# Mitigation Between Regional Transportation Needs and Preservation of Eelgrass Beds

## <u>Interim Report of Phase I Results</u>

by

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## Introduction

Demand for increased ferry service and expanding regional transportation plans mandate that the Washington State Department of Transportation (WSDOT) consider widening existing dock structures over the waters of Puget Sound. However, concerns about the impacts of dock structures and ferry operations on eelgrass (*Zostera* spp.) habitat structure, function, and support of fisheries resources has prompted natural resource agencies to require that widening of ferry docks or construction of new facilities impose minimal or no impact on the eelgrass resource. To address the critical need for further information, WSDOT instituted an applied research project by the University of Washington's School of Fisheries (UW/SOF)—Wetland Ecosystem Team (WET)—and School of Marine Affairs (UW/SMA), and Battelle Pacific Northwest Laboratories' Marine Sciences Laboratory (PNL/MSL), to develop a quantitative understanding of how docks affect eelgrass habitats and how to minimize (i.e., mitigate) this effect.

### *Background*

Eelgrass (*Zostera marina* L.) is a rooted flowering plant that in Puget Sound grows in sand to mud substrates between mean lower low water (MLLW) and approximately -20 ft (6.1 m) MLLW. It forms densely vegetated “beds” or “meadows” and constitutes one of the most structurally complex of lower littoral and sublittoral estuarine/marine habitats. Eelgrass beds are well known to support important fisheries and wildlife resources, including juvenile salmon, Dungeness crab, Pacific herring, and many types of waterbirds.

Docks over water primarily effect eelgrass through light limitation (“shading”), but associated ferry operations may also disturb the eelgrass habitat directly (e.g., scouring by propeller wash) or indirectly (e.g., resuspension of bottom sediments and subsequent light limitation due to turbidity). Eelgrass requires an underwater light environment sufficient to maintain growth and reproduction, and reduction or alteration of this light environment can result in reduced growth rates and plant loss. The research challenge is to determine the configuration and arrangement of docks that constitute "significant" light reduction and promote other disturbances of eelgrass, and to evaluate alternative designs that would prevent or compensate for the impacts.

### *Objective*

The objective of this joint research program is to develop a causal and quantitative understanding of how docks affect eelgrass habitats and how to mitigate this effect. An indirect objective is to interpret the consequences of eelgrass habitat alterations and mitigation to fish, shellfish and other living resources using eelgrass.

### *Approach and Work Plan*

Six tasks, and associated subtasks, were defined to assess impacts of docks on eelgrass distribution and to recommend mitigation alternatives:

- Task 1—Review existing literature and data on light requirements of eelgrass
- Task 2—Implement a field monitoring program
- Task 3—Evaluate the feasibility of using artificial lighting and selected physical structures to reduce the shading effect of docks.
  - Subtask 3.1—field tests of the use of artificial lighting and physical structures
  - Subtask 3.2—studies of the photosynthesis and growth response of eelgrass to artificial lighting

- ♦ Subtask 3.3—evaluate the effects of various grating types or other physical structures to reduce shading
- Task 4—Identify mitigation alternatives
  - ♦ Subtask 4.1—conduct an inventory of potential eelgrass mitigation sites
  - ♦ Subtask 4.2—complete an inventory of overwater structures
- Task 5—Perform data filing, quality assurance, and initial summary analysis
- Task 6—Manage study and communicate information

This research is being accomplished in two phases: Phase I, conducted between May 1994 and June 1995, included Tasks 1, 2, 3 (in part) and 4 (in part); the on-going Phase II includes the remaining tasks and will be completed in June 1996.

Research was focused on three existing ferry terminals: Clinton, Edmonds, and Port Townsend. Although studies were conducted at all sites, due to immediately pending dock expansion plans and permit applications, our most detailed investigation and analysis during Phase I focused on the Clinton ferry terminal, and most of the examples described herein are from that site.

Evaluating ecological interactions between environmental conditions and biotic responses of a complex habitat such as eelgrass requires a tightly coupled, interdisciplinary research effort. We assembled a diverse team of UW/SOF-WET, UW-SMA, and MSL estuarine/coastal scientists to address these tasks. The team and their relevant expertise was composed of the following:

<u>University of Washington</u>

- ♦ *School of Fisheries*
  - ∗ Charles A. Simenstad, Senior Fishery Biologist; estuarine/coastal marine ecology, food web structure, wetland restoration
  - ∗ Jeffery R. Cordell, Fishery Biologist; estuarine/coastal marine ecology, benthic and epibenthic invertebrate taxonomy and ecology
  - ∗ James Norris, Fishery Consultant; seagrass videography, fisheries
- ♦ *School of Marine Affairs*
  - ∗ Annette M. Olson, Assistant Professor; community ecology, coastal management, conservation biology
  - ∗ Sandy Wyllie-Echeverria, Research Analyst; seagrass autecology, ethnobotany, videography

<u>Battelle Marine Sciences Laboratories</u>

- ∗ Ronald M. Thom, Senior Research Scientist; estuarine/coastal marine ecology, marine plant/algal physiology, wetland restoration
- ∗ David Shreffler, Fishery Biologist; fisheries, wetland restoration

The primary investigators responsible for the different subtasks are indicated under the following descriptions of the component research tasks.

In Phase I, we adopted elements of both "depth limits" and a "carbon balance" approaches in designing field and laboratory studies based on the results of our literature review. Our principal tasks during this phase included:

1. In our field sampling, we correlated *in situ* light transects with sampling of eelgrass distribution, coverage, density, biomass and epiphyte biomass.
2. To link light availability to growth and survival of Puget Sound eelgrass, we conducted a series of mesocosm experiments at the MSL facility.
3. To quantify spatial and temporal variation in the light environment, we deployed continuous recording *in situ* light intensity meters at the Clinton ferry terminal.

4. Although not initially conceived in the Phase I Scope of Work, we also developed a three-dimensional physical model of the Clinton terminal that permits us to track the shadow of the terminal as it crosses eelgrass habitat in different seasons.

## Task-Specific Methods and Results

### *Task 1—Review Existing Literature and Data on Light Requirements of Eelgrass (A. Olson)*

The design, construction, and operation of dock facilities (as well as other shoreline structures) potentially affect the extent and quality of eelgrass habitats by direct shading, physical disturbance, and sedimentation. During Phase I, we reviewed the scientific literature on the light requirements of eelgrass and evaluated alternative models for managing the light environment of seagrasses. Our specific objective was to evaluate all relevant information on *Z. marina*; however, we also utilized information on other *Zostera* spp. and other seagrasses if applicable.

#### *Methods*

Using electronic bibliographic databases, we searched for literature on light requirements of eelgrass, concentrating on U.S. studies, but including Europe and Asia (no references on Asian populations were located). We also surveyed existing policy documents on management of light regimes or overwater structures.

#### *Results*

We found that the bulk of research has focused on physiological-, individual-, and population-level responses to changes in light regime; the effect of light on the structure, persistence and functioning of eelgrass beds has rarely been directly studied. Furthermore, we found few published studies on light requirements of eelgrass in the Pacific Northwest; most studies we surveyed have been conducted in the Atlantic and in California, where physical conditions differ substantially from those in Puget Sound.

<u>Management focus</u>. In the United States, regulation of direct disturbance to seagrasses (as well as planning for conservation of seagrass habitats) occurs under the Clean Water Act, Coastal Zone Management Act, and other federal, state and local mandates. Management of direct disturbance may also include issuance of guidelines for dock design and restrictions on moorage and vessel operation in seagrass habitats. In Washington State, management standards for seagrasses focus exclusively on direct physical alteration and/or destruction of seagrass habitats.

Management of the light environment for submerged aquatic vegetation (SAV, including seagrasses and freshwater macrophytes) has been proposed or implemented in several Atlantic Coast jurisdictions. In Washington State, however, mechanisms for management of the light environment do not exist, and the light requirements of seagrasses are not reflected in water quality or other management standards. Furthermore, specific standards that regulate shading impacts of docks and other shoreline structures on seagrasses appear to be lacking in the U.S., and field studies that document shading impacts are rare.

<u>Light requirements and light environment</u>. Light requirements of seagrasses are not simple to define, because the light received by a leaf does not translate directly into a "healthy," persistent seagrass bed. Instead, a complex set of adaptations determines a plant's carbon balance—a measure of how the plant uses light and allocates photosynthetic products—and thus its potential for survival, growth, and reproduction. Describing the light environment is also complex. Plants are able to use only certain spectra of the available light, and the quantity and quality of the light environment varies in time and space.

We found two main approaches to defining the light requirements and describing the light environment of seagrasses in a management context. One approach (the "seagrass depth limits" model) makes the assumption that, if seagrasses are present, the available light must be sufficient. Seagrasses themselves are viewed as "integrators" of the light environment: Seagrass depth limits are correlated with mean light attenuation in the water column to infer the minimum light needed to support seagrass populations. Those taking the "depth limits" approach also assume that plant distribution reflects average light conditions. The average light attenuation in the water column (or the proportion of surface irradiance reaching the leaves) is thus used as an indicator of the quality of the light environment.

An alternative approach attempts to incorporate more biological complexity in a model that predicts plant carbon balance in a given light environment (the "carbon balance" model). This approach assumes that, if available light is sufficient to produce a positive net carbon balance, plants will grow and persist in that light environment. Carbon balance is determined experimentally in laboratory studies of photosynthetic response to light. Those taking the alternative "carbon balance" approach note that variation in the light environment may be more important for plant distributions than average conditions. The daily period of irradiance-saturated photosynthesis ($H_{sat}$) is thus used as an index of the quality of the light environment.

### *Task 2—Implement a Field Monitoring Program (C. Simenstad, R. Thom, J. Cordell, S. Wyllie-Echeverria, A. Olson, J. Norris)*

The field program in Phase I was designed to map the distribution and relative coverage of eelgrass and to determine the probable limiting factors on eelgrass at the ferry terminals. We proposed to infer limiting factors from systematic sampling of irradiance and selected eelgrass habitat parameters, including growth rate, epiphyte loads, patch size and dynamics, and shoot density under and immediately adjacent to existing docks and in adjacent control eelgrass beds. *In situ* monitoring of the light environment was conducted to correlate eelgrass distribution with light availability (following the "depth limits" model identified in the literature survey) and to describe the impact of the dock structure (and possibly of the propeller wash turbidity plume) on light availability.

#### *Methods*

In the area surrounding each ferry terminal, eelgrass was mapped using underwater videography in association with a Global Positioning System (GPS). An underwater video camera was towed behind a boat along 14 transects at Edmonds, 45 transects at Port Townsend and 26 transects at Clinton. The transects crisscrossed the entire meadow within at least 200m on either side of each terminal. The video images were analyzed to characterize cover classes of eelgrass and these data were transferred to a Geographic Information System (GIS) to produce plots of the cover of eelgrass near the terminals. Eelgrass distribution, cover and density sampling was also extended under the dock using conventional diver and walking transects.

Eelgrass densities, percent cover, and biomass and epiphyte loads were quantified along three approximately 150-m long transects at each terminal in summer 1994. The transects, which ran parallel to shore and included a mid-section under the terminal, were placed in the inner, mid and outer portions of the eelgrass meadow at the terminals. Biological samples were collected from within 0.25 $m^2$ quadrats at five intervals along these transects. In addition, irradiance was measured at each of these points. Divers also noted disturbances of the eelgrass associated with the docks (e.g., sedimentation, scouring, biological disturbance).

Light incidence measurements were made over two diel (day-night) cycles at the three ferry terminals during the period of eelgrass field sampling in summer 1994. In addition, the Clinton terminal was selected for a more detailed, higher (temporal) resolution sampling of the local light environment. On 8 June 1995, three Inset HOBO® continuous-recording *in situ* light intensity meters were deployed at three locations: (1) on the roof of the equipment shed (in air/no shade), (2) at approximately -5.5 m (MLLW) and approximately 30 m south of the main deck of the terminal (submerged/no shade), and (3) at approximately -5.5 m (MLLW) underneath the north edge of the dock (submerged/in shade). The submerged stations were located near the lower depth limit of eelgrass at the site, thus recording the minimum light levels reaching the eelgrass beds. A HOBO® continuous recording *in situ* temperature meter was also installed at the submerged/no shade station.

An exploratory study was also conducted to evaluate the use of computer-assisted drafting (CAD) software to describe or predict the distribution of shade cast by an over-water structure such as the ferry docks. A three-dimensional (3-D) model of the Clinton terminal, and of the bathymetry in its vicinity, was constructed using Form Z® CAD software, with data provided by WSDOT and the UW team. Form Z has a shadow-casting function which produces an image of the shadow cast by a 3-D model at any specified date, time, and latitude/longitude position. Shadows of the Clinton model were rendered at half-hour intervals (from 10 AM to 2 PM) for two dates (summer and winter solstices). Shadow images were saved and exported to a desktop GIS system (Map-II®), where images were consolidated into shade-density classes representing the percent of time a given location on the bottom lay in the shade of the dock. Images of the dock and of the eelgrass bed were then superimposed with the shade-density classes to produce a composite image.

***Results***

As has been documented for certain large dock and overwater structures in Puget Sound and elsewhere, there is a common proximal effect of the docks on eelgrass distribution and coverage. This is illustrated by the general "halo" effect of eelgrass absent around the dock at Clinton (Fig. 1). Eelgrass distribution and coverage indicates that several factors other than shading are also affecting eelgrass at the terminals. At a distance from the dock, most of the eelgrass distribution can be explained by high and low tidal elevation (depth) limits, although there are some areas near active ferry slips that indicate potential disturbance (e.g., scouring or turbidity plumes) effects and some gaps in otherwise dense eelgrass beds that also indicate localized disturbance effects (e.g., a deposited tire, pipe, or outboard boat propeller scar).

Our initial results may be summarized as follows:

- shoot density ranged from 20 to over 800 $m^{-2}$ within the main distribution of the meadows (illustrated for the Clinton terminal in Fig. 2);
- light (which covaried with depth, tide and water clarity) and proximity to the dock (irrespective of light) were probably the main factors controlling eelgrass distribution at all sites;
- areas where light and depth are adequate for eelgrass growth, but where eelgrass was not found, indicate local disturbances (such as propeller wash and biological reworking of sediments by enhanced populations of seastars and Dungeness crab) may contribute to eelgrass loss; and,
- the docks and adjacent eelgrass meadows were observed to contain a diverse assemblage of fish and invertebrates.

Based on the initial (July 1995) results of the three HOBO® continuous-recording *in situ* light intensity meters, approximately 90% of the solar input (Figure 3a) is attentuated at the water surface and/or in the water column (Figure 3b&c; note $\log_{10}$-based scale). Approximately 95% of this attenuated light is additionally lost due to shading by the dock structure (Figure 3c, also $\log_{10}$-based scale). Solar input (natural log of in air/no shade station) was a reasonably good predictor ($R^2$ = .898) of light intensity (natural log) at the submerged/in sun station (Figure 4a); but a poorer predictor ($R^2$ = .645) of light intensity at the submerged/in shade station (Figure 4b).

Two limitations of these data are: (1) the difficulty of relating light intensity readings to photosynthetically active radiation (PAR, the preferred measure of light required by the plants); and (2) the time scale of the *in situ* HOBO® recording (every 35 min) may not capture the attenuation due to the ferry propeller was plume. Attenuation of light intensity may differ significantly from that of PAR--that is, a relatively "bright" environment may nevertheless be depleted in PAR due to the presence of selective "filters" such as phytoplankton in the water column. Solar input and light attenuation at the sea surface and in the water column vary naturally. Light attenuation due to the dock structure is easily detectable above the background variation. However, data from the HOBO®s will allow us to begin to distinguish the natural and anthropogenic sources of variation in the underwater light environment adjacent to a ferry terminal.

Initial results from the 3-D CAD-based simulation of dock shading are extremely promising. Comparison of differences between mid-summer (Fig. 5a) and mid-winter (Fig. 5b) shading of the eelgrass at the Clinton ferry terminal suggests that shading is not likely the primary limiting factor accounting for low or no eelgrass cover immediately adjacent to the dock. The "halo" effect is either not encompassed by any shading (i.e., south side of dock) or considerable portion of the eelgrass (i.e., on north side) is shaded but shows no major decline in coverage.

Similarly, eelgrass and epiphytes do not illustrate a gradient of decreasing biomass or standing stock with proximity to the dock, as might be predicted if light is limited by shading. The biomass of both eelgrass and attached epiphytes (Fig. 6) show no consistent trends, and the highest values are often adjacent to the dock (see high transect, Fig. 6). The ratio of epiphyte dry weight to eelgrass shoot dry weight (Fig. 7), an indicator of epiphyte biomass standardized to the amount of eelgrass to which it is attached, is characterized by considerable variability with no identifiable trends associated with proximity to the dock. There is also considerable variability among the ratio of epiphyte dry weight to eelgrass shoot dry weight at the three ferry terminal study transects (Fig. 8), with considerably more relative epiphyte biomass (per eelgrass shoot biomass) at two Port Townsend (low North & mid- North) and one Clinton (low North) transects compared to two other Clinton (mid- North, hi- North) transects.

### *Task 3—Evaluate the Feasibility of Using Artificial Lighting and Selected Physical Structures to Reduce the Shading Effect of Docks (R. Thom)*

The objective of this task was to determine the types of lighting and structures that may be feasible for application at ferry terminals to improve conditions for growth of eelgrass. In Phase I, we conducted laboratory tests of the use of artificial lighting and physical structures

#### *Methods*

We conducted experiments with light suspended over tanks containing eelgrass, light measurements under cement blocks containing glass inserts, placement of reflective material under the docks, and measurements of eelgrass growth under varying levels of irradiance. Quartz halogen lighting was tested in covered flowing seawater tanks containing eelgrass. Light fixtures were set up over the tanks and the growth rate of the eelgrass was measured relative to controls and total dark conditions. Light transmittance through blocks containing glass inlays was measured during diel cycles. Monitoring of the growth rates of plants under varying levels of solar irradiance has been ongoing since Fall 1994. These experiments involve four light level treatments, with three replicates for each treatment. Growth of the plants is measured on a weekly to biweekly basis. Light is being continuously recorded.

#### *Results*

The results to date are as follows:

- The quartz halogen lights supported eelgrass growth, but at very high intensities which may not be economical or feasible in field applications;
- the glass block transmitted approximately 60% of ambient photosynthetically active radiation (Fig. 8), and are feasible for incorporation into dock structures to promote eelgrass growth;
- aluminum foil attached under the MSL dock increased reflected light, which suggests that use of light-colored and reflective paint and other materials may increase light under docks; and,
- growth of eelgrass in the tanks occurred at all natural light levels but was much reduced at approximately 50% of ambient light.

### *Task 4—Identify Mitigation Alternatives (R. Thom, S. Wyllie-Echeverria))*

We conducted specialized studies at Clinton terminal to assist in the development of the mitigation plan for expansion of the terminal. The overall mitigation goal developed for the Clinton Ferry Terminal Expansion Project was no net loss of eelgrass on the project site with a subgoal to evaluate some new concepts in mitigating shading effects of overwater structures. We inventoried potential eelgrass mitigation sites, with the highest priority given to sites for restoration close to the Clinton ferry terminal. We also developed a conceptual mitigation plan that discussed the design and essential elements of mitigation needed for interagency coordination. The justification and essential elements were discussed with WSDOT. We participated in interagency meetings to discuss the conceptual plans. Finally, we developed a mitigation plan in coordination with WSDOT staff, incorporating comments and specifications for constructing the site.

Although not originally part of the study, questions regarding potential mitigation sites arose during the interagency meetings. The issues were related to propeller wash and accelerated bottom current velocities, as well as suitability of substrata for transplanting. We measured the effects of propeller wash on bottom currents and bottom irradiance at Clinton terminal on two occasions. To develop information on the effects of varying substrata types on growth of transplants, we initiated experiments in flowing seawater tanks which contained eelgrass transplanted into pots containing various substrata types.

#### *Methods*

The inventory of possible mitigation sites included potential eelgrass restoration sites adjacent to the terminal and marshes in the Snohomish River estuary. Using aerial photographs as a guide, subtidal areas vacant of eelgrass were examined using SCUBA. Notes were recorded on substrata, depth disturbances, and other aspects of the site that might affect the survival of eelgrass. The sites examined in the Snohomish estuary consisted of diked marshes that were located on WSDOT property.

Current speeds and irradiance were measured at points next to the terminal, where the plume of the propeller wash was visible over areas where eelgrass would be expected to exist. Currents were measured with hand held current meters, and irradiance was measured with a LICOR® system. Repeated measurements were made for at least four landings and sailings during each visit to the site.

The substrata experiment consisted of five substratum types placed in 10-cm diameter Plexiglass® tubes. Five eelgrass shoots were transplanted into each tube using the bare root method. Five replicates were run for each treatment. The substrata types consisted of: muddy sand from the eelgrass meadow; muddy sand from an adjacent area containing the green alga *Ulva* sp. but no eelgrass; mud from a channel in a salt marsh; medium-coarse beach sand; beach sand mixed with gravel; and gravel mixed with small rock. Growth was measured weekly for six week after an initial six-week period of stabilization following transplanting.

#### *Results*

Preliminary results of our evaluations of mitigation strategies concluded that:

- A total of 13 areas or subareas have been identified for transplanting of eelgrass covering a total of 3,073 $m^2$;
- measurements at Clinton showed that the plume created during ferry arrival and departure can extend up to 80 m from the dockside end of the vessel;
- propeller wash accelerates current in the plume up to 3.5 m $s^{-1}$ within five seconds (Fig. 9);
- the net effects of the propeller wash are to redistribute sediments and associated biota and lower irradiance; and,
- eelgrass grew somewhat better in muddier sediments as compared to coarser sediment (Fig. 10), and growth rate in sediments from potential mitigation areas (without eelgrass)

adjacent to the Clinton eelgrass meadows were higher than in sediments from inside the eelgrass bed.

### *Task 5—Perform Data Filing, Quality Assurance, and Initial Summary Analysis (C. Simenstad, J. Cordell)*

This complex, comprehensive study is generating a large volume of data that will be used in an integrative fashion to address eelgrass management issues among WSDOT and other state and federal resource management agencies. In Phase I, we have initiated compilation of these data into a geographically-organized (e.g., GIS) database that will enable analysis and plotting of spatially-explicit information. Some delay has occurred due to the lack of prior data and imagery (e.g., basic structure, topography, bathymetry) in GIS or CAD form of several of the ferry terminals. All video tapes have been archived with GPS location stamps.

### *Task 6—Manage Study and Communicate Information (C. Simenstad, R. Thom, A. Olson)*

Throughout the project, we have sought to maximally communicate information about this project to WSDOT and interested natural resource management agencies. During Phase I, two presentations were made to WSDOT and other state agency personnel describing the project's scope, approach and preliminary results. With the support of WSDOT and TRAC, we have also sought to broadly communicate information and preliminary results of this project to the appropriate agencies and other professional forums. Examples of three such presentations include:

- **Society for Ecological Restoration** 1995 International Conference, September 14-16, 1995, Seattle, WA: Thom, R., D. Shreffler, C. Simenstad, A. Olson, and S. Wyllie-Echeverria. *Mitigating impacts from ferry terminals on eelgrass*.
- **Third Thematic Conference on Remote Sensing for Marine and Coastal Environments**, September 18-20, 1995, Seattle, WA: Wyllie-Echeverria, S., A. Olson, J. Norris, B. Feist, J. Cordell, C. Simenstad, J. Osborne, D. Shreffler, and R. Thom. *Subtidal eelgrass surveys in Puget Sound Basin: a videographic approach.*
- **Estuarine Research Federation** 13th International Conference, November 12-16, 1995, Corpus Christi, TX: Thom, R., D. Shreffler, J. Cordell, C. Simenstad, A. Olson, and S. Wyllie-Echeverria. *Mitigating impacts of ferry terminals on eelgrass in Puget Sound*.

## Summary and Integration in Phase II

Based on the current understanding from the Phase I studies and the exercise of developing the draft mitigation plan for the Clinton ferry terminal, we have synthesized a conceptual model of ferry dock impacts and mitigation measures (Fig. 11). The goal of this mitigation strategy is no net loss of eelgrass on the project site by avoiding, minimizing and compensating for dock construction and operations impacts. Accordingly, our approach is multifaceted and sequential, including:

- reduction in impacts as much as possible in the initial design and construction of the project;
- avoidance of subsequent impacts associated with operations; and
- reducing local habitat fragmentation and deterioration through restoration of previously disturbed eelgrass patches by transplanting eelgrass into these areas.

The present distribution and coverage of eelgrass is due to historical (not presently active) as well as on-going processes. Disturbance to the eelgrass meadow can be partitioned into two phases: construction and operation. Terminal expansion will have short-term direct effects and longer term impacts on eelgrass. Initial construction activities can be predicted to have some limited effects on eelgrass, although these activities will largely be conducted away from existing eelgrass. Mitigation measures would be directed toward eliminating any longer-term effects, such as unavoidable dock coverage.

In the case of this mitigation strategy applied to the expansion of the Clinton ferry terminal, impacts expected under the original design plan for the terminal have been either avoided or minimized. For example, ferry propeller wash impacts have been avoided by relocating the ferry landing slips farther offshore. Impacts from shading have been minimized through incorporation of light transmitting structures (i.e., glass blocks, grating) in the terminal deck, and by lengthening the dock. Lengthening the dock reduced its width at the point where it crosses the eelgrass meadow. Maintenance activities will be reduced dramatically by the use of concrete pilings and decking rather than timber. This same construction modification will reduce the dock “footprint” by 1/3. We also recommend modifications in ferry operations that would reduce chronic disturbances from propeller wash plumes and scouring at the depth limit of eelgrass distribution.

During Phase II, we will: (1) complete all mapping and characterization of the eelgrass and light environments around the three ferry terminal sites; (2) use the results of the literature survey for interpreting results of our field and lab studies; and, (3) assess optimum mitigation approaches including avoidance, transplant design and technique, recommend appropriate monitoring protocols and suggest future research. Acquisition or development of digital information on the topographic, bathymetric and ferry terminal structure for the Edmonds and Port Townsend sites will enable us to merge these data layers with our existing GIS-based information on eelgrass distribution and cover.

The impact of shading will be further interpreted by refining our quantitative understanding of dock limitations on the local proximal light environment relative to eelgrass light requirements. We are currently redeploying the HOBO® light intensity sensors in a transect across a gradient of shading to the north of the Clinton terminal to attempt to correlate *in situ* light intensity with shade distribution maps from the 3-D model. Recording frequency will be increased (to every 5 min), in an attempt to detect the magnitude of any effects of the propeller-wash plume on light intensity. Additional light profiles will be conducted with the LICOR® PAR light meter, to attempt to correlate light intensity readings with PAR under different atmospheric, sea surface, and water column conditions.

Within the limited scope of Phase II (additional refinement of the 3-D model was not budgeted for Phase II), we will continue to develop the use of the 3-D CAD-based models to (1) describe the shade cast by an existing dock on an eelgrass bed, (2) compare the shadows of existing docks, and (3) evaluate the shade cast by proposed dock designs. Our preliminary model lacks some critical, detailed information for which digital data was not available—superstructures on the terminal deck and the recreational dock to the north of the terminal are not modeled, and shade (and thus sunlight) underneath the dock itself is not rendered. Shadows for the Clinton terminal will be rendered for two additional dates (vernal and autumnal equinoxes) and composite images of shade-density generated. An annual "shade budget" will also be generated.

Figure 1

# Eelgrass Survey Map: Clinton Ferry Terminal

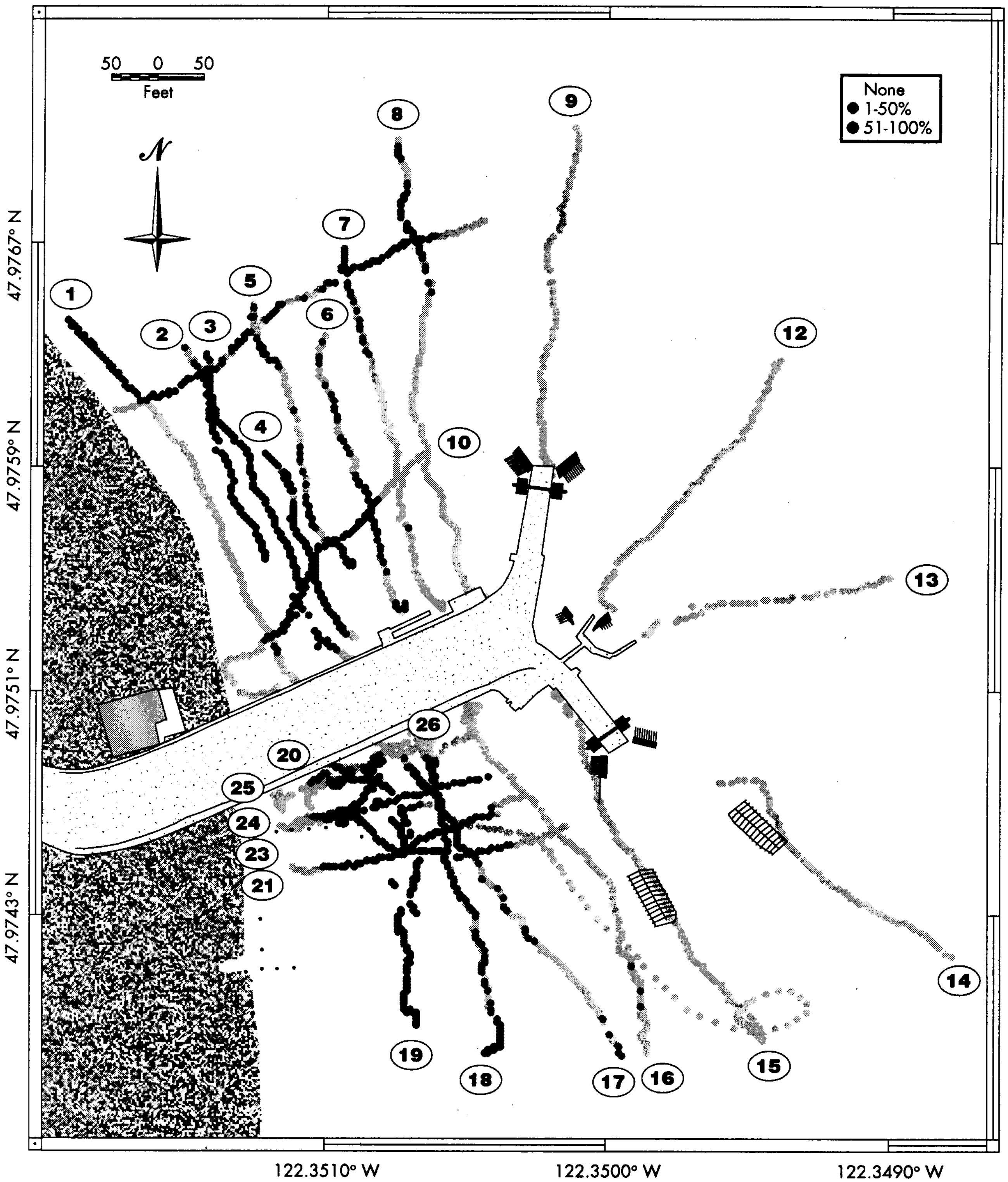
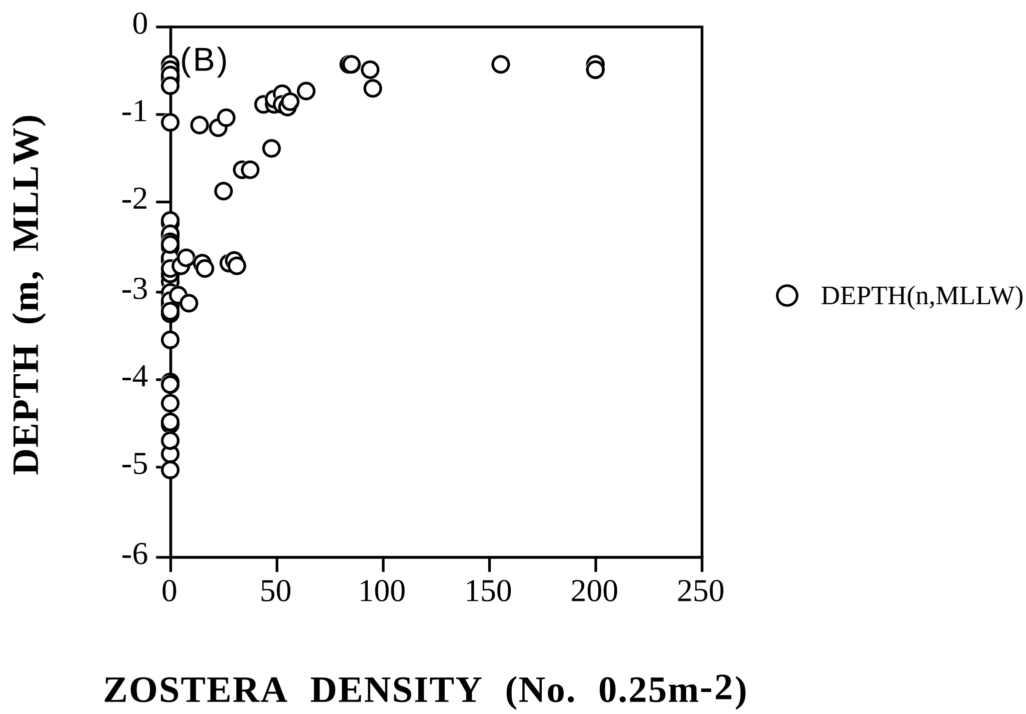


Figure 2



(B)
DEPTH (m, MLLW)
0
-1
-2
-3
-4
-5
-6
0
50
100
150
200
250
DEPTH(n,MLLW)
ZOSTERA DENSITY (No. 0.25m-2)

Figure 3a

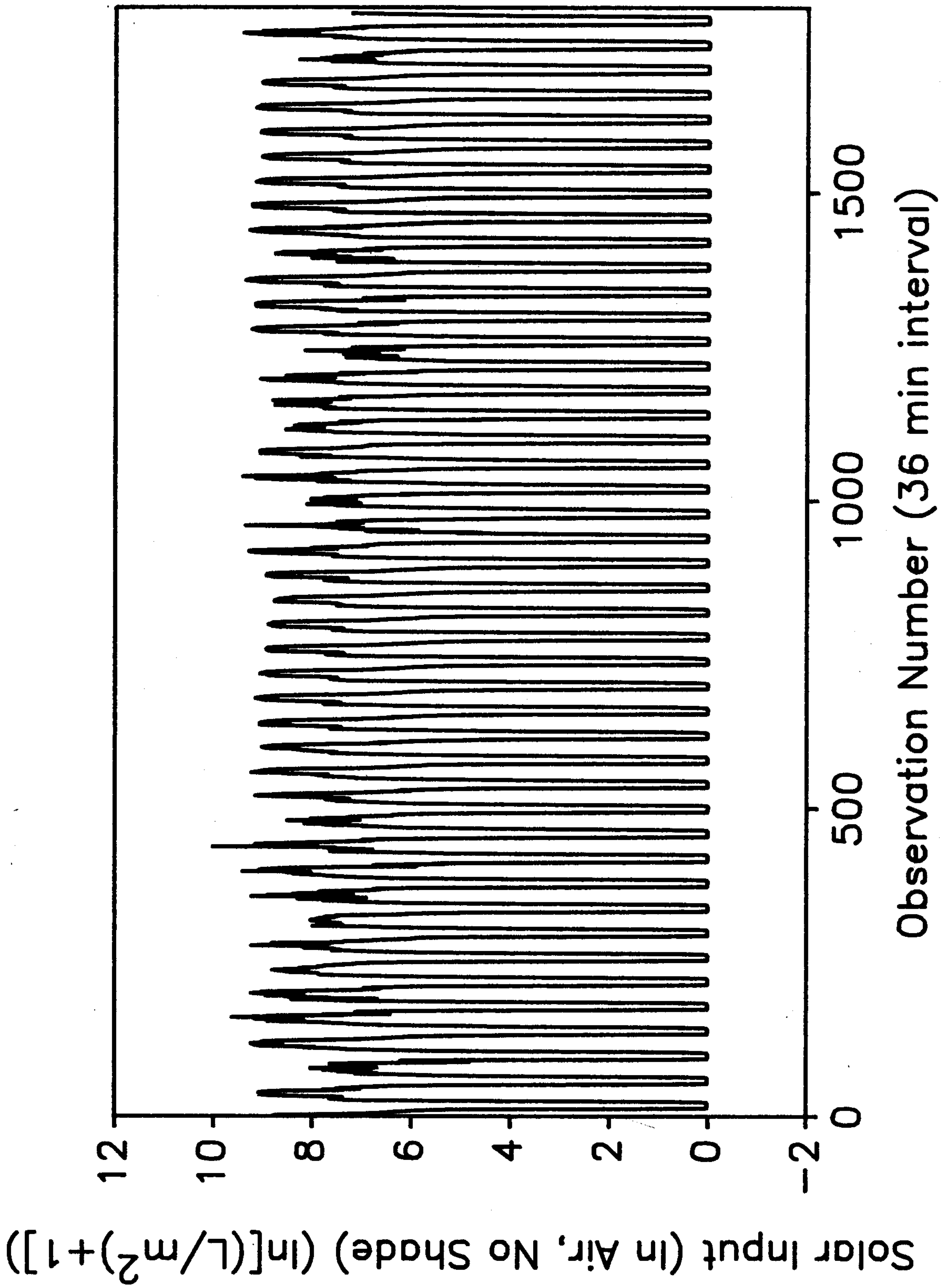
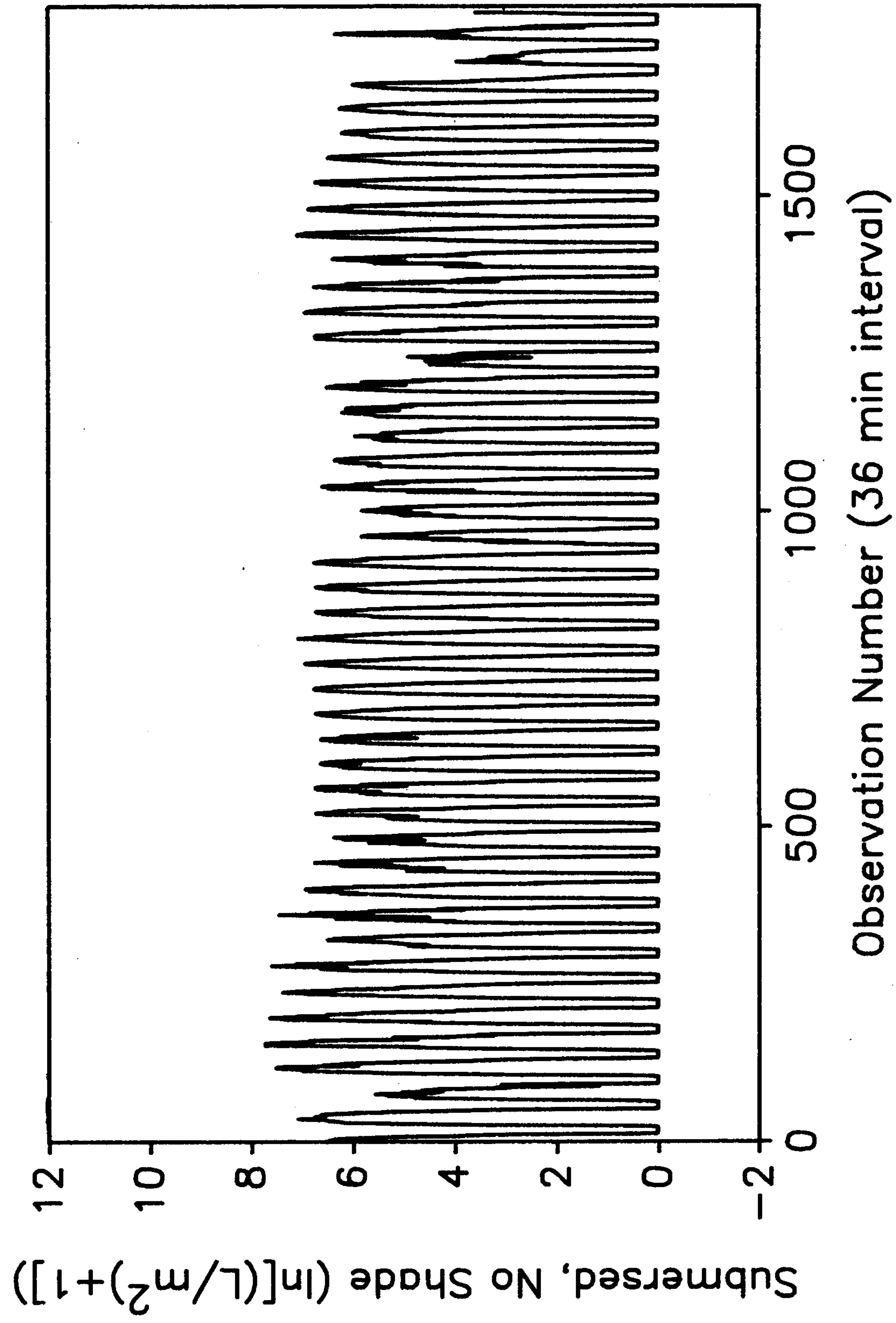

Observation Number (36 min interval)
Solar Input (In Air, No Shade) (ln[(L/m2)+1])
0
500
1000
1500
12
10
8
6
4
2
0
−2

Figure 3b



Submersed, No Shade (ln[(L/m$^2$)+1])
12
10
8
6
4
2
0
−2
0
500
1000
1500
Observation Number (36 min interval)

Figure 3c

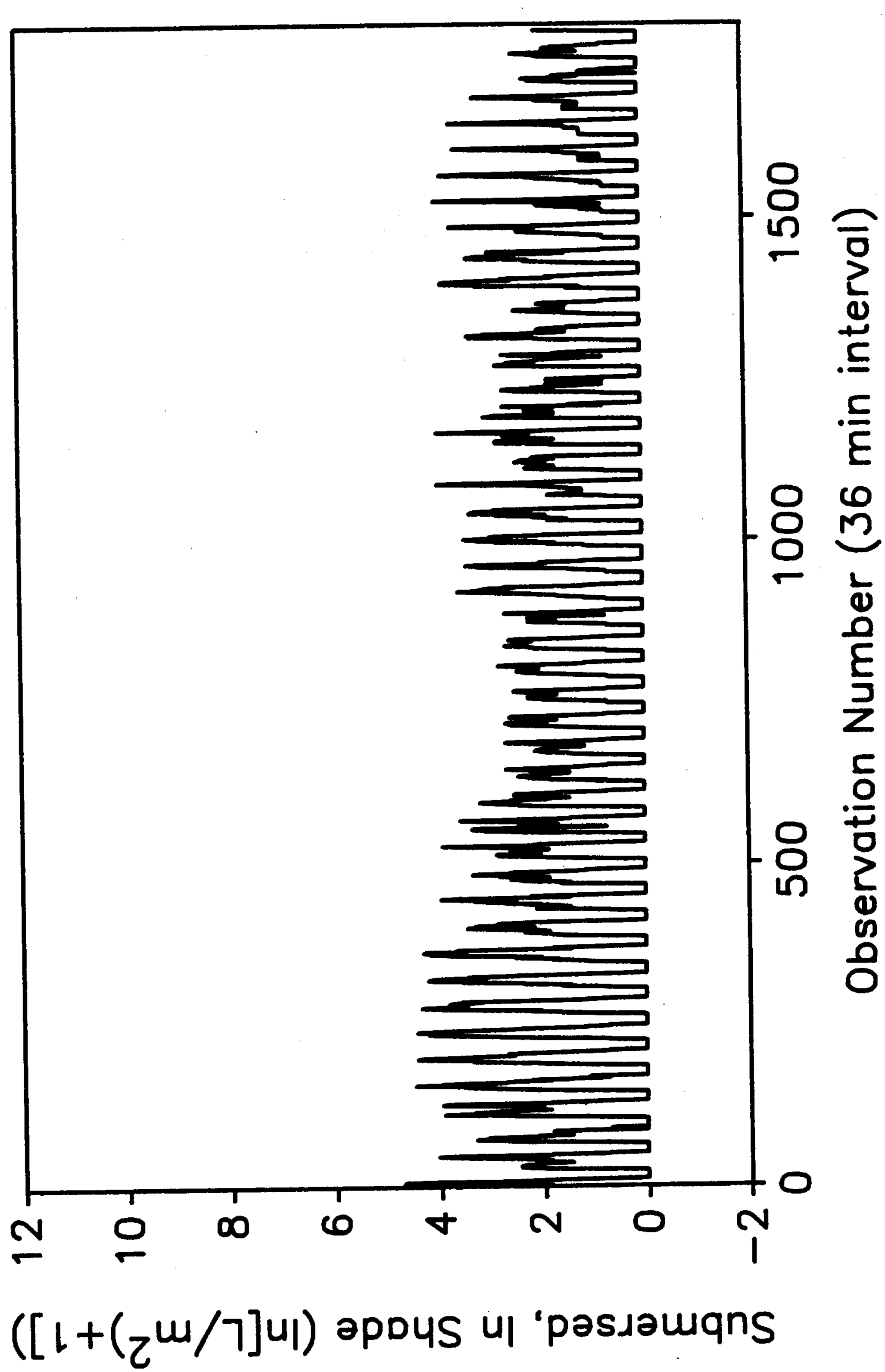
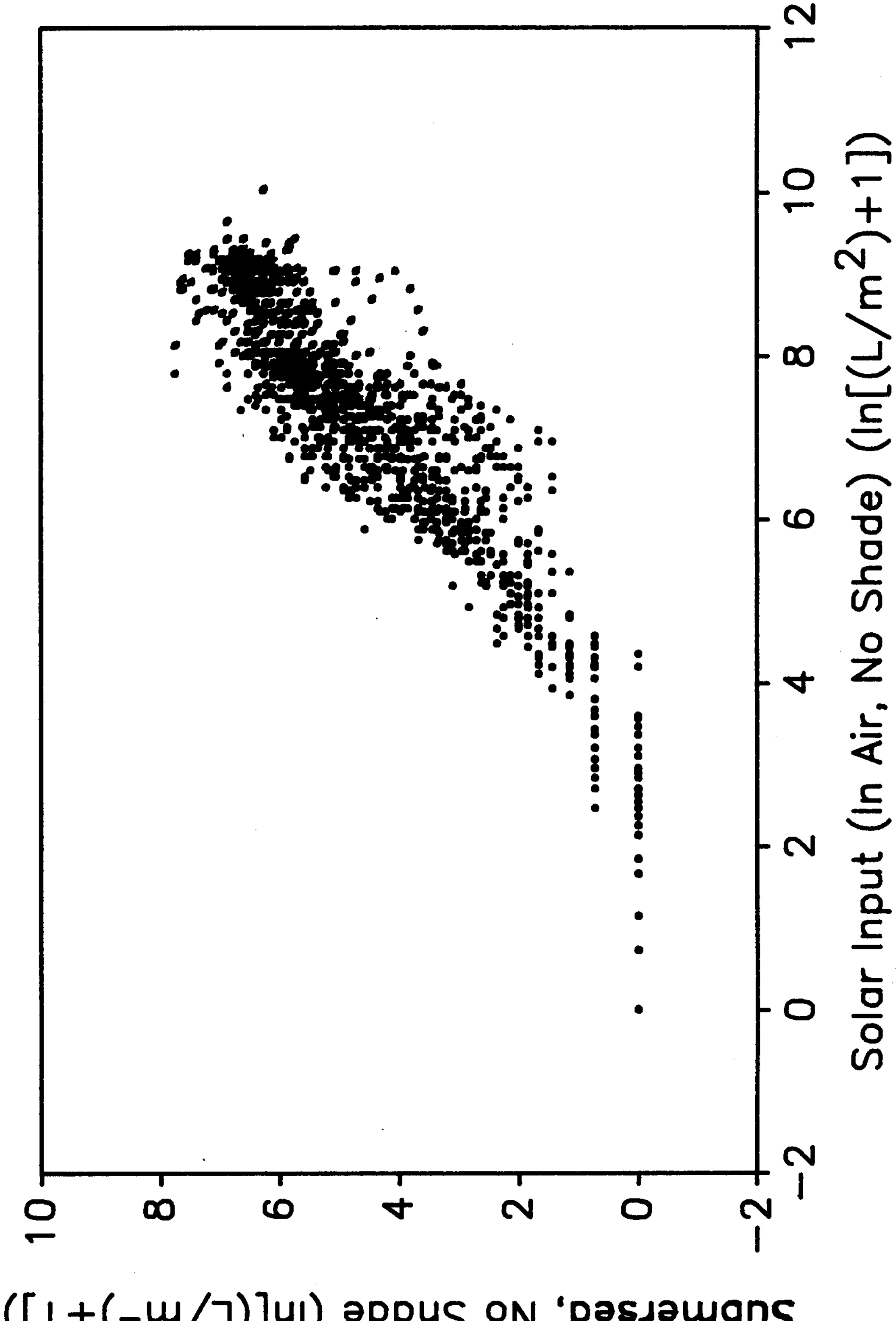

Submersed, In Shade (ln[L/m$^2$)+1])
12
10
8
6
4
2
0
−2
0
500
1000
1500
Observation Number (36 min interval)

Figure 4a



Solar Input (In Air, No Shade) (ln[(L/m2)+1])
Submersed, No Shade (ln[(L/m2)+1])
−2
0
2
4
6
8
10
12

Figure 4b

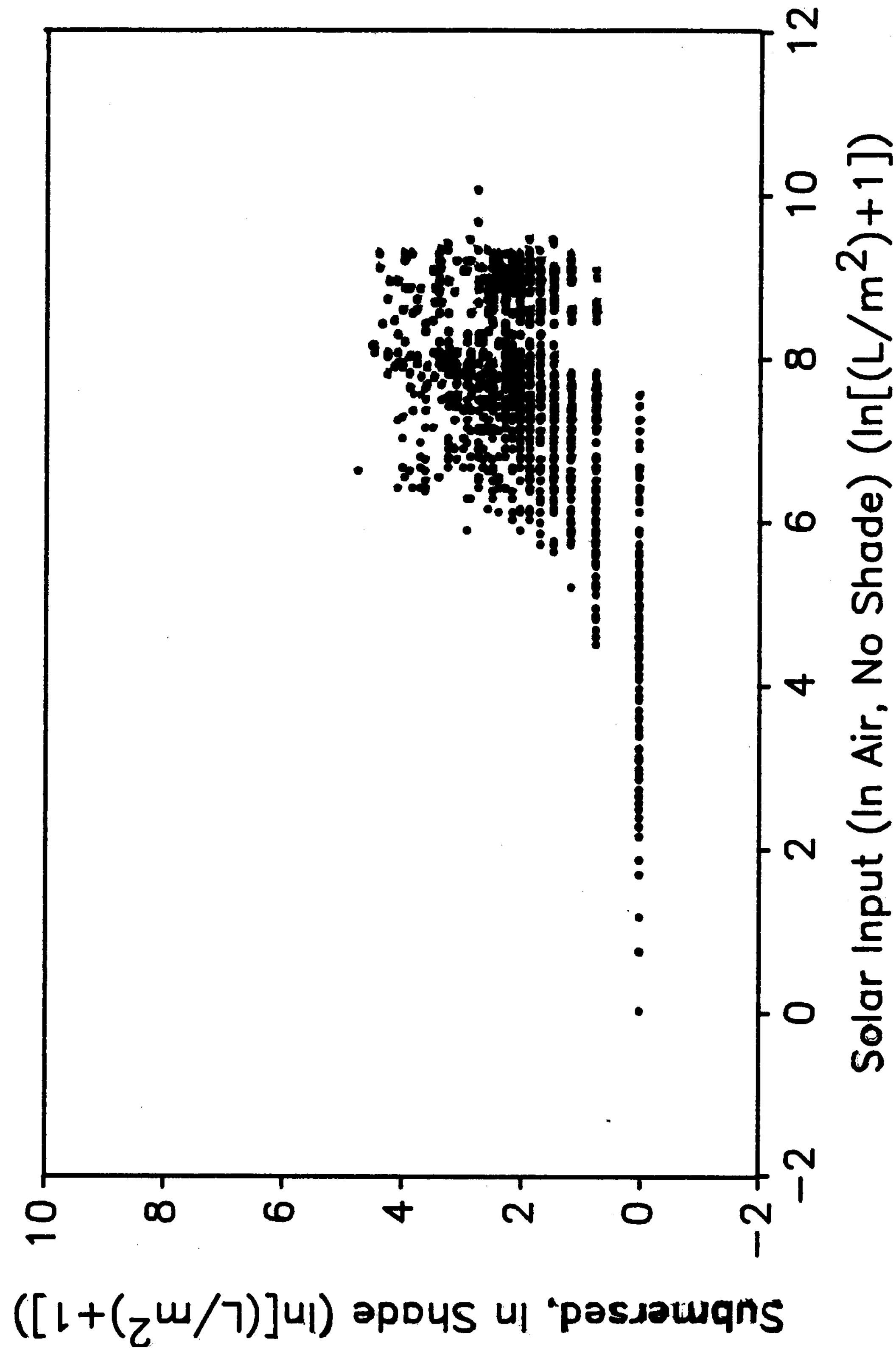
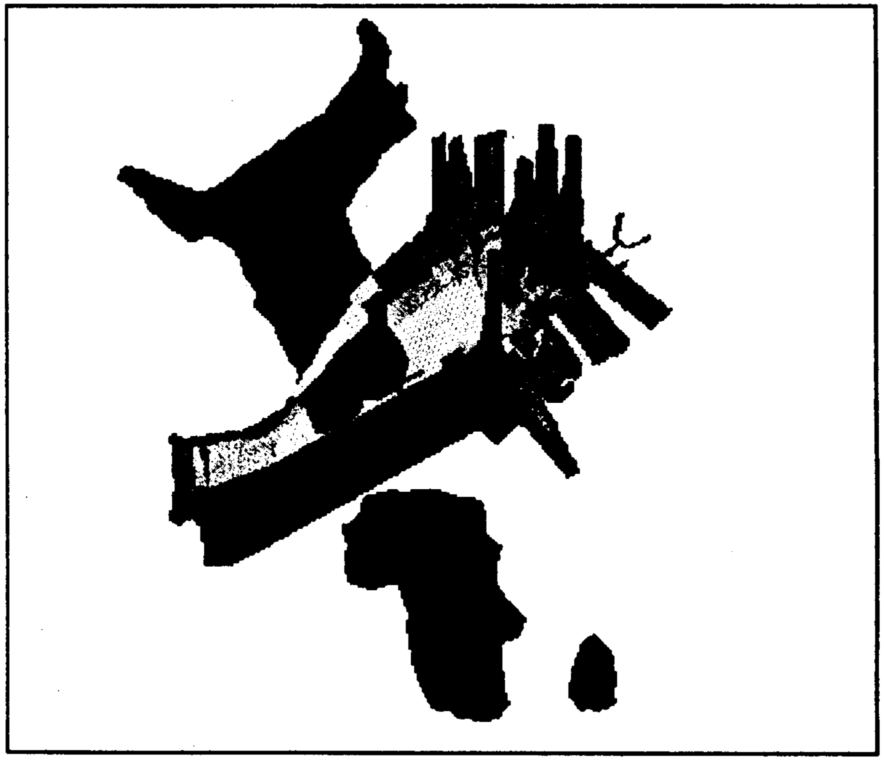

Submersed, In Shade (ln[(L/m^2)+1])
Solar Input (In Air, No Shade) (ln[(L/m^2)+1])
−2
0
2
4
6
8
10
12

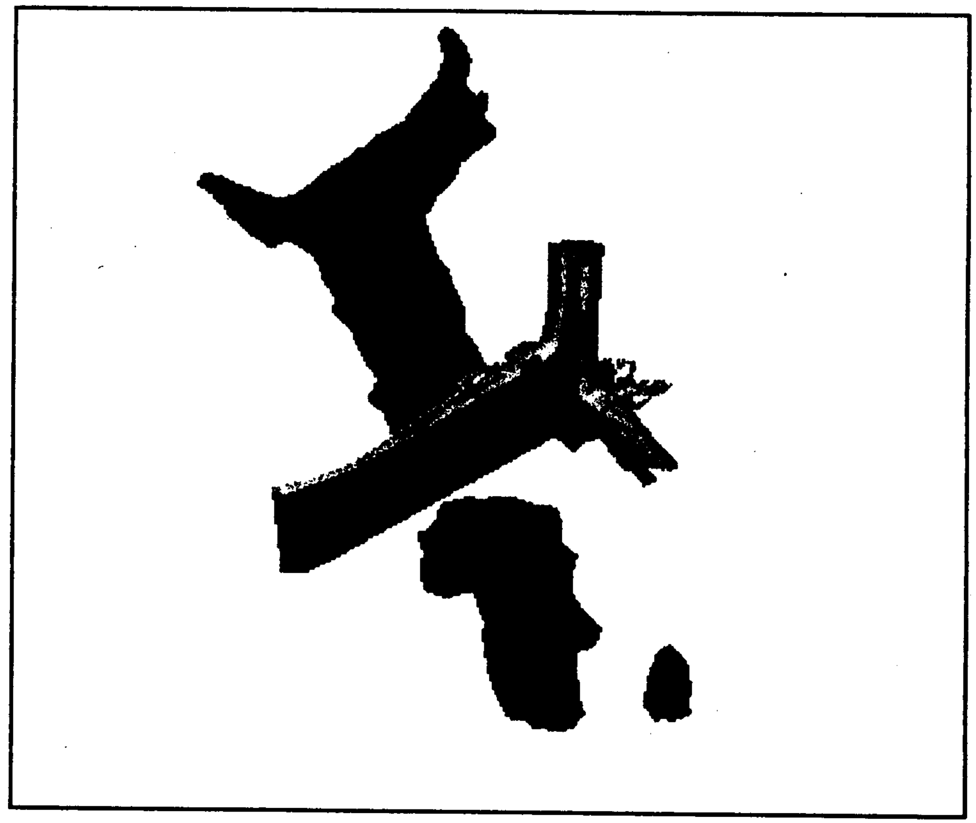
Figure 5a

December Dock, Eelgrass and Shadows



| | | |
|---|---|---|
| 2 | (4039) | dock |
| 3 | (8915) | eelgrass |
| 6 | (3401) | shade.5 to 1 hour |
| 8 | (334) | shade.5 to 1 hour & eelgrass |
| 10 | (1807) | shade 1.5 to 2 hours |
| 12 | (199) | shade 1.5 to 2 hours & eelgrass |
| 13 | (1020) | shade 2.5 to 3 hours |
| 14 | (140) | shade 2.5 to 3 hours & eelgrass |
| 15 | (1250) | shade 3.5 to 4 hours |
| 16 | (678) | shade 3.5 to 4 hours & eelgrass |

June Dock, Eelgrass and Shadows



| | | |
|---|---|---|
| 2 | (4039) | dock |
| 3 | (10095) | eelgrass |
| 6 | (426) | shade .5 to 1 hour |
| 8 | (36) | shade .5 to 1 hour & eelgrass |
| 9 | (764) | shade 1.5 to 2 hours |
| 10 | (78) | shade 1.5 to 2 hours & eelgrass |
| 11 | (388) | shade 2.5 to 3 hours |
| 12 | (56) | shade 2.5 to 3 hours & eelgrass |
| 13 | (112) | shade 3.5 to 4 hours |
| 14 | (1) | shade 3.5 to 4 hours & eelgrass |
| 15 | (3) | shade 4.5 hours |

Figure 5b

Figure 6

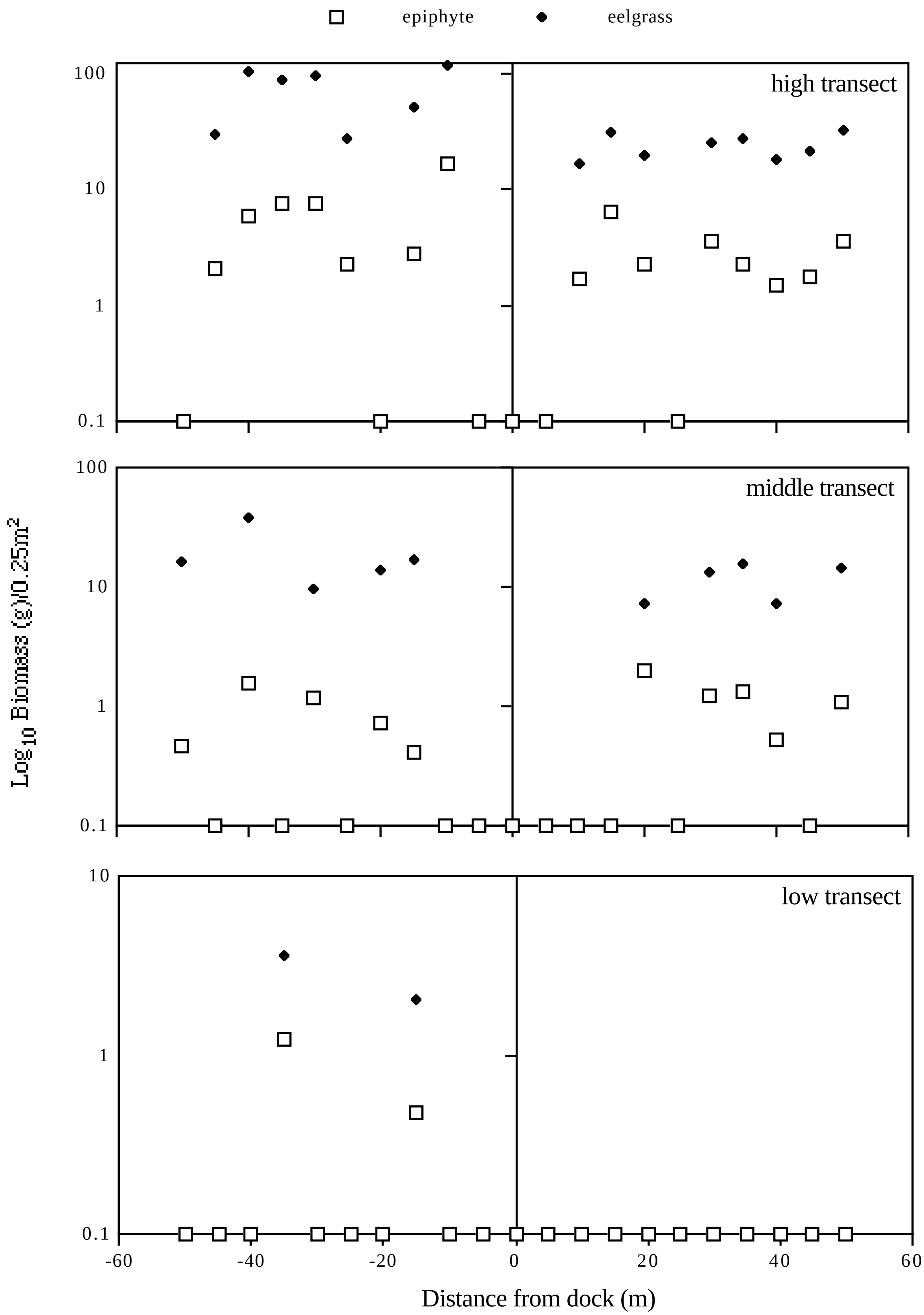
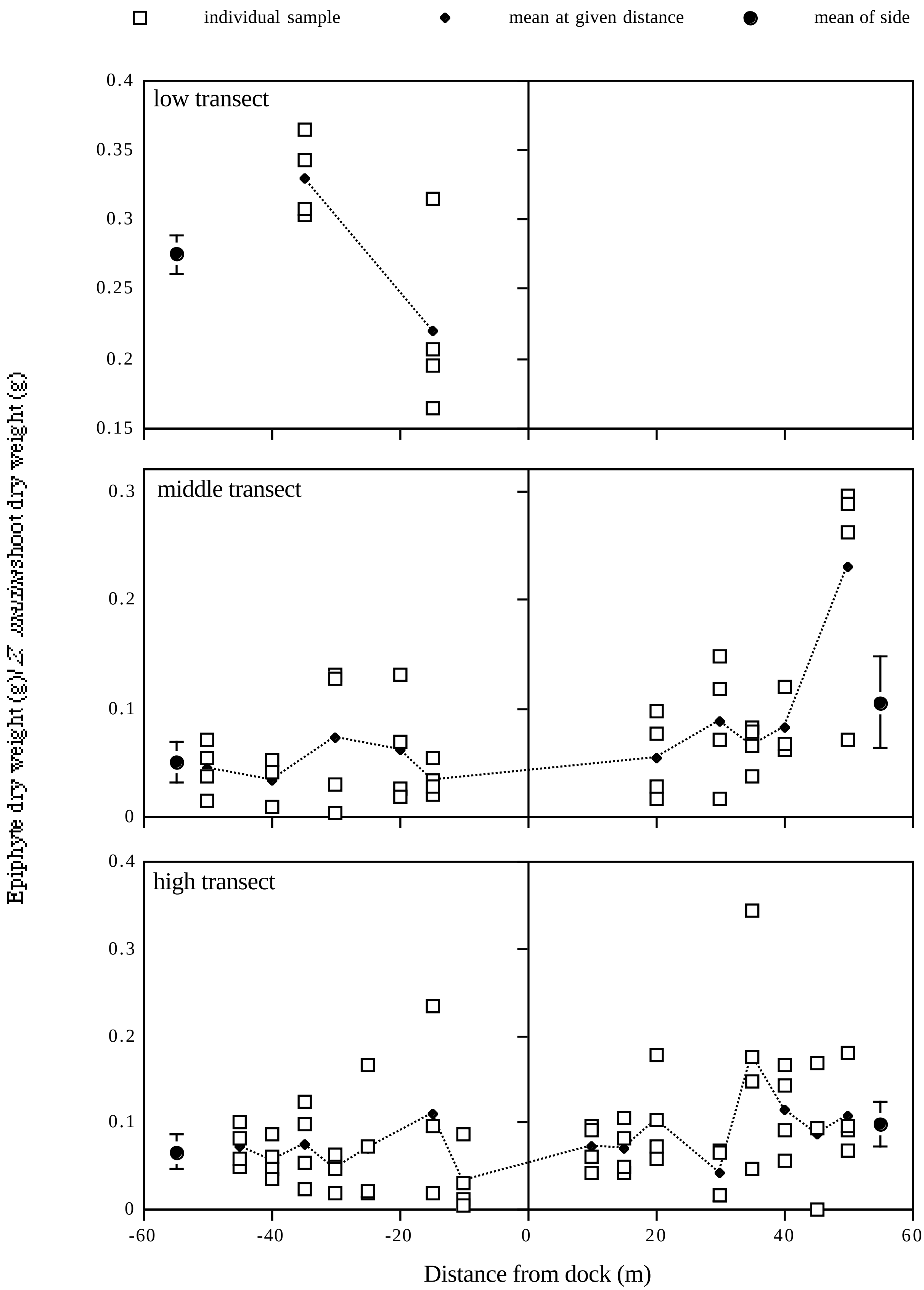

epiphyte
eelgrass
high transect
middle transect
low transect
Log10 Biomass (g)/0.25m2
100
10
1
0.1
-60
-40
-20
0
20
40
60
Distance from dock (m)

Figure 7



individual sample
mean at given distance
mean of side
low transect
middle transect
high transect
0.4
0.35
0.3
0.25
0.2
0.15
0.3
0.2
0.1
0
0.4
0.3
0.2
0.1
0
-60
-40
-20
0
20
40
60
Epiphyte dry weight (g)/ Z. marina shoot dry weight (g)
Distance from dock (m)

Figure 8

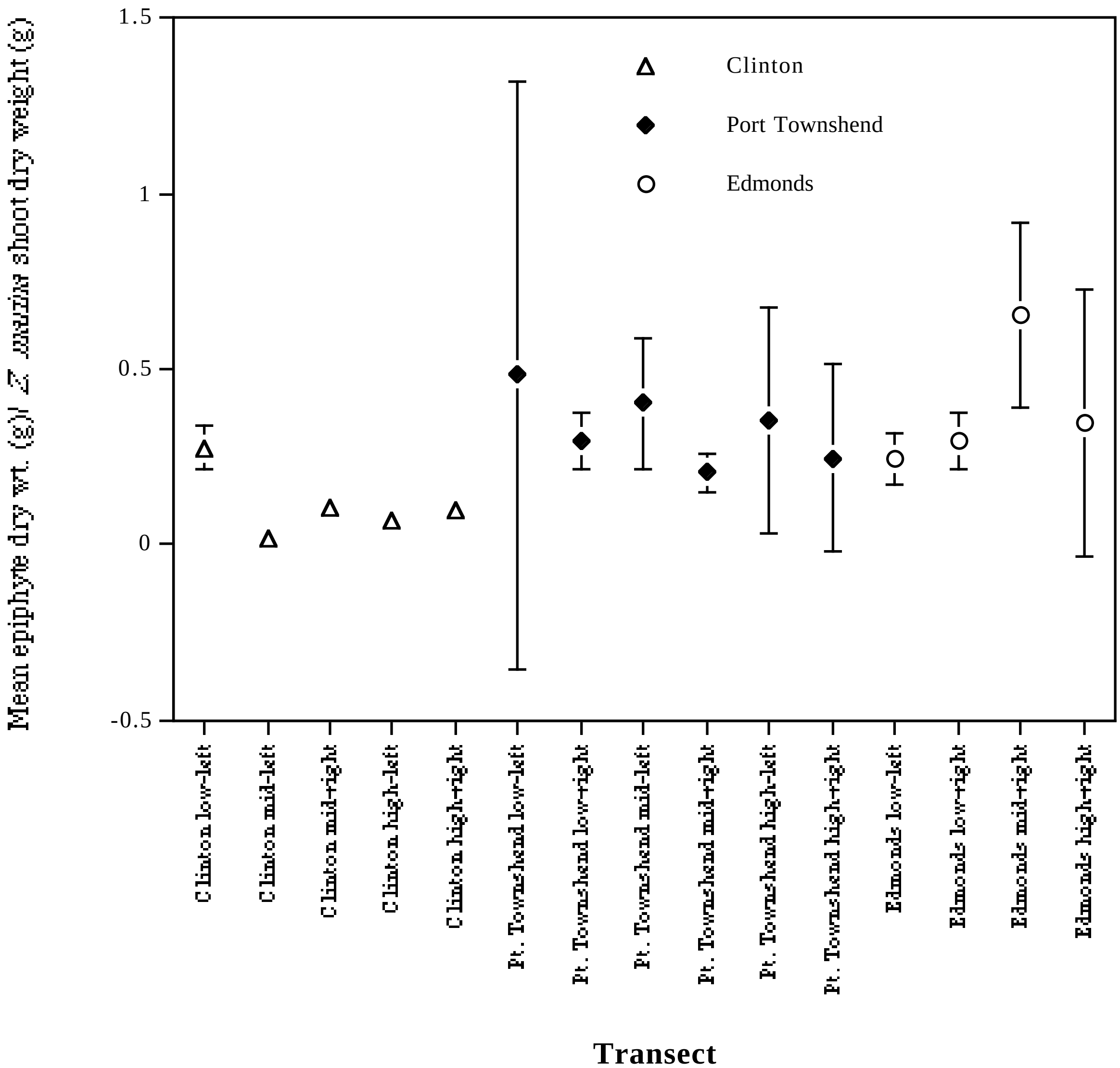
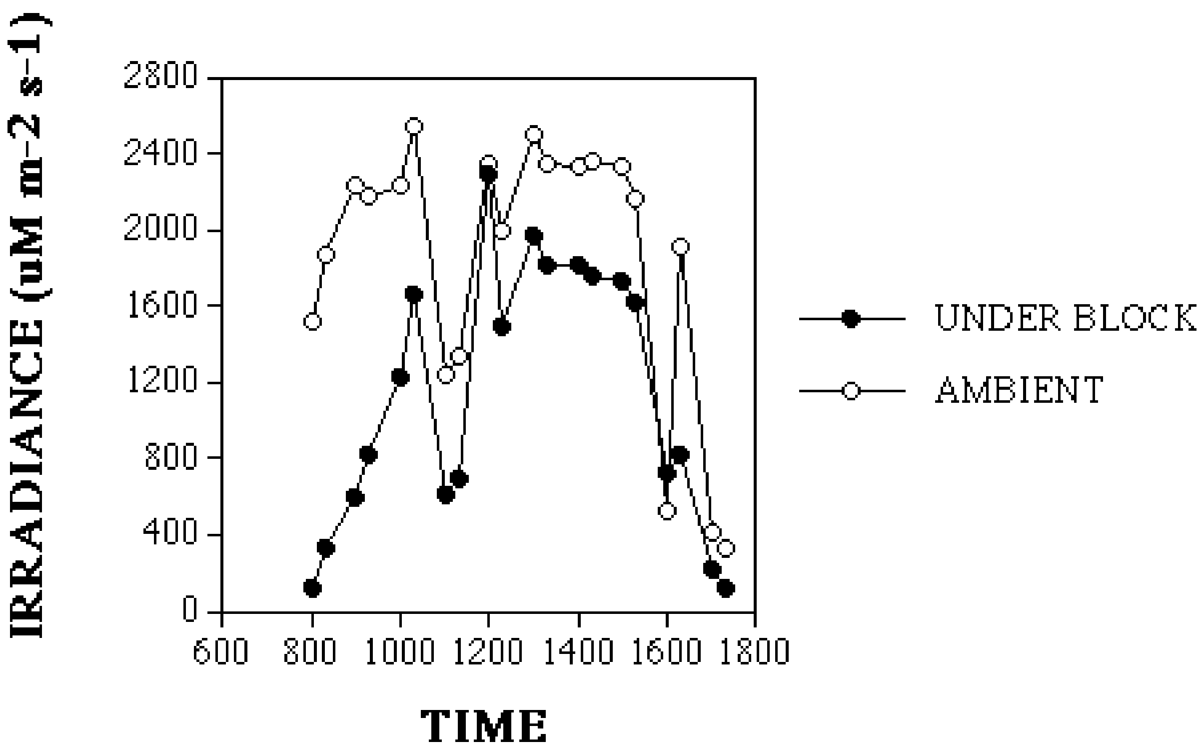

Mean epiphyte dry wt. (g)/ Z. marina shoot dry weight (g)
1.5
1
0.5
0
-0.5
Clinton
Port Townshend
Edmonds
Clinton low-left
Clinton mid-left
Clinton mid+right
Clinton high-left
Clinton high+right
Pt. Townshend low-left
Pt. Townshend low+right
Pt. Townshend mid-left
Pt. Townshend mid+right
Pt. Townshend high-left
Pt. Townshend high+right
Edmonds low-left
Edmonds low+right
Edmonds mid+right
Edmonds high+right
Transect

Figure 9


IRRADIANCE (uM m-2 s-1)
2800
2400
2000
1600
1200
800
400
0
600
800
1000
1200
1400
1600
1800
TIME
UNDER BLOCK
AMBIENT

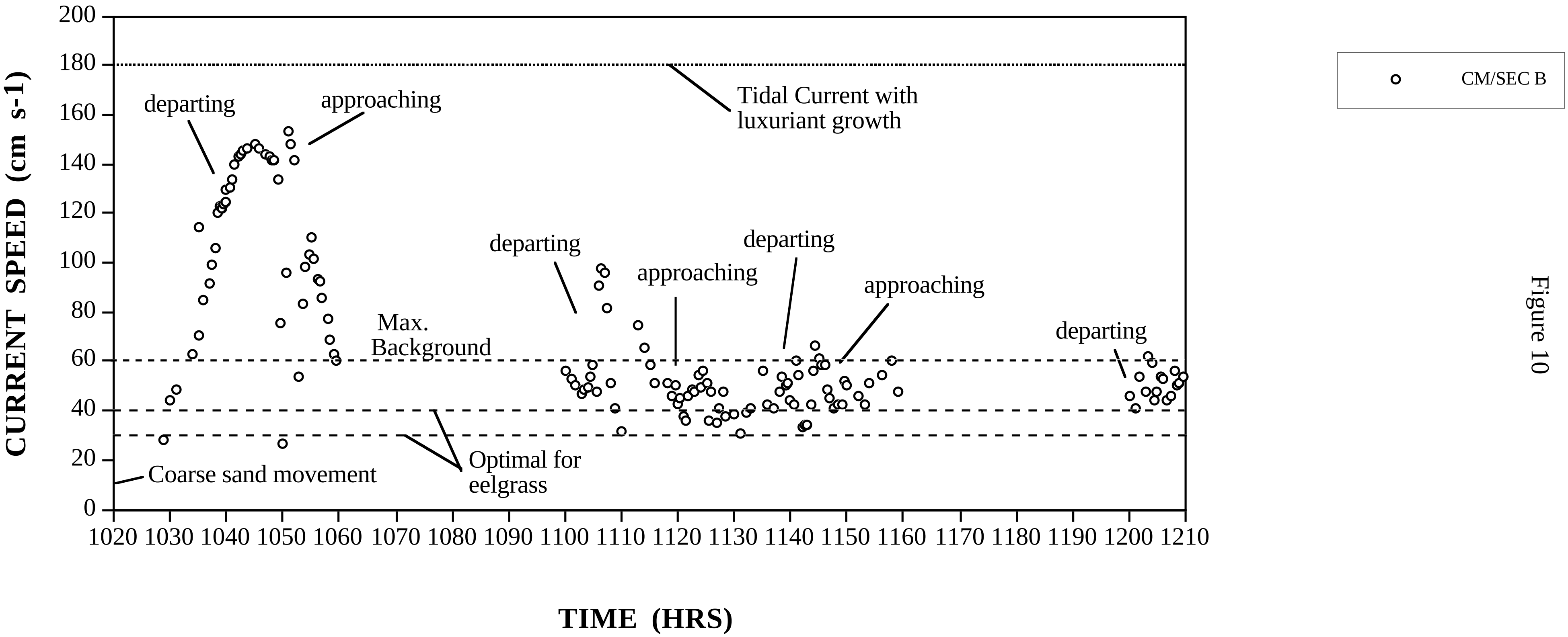

CURRENT SPEED (cm s-1)
200
180
160
140
120
100
80
60
40
20
0
1020 1030 1040 1050 1060 1070 1080 1090 1100 1110 1120 1130 1140 1150 1160 1170 1180 1190 1200 1210
TIME (HRS)
departing
approaching
Tidal Current with
luxuriant growth
departing
approaching
departing
approaching
departing
Max.
Background
Optimal for
eelgrass
Coarse sand movement
CM/SEC B

Figure 10

Figure 11

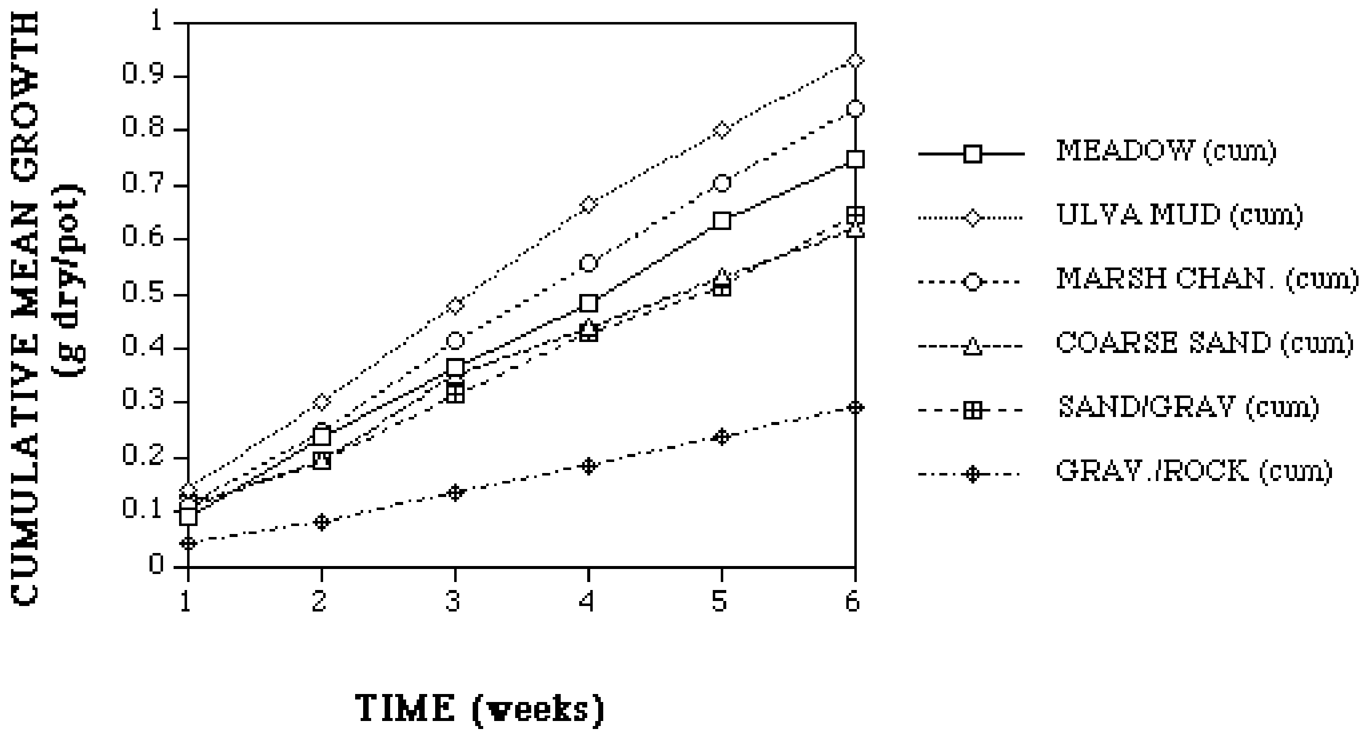
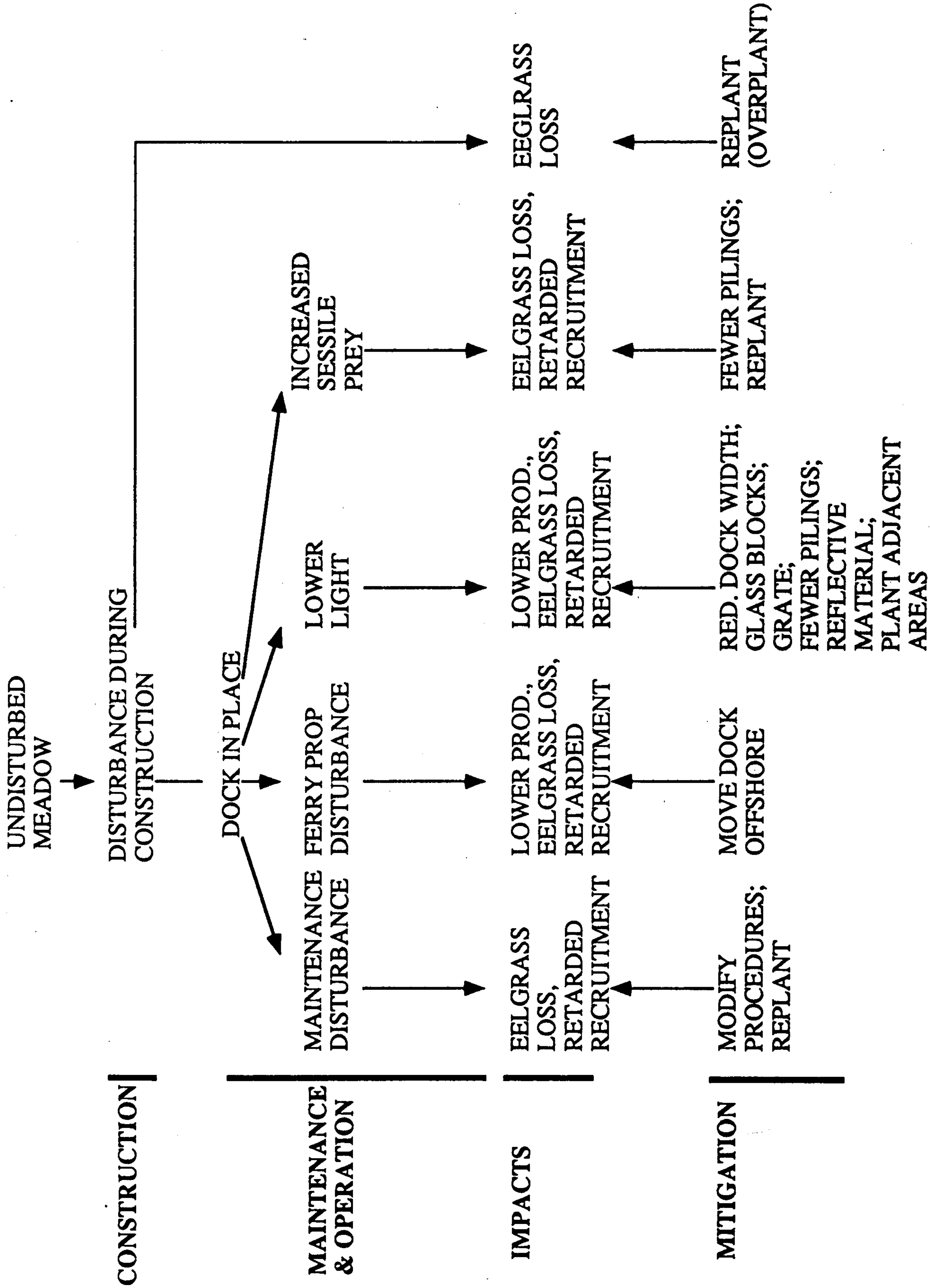

CUMULATIVE MEAN GROWTH
(g dry/pot)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
TIME (weeks)
MEADOW (cum)
ULVA MUD (cum)
MARSH CHAN. (cum)
COARSE SAND (cum)
SAND/GRAV (cum)
GRAV./ROCK (cum)

Figure 12


CONSTRUCTION
MAINTENANCE & OPERATION
IMPACTS
MITIGATION
UNDISTURBED MEADOW
DISTURBANCE DURING CONSTRUCTION
DOCK IN PLACE
MAINTENANCE DISTURBANCE
FERRY PROP DISTURBANCE
LOWER LIGHT
INCREASED SESSILE PREY
EELGRASS LOSS, RETARDED RECRUITMENT
LOWER PROD., EELGRASS LOSS, RETARDED RECRUITMENT
LOWER PROD., EELGRASS LOSS, RETARDED RECRUITMENT
EELGRASS LOSS, RETARDED RECRUITMENT
EEGLRASS LOSS
MODIFY PROCEDURES; REPLANT
MOVE DOCK OFFSHORE
RED. DOCK WIDTH; GLASS BLOCKS; GRATE; FEWER PILINGS; REFLECTIVE MATERIAL; PLANT ADJACENT AREAS
FEWER PILINGS; REPLANT
REPLANT (OVERPLANT)