5. Sediment Contamination

Background

Another issue of major environmental concern is the pollution of estuarine sediments with chemical contaminants. A wide variety of organic compounds and metals are discharged into estuaries from industrial, agricultural, and urban sources. The contaminants are adsorbed onto suspended particles and eventually settle to the sediments. There they can exert toxic effects on the benthic community that lives in the sediments and can indirectly affect human health as well.

The MAIA program measured the concentrations of 91 chemical constituents in sediments, as well as their toxic effects of the sediments on amphipods (crustaceans living in the sediments). The results can be used to identify the most polluted areas and give clues regarding the sources of the contaminants. The data may also aid in developing management plans that clean up polluted sites.

The analytes measured include: 1) metals such as arsenic, cadmium, lead, mercury and zinc, which can be toxic in high enough levels; 2) PAHs and aliphatic hydrocarbons, which are petroleum residues and components produced by combustion, as well as biogenic and naturally-occurring substances; and 3) synthetic organic chemicals, including PCBs used in insulators and capacitors, pesticides, and organotins (a component of anti-fouling paint).

Several factors strongly influence the extent and severity of contamination by these toxic compounds. Fine-grained sediments high in organic matter are better able to adsorb the pollutants than are coarser particles. The finer particles are also more likely to be resuspended by currents and transported to regions far from their point of origin. For these reasons, silty muds usually contain the highest concentrations of contaminants.

In some cases, sediments may bind the toxicants so strongly that they no longer pose a threat to organisms. However, if organic-rich particles are ingested or the chemicals are otherwise released, the toxicants enter the food web. Shellfish, fish, and other organisms tend to “bioaccumulate” toxicants, threatening larger consumers, including humans. Environmental managers are often forced to curtail fishing and close shell-fisheries in heavily-contaminated regions causing significant economic expense.

In this chapter, we review the results of three recognized measures of chemical contamination: the concentrations of metallic and organic toxicants in sediments and the toxicity of the sediments toward an abundant and important benthic organism.

Metal Contaminants in Sediments

Metals are generally not harmful to organisms at concentrations normally found in estuarine sediments. Some, like zinc, are essential for normal metabolism but are toxic above a critical threshold. We use the approach of Long, et al. (1995) to characterize contamination in sediments. These researchers reviewed field and laboratory studies and identified nine metals that were observed to have ecological or biological effects on organisms. They defined ERL values as the lowest concentration of a metal that produced adverse effects in 10% of the data reviewed. Similarly, the ERM designates the level at which half of the studies reported harmful effects. Metal concentrations below the ERL value are not expected to elicit adverse effects, while levels above the ERM value are likely to be very toxic.

Metal Contamination of Sediments

Method: Sediments were collected with a modified Van Veen grab sampler, and the top two cm were analyzed for chemical constituents. The levels of nine metals are compared to ERL and ERM limits, and a site is assessed based on exceedances of these limits.
Units: None are applicable.
Assessment categories:
Good: No ERL exceedances
Intermediate: Any ERL (but no ERM) exceedance
Poor: Any ERM exceedance

This method of characterizing sediment toxicity has been criticized because it does not evaluate the interaction of multiple chemicals (complex mixtures) nor does it account for the possible mitigating effects of organic components in sediments that may bind the metals and render them harmless. Nevertheless, the method provides a uniform perspective for evaluating contaminant levels within and among estuaries.

Figures 5-1 and 5-2 depict concentrations of metals in sediments expressed in relation to ERL and ERM values. A station is rated "good" if the concentrations of all nine metals are below the ERL limit. An "intermediate" rating applies if any metal exceeds an ERL limit, and a "poor" rating signifies exceedance of an ERM limit for any metal. Plots of the concentrations of the metals are presented in Appendix D.

Overall, 31 ± 7% of mid-Atlantic estuarine area has sediments that exceed at least one ERL limit. Arsenic and nickel are the most common contaminants, present in about half of the sites at levels greater than the ERL. Zinc, chromium, mercury, and copper exceed the ERL in about a quarter of the sites.

The estuaries most frequently exceeding an ERL limit include the Delaware, Schuylkill, and Salem Rivers; the upper Chesapeake mainstem; Severn and South Rivers; and the upper Potomac River. In addition, the Chowan and Neuse Rivers show high levels of mercury.

Another 9 ± 3% of the area exceeded an ERM limit, usually because of nickel and/or zinc. These more serious exceedances were most evident in the Delaware, Schuylkill, South, and Severn Rivers.

Over half of the Chesapeake Bay has metal concentrations above the ERL limit, usually for arsenic and nickel. Fifteen percent of the region exceeds an ERM value, largely because of high nickel levels. The heavily-urbanized Severn, South, and Potomac Rivers and the upper mainstem are notable for especially high levels of nearly *all* metals in Table 5-1. Generally, the northern bay and western tributaries are more polluted than elsewhere in the estuary.

The sediments of the coastal bays include generally low concentrations of metals. A few stations in the Chincoteague Bay have arsenic and zinc levels above the ERL limit. No sites exceed an ERM limit.

Table 5-1. ERL and ERM Limits for Metals.

Metal Contaminants in Sediments		
Metal	ERL*	ERM*
Arsenic (As)	8.2	70
Cadmium (Cd)	1.2	9.6
Chromium (Cr)	81	370
Copper (Cu)	34	270
Lead (Pb)	47	220
Mercury (Hg)	0.15	0.71
Nickel (Ni)	21	52
Silver (Ag)	1	3.7
Zinc (Zn)	150	410

* units are µg/g dry sediment, equivalent to ppm

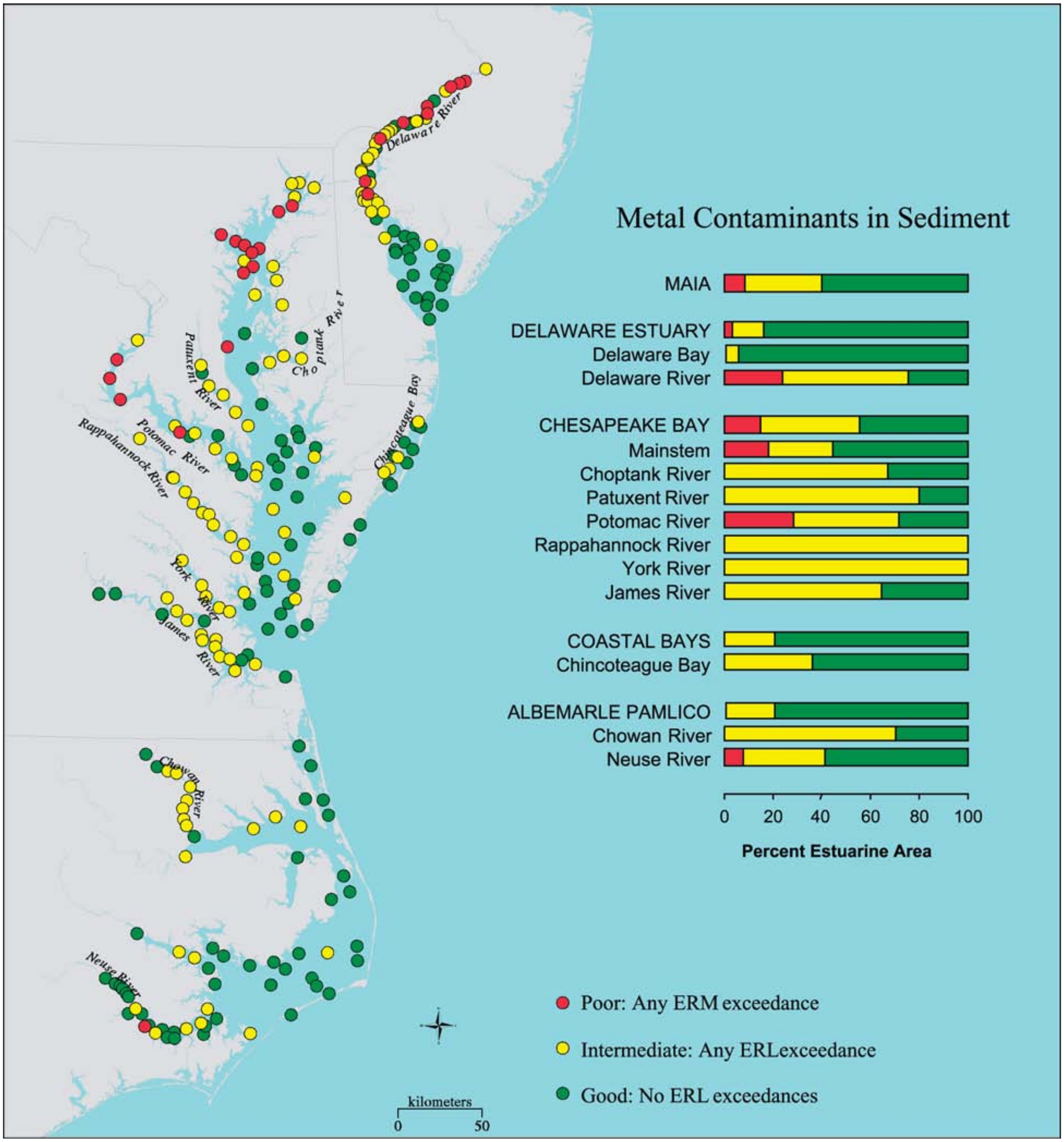


Figure 5-1. ERL and ERM Exceedances for Metals in Sediments.

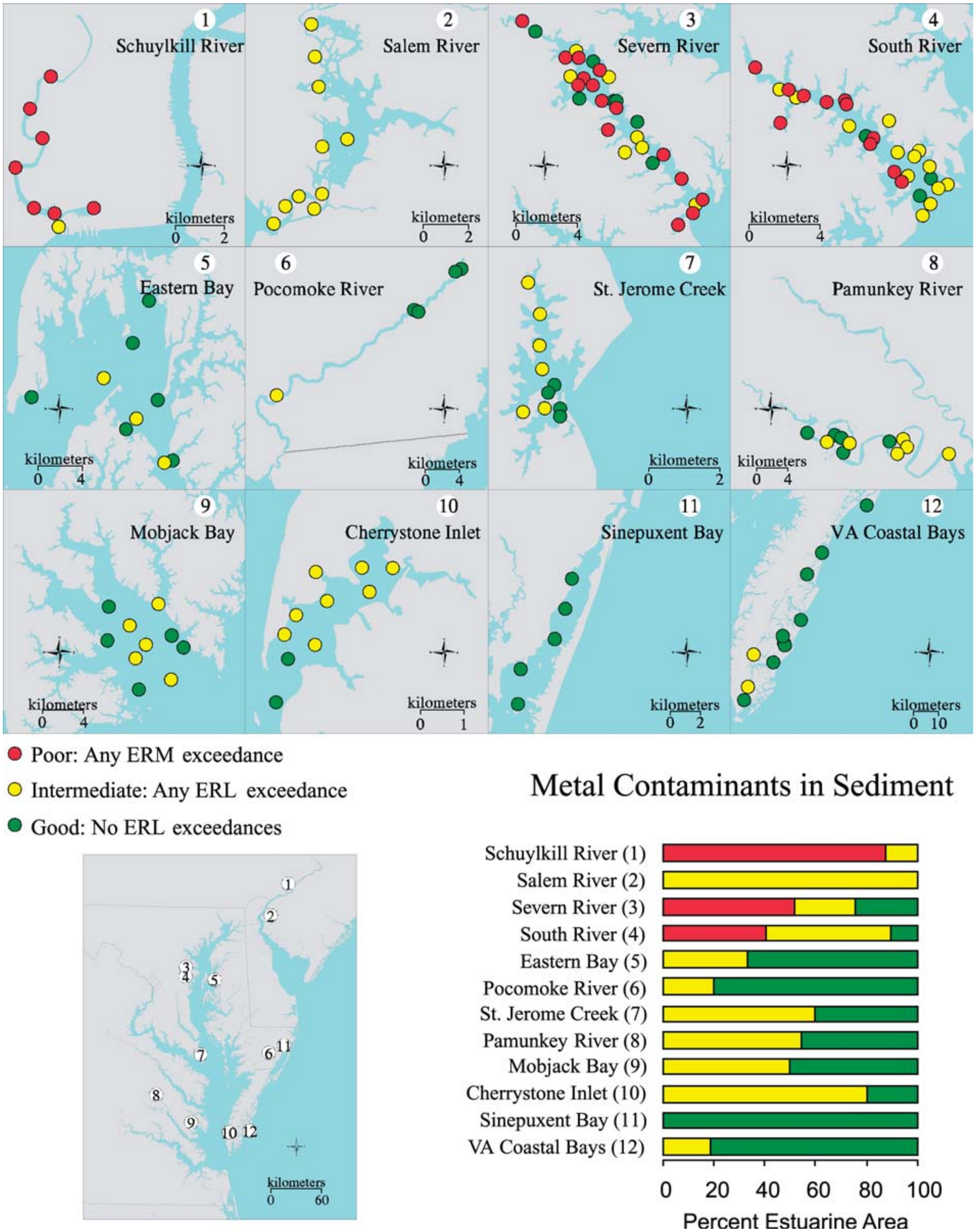


Figure 5-2. ERL and ERM Exceedances for Metals in Intensively-Sampled Systems.

In the APES, about 20% of the estuarine area exceeds an ERL limit (40 to 70% in the case of the Chowan and Neuse Rivers). As in other mid-Atlantic systems, arsenic and nickel levels are high. The Chowan River and parts of Albemarle Sound are notably high in mercury as well.

Organic Contaminants in Sediments

We can perform the same ERL/ERM analysis to characterize the levels of organic contaminants in estuarine sediments. Table 5-2 lists 19 organic analytes and associated ERL and ERM limits as defined by Long, et al. 1995. Concentrations of organic toxicants below the ERL value are not expected to cause adverse ecological effects, while concentrations above the ERM value are likely to be very toxic.

Figures 5-3 and 5-4 show the condition of sediments in the MAIA region and intensively-sampled systems, expressed in terms of ERL and ERM exceedances. On the maps, yellow designates an exceedance of any ERL limit, and red shows an exceedance of any ERM limit. Appendix D includes plots that show the concentrations of representative organic compounds. This format highlights estuaries that exhibit very high concentrations of toxicants.

In the MAIA region overall, 28 $\pm$ 6% of the estuarine area exceeds at least one ERL limit, and only 1% exceeds an ERM value. The maps show many stations that are designated "intermediate" and colored yellow. In large part, this can be attributed to total DDT levels, which narrowly exceed the ERL limit at many stations. Below, we highlight estuaries in which many toxicants are present in high concentrations.

In the Delaware Estuary, the Delaware and Schuylkill Rivers show very high levels of PAHs, pesticides, and PCBs. The concentrations of pesticides 4,4'-DDE and DDT generally exceed ERL limits in these rivers. The Delaware Bay and Salem River are rated in "good" condition, except for slightly elevated total DDT levels.

Most of the estuaries in the Chesapeake Bay have concentrations of toxicants that are below ERL limits, other than the mildly high DDT levels. Exceptions include the upper mainstem, in particular the Severn and South Rivers, where the concentrations of all toxicants exceed ERL limits by moderately large margins (see Appendix D).

Table 5-2. ERL and ERM Values for Organics.

Organic Contaminants in Sediments

Analyte	ERL*	ERM*
Polycyclic Aromatic Hydrocarbons (PAHs)		
Acenaphthene	16	500
Acenapthylene	44	640
Anthracene	85	1100
Fluorene	19	540
2-Methyl Napthalene	70	670
Napthalene	160	2100
Phenanthrene	240	1500
Benz(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Chrysene	384	2800
Dibenzo(a,h)anthracene	63	260
Fluoranthene	600	5100
Pyrene	670	2600
Low MW PAH	550	3160
High MW PAH	1700	9600
Total PAH	4000	45000
Pesticides and PCBs		
4,4'-DDE	2.2	27
Total DDT	1.6	46
Total PCBs	23	180

* units are ng/g dry sediment, equivalent to ppb

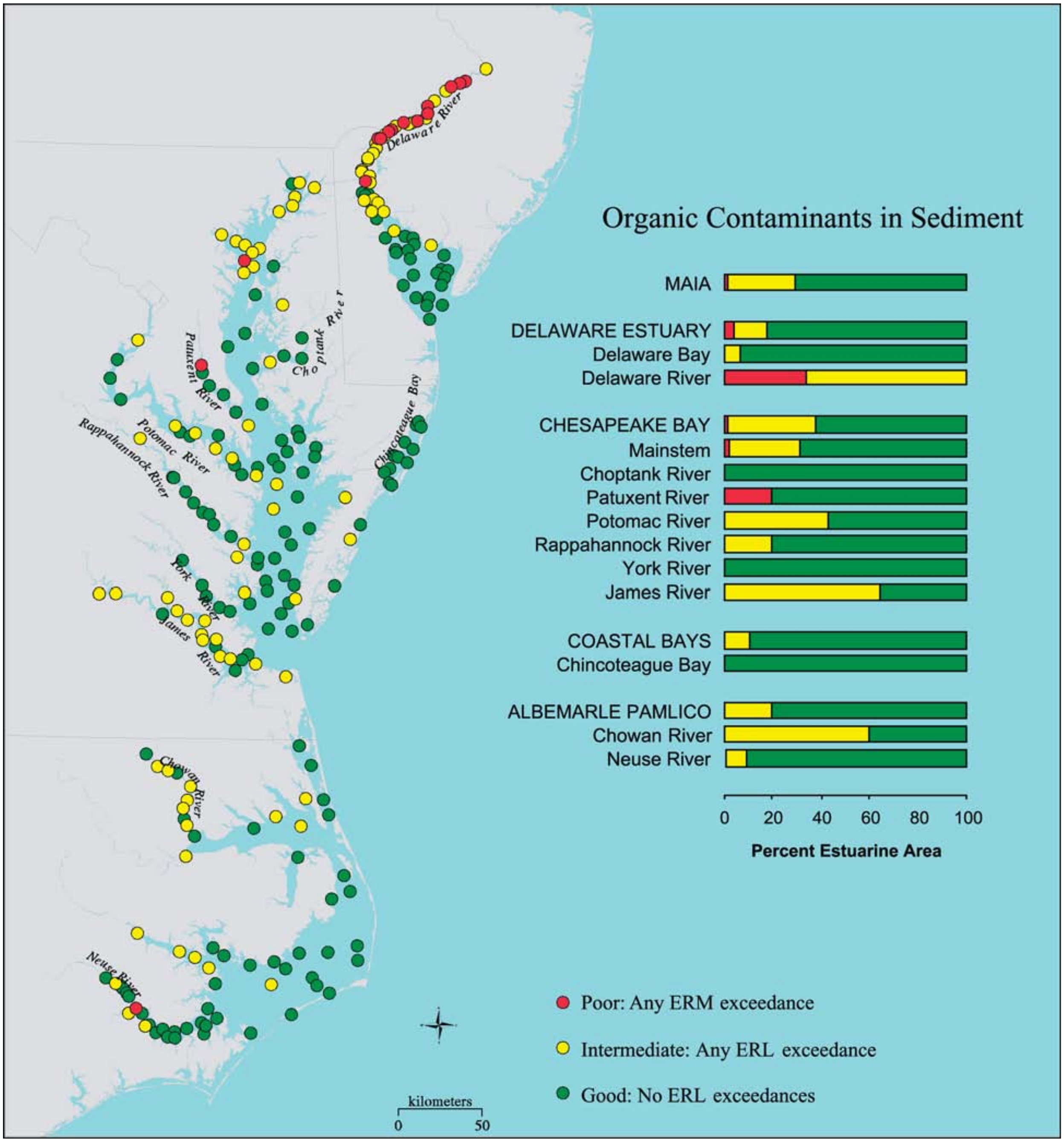


Figure 5-3. ERL and ERM Exceedances for Organic Compounds in Sediments.

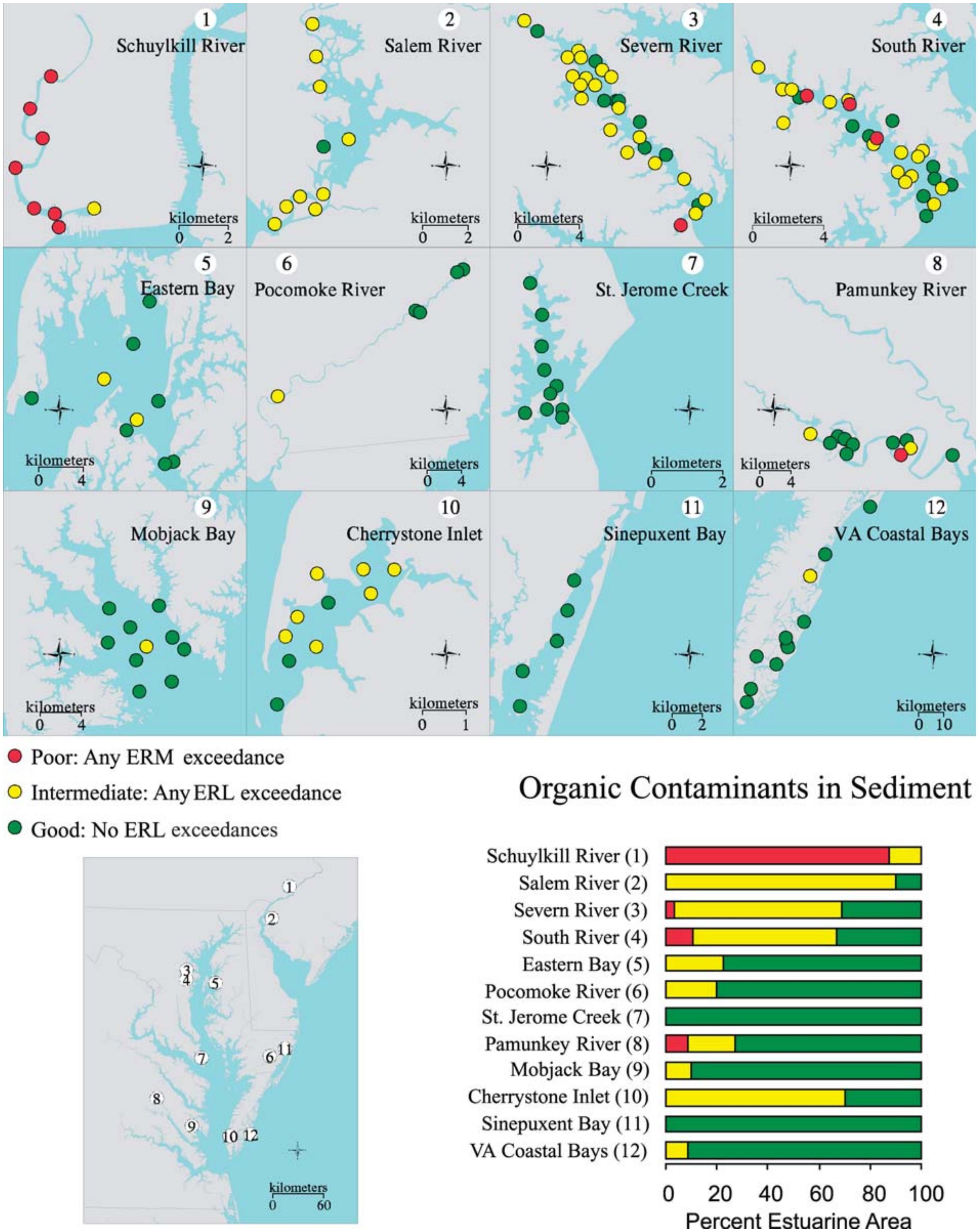


Figure 5-4. ERL and ERM Exceedances for Organics in Intensively-Sampled Systems.

The Maryland and Virginia coastal bays generally have low levels of organic toxicants. Likewise, there is no systematic evidence of wide-scale contamination by organic toxicants in the APES.

Organic Contamination in Sediments

Method: Sediments were collected with a modified Van Veen grab sampler, and the top two cm were analyzed for chemical constituents. The levels of 19 organic toxicants are compared to ERL and ERM limits, and a site is assessed based on exceedances of these limits.
Units: None are applicable.
Assessment categories:
Good: No ERL exceedances
Intermediate: Any ERL (but no ERM) exceedance
Poor: Any ERM exceedance

Sediment Toxicity (Amphipod Survival)

In addition to measuring the concentrations of toxic chemicals in sediments, the MAIA program performed several bioassay analyses in which sensitive organisms were exposed directly to the sediments. Here, we examine the results of the static ten-day assay conducted using the amphipod *Ampelisca abdita* (EPA 1994, 1995), a common but ecologically important crustacean that lives in estuarine sediments.

The bioassay is simple in concept. In the laboratory, twenty juvenile amphipods are added to the sediments from a site, and their survival rate, relative to a control test, is calculated after a ten-day exposure. The sediment condition is classified as "good" (low toxicity) when survival is greater than 80%, and "poor" (high toxicity) for survival rates less than or equal to 60%.

Figures 5-5 and 5-6 show the results of the assay. Sediments are not harmful to amphipods in 99% of the mid-Atlantic estuaries.

The major exception to this observation occurs in the Delaware Estuary, where parts of the Delaware and Schuylkill Rivers exhibit some amphipod survival rates below 25%, possibly in response to the high levels of metals and organic toxicants in the sediments of these rivers.

The relationship is not as simple in the Chesapeake Bay. Sediment toxicity is evident in the Pamunkey River and Cherrystone Inlet, which are relatively uncontaminated with sediment toxicants. Moreover, there is no sign of toxicity in the sediments of Severn or South Rivers, despite the presence of abundant contaminants.

There are no indications of sediment toxicity in the coastal bays.

In the APES, the sediments of the Chowan River appear to be highly toxic to amphipods. These sediments are moderately contaminated with mercury and nickel but less so than other estuaries that passed the survival test.

Sediment Toxicity

Method: The top two centimeters of sediment are reserved from samples collected with a modified Van Veen grab sampler. The survival rate of the amphipod *Ampelisca abdita* is measured in the laboratory following exposure to sediments in a 10-day assay.
Units: Percent survival compared to a control.
Map categories:
Low Toxicity: > 80% survival
Intermediate: > 60% to 80% survival
High Toxicity: ≤ 60% survival

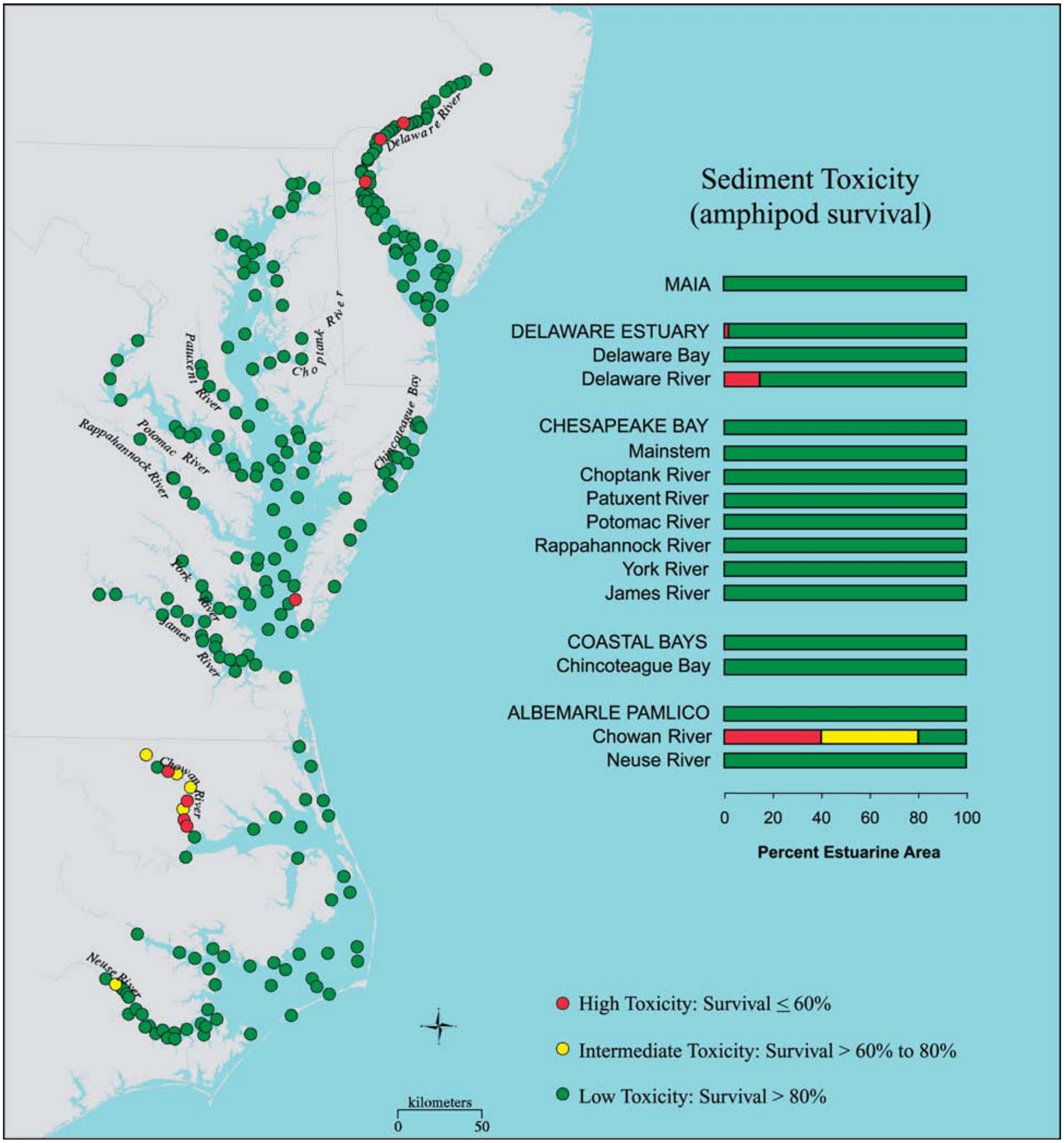


Figure 5-5. Survival Rate of *Ampelisca abdita* Exposed to Sediments.

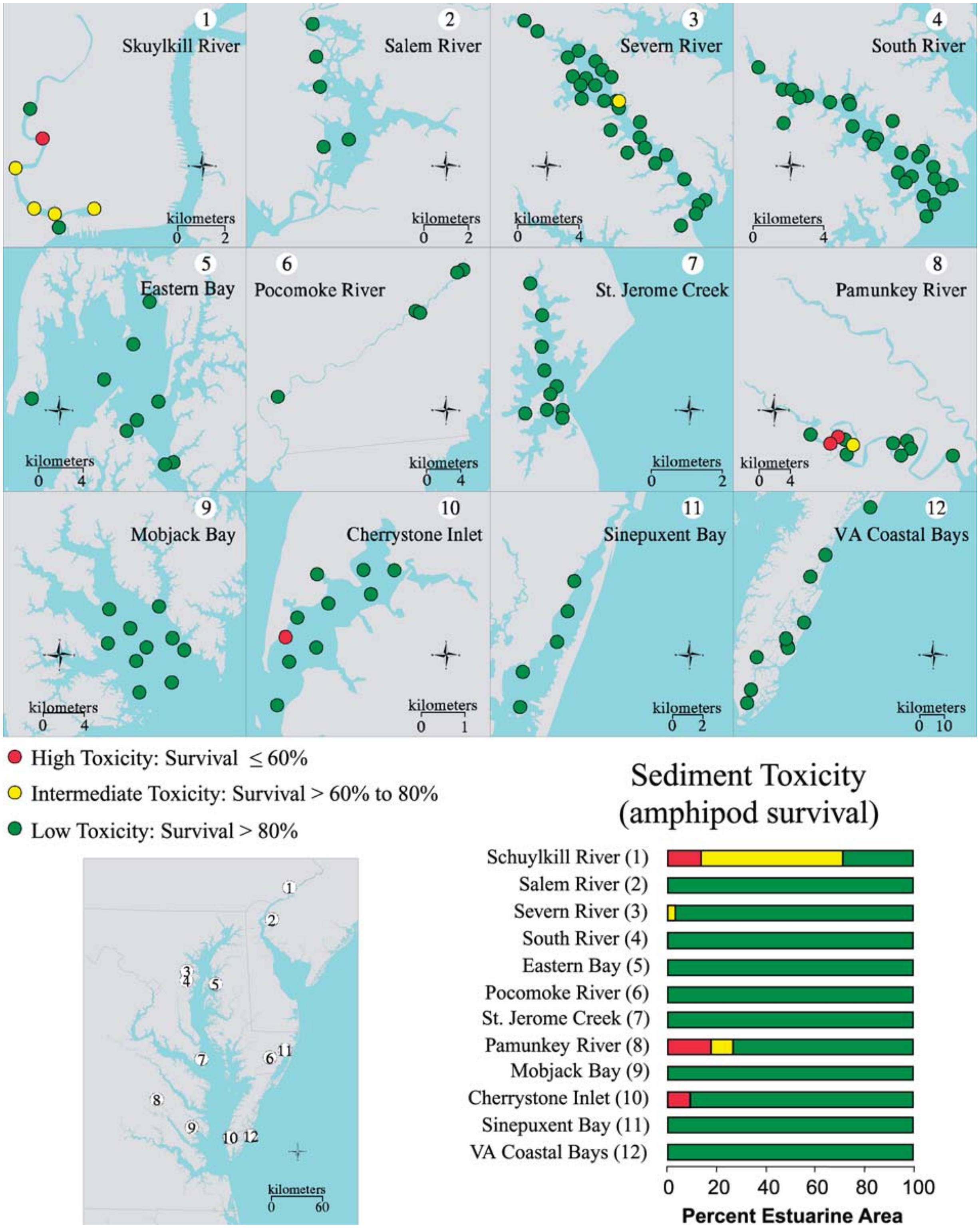


Figure 5-6. Survival Rate of *Ampelisca abdita* in Intensively-Sampled Systems.

Summary: Sediment Contamination

Figure 5-7 summarizes some of the major findings of this chapter. Vertical bars in the figure represent the area of an estuary displaying poor conditions.

Most estuaries have sediments that are contaminated with metals and toxic organic compounds. In the MAIA region overall, 30 to 40% of the estuarine area exceeds at least one of the ERL or ERM limits for metals and organic toxicants. Only 1% of the region's sediments is characterized as toxic, based on the amphipod survival assay.

Arsenic and nickel are the metals most often exceeding ERL or ERM limits in the region, followed by mercury and zinc. The concentrations of organic toxicants are highly correlated, that is, when one compound is abundant at a site, it is likely that other compounds are present as well.

Sediments in the Delaware, Schuylkill, and Salem Rivers in the upper Delaware Estuary are very heavily contaminated by both metals and organic toxicants. These rivers exhibit the highest concentrations of toxicants in the mid-Atlantic region. Pollution by pesticides is common in these systems. Large fractions of these sediments are found to be toxic, as determined by an amphipod survival bioassay.

Wide-spread sediment contamination is also evident in the estuaries in the Chesapeake Bay. Metals more than organics are likely to exceed ERL or ERM levels in these systems. Patterns of excessive contamination are most apparent in the upper mainstem and in the Severn and South Rivers, where concentrations of all metals and organic toxicants are several times higher than in neighboring systems. Remarkably, these highly contaminated sediments show little indication of being toxic.

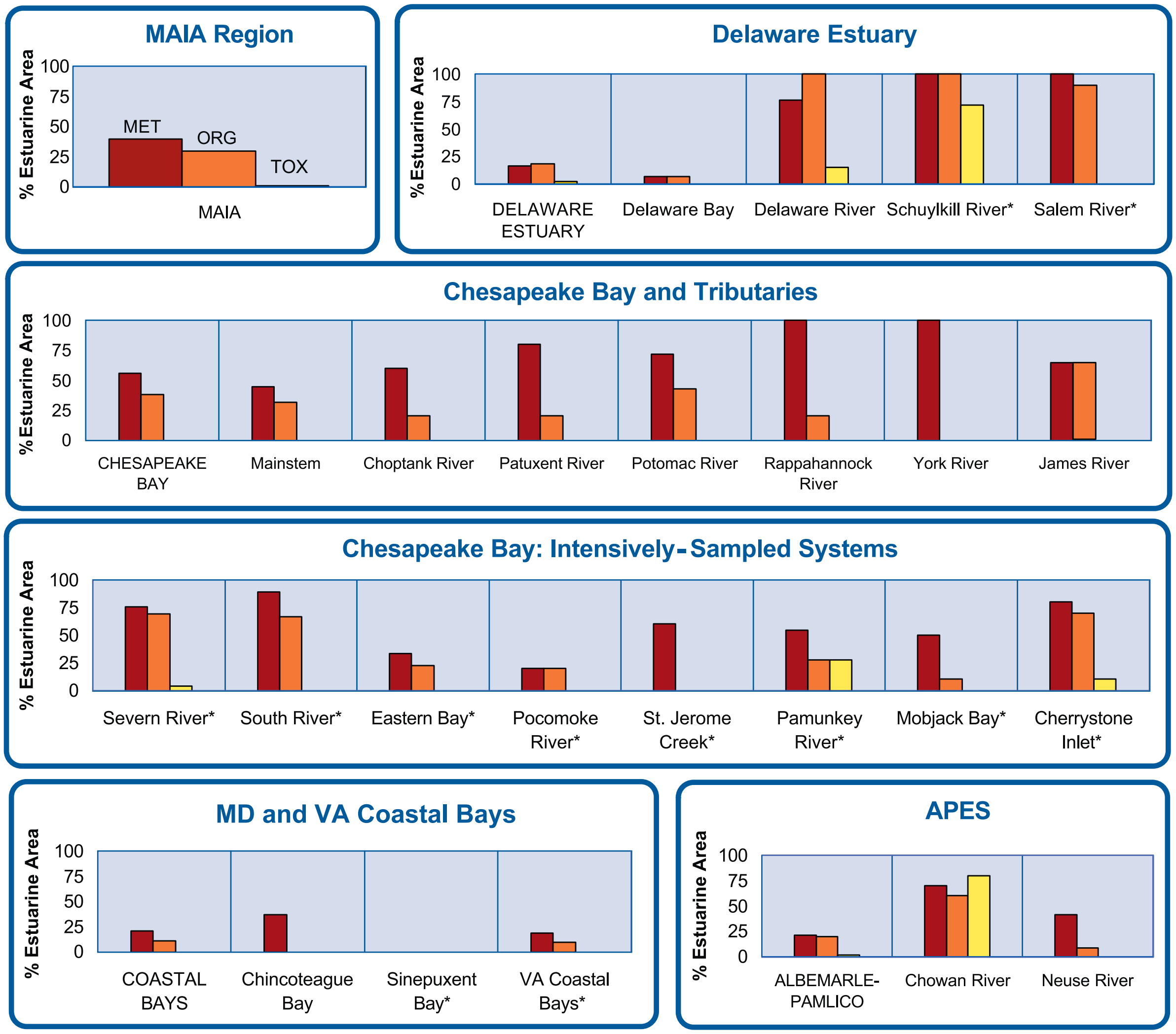
About a third of the Chincoteague Bay exceeds ERL limits for arsenic or nickel. Otherwise, the Maryland and Virginia coastal bays generally have low levels of metals and organic toxicants and no indication of sediment toxicity.

The APES is moderately contaminated with mercury, nickel, and pesticides. Much of the Chowan River sediments are contaminated and toxic.

Several general observations are evident from this chapter. Contaminated sediments are common in the mid-Atlantic estuaries. About a third of the estuaries have concentrations of metals and organic toxicants high enough to be harmful to organisms.

A number of estuaries stand out because of the extent and severity of contamination. These include the Delaware River, Schuylkill River, and Salem River in the Delaware Estuary; and the upper mainstem and the Severn and South Rivers in the Chesapeake Bay. All are situated near urban centers, which are the likely sources of the toxicants.

Only a small fraction of the region's sediments is characterized as toxic, despite the high levels of sediment contamination. Is the amphipod survival assay an effective measure of sediment toxicity? One plausible explanation for the poor correlation is based on the observation that organic material in sediments may bind toxicants so tightly that they are unavailable to harm organisms. The likelihood of this explanation is currently under study.



* Intensively-sampled systems

Legend. The indicator parameters used to characterize sediment conditions, along with threshold values indicating impairment.

MET	ORG	TOX
Metals in Sediment Any ERL/ERM Exceedances	Organics in Sediment Any ERL/ERM Exceedances	Sediment Toxicity (Amphipod) ≤ 80% Survival

Figure 5-7. Summary of Sediment Contamination Indicators. Evidence that the sediment in an estuary is contaminated and harmful to organisms. The vertical bars represent the percentage of estuarine area exhibiting impaired conditions. Threshold values indicating impaired conditions are listed in the legend.