ECOLOGICAL CONSIDERATIONS IN WETLANDS TREATMENT OF MUNICIPAL WASTEWATERS

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Vegetation in Wetlands Receiving Sewage Effluent: The Importance of the Seed Bank

Dennis F. Whigham

Van der Valk (1981,1982) has proposed a model for studying changes in wetland vegetation that is based on three life-history attributes: (1) life span, (2) propagule longevity, and (3) propagule establishment requirements. The model assumes that knowledge of these attributes for species in a wetland would enable one to predict vegetation composition under various hydrologic (and other environmental) conditions. Although the model needs to be modified or expanded to permit quantification of population properties (e.g., biomass, aerial coverage, and so forth), it provides a suitable framework to evaluate the types of changes that might occur when wetlands are used for wastewater management.

The purpose of this paper is to discuss the effects that wastewater application might have on wetland vegetation. Because two of the three attributes used in van der Valk's model relate to the seed bank, the paper will focus primarily on the effects that altered hydrologic and nutrient patterns have on recruitment from the seed bank.

SEED BANKS IN WETLANDS

Seed banks have been shown to be important in a number of terrestrial ecosystems (see discussion in Harper 1977), but there have been only a few studies of seed banks in wetlands even though water-level manipulations have been used for many years to regulate wetland vegetation (Keddy and Reznicek 1982; Meeks 1969). Seed banks have been shown to be very important in the vegetation dynamics of midwestern prairie pothole wetlands that are subject to periodic droughts (van der Valk and Davis 1976, 1978; Millar 1969). Seed banks have also been shown to be important in littoral wetlands where long-term patterns of species diversity are maintained because of periodic natural drawdowns (Keddy and Reznicek 1982; Dykyjová and Květ 1978). Seed banks have also been studied in freshwater wetlands that are subjected to daily tidal activity (Leck and Graveline 1979; Ristich, Fredrick, and Buckley 1976), and Junk (1970) has suggested that buried seeds are important in Amazonian riverine and lacustrine wetlands that are subject to dramatic annual changes in water levels.

I have found no studies of the relationship between vegetation composition and seed banks for permanently flooded herbaceous wetlands in which the period of drawdown is very brief. Neither have I found any studies of seed banks in forested wetlands, although Curtis Richardson (personal communication) suggests that recruitment from the buried seed pool is not very important in northern bogs. In contrast, Christensen et al. (1981) have suggested that the seed bank may be important in forested southeastern Pocosin wetlands where the peat substrate is subjected to fire during periodic droughts. In tundra wetlands, recruitment from the seed pool seems to be unimportant for herbs and minimally important for shrubs (Callaghan and Collins 1981).

Although the data base on wetland seed banks is meager, it appears that they are most important in wetlands that are subject to daily, seasonal, annual, or less frequent periods of drawdown.

Under what conditions would the seed bank be least important? Any attempt to answer this question requires an understanding of the autecology of wetland plants, and a brief review of van der Valk's model will demonstrate the importance of autecological data. The model (Table 15.1) includes three life spans: annuals (A), perennials that do not form large clones and/or spread slowly (P), and perennials that form large clones by vegetative growth (V); and two types of propagule (primarily seed) longevity: species with long-lived propagules that are called seed bank species (S) and species with short-lived propagules, called dispersal species (D). Finally, the model includes two seedling-establishment scenarios: plants that require a period of drawdown for germination and establishment are called Type I species, and plants that can become established under flooded conditions are called Type II species. When all possible combinations of the three categories are considered, there are 12 types of species (Table 15.1).

Water-level fluctuations are critical to the model. Figure 15.1 shows one example of how species are eliminated when a wetland normally exposed to fluctuation in the water levels is permanently flooded. In permanently flooded wetlands, all Type I species would be eliminated and their propagules eliminated from the seed bank unless they were annually replenished by dispersal from other areas. The highest diversity of life-history types would be expected to occur in wetlands where water levels fluctuate, particularly with a period of drawdown occurring when Type I species would germinate.

A second example is presented in Table 15.2, which shows that the diversity of annuals (A)--species that are dependent on the seed bank--declines in a freshwater tidal wetland along a drawdown gradient. Maximum diversity occurs on the high marsh, where the substrate is exposed twice daily. Lowest diversity occurs in permanently inundated ponds. There is evidence that seeds of most species in freshwater tidal wetlands are distributed throughout the wetland (Whigham, Simpson, and Leck 1979; Whigham and Simpson 1982) so that the existing vegetation in permanently flooded areas does not mirror the species composition of seeds in the seed bank. The seed bank in permanently flooded habitats, therefore, has less influence on vegetation composition compared to high marsh and stream bank areas where the vegetation closely mirrors the composition of the seed bank (Simpson et al. 1984).

Table 15.1
Classification of Wetland Plants Used in van der Valk's Succession Model

Type of Plant	Propagule Longevity	Establishment Requirement	Symbol
Annual (A)	Short-lived (D)	Drawdown (I)	AD-I
		Flooded (II)	AD-II
	Long-lived (S)	I	AS-I
		II	AS-II
Perennial (P)	S	I	PS-I
		II	PS-II
	D	I	PD-I
		II	PD-II
Vegetative perennial (V)	S	I	VS-I
		II	VS-II
	D	I	VD-I
		II	VD-II

Source: Data from A. G. van der Valk, 1981.

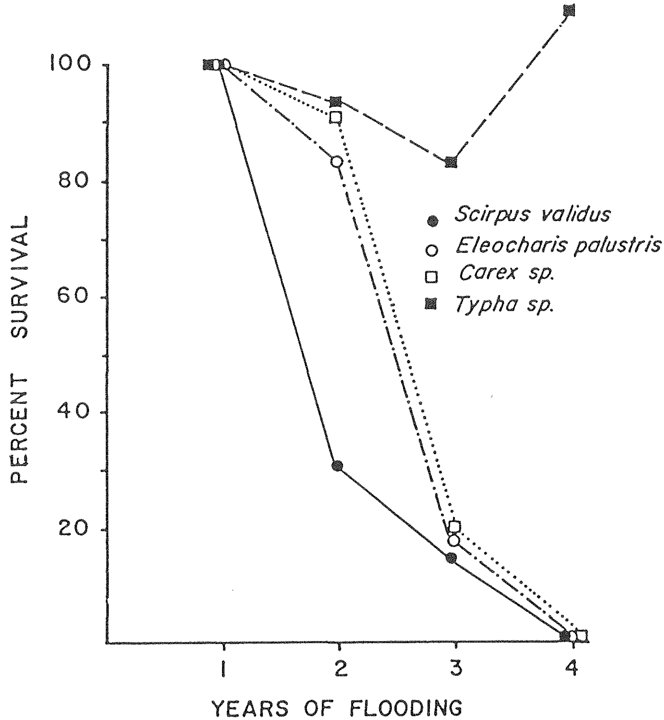

Figure 15.1
Survival of dominant species in a wetland following establishment of permanently flooded conditions. (After S. W. Harris and W. H. Marshall, 1963)

EFFECTS OF WASTEWATER ADDITIONS

Wastewater application would most likely increase the depth of flooding, duration of flooding, and/or frequency of flooding. In addition, there would be significant increases in nutrient loading. Nutrient additions have been shown to cause increased biomass production in both coastal salt marshes (Valiela, Teal, and Sass 1975; Valiela, Teal, and Persson 1976) and the following inland freshwater wetlands: herbaceous wetlands (Zoltek et al. 1979) and cypress domes in Florida (Odum and Ewel 1978), bogs in Michigan (Kadlec 1980; Tilton and Kadlec 1979), and artificial wetlands in New York (Small 1976; Woodwell 1977; Woodwell et al. 1974). Production did not increase in a freshwater tidal wetland receiving chlorinated, secondarily treated wastewater (Whigham, Simpson, and Lee 1980).

Increased production could have an indirect effect on the seed bank due to the competitive elimination of some species by aggressive Type V species that form monocultures. Examples would be Typha spp., surface mats of floating vegetation such as Lemna (Odum and Ewel

Table 15.2
Importance Values of Annual Species in Three Habitats Within a Freshwater Tidal Wetland

Species	High marsh	Pondlike	Pond
Bidens laevis	98.9	-	-
Polygonum punctatum	39.5	44.6	49.6
Impatiens capensis	32.6	-	-
Polygonum arifolium	20.2	-	-
Zizania aquatica	9.9	32.6	-

Source: Data from Whigham 1974.

1978), and Phragmites. Expansion of aggressive Type V species following wastewater addition has been documented by Tilton and Kadlec (1979).

In other instances, the seed bank may be influenced by loss of some species following wastewater addition. Species losses have been found for bogs (Curtis Richardson, personal communication) and freshwater tidal wetlands (Whigham, Simpson, and Lee 1980). In the latter instance, recovery was very rapid following cessation of wastewater application (Robert Simpson, personal communication).

The seed bank would be expected to become less important in wetlands where the hydrology is altered and permanent standing water conditions are created. This situation is shown in Figure 15.2. By maintaining permanent standing water, all species that require a drawdown for establishment (AS-I, PS-I, VS-I, AD-I, PD-I, and VD-I) could be eliminated. If VD-I and VD-II species (e.g., Typha) ultimately dominate the site, AS-II, AD-II, short-lived PD-II, and short-lived PS-II might also be eliminated.

There would probably be no change in the importance of the seed bank in wetlands where seeds are of minor importance (e.g., salt marshes, northern bogs, and wetlands that are permanently flooded or are already dominated by Type V species). One would also predict that there would be no change in the importance of the seed bank in wetlands that have regular drainage (freshwater tidal wetlands), periodic drawdown (Playa wetlands, herbaceous wetlands in Florida), or undergo climate extremes (Prairie glacial wetlands).

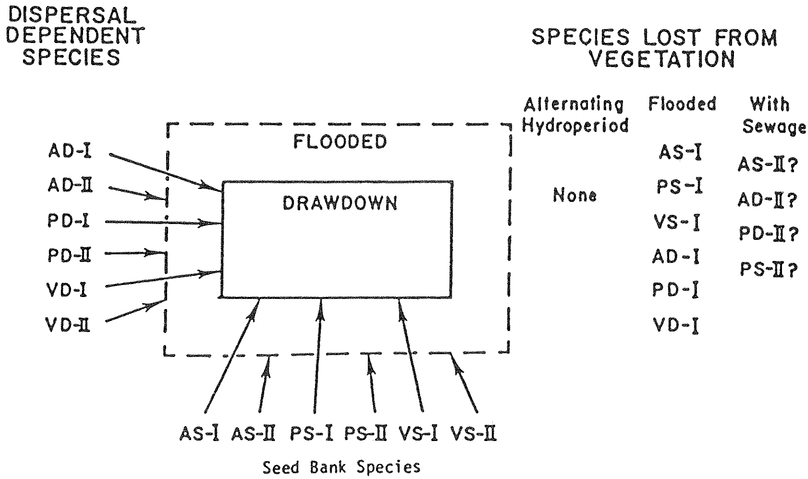

Figure 15.2
Diagrammatic representation of van der Valk's (1982) model and the changes that would result from water level changes and nutrient additions. (Refer to Table 15.1 for description of symbols.)

MANAGEMENT IMPLICATIONS

Much of the previous discussion is, unfortunately, speculative. Van der Valk (1981, 1982) has shown that the model can be used to predict vegetation changes associated with water-level manipulations. There are no data for wetlands that have received wastewater for extended periods of time to test the model. The model does, however, provide insight into management strategies to be used to minimize impacts due to wastewater irrigation.

As has been suggested in the previous section, the addition of wastewater can influence vegetation composition by enabling some species to become more important and by eliminating others. Changes can occur because of increased nutrient loading alone or in concert with changing hydrologic patterns. Deleterious effects can be avoided by minimizing changes in the hydrologic regime. In particular, increasing the depth of flooding, frequency of flooding, and duration of flooding should be avoided because those conditions have a negative impact on the seed pool. In addition, it has been shown that primary production and, consequently, nutrient retention are less under flooded conditions. Wastewater addition would be expected to have minimal effects in systems that have frequent drawdown, since diversity appears to be greatest in those types of wetlands, and the seed pool would be minimally affected under such conditions.

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DISCUSSION

Larson: I'd like to make a couple of comments. First, in selecting papers for this session, we did not select from the rather well developed literature on manipulation of water levels for wildlife purposes. There is quite a lot to be drawn out of that literature without reinventing the wheel. The other point is that some years ago the National Wetlands Technical Council, under NSF sponsorship, held a symposium in Athens, Georgia, and came out with a moderately well distributed report. It contained the very important conclusion that a great deal more work needed to be done on hydrology. And this afternoon we've had a specific reference to hydrology. I must confess that at least as regards my examination of the literature, not enough funding from the important federal sources, nor enough effort to secure funding from private sources, has gone into hydrology, whether surficial or subsurface. A great deal of what we've talked about this afternoon and an immense amount of what we'll talk about at this whole workshop is going to remain wide open because we have not engaged enough hydrologists to look at wetlands. To the extent we don't do that, we will continue to have many unanswered questions. Are there any questions for Dennis?

Zedler: Dennis Whigham's and Barbara Bedford's papers both suggest that what is causing all the species composition change is the hydrology. It seems to have nothing to do with nutrients. To me, that's a bit surprising. You didn't say it was all due to the water level, but that certainly seems like the most important impact of wastewater treatment.

Whigham: I think that in the case of Typha, for example, it will increase its presence in the wetland just because of the additional nutrients.

Zedler: It becomes more productive, but it won't shift to a new type of wetland just because of nutrients.

Guntenspergen: Joy, there is some work I've been doing for my Ph.D. thesis in artificially fertilizing freshwater marshes. In some cases, I have seen species compositional changes due entirely to the nutrient additions and having nothing at all to do with hydrology.

Valiela: John Teal and I have a system in which we irrigate one hectare of salt marsh with a solution of simulated sewage effluent. We also have adjoining plots where we add only freshwater, and we can measure no change at all due to the addition of freshwater. All the change that we measure is associated with nutrient additions and, also, the elevation of the marsh surface in relation to tidal heights.

Larson: Are you maintaining the depth and replicating the periodicity of the normal inundation?

Valiela: No. We irrigate during low tide in order to get the maximum impact possible. We still don't get an impact. In fact, salinity of the pore water hardly changes, in spite of the fact that we're adding a couple of inches of rain per week.

Richardson: A few years ago, Al Wentz, in his dissertation on the phosphorus content in the Houghton Lake study, compared some plots where we had added simulated sewage effluent to some where we added just plain water in the same amount for the control. We lost several species of early aster on the nutrient plots, but not on the control plots.

Bedford: I wasn't implying that the only changes observed were due to water. What I was saying was that we don't have enough experimental evidence to suggest what proportion of the change is due to nutrients and what is due to water. In most cases you're going to get both of them at once. So there are some things you can infer from the water-level changes. For the nutrients, I tried to suggest some basis from which we might infer what's happening from the magnitude of change. If you have a system that's already nutrient-saturated, not nutrient-limited, you're not likely to get the magnitude of change that you would in a nutrient-poor system.

Kaczynski: I'd like to make a practical observation from the point of view of someone designing these systems. If you're getting serious species changes, it sounds to me as if you have not done your homework in terms of looking at the application. If you had undersized the wetland relative to the amount of effluent you're putting in (in other words, you're overapplying the effluent), you could use agricultural application techniques to determine the acreage of application relative to the water portion of the effluent. I'd suggest you go back and look at that.

Bedford: We need a basis for comparison with the experimental work that's been done on natural systems. For example, most of the existing work has been done in the South, but we don't have a basis for comparing response to the different loading rates in the North. Changes are undoubtedly related to loading rates, but we don't have enough data. I believe you're right. We might obtain better initial estimates by using irrigation application techniques.

Ewel: Victor [Kaczynski], you're making an assumption that a substantial species change is serious. But I would challenge you that in some cases substantial species changes are not necessarily serious. You can get the same change in production with a major species change in one kind of system and no species change in another. Who's to say that one is serious and one is not? So, I think we have to find a better measure than species composition before we can ask people to apply sophisticated design criteria.

Kaczynski: I would agree, if you're interested in wetland function.

Ewel: It would be nice if we all had gas analyzers or something to clamp over these species and measure productivity. But it's not that easy.