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THE EFFECTS OF GRAZERS AND LIGHT PENETRATION ON THE SURVIVAL OF TRANSPLANTS OF *VALLISNERIA AMERICANA* MICHX IN THE TIDAL POTOMAC RIVER, MARYLAND

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ABSTRACT

Carter, V. and Rybicki, N.B., 1985. Effects of grazers and light penetration on the survival of transplants of *Vallisneria americana* Michx in the tidal Potomac River, Maryland. *Aquat. Bot.*, 23: 197—213.

Poor light penetration and grazing are among the factors potentially responsible for the lack of submersed aquatic macrophytes in the tidal Potomac River. Between 1980 and 1983, plugs, sprigs and tubers of *Vallisneria americana* Michx were transplanted from the oligohaline Potomac Estuary to six sites in the freshwater tidal Potomac River. Transplants made in 1980 and 1981 were generally successful only when protected by full exclosures which prevented grazing. Grazing resulted in the removal of whole plants or clipping off of plant leaves in unprotected plots. Plants protected in the first year were permanently established, despite the occurrence of grazing in subsequent years, at Elodea Cove and Rosier Bluff, where light penetration was high (average 1% light level was 1.6—1.7 m). Plants were not permanently established at Goose Island, where light penetration was lower (average 1% light level was 1.4 m) and grazing occurred, or Neabsco Bay where light penetration was very low (average 1% light level was 1.0 m) and grazing may not have occurred. In 1983, Secchi depth transparencies in the upper tidal river were improved significantly compared to 1978—1981. Both protected and unprotected transplants thrived in 1983.

INTRODUCTION

Between 1978 and 1981, the U.S. Geological Survey conducted an annual survey of submersed aquatic vegetation in the tidal Potomac River and Estuary. The survey, combined with a review of historic trends, showed a major decline in submersed aquatic macrophytes since the early 1900s (Haramis and Carter, 1983). The freshwater tidal river was essentially devoid of plants and only very sparse populations remained in the mesohaline estuary. Plant populations were largely confined to the oligohaline estuary (transition zone), where the saltwater—freshwater interface fluctuates daily in response to tide and seasonally in response to changing river discharge. Following the survey, we postulated that light penetration and grazing were among the factors responsible for the lack of plants in the tidal river (Carter et al., 1983; Haramis and Carter, 1983).

Between 1980 and 1983, we undertook a series of transplant experiments with *Vallisneria americana* Michx to determine whether submersed macrophytes could survive under existing conditions and whether grazing or differences in light penetration would influence survival. We also examined differences between natural and transplanted beds and evaluated two different transplanting methods.

Vallisneria americana was chosen for the transplants because records show that extensive beds of this species covered the shallow flats below Washington, D.C., before the late 1930s (Cumming et al., 1916; Secretary of the Treasury, 1933). In addition, studies by Titus and Adams (1979) of the coexistence and comparative light relationships of *Myriophyllum spicatum* L. and *Vallisneria americana* in Wisconsin lakes showed that *Vallisneria* has an excellent physiological adaptability to low light regimes, such as exist in the tidal river. During the winter, *Vallisneria* beds are composed solely of tubers. All other plant materials, including rhizomes, have decayed or been transported from the site. Winter cores taken in 1981 and 1984 showed that the tubers are distributed within the top 30 cm of sediment. Plants grow from tubers or seeds in late April or May. Leaf elongation and replacement continues throughout the summer, with flowering occurring from early July through early September. Plants die back in November.

Seagrasses (submersed aquatic species adapted to marine environments) have been successfully transplanted to natural sites using a variety of planting and anchoring techniques (van Breedveld, 1975; McMillan and Phillips, 1979; Goforth and Peeling, 1980; Phillips, 1982; Zieman, 1982; R.J. Orth, Virginia Institute of Marine Science, personal communication, 1983). However, few records exist for successful transplants of freshwater or oligohaline species to natural sites. Jupp and Spence (1977) made reciprocal transplants of *Potamogeton filiformis* Pers. between a sheltered and an exposed site in Loch Leven, Scotland. Bourne (1932) planted at least 10 000 entire plants each, plus tubers and seeds of *Potamogeton pectinatus* L., *P. perfoliatus* L., and *Vallisneria americana* in Back Bay, Virginia. Planting was done by hand in shallow water and plants were sunk in small baskets, balls of clay, or wrapped in strips of a metallic alloy in deeper water. No plants survived in open water or ponds connected to Back Bay by open ditches, but luxuriant growth of all plants was obtained in most ponds protected by bulkheads.

STUDY SITE AND METHODS

The Potomac River is the second largest tributary entering the Chesapeake Bay in terms of drainage area and discharge, contributing about 18% of the total freshwater inflow (Pritchard, 1952). The tidal river between Chain Bridge, Maryland and Quantico, Virginia (Fig. 1), contains fresh water except in extremely dry years. Extensive saltwater—freshwater mixing occurs in the oligohaline estuary (transition zone) between Quantico and the Route 301 Bridge. The tidal river has an average depth of 6 m; a deep

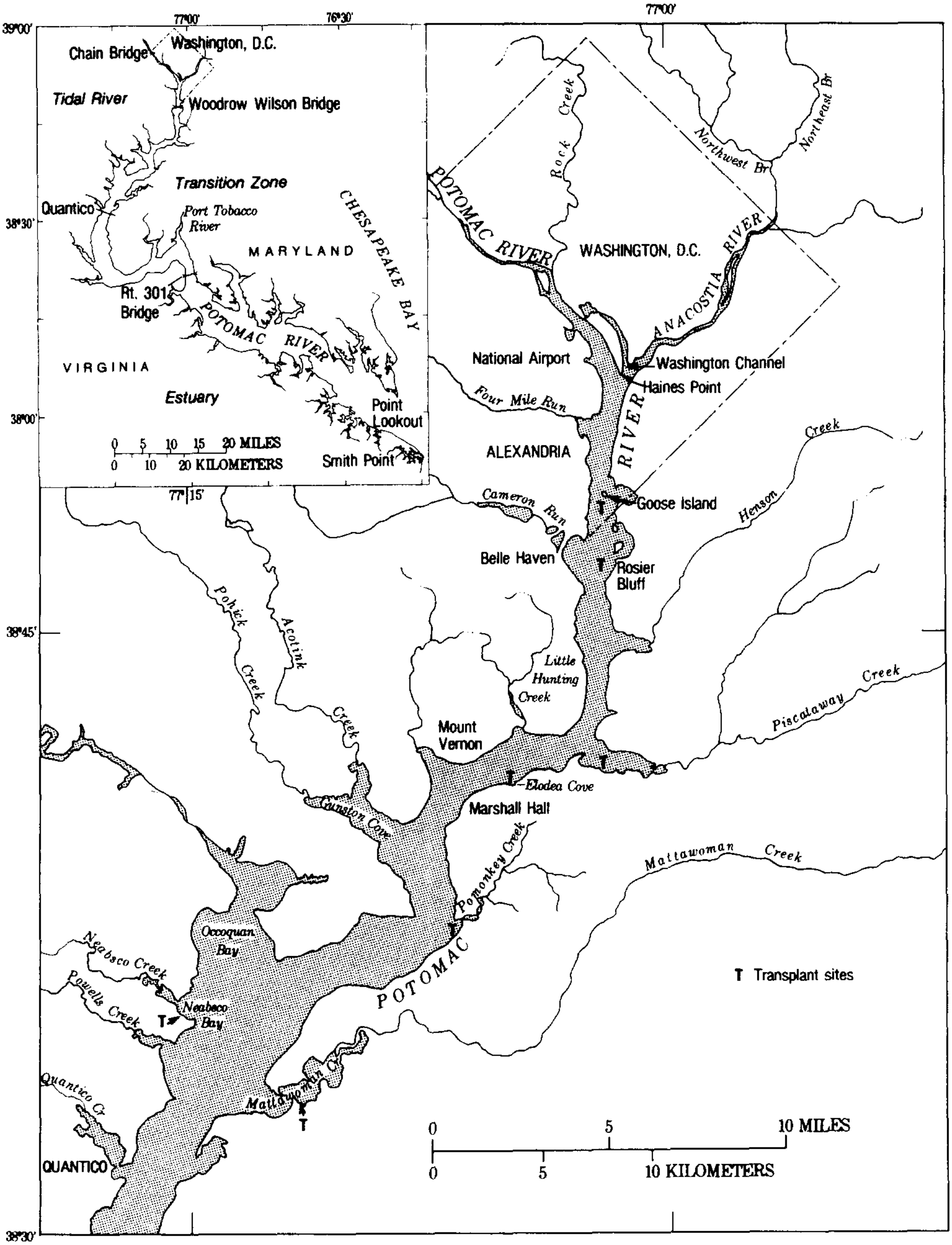

Fig. 1. Tidal Potomac River showing location of transplant sites.

channel is flanked on one or both sides by wide shallow flats or shoals with water depths suitable for the growth of submersed aquatic macrophytes. The tidal range in this reach is about 1 m.

Transplant experiments were conducted in the tidal river in 1980, 1981 and 1983; experimental design in each year was based on previous results. During 1980, transplants were made at Piscataway Creek, Goose Island, Rosier Bluff, Mattawoman Creek, Elodea Cove and Pomonkey Creek (Fig. 1). In 1981, four transplant sites were selected for more intensive study: Goose Island, Rosier Bluff, Elodea Cove and Neabsco Bay. In 1983, only the Rosier Bluff site was planted to test the hypothesis that larger bed size might enhance survival and result in a more permanent plant population.

Sprigs, tubers and plugs of *Vallisneria americana* (Fig. 2) were removed from Port Tobacco River beds (Fig. 1, inset) using a post-hole digger. Washed sprigs (individual plants with roots) and tubers were placed in plastic bags with river water and transported in coolers; plugs (cores of sediment containing tubers and rooted plants) were placed intact in coolers for transport. Fifty to sixty sprigs were planted by hand at water depths between 0.5 and 1 m to form 1-m^2 plots at each site. Plugs estimated to contain 3—6 plants each were planted (1981 only) in shallow trenches. In 1983, both sprigs and tubers were planted in two adjacent 1 × 8-m plots with a 0.5-m unvegetated center strip.

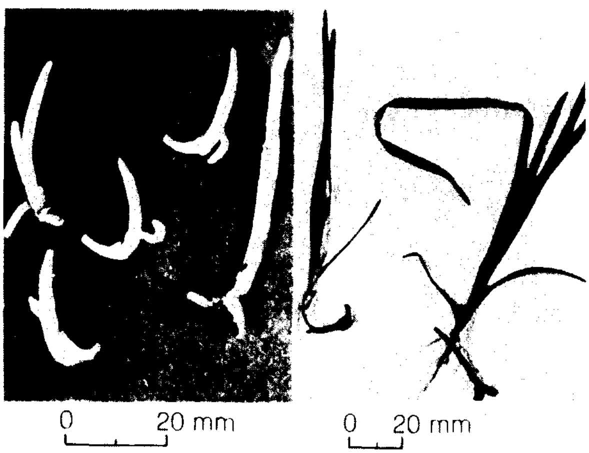

Fig. 2. Tubers (left) and sprigs (right) of *Vallisneria*.

Hardware cloth and wood exclosures (1 m^2) were placed around selected transplant plots to assess the effect of grazers on plant survival. Three types of exclosures were used in 1981 (Fig. 3): full exclosures with a hardware cloth top (6 mm mesh which permitted light to reach the plot) and a door for access; topless exclosures to see if the grazers would swim or climb over the top; three-sided exclosures to see if the grazing was mostly by bottom dwellers. Only the full exclosures were used during 1980 and

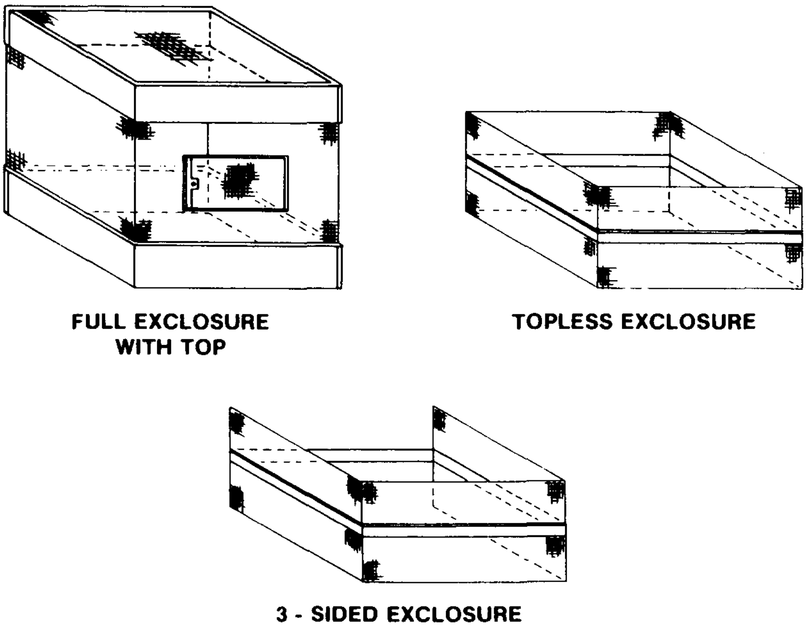

Fig. 3. Design of exclosures for experimental transplants in the tidal Potomac River.

1983. In 1983, eight exclosures were placed side-by-side to form a 1 × 8-m protected plot at Rosier Bluff. Exclosures were removed at the end of the first growing season, leaving plots unprotected in following years. Transplant sites were visited at intervals from 1980 through 1983. Regrowth in the following year or after clipping, condition and density of plants and length of leaves were recorded.

Turtle traps (modified fish traps with a funnel opening) were set out over two transplant plots at Rosier Bluff in 1983. These traps, requiring daily inspection, were only in use for 2—3 weeks during the summer.

Water transparency was measured with a Secchi disk. Secchi-disk data were analyzed using two-factorial analysis of variance (ANOVA) and Duncan's multiple-range test (Duncan, 1951; Kramer, 1956) as well as the F test for significance of differences between two variances and an approximate t-test for comparison of means when sample variances are unequal (Sokal and Rohlf, 1969; pp. 374—375). During 1981, photosynthetically active radiation (PAR) of 400—700 nm wavelengths was measured with a LICOR 185B Quantum Radiometer—photometer equipped with an underwater sensor. Light energy in $\mu E\ m^{-2}\ s^{-1}$ was measured above the water surface, just below the surface and at 20-cm increments below the surface.

In the summers of 1982 and 1984, cores were taken in the transplanted plots at Rosier Bluff, a natural *Vallisneria* bed in Washington Channel (Fig. 1) and two natural beds of *Vallisneria* in the oligohaline estuary, to compare plant density and rhizome development. Additionally, observations were made on distribution of plants and tubers in the donor bed in the Port Tobacco River during collection. Sediment type was determined for all sites.

RESULTS

Site observations made during all kinds of weather showed that the exclosures did not reduce turbulence, wave action or turbidity. Disappearance of unprotected plants was attributed to grazers at sites where protected plants survived and to unfavorable growing conditions where protected plants failed to survive. Either entire plants disappeared soon after planting or clipping of plants occurred between the middle of July and the middle of October.

1980 transplants and subsequent regrowth in 1981 and 1982

Initial transplants made in May at Rosier Bluff, Piscataway Creek, Pomonkey Creek and Mattawoman Creek were all unprotected and disappeared within 1 month. Transplants made in July and protected by exclosures at Rosier Bluff, Elodea Cove and Goose Island grew well and flowered; those planted at the same time in unprotected plots survived only in Elodea Cove (Table I). There was dense new growth in the previously protected transplant plots at Rosier Bluff and Elodea Cove in 1981. By October 1981, the plants at Rosier Bluff had been clipped off to 2 cm high; the plants in Elodea Cove had not been grazed. At Rosier Bluff, in June 1982, the 1980 full-exclosure plot had dense growth and plants 30 cm in length. In mid-July, these plants were clipped off to about 2 cm in length; leaf elongation and development of new leaves continued and clipping occurred again in August and September. At Elodea Cove, in 1982, the 1980 full-exclosure plot had plants 15 cm long in July, but the plot could not be located in August. We have no records of clipping at Elodea Cove, but our visits to this site were poorly timed to see grazed plots, which are obscured by turbid water at other than low tide.

1981 transplants and subsequent regrowth in 1982

In 1981, different types of exclosures were tested and the success of transplants made with plugs and sprigs was compared (Tables II—V). Transplant success was excellent (75—100% of plants survived and flowered) to good (50—75% of plants survived and flowered) inside full exclosures except at Neabsco Bay (Table II) where only a few plants from plugs in the full exclosure survived into the autumn. Success was good to fair (<50% survival) in plots with partial exclosures and no plants remained in unprotected plots at Goose Island and Neabsco Bay. At Goose Island (Table III), a few plants were clipped off but survived in the topless exclosure,

TABLE I

Survival of 1980 transplants in the tidal Potomac River. Plants unprotected after first growing season. Transplant plot is 1 m^2

Site/year	Date	Full exclosure with sprigs	No exclosure with sprigs
Rosier Bluff	16 July	62 planted	70 planted
1980	21 July	n.d.	C
	14 Oct.	E — thick growth	N
1981	21 July	R — 70 cm tall	N
	9 Oct.	C	N
1982	30 June	R — 30 cm tall	N
	21 July	C — 2 cm tall	N
	17 Aug.	C — 5 cm tall, 60-cm^2 bed	N
	17 Sept.	R — 20 cm tall, 1.5-m^2 bed	N
	30 Sept.	C — 2 cm tall, 1.5-m^2 bed	N
1983	7 July	R — 2.6-m^2 bed	N
	9 Aug.	C	N
	21 Sept.	C — 3—12 cm tall	N
Rosier Bluff 1983	28 Oct.	C — 6 cm tall, joined with 1981 bed; 5 × 6 m	N
Goose Island	15 July	50 planted	50 planted
1980	21 July	F — 5 plants	C
	14 Oct.	E — dense growth	N
1981	8 July	N	N
Elodea Cove	28 July	60 planted	74 planted
1980	20 Aug.	E — 45 plants	E — 56 plants
	14 Oct.	E	E
1981	6 Aug.	R — 40 plants 50 cm tall, flowering	N
	9 Oct.	R	R
1982	20 July	R — 90-cm^2 bed, 15 cm tall	N
	17 Aug.	Not found	N
1983	4 Aug.	R	N

First year: E, excellent, 75—100% survival; G, good, 50—75% survival; F, fair, <50% survival; C, clipped off by grazers; N, no plants. Subsequent years: R, regrowth; C, clipped; N, no plants.

TABLE II

Survival of 1981 transplants at Neabsco Bay in the tidal Potomac River. Plants unprotected after first growing season. Transplant plot is 1 m^2

Date	Full exclosures with plugs	Full exclosures with sprigs	Topless exclosures with sprigs	Three-sided exclosures with sprigs	No exclosures with plugs	No exclosures with sprigs
1981						
31 May	50—100 plants and tubers planted				50—100 plants and tubers planted	
16 June	G	50 planted	50 planted	50 planted	G	50 planted
14 July	G — 60 cm tall, many epiphytes	F — 20 plants remain, 20 cm tall	G — 60 cm tall, many epiphytes	N	F — plants lying down, look unhealthy 30 cm tall	N
25 Aug.	F — plants lying down, look unhealthy 20 cm tall	F — plants lying down, look unhealthy 30 cm tall	F — plants lying down, look unhealthy 20-50 cm tall	N	N	N
21 Oct.	F — look unhealthy	N	N	N	N	N
1982						
17 Aug.	R — 2 plants, 15 cm tall	N	N	N	N	N
17 Sept.	N	N	N	N	N	N
1983						
2 Aug.	N	N	N	N	N	N

First year: E, excellent, 75—100% survival; G, good, 50—75% survival; F, fair, <50% survival; N, no plants; C, clipped off by grazers. Subsequent years: R, regrowth; C, clipped; N, no plants.

TABLE III

Survival of 1981 transplants at Goose Island in the tidal Potomac River. Plants unprotected after first growing season. Transplant plot is 1 m^2

Date	Full exclosures with plugs	Full exclosures with sprigs	Topless exclosures with sprigs	Three-sided exclosures with sprigs	No exclosures with plugs	No exclosures with sprigs
1981						
12 May	50 — 100 plants and tubers planted				50 — 100 plants and tubers planted	
16 June	E	50 planted	50 planted	50 planted	G	50 planted
21 July	E — 100 cm tall	E — 100 cm tall	F — 20 cm tall	F — 20 cm tall	N	N
9 Aug.	E — 40 cm tall, flowering	E — 40 cm tall	C — 1 cm tall	C — 1 cm tall	N	N
9 Oct.	G — 25 plants remain, 30 cm tall	G — 38 plants remain, 30 cm tall	F — 5—10 cm tall	N	N	N
1982						
20 July	N	N	N	N	N	N
1983[1]						
3 Oct.	N	N	N	N	N	N

First year: E, excellent, 75—100% survival; G, good, 50—75% survival; F, fair, <50% survival; N, no plants; C, clipped off by grazers. Subsequent years: R, regrowth; C, clipped; N, no plants.
[1]Aerial survey.

TABLE IV

Survival of 1981 transplants at Elodea Cove in the tidal Potomac River. Plants unprotected after first growing season. Transplant plot is 1 m^2

Date	Full exclosures with plugs	Full exclosures with sprigs	Topless exclosures with sprigs	Three-sided exclosures with sprigs	No exclosures with plugs	No exclosures with sprigs
1981						
1 May	50—100 plants and tubers planted				50—100 plants and tubers planted	
1 June	E	50 planted	50 planted	50 planted	G	50 planted
21 July	E — 100 cm tall	E — 90 cm tall	G — 20 cm tall	F — 5 cm tall	F — 10 cm tall	N
6 Aug.	E — plants flowering	E — plants flowering	G — 50 cm tall, plants flowering	n.d.	F — 50 cm tall	F — 30 cm tall
9 Oct.	E — door ajar	E — door ajar	E — plants 16 cm tall	E — plants 16 cm tall	F	N
1982 all site visits	N	N	N	N	N	N
1983						
4 Aug.	R	R	R	R	R	R

First year: E, excellent, 75—100% survival; G, good, 50—75% survival; F, fair, <50% survival; C, clipped off by grazers; N, no plants. Subsequent years: R, regrowth; C, clipped; N, no plants.

TABLE V

Survival of 1981 transplants at Rosier Bluff in the tidal Potomac River. Plants unprotected after first season. Transplant plot is 1 m^2

Date	Full exclosures with plugs	Full exclosures with sprigs	Topless exclosures with sprigs	Three-sided exclosures with sprigs	No exclosures with plugs	No exclosures with sprigs
1981						
11 May	50—100 plants and tubers planted				50—100 plants and tubers planted	
16 June	E	50 planted	50 planted	50 planted	G	50 planted
21 July	E — 60 cm tall	E — 45 cm tall	E — 55 cm tall	F — 32 cm tall	F — 25 cm tall	F — 35 cm tall
5 Aug.	E	E	G	G	G	G
9 Oct.	C — cage door open	E	C	C	C	C
1982						
17 Aug.	N	C — 5 cm tall, 30-cm^2 bed	N	N	N	N
17 Sept.	N	R — 20 cm tall, 30-cm^2 bed	N	N	N	N
30 Sept.	N	C — 2 cm tall, 90-cm^2 bed	N	N	N	N
1983						
7 July	N	R — 1.1 × 1.9-m bed	N	N	N	N
9 Aug.	N	C	N	N	N	N
22 Sept.	N	R — 40 cm tall	N	N	N	N
28 Oct.	N	C — 6 cm tall, coalesced w/1981 bed; 5 × 6 m	N	N	N	N

First year: E, excellent, 75—100% survival; G, good, 50—75% survival; F, fair, <50% survival; N, no plants; C, clipped off by grazers. Subsequent years: R, regrowth; N, no plants; C, clipped.

but no plants survived in the three-sided exclosure. At Elodea Cove (Table IV), there was good survival in both the three-sided and topless exclosures and fair survival in the unprotected plot planted with plugs. At Rosier Bluff (Table V), partially protected and unprotected plants did well until autumn, when they were clipped off at the base. As a basis for comparison, the large (500 m^2) natural bed of *Vallisneria* at Washington Channel increased in area and plants flowered in 1981. We found several small (1 m^2) natural beds of *Vallisneria* along the Virginia shore of the tidal river.

First year survival in plots planted with plugs was approximately the same as that in plots planted with sprigs; however, plants did not regrow the following year in most of the plots planted with plugs. It is more difficult to collect, transport and plant the plugs. Sprigs can be planted rapidly, even in fairly deep water and once planted, they are not easily pulled up. Tubers found while washing sprigs free of sediment can easily be planted along with the sprigs.

All of the 1981 transplant sites were revisited several times during 1982 (Tables II—V). There was no plant growth at Goose Island. At Rosier Bluff, in mid-August, plants in the 1981 full-exclosure plot had been clipped off to about 5 cm in length. Leaf elongation and development of new leaves continued and clipping occurred again in September. At Elodea Cove, the 1981 transplant was not located. Two sprigs of *Vallisneria*, 15 cm long, were found at Neabsco Bay in August. By the end of September 1982, the only remaining plants were at Rosier Bluff. None of the plants in the transplanted plots at Rosier Bluff flowered during 1982.

We compared summer cores (1981) taken from the transplant plot at Rosier Bluff (sand), the natural bed at Washington Channel (sand—gravel—rock sample extremely difficult to take and probably not an adequate representation of the site) and 2 vegetated sites in the Port Tobacco River (sand and silty clay). The transplant plot had denser growth (15 plants per core) than the other sites (2—6 plants per core) and a thick, dense mat of rhizomes. Plants were 100—160 cm long at Washington Channel and about 60 cm in length at the other three sites. The natural bed of *Vallisneria* in the Washington Channel was visited twice in 1982. This bed had expanded in size and the plants were 1.3—1.6 m long and flowering in mid-July. The small beds found on the Virginia side in 1981 could not be found.

1983 transplants

In 1983, twelve species of submersed aquatic macrophytes were found in the upper reach of the tidal river above Mount Vernon and in Mattawoman Creek (Carter et al., 1985a). All transplants made at Rosier Bluff in 1983 had excellent survival and flowered. The large plots expanded from 2.5 × 8 m to 6 × 11 m. Plants regrew at the site of the 1980 and 1981 fully-exclosed plots and, by autumn, finally coalesced into a 5 × 6-m bed. All unprotected plots at Rosier Bluff were grazed (clipped) repeatedly beginning in August. Plant growth was luxuriant inside turtle traps at Rosier Bluff, however, only one juvenile red-bellied turtle (*Pseudemys rubiventris* Le Contre) and a few fish fry were caught in the traps. In Elodea Cove, a small number of plants were found growing in the 1980 and 1981 transplant plots; small natural beds (1 m^2) were also found at Elodea Cove.

Light penetration

Duncan's (1955) multiple-range test showed that there was no significant Secchi depth transparency difference between the tidal river and the oligohaline estuary zone in 1978—1981 (95% confidence interval) (Carter et al., 1985b). The 1981 average PAR measurements for several sites (Paschal et al., 1982; Coupe and Webb, 1984) are summarized in Fig. 4. The depth of deepest vegetation and the depth of greatest vegetative biomass at three naturally-vegetated sites are shown on the graph. During the spring, when the plants are actively growing toward the surface, the 10% light level varied between 0.5 and 1.05 m and the 1% light depth varied between 1.0 and 2.05 m. One percent light depths averaged between 1.4 and 1.6 m during the summer. Plants protected in the first year were permanently established, despite the occurrence of grazing in subsequent years at Elodea Cove and Rosier Bluff where light penetration was high (average 1% light level was 1.6—1.7 m). Plants were not permanently established at Goose Island where light penetration was lower (average 1% light level was 1.4 m) and grazing occurred, or Neabsco Bay where light penetration was very

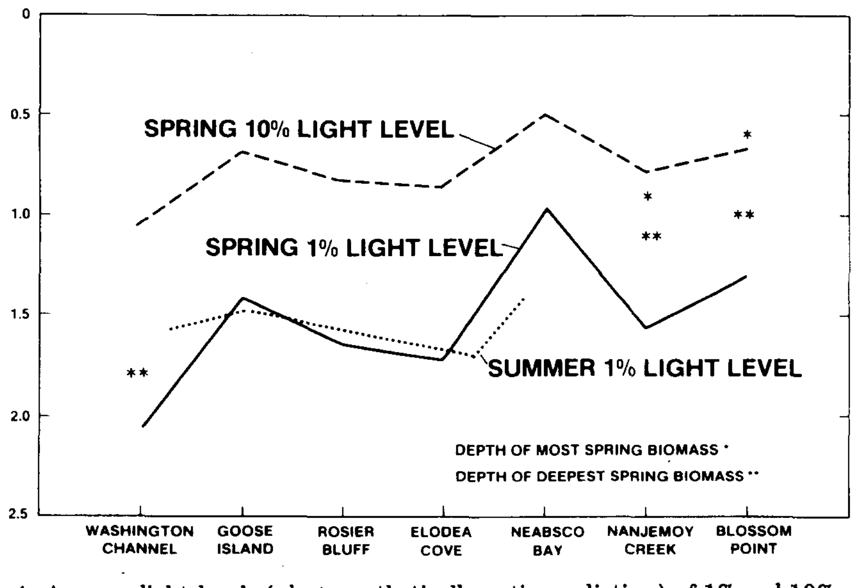

Fig. 4. Average light levels (photosynthetically active radiation) of 1% and 10% at selected sites in the tidal Potomac River and transition zone, 1981. Blossom Point and Nanjemoy Creek are transition zone sites.

low (average 1% light level was 1.0 m) and grazing may not have occurred.

Secchi depth data for 1978—1981 (Paschal et al., 1982) were re-examined and compared to those from 1983 (Carter et al., 1985a). We subdivided the tidal river into two reaches, Washington Channel to Marshall Hall (upper tidal river) where the resurgence of plants occurred and below Marshall Hall to Quantico (lower tidal river) where very few plants were found. The data showed:

(1) Light penetration was significantly greater in the upper tidal river than in the lower tidal river in 1978—1981 ($P < 0.01$) (Table VI).

(2) Light penetration in the upper tidal river was significantly better than that in the oligohaline estuary ($P < 0.01$), but light penetration was not significantly different in the lower tidal river and oligohaline estuary in 1978—1981.

(3) In July and August of 1983, light penetration in the upper tidal river was significantly greater than that in the lower tidal river ($P < 0.01$).

(4) Light penetration in 1983 in the upper and lower tidal river was significantly greater than that in the upper and lower tidal river in July—October 1978—1981 ($P < 0.01$).

In all cases, the lower tidal river was the most turbid.

TABLE VI

Secchi depth in the upper and lower tidal river, July—October 1978—1981 and July—October 1983

Location/date	Depth (cm)		
	Mean	SE	*N*
Upper tidal river			
July—Oct. 1978—1981	51.8	3.28	38
July—Oct. 1983	85.5	4.69	48
July—Aug. 1983	87.3	5.20	39
Lower tidal river			
July—Oct. 1978—1981	38.8	1.29	72
July—Oct. 1983	50.8	4.96	13
July—Aug. 1983	50.8	4.96	13

DISCUSSION

Grazing can affect the establishment, permanence, vigor and structure of *Vallisneria* beds in our area. Other studies have documented changes in bed structure and reduction in end-of-season biomass caused by grazing (Greenway, 1974; Jupp and Spence, 1977; Bjorndal, 1980; Zieman, 1982). The most likely grazers in the Potomac River are waterfowl, muskrat (*On-*

datra zibethecus Mirriam) (Chapman and Feldhaver, 1982) and the red-bellied turtle. Although the common carp (*Cyprinus carpio* L.) uproots plants and increases local turbidity searching for food in shallow soft sediments, it is not generally considered an efficient grazer (King and Hunt, 1967). There are no records of the Asian grass carp (*Ctenopharyngodon idella* Valenciennes), an avid herbivore, in the tidal river. One juvenile red-bellied turtle was caught in our traps and red-head ducks (*Aythya americana* Exton) were observed grazing *Vallisneria* at the site in 1983.

Full exclosures exclude all grazers and at sites where grazing occurs only plots protected in the first year returned. Because there was little difference in plant survival in topless and three-sided exclosures, grazers obviously are not restricted to the lower part of the water column. We suspect that all or any of the three potential grazers — turtles, waterfowl and muskrats — could have eaten or clipped the transplants at sites where survival was good in exclosures; however, more sophisticated traps and periods of intensive observation would be needed to decide which one.

In addition to protection from grazers, light penetration was an important factor in transplant success. Decreases in light penetration, due to siltation and turbidity, have been cited as the cause of the submersed aquatic vegetation decline in the tidal Potomac River (Martin and Uhler, 1939; p. 120; Slavik and Uhler, 1951). PAR measurements in 1981 showed that light penetration was less at Neabsco Bay and Goose Island (transplant sites where no plants survived) than at Rosier Bluff and Elodea Cove. The lower tidal river was consistently more turbid than the upper tidal river and this may account for the failure of transplants at Neabsco Bay. However, the oligohaline estuary was well vegetated, in spite of turbidity similar to that in the lower tidal river, so other factors (e.g., differences in the spectral distribution of light or nutrient availability) must also play a role in plant success. It is interesting to note that water clarity in the upper tidal river improved dramatically in 1983, at the same time that the total suspended solid load from the Blue Plains Sewage Treatment Plant was considerably reduced (Table VII) (W. Bailey, Blue Plains Sewage Treatment Plant, written communication, 1984).

Light penetration and grazing may have a synergistic effect on plant survival. When environmental conditions are marginally suitable for the establishment of vegetation because of poor light penetration, a minimum bed size or a critical population density/unit area may be required for successful establishment of plant populations. Plants affect their environment in ways which may increase the long-term survival of the population by reducing turbidity locally and anchoring the sediments. Bed size may be important for achieving sufficient turbidity reduction or sediment stabilization in marginal sites. Additionally, plants tend to baffle wave action and thus provide protection for less well-anchored species such as *Ceratophyllum demersum* L. Well-established *Vallisneria* beds should withstand grazing pressure, but the vitality of small, unprotected beds may be reduced by the high turbidity of the tidal river combined with the grazing of plants during July through October, when flowering and seed and tuber production occurs. *Vallisneria* plants in grazed plots in the tidal river become denser and shorter and develop multiple new leaves; they do not reproduce by flowering. Tuber development may be retarded or tubers may be smaller and less numerous as a result of reduced photosynthetic area. The regrowth after grazing in Elodea Cove and Rosier Bluff was in water < 0.6 m at low tide, so turbidity effects may have been minimized. The natural bed of *Vallisneria* at Washington Channel is large enough to maintain a viable population despite grazing. Grazing may be minimal in this location because there is little available habitat and much disturbance: the shore is bulkheaded and the adjacent area is highly urbanized. In addition, water clarity was best at this site.

TABLE VII

Total suspended solids output from the primary outlet of Blue Plains Sewage Treatment Plant, 1982 and 1983

Month	Monthly mean in mg l^{-1} (number of observations)	
	1982	1983
April	9.8 (30)	1.2 (20)
May	4.16 (31)	1.0 (31)
June	7.09 (30)	1.3 (30)
July	4.82 (31)	1.1 (30)
August	5.18 (31)	1.2 (31)
September	6.7 (30)	1.2 (30)
October	5.24 (31)	1.3 (31)

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