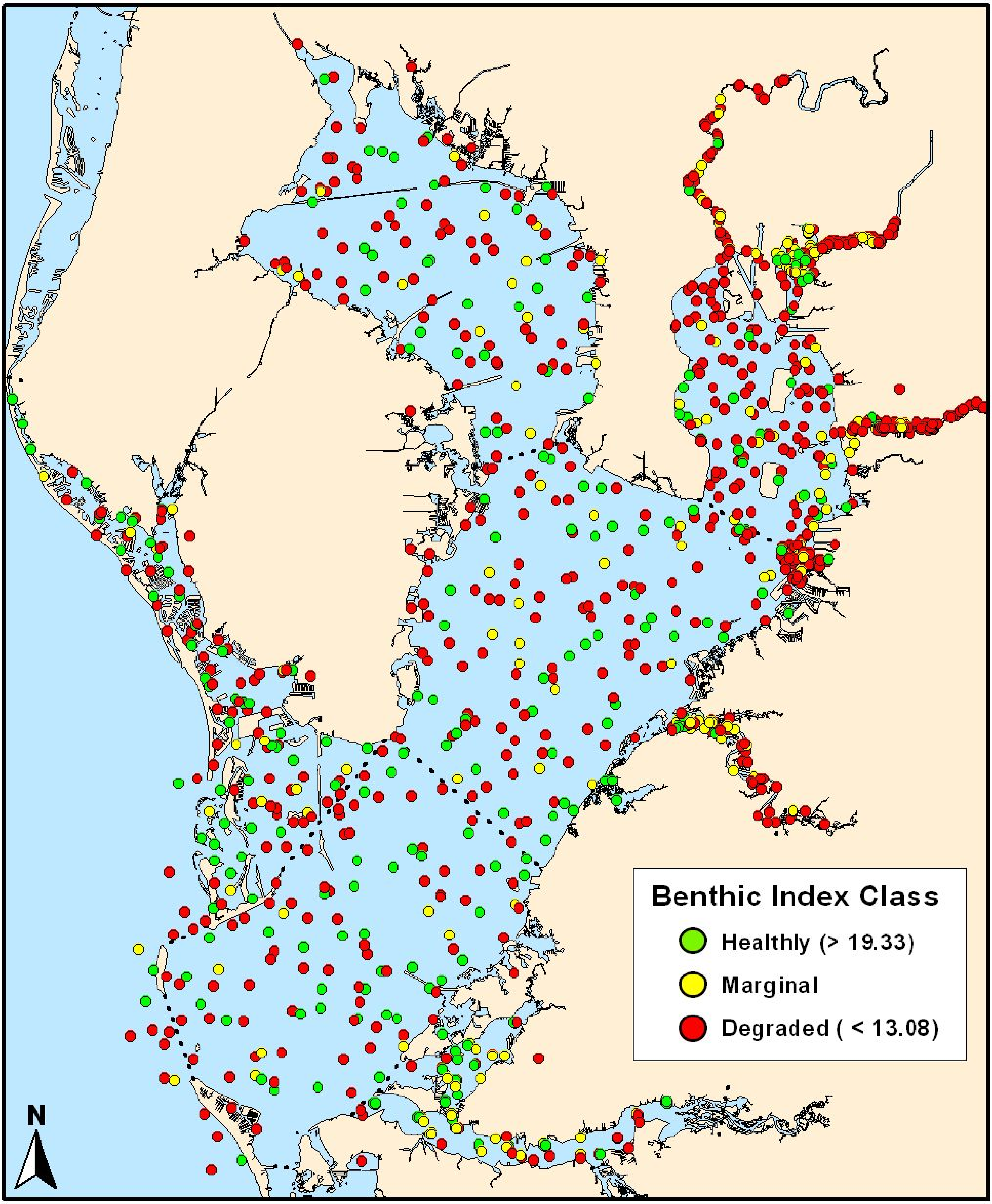

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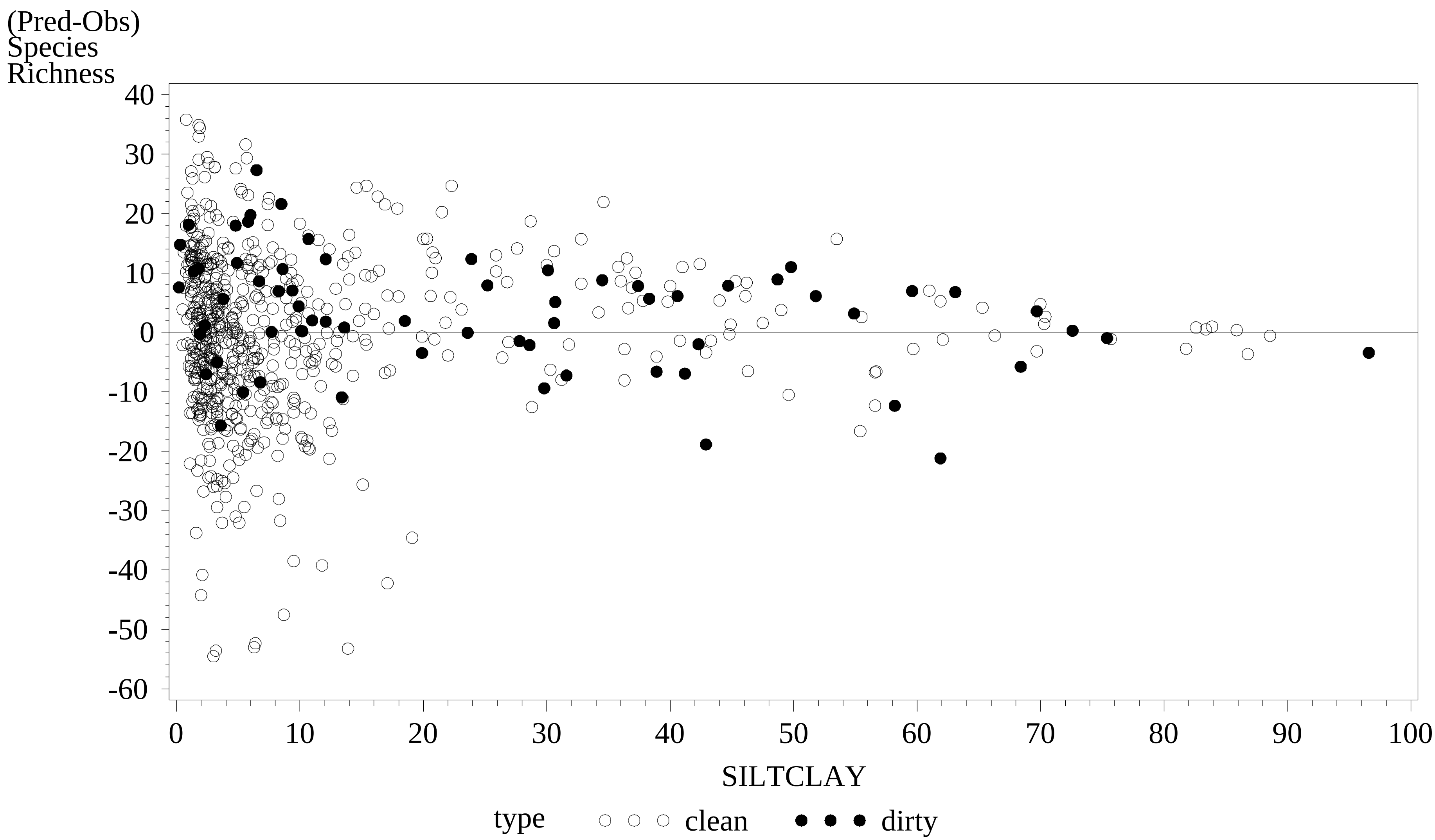
Figure 5

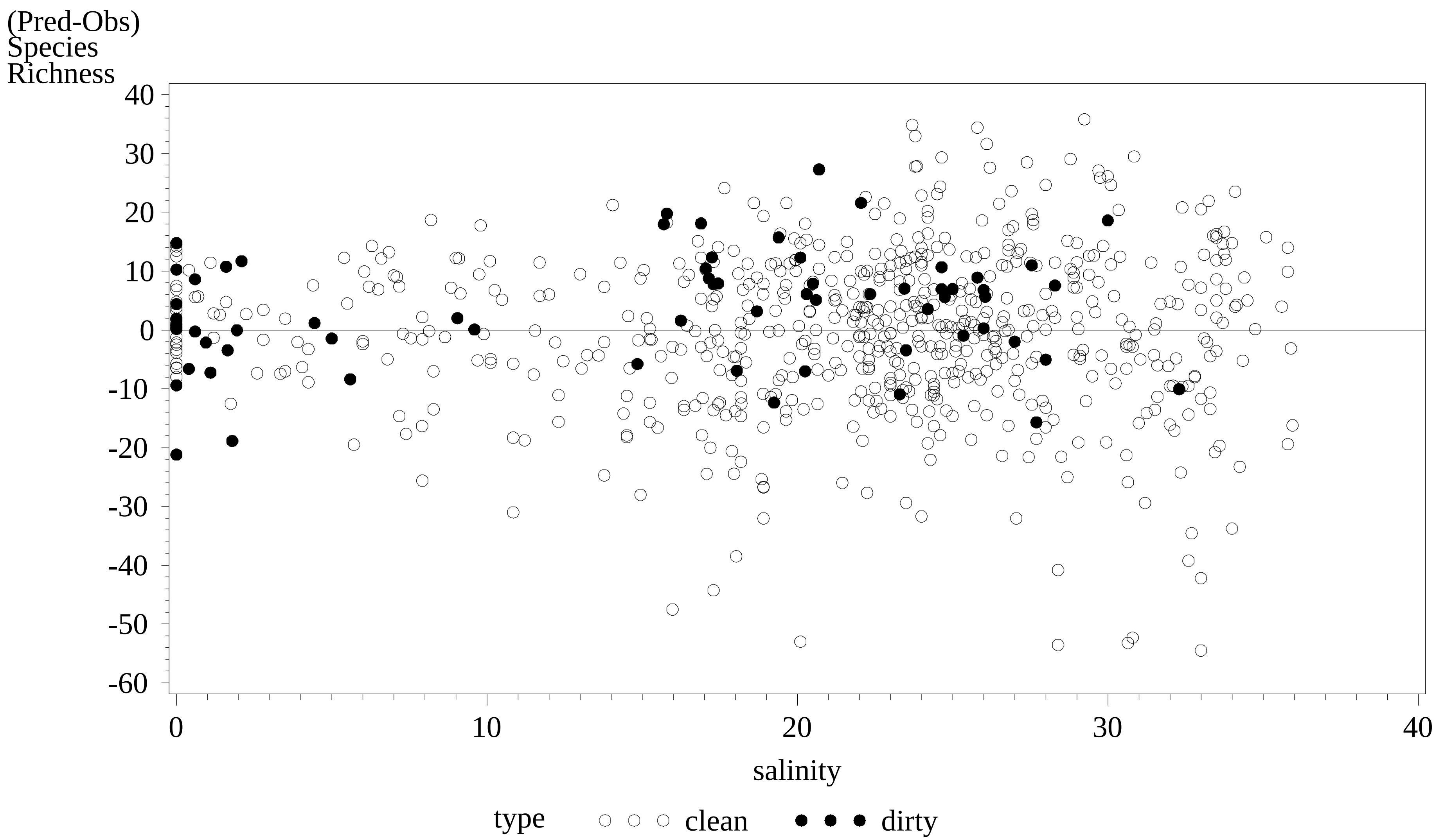
Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity



(Dirty defined as at least 1 PEL exceeded)

Figure 6

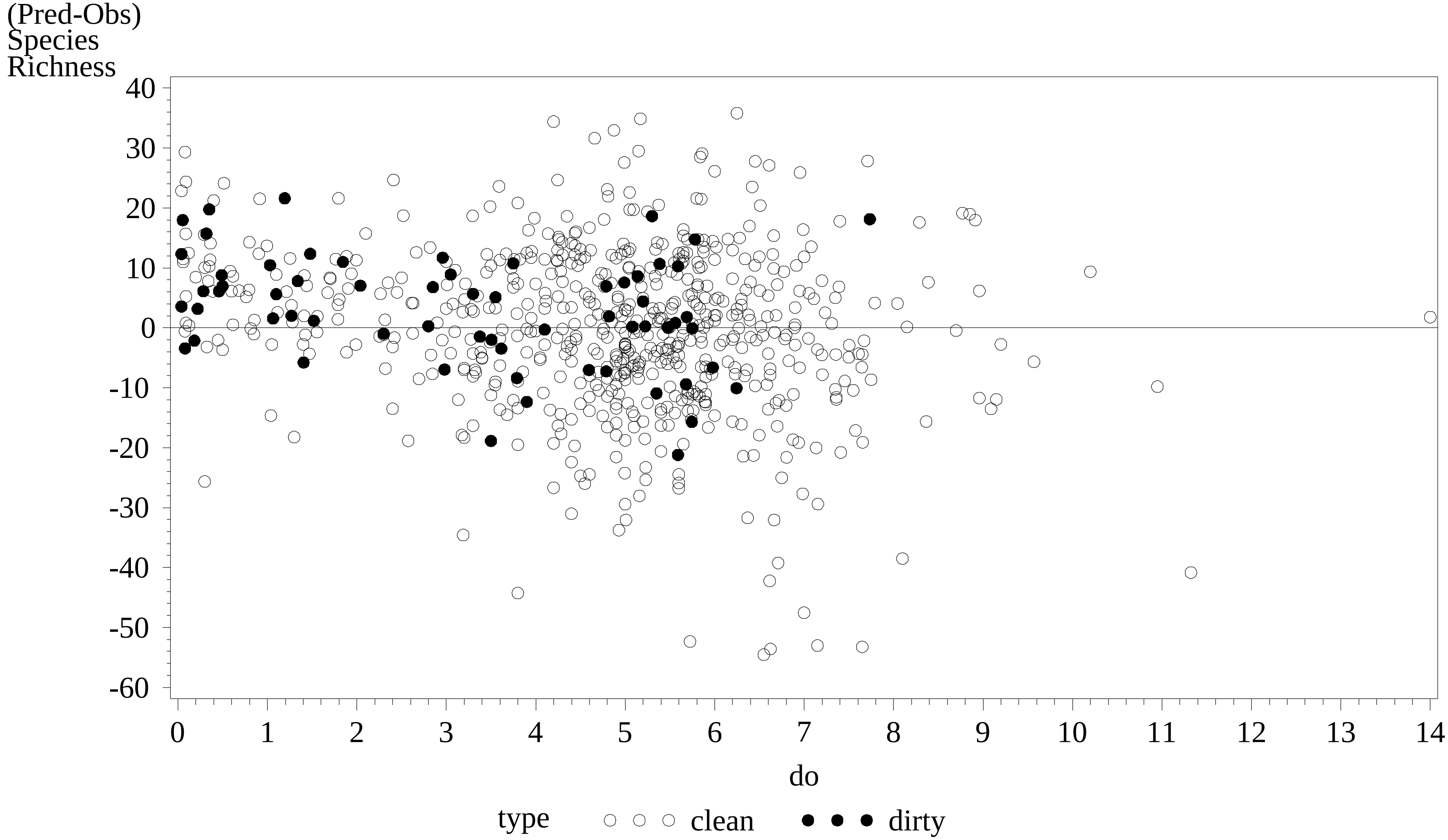
Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity



(Dirty defined as at least 1 PEL exceeded)

Figure 7

Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity



(Dirty defined as at least 1 PEL exceeded)

Figure 8

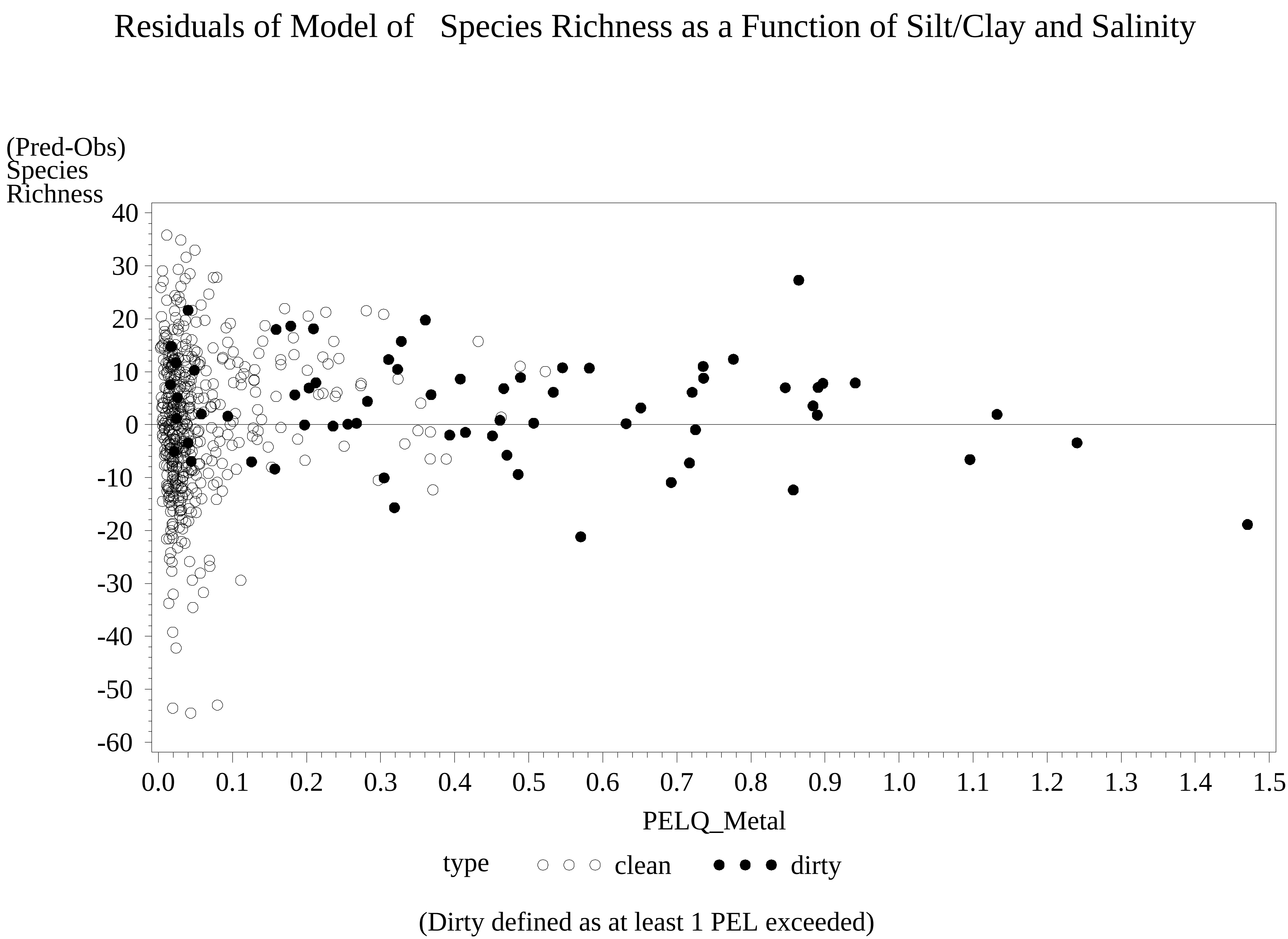
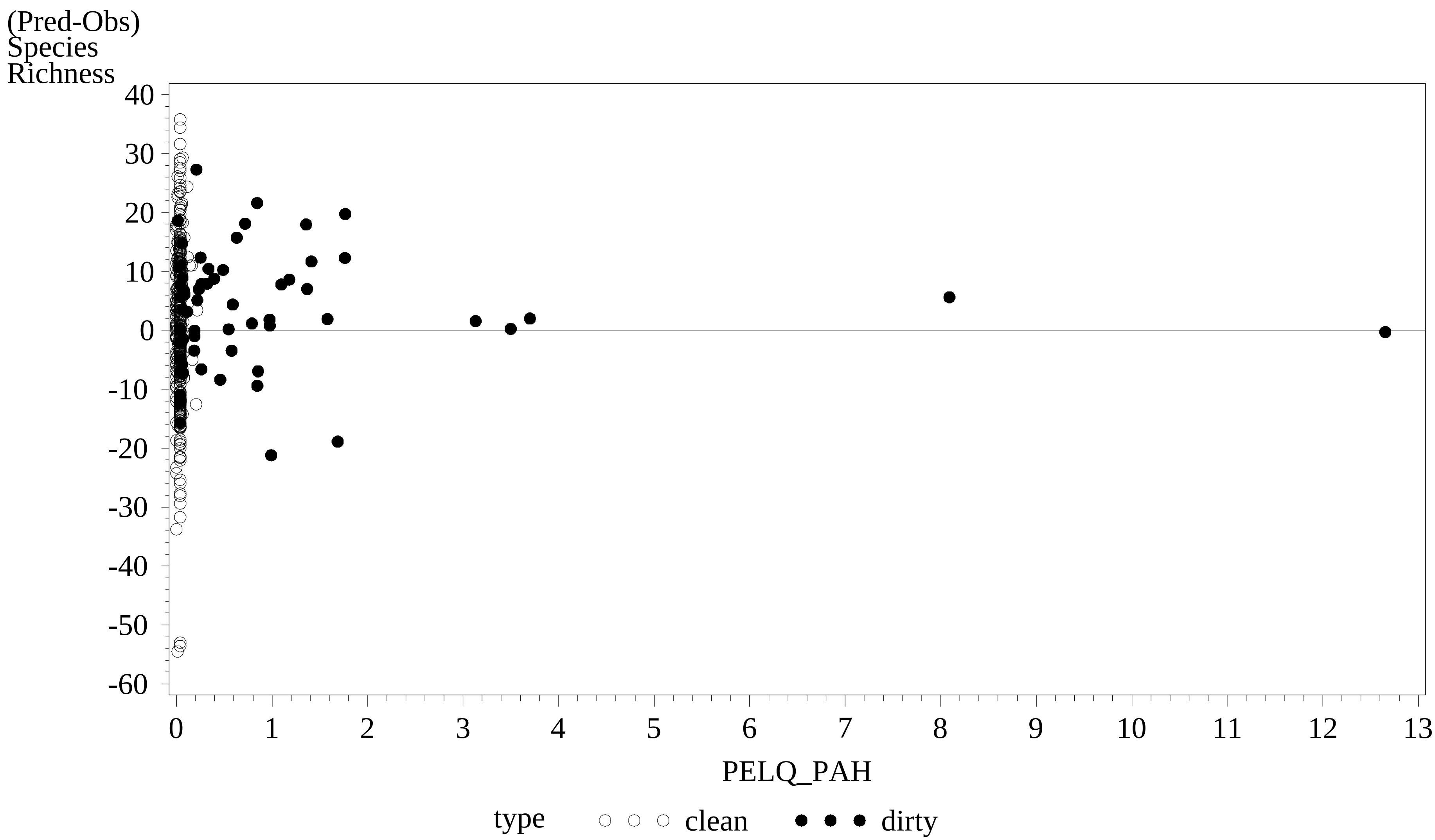

Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity
(Pred-Obs)
Species
Richness
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
PELQ_Metal
type
clean
dirty
(Dirty defined as at least 1 PEL exceeded)

Figure 9

Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity



(Dirty defined as at least 1 PEL exceeded)

Figure 10

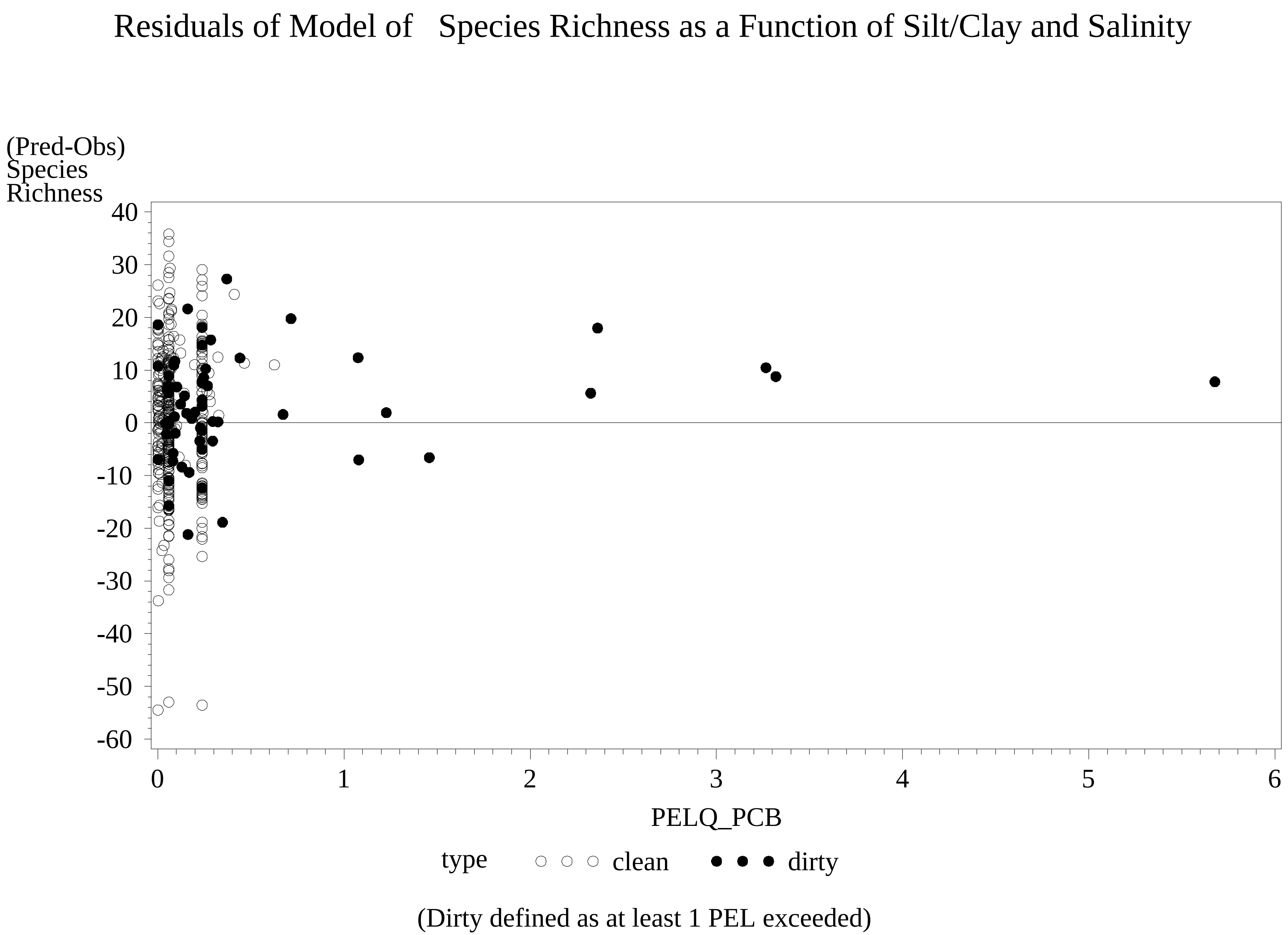

Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity
(Pred-Obs) Species Richness
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
1
2
3
4
5
6
PELQ_PCB
type
clean
dirty
(Dirty defined as at least 1 PEL exceeded)

Figure 11

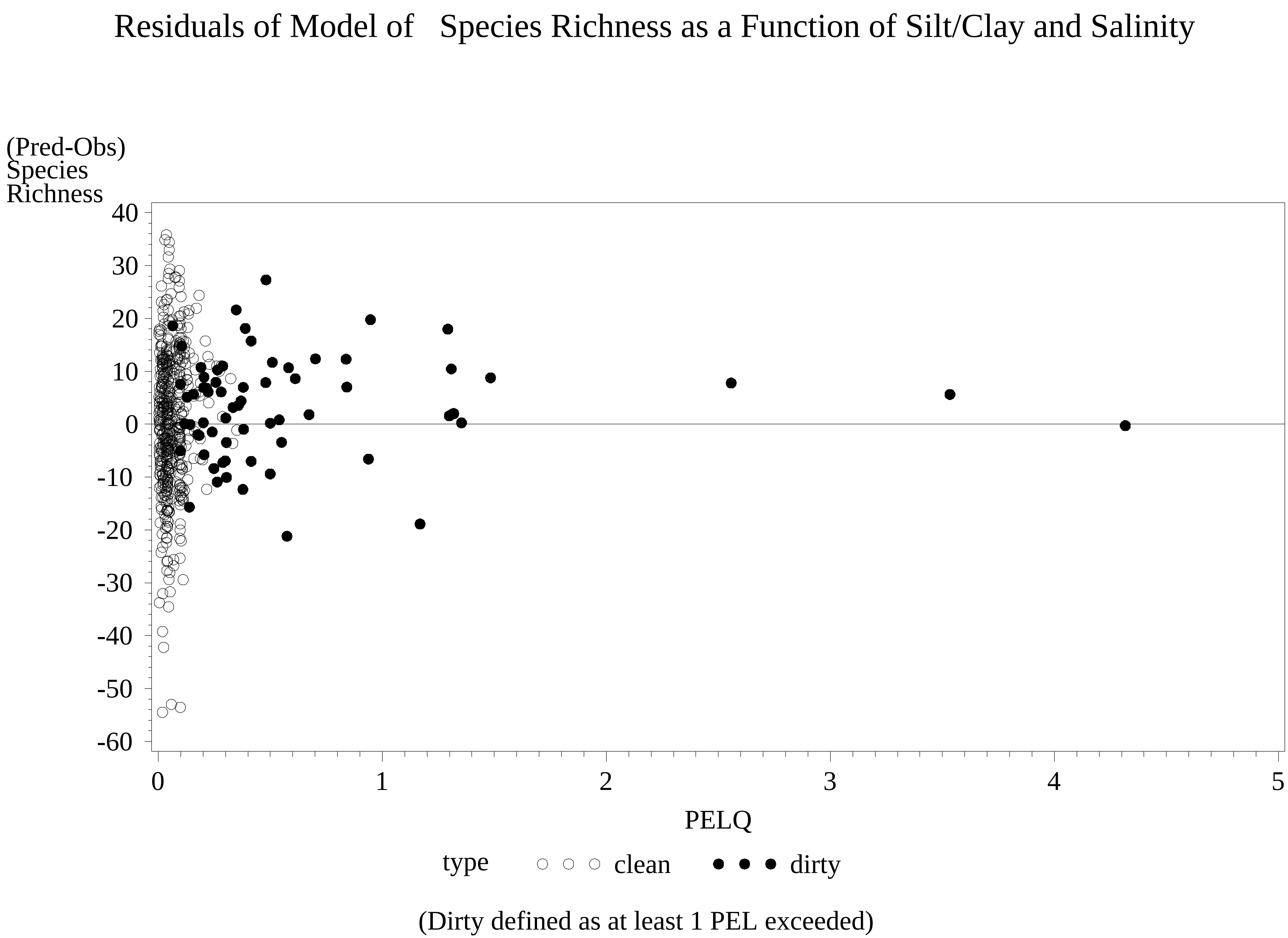

Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity
(Pred-Obs)
Species
Richness
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
1
2
3
4
5
PELQ
type
clean
dirty
(Dirty defined as at least 1 PEL exceeded)

Figure 12

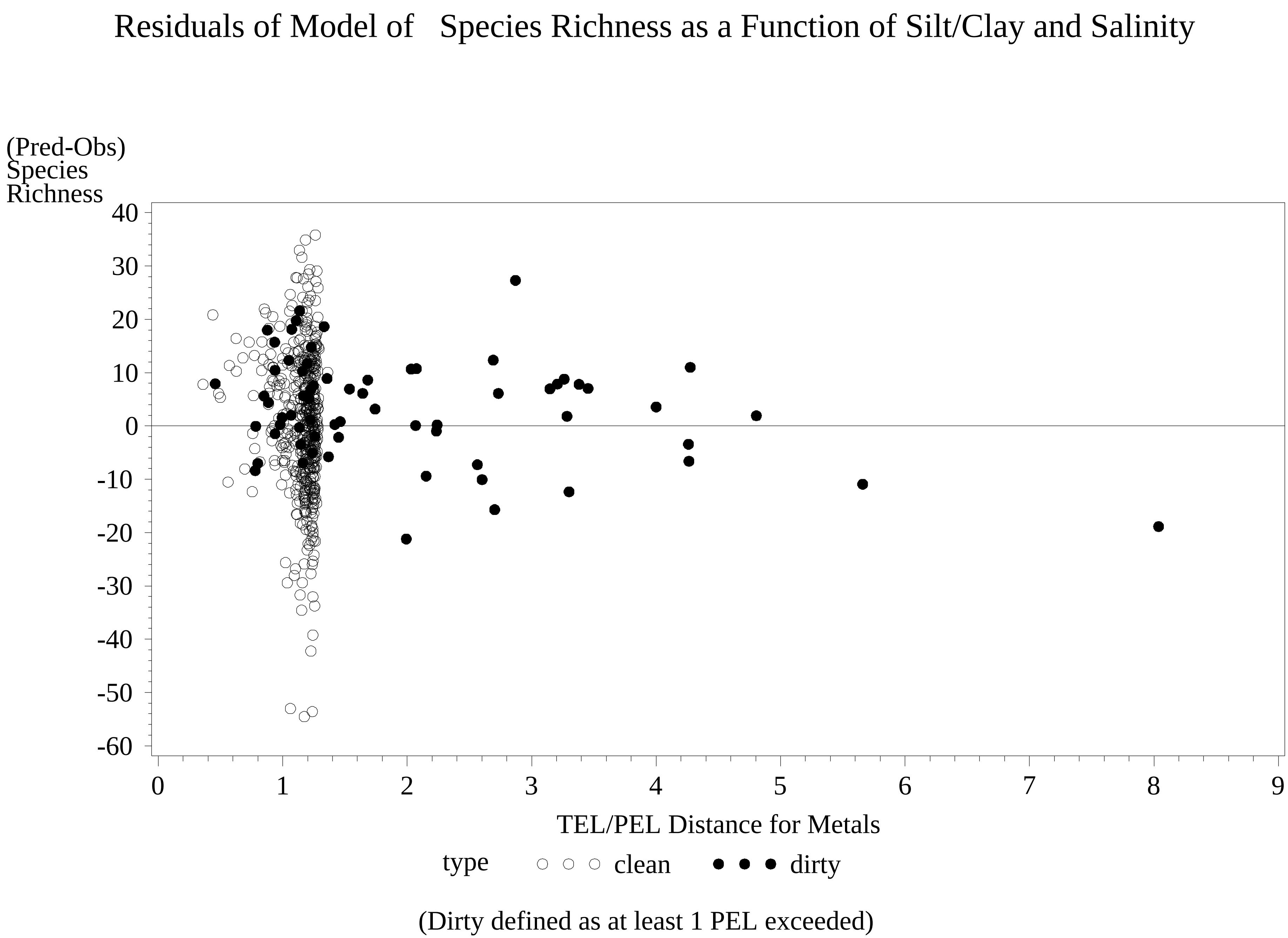

Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity
(Pred-Obs) Species Richness
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
1
2
3
4
5
6
7
8
9
TEL/PEL Distance for Metals
type
clean
dirty
(Dirty defined as at least 1 PEL exceeded)

Figure 13

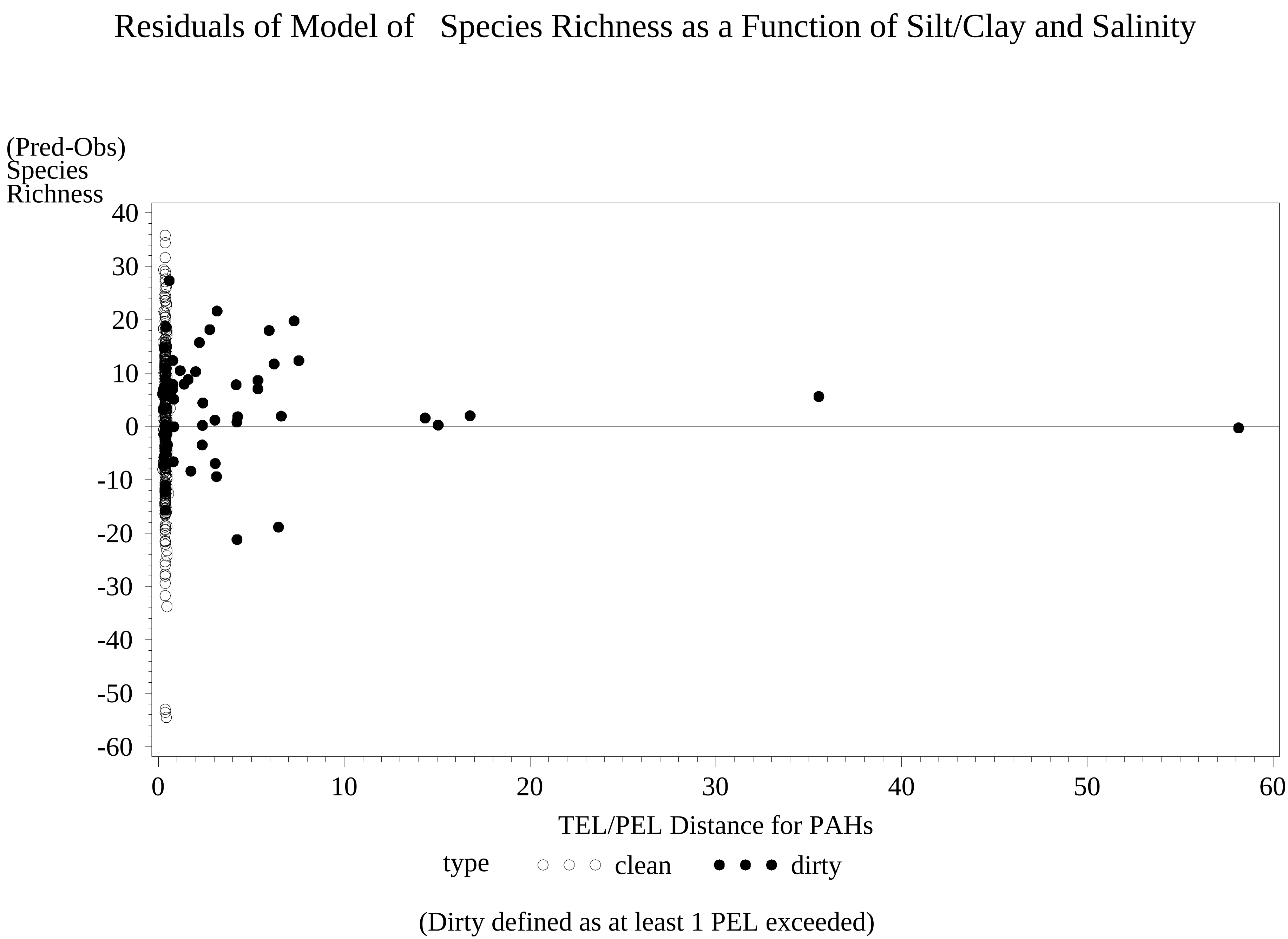
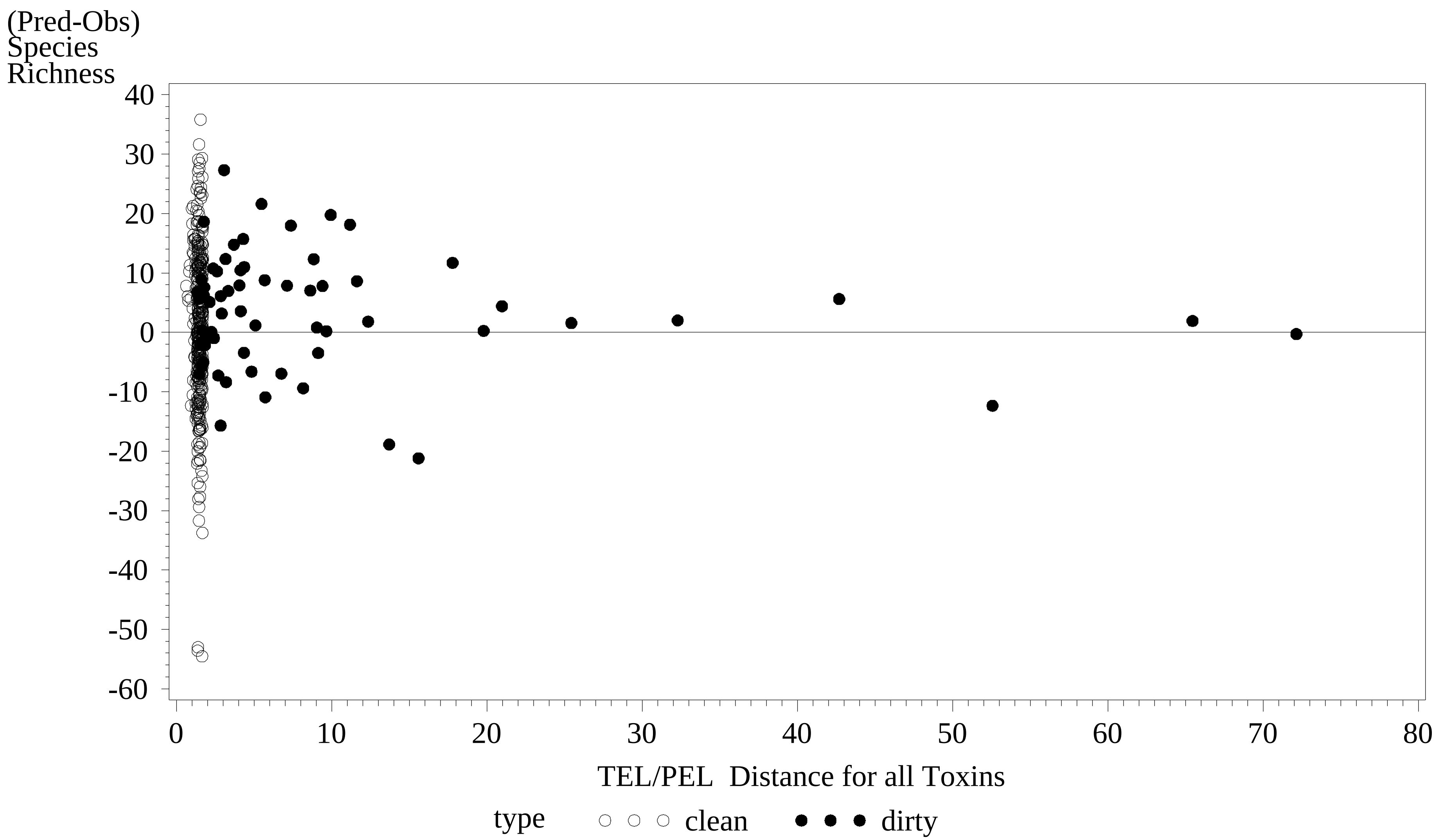

Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity
(Pred-Obs)
Species
Richness
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
10
20
30
40
50
60
TEL/PEL Distance for PAHs
type
clean
dirty
(Dirty defined as at least 1 PEL exceeded)

Figure 14

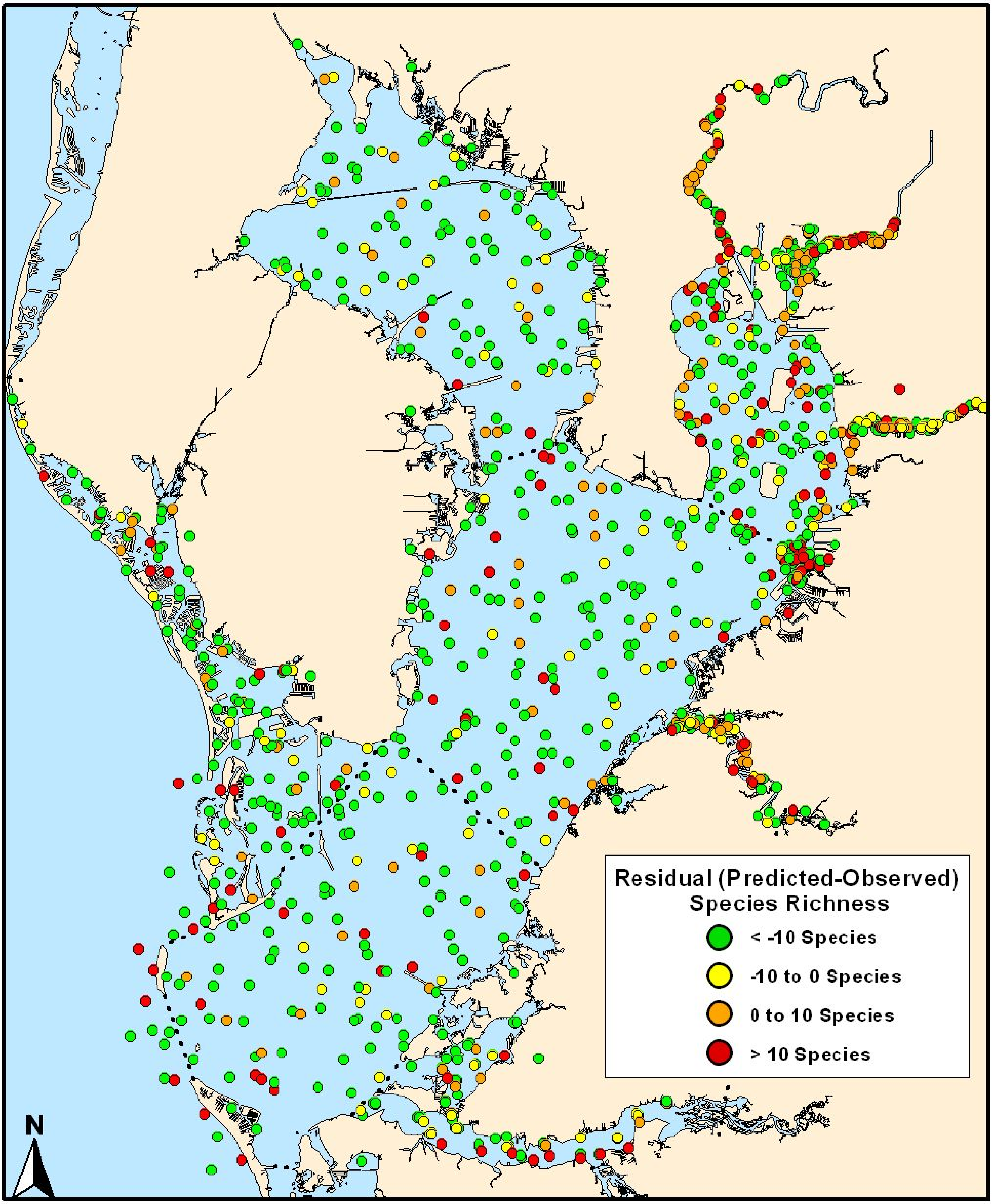
Residuals of Model of Species Richness as a Function of Silt/Clay and Salinity



(Dirty defined as at least 1 PEL exceeded)

Figure 15

Species Richness Model Residuals Plotted by Sample
Tampa Bay



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Map Series No. A0252901

Figure 16

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Alafia River

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Cadmium	8	8	5
Chromium	8	7	3
Chlordane	7	1	1
Dibenz(a,h)anthracene	7	7	1
Zinc	8	5	1
Acenaphthene	7	5	0
Acenapthylene	7	4	0
Silver	8	2	0
Anthracene	7	1	0
Benz(a)anthracene	7	2	0
Benzo(a)pyrene	7	1	0
Chrysene	7	1	0
Copper	8	6	0
DDE	7	1	0
Fluoranthene	7	2	0
Flourene	7	1	0
Total LMW-PAHs	7	1	0
Total PAHs	7	1	0
Lead	8	7	0
Total PCBs	6	1	0
Phenanthrene	7	1	0
Pyrene	7	3	0
Total HMW-PAHs	7	4	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Big Bend

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Copper	2	1	1
Zinc	2	2	1
Cadmium	2	1	0
Chromium	2	1	0
Lead	2	1	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Boca Ciega Bay

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Chromium	3	1	1
Copper	3	2	1
Zinc	3	1	1
Acenaphthene	2	2	0
Acenapthylene	2	2	0
Lead	3	1	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Hillsborough Bay

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Chromium	19	15	9
Chlordane	18	6	5
Zinc	19	10	5
Dibenz(a,h)anthracene	18	17	4
Lead	19	14	4
Pyrene	18	8	4
Total HMW-PAHs	18	8	4
Benz(a)anthracene	18	8	3
Chrysene	18	8	3
Phenanthrene	18	5	3
Acenaphthene	18	17	2
Acenapthylene	18	16	2
Benzo(a)pyrene	18	8	2
DDD	18	4	2
Fluoranthene	18	8	2
Total PCBs	18	9	2
Copper	19	11	1
DDT	18	2	1
Total LMW-PAHs	18	6	1
Total PAHs	18	7	1
Silver	19	6	0
Anthracene	18	5	0
Cadmium	19	13	0
DDE	18	6	0
Total DDT	18	6	0
Dieldrin	18	2	0
Flourene	18	5	0
Napthalene	18	9	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Hillsborough River

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Dibenz(a,h)anthracene	35	35	32
Chlordane	36	32	27
Total HMW-PAHs	35	34	26
Benzo(a)pyrene	35	34	24
Phenanthrene	35	34	24
Pyrene	35	34	24
Chrysene	35	34	23
Fluoranthene	35	34	23
Benz(a)anthracene	35	34	20
Total LMW-PAHs	35	32	15
Total PAHs	35	34	15
Lead	39	29	14
Acenaphthene	35	30	11
Anthracene	35	29	9
Copper	39	27	7
Zinc	39	18	6
DDD	35	30	5
DDT	35	11	4
Flourene	35	24	4
Chromium	39	6	3
Dieldrin	35	5	3
Total PCBs	30	26	3
Cadmium	39	22	1
Total DDT	35	27	1
Acenapthylene	35	28	0
Silver	39	8	0
Arsenic	39	5	0
DDE	35	20	0
Napthalene	35	20	0
Lindane	35	3	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Little Manatee River

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Silver	3	1	1
Copper	3	2	1
Lead	3	1	1
Acenaphthene	3	2	0
Acenapthylene	3	2	0
Cadmium	3	1	0
Chromium	3	1	0
DDE	3	1	0
Dibenz(a,h)anthracene	3	2	0
Zinc	3	2	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Lower Tampa Bay

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Chlordane	4	2	1
Copper	4	2	1
Lead	4	1	1
Lindane	4	1	1
Acenaphthene	4	4	0
Acenapthylene	4	4	0
Dibenz(a,h)anthracene	4	3	0
Dieldrin	4	1	0
Total PCBs	4	2	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Manatee River

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Chlordane	2	1	1
Zinc	2	1	1
Benz(a)anthracene	2	1	0
Benzo(a)pyrene	2	1	0
Chrysene	2	1	0
Chromium	2	1	0
Copper	2	1	0
Dibenz(a,h)anthracene	2	1	0
Fluoranthene	2	1	0
Total PAHs	2	1	0
Pyrene	2	1	0
Total HMW-PAHs	2	1	0

Table 1   Summary of PEL   and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=McKay Bay

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Dibenz(a,h)anthracene	2	2	2
Benz(a)anthracene	2	2	1
Benzo(a)pyrene	2	2	1
Chlordane	2	1	1
Chrysene	2	2	1
DDD	2	2	1
Fluoranthene	2	2	1
Pyrene	2	2	1
Total HMW-PAHs	2	2	1
Acenaphthene	2	2	0
Acenapthylene	2	2	0
Anthracene	2	1	0
Total DDT	2	2	0
Flourene	2	1	0
Napthalene	2	2	0
Total LMW-PAHs	2	1	0
Total PAHs	2	2	0
Total PCBs	2	1	0
Phenanthrene	2	1	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Middle Tampa Bay

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Benzo(a)pyrene	1	1	1
Chlordane	2	2	1
Chrysene	1	1	1
Dibenz(a,h)anthracene	1	1	1
Lead	2	1	1
Total HMW-PAHs	1	1	1
Silver	2	1	0
Arsenic	2	1	0
Benz(a)anthracene	1	1	0
Cadmium	2	1	0
Chromium	2	1	0
Copper	2	1	0
DDE	2	1	0
DDT	2	1	0
Fluoranthene	1	1	0
Total PAHs	1	1	0
Phenanthrene	1	1	0
Pyrene	1	1	0
Zinc	2	1	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Old Tampa Bay

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Lead	3	3	3
Chlordane	3	1	1
Chromium	3	2	1
Copper	3	3	1
Zinc	3	2	1
Acenaphthene	3	3	0
Acenapthylene	3	3	0
Arsenic	3	2	0
Cadmium	3	2	0
DDE	3	1	0
DDT	3	1	0
Total DDT	3	1	0
Dibenz(a,h)anthracene	3	1	0
Total PCBs	3	1	0

Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Palm River

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Zinc	12	11	10
Lead	12	10	9
Cadmium	12	12	6
Chromium	12	11	6
Total PCBs	10	9	5
Dibenz(a,h)anthracene	12	12	4
Chlordane	12	6	2
Benz(a)anthracene	12	10	1
Benzo(a)pyrene	12	10	1
Chrysene	12	10	1
Dieldrin	12	6	1
Fluoranthene	12	11	1
Phenanthrene	12	9	1
Pyrene	12	11	1
Total HMW-PAHs	12	11	1
Acenaphthene	12	7	0
Acenapthylene	12	9	0
Silver	12	4	0
Anthracene	12	2	0
Arsenic	12	1	0
Copper	12	10	0
DDD	12	6	0
DDE	12	2	0
Total DDT	12	3	0
Flourene	12	2	0
Napthalene	12	7	0
Total LMW-PAHs	12	3	0
Total PAHs	12	10	0
Lindane	12	2	0

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Table 1 Summary of PEL and TEL Exceedances for Samples having any PEL Value Exceeded
Sorted by the Contaminant with the Most Frequent PEL Exceedances

Stratum=Terra Ceia Bay

Contaminant	Number of Samples with >=1 PEL Exceeded	TEL Exceedances	PEL Exceedances
Copper	2	2	1
Lead	2	2	1
Acenaphthene	2	2	0
Acenapthylene	2	2	0
Cadmium	2	2	0
Zinc	2	2	0