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Impacts of Marine Docks on Eelgrass in New England: A Spreadsheet-Based Model for Managers and Planners

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Introduction

The management of marine environmental impacts associated with small docks and piers remains a difficult issue for regulators, managers, and planners (Burdick and Short 1999, MacFarlane et al. 2000, Shafer et al. 2008). Increases in permit applications coupled with continued coastal development necessitate the formulation of a reliable management tool to help resource managers and the planning community evaluate and design dock structures with minimal impacts to fragile coastal resources (Kelty and Bliven 2003). For background information on the potential impacts of docks to seagrass habitat, see Burdick and Short (1999) and Shafer at al. (2008).

Building upon a previous dock design model (Burdick and Short 1999) and our CD ("Dock Design with the Environment in Mind", Burdick and Short 1998), we developed a spreadsheet-based model that calculates the impact of an individual dock on eelgrass, employing the end-user's actual site-specific dock construction specifications. The new model is called DEC: "Dock Eelgrass Calculator," http://marine.unh.edu/jel/faculty/fred2/seagrass-tools.htm and represents an advance over our previous model by providing the user with a transparent spreadsheet process that calculates the estimated reduction in eelgrass caused by an existing or proposed dock. Impacts for each 3 meter (10 foot) section of dock to be built over eelgrass habitat are analyzed to yield the percent of expected eelgrass loss at a given site. The DEC model produces estimates of average impacts to eelgrass caused by direct shading under the dock. DEC has been packaged for easy application (in Microsoft® Excel®) to site-specific projects by (1) those designing docks and piers, and (2) those reviewing dock and pier proposals under environmental rules and regulations. DEC represents an advance over our previous dock design model because it is capable of evaluating a wider range of docks and tidal conditions, and all model parameters can be conveniently adjusted by the user to determine the best configurations for a dock over an eelgrass bed.

Objectives

We had two main objectives in the present study: a more broadly applicable model and a model that is easier to use. Our goal was to build on our previous model (Burdick and Short 1999) to encompass wider tidal ranges and a more accessible model for people with a wide range of interests and abilities, from homeowners to the regulatory, planning and engineering communities. With DEC, we worked to create a simple and interactive interface for entering dock parameters to evaluate results and explore design options to reduce dock impacts to eelgrass. We aimed to create a downloadable, spreadsheet model to evaluate a wide range of docks and their impacts to eelgrass.

Study Sites

Site data were collected at 22 dock configurations in 2006; only docks with eelgrass adjacent to or below them were selected for inclusion in our study. The docks sampled included five (5) configurations in Rhode Island, eight (8) configurations in Massachusetts, and one (1) in southern Maine (Figure 1). These new sites more than doubled the docks measured in 1993 (Burdick and Short 1998, 1999), yielding a total of 43 measured dock configurations representing environmental conditions from Rhode Island to southern Maine used in creating the DEC model. Efforts to extend the study to North Carolina were not successful as the NOAA collaborators were unavailable. Inclusion of docks in southern Maine and New Hampshire was limited, as few met the minimum requirements for inclusion in the study (i.e., dock extended into or adjacent to an eelgrass bed). The DEC model is based on a wider variety of docks than the 1998 study and, importantly, a greater tidal range, making it more useful for application throughout New England.

Field Methods

Dock Dimension Measurements

Each dock structure was measured to record the parameters denoted on the field data sheet. The location and explanation of each of these measures are illustrated in Figure 2. Dock orientation (compass bearing, recorded in degrees from north and uncorrected for declination) was measured with a hand-held compass while standing on the dock, facing seaward along the long axis of the dock. In the original study, the northern vs. southern aspect of docks were tested and found to have no significant effect on eelgrass bed quality. Therefore, bearing was converted to 0-90^{o} for input to the model. We noted if the dock was permanent or seasonal and if any floats were attached or infrastructure present to accommodate such additional structures. Also, we noted if a boat was presently tied to the dock, as well as dock construction materials used (i.e., wood, steel, fiberglass grating, etc.).

Dock length and width were measured horizontally along the deck surface, while thickness was measured as the maximum vertical thickness of the deck (top of decking to bottom of supporting joists. Cross-bracings, if present, were not added to this measurement of thickness). Length of dock along adjacent bed refers to the lateral distance of eelgrass that intersects the length of the dock. If eelgrass was present along *both* sides of the dock, we recorded the side with the longer extent but noted the second measurement. Additionally, we noted the age of the dock if a construction date was found on the structure or when additional information was available from the local municipality (e.g., permits, as-built plans, etc.).

Deck height above water was measured from the underside of the deck joists (deck base) to the water surface and the time was noted. We also estimated the height above the high water mark (HWM) by measuring the distance from the deck base down to the upper edge of the water stains on the dock pilings. Similarly, we measured the distance from the upper edge of the HWM down to the water surface, noting the time on the data sheet that the measurement was made. Mean sea level (MSL) was calculated using the tidal range for the location, the tides for the day of the observation, and the time of the observation. Height of the deck base over mean sea level was then determined by correcting the deck base height above water by accounting for tide. Finally, we recorded the deck height above the marine bottom by measuring from the deck base to the sea floor.

Transect Establishment

A series of transects was established at each dock, originating from the center line of the dock as shown in Figure 2. Beginning from the landward portion of the dock, the first transect was placed at the center of the first dock section (T-1) that intersected an adjacent eelgrass bed. Additional transects (T-2, and so on) were placed approximately 3 meters apart consecutively along the remaining seaward length of the dock, alternating from side to side, when eelgrass was present in the vicinity. The number of transects completed at each dock was determined by the presence and location of eelgrass and the total length of the dock. In cases where the dock dimensions changed (e.g., floating section, tiered section, ramp or gangway), we repeated the procedures above, starting from the point where eelgrass (if present) intersected the new type of structure.

Each transect included one sampling station under the dock (Station 1) and extended perpendicular to the long axis of the dock to a station located a sufficient distance away to avoid potential effects from the dock structure (Station 4; Figure 2). Typically, the farthest sampling station was 8 meters from the dock center. For each transect, up to two other stations were sampled, between Stations 1 and 4. If there was no eelgrass under the dock, a station was sampled in the first adjacent eelgrass bed encountered following the next whole meter interval (e.g., 3 m) along the transect (Station 2). Another station (Station 3) was selected at the midpoint between Station 2 and Station 4. If eelgrass was present under the dock, Station 2 was located 2 m from the dock and Station 3 was located 4 m from the dock (Figure 2). For one very large dock (Coast Guard Pier, Provincetown, Massachusetts), Station 2 was collected at 4 m, Station 3 at 6 m, and Station 4 at 10 m from the dock center.

Eelgrass Measurements

Eelgrass beds were characterized in the field by 1) estimating percent cover of eelgrass canopy at each transect station, and 2) estimating bed quality at the station located under the dock (Station 1) by comparing eelgrass at this station to eelgrass present in the far station (Station 4; outside of dock effects). Percent cover was determined by lowering a $0.25m^2$ quadrat to the bed surface and visually estimating percent cover of live eelgrass within the quadrat (Duarte and Kirkman 2001).

Eelgrass quality was rated by assigning a number (0-9) representing bed quality when compared to nearby eelgrass beds without dock effects. For example, 0 = no eelgrass, 1 = no eelgrass immediately under, but some adjacent to the dock, 5 = half that of surrounding beds, and 9 = visually similar to surrounding beds, interpolated to the nearest whole number for intermediate conditions. Again, bed quality was recorded only for plots located under the dock, *i.e.,* within the footprint of the dock or float. The number of transects of data collected for each dock structure depended on the length of the structure and the presence of eelgrass. Eelgrass cover can be reduced for a variety of reasons that may be unrelated to dock structure (e.g., rocky substrata or bioturbation). Thus, for structures with two estimates of percent cover, only the highest value was used; for structures with three or more estimates, the top two values were averaged to determine the representative percent cover of eelgrass that was able to grow under a dock.

Data Analysis

For docks with multiple configurations (e.g., fixed on pilings, ramps, or floats), each configuration was considered a unique observation. In cases where data were collected from multiple transects, values were averaged to construct the model. However, data from each transect was input individually to the spreadsheet so that the overall impacts to eelgrass could be calculated for each section of dock. New data from 22 dock configurations were applied to the original model and the residuals were examined to determine how well the old model fit the new data. Variation within and between dock and eelgrass variables was examined using correlation matrices and stepwise regressions, and a new model (the DEC) was developed for docks .

Impacts to eelgrass beds adjacent to dock structures were assessed by determining the amount of eelgrass vegetative cover visually estimated in 0.25 m^2 quadrats collected at the transect stations. Cover was then compared to the cover of unimpacted eelgrass at the farthest distance from the dock (Station 4, Figure 2). Estimates of impacts to eelgrass beds for each specific dock were calculated separately for each dock section where eelgrass occurred, or where eelgrass would have occurred if no dock had been built, based on an assessment of adjacent beds. For under the dock, the impact was calculated for dock width and section length; for 0 to 3 meters, the impact for eelgrass at 2 meters was used; and for 3 to 5 meters the impact at 4 meters was used. A conservative assumption of no impact beyond 5 meters was used (recall the sample at 8 meters from the dock was assumed to be unimpacted by the dock and associated boating activity). The greater horizontal distances for the large Coast Guard pier in Provincetown were re-coded to the typical distances to develop the distance-impact relationships, but actual data were used to calculate specific impacts from the intertidal and subtidal portions of the pier.

Results and Discussion

Dock Characteristics

Data from a total of 43 dock configurations associated with eelgrass are incorporated into this study; 22 were sampled in 2006, and 21 were sampled in 1993. First, some of the general physical characteristics of the docks are examined and differences between the two sample dates are shown. Further differences between sampling years with respect to impacts to the eelgrass beds are highlighted through the application of the original regression model (developed to predict eelgrass bed quality under docks) to the bed quality found under docks in 2006. Finally, we used data from fixed docks for both time periods to develop the new predictive DEC model and applied the DEC to our new sampling protocol to estimate dock impacts to eelgrass under docks.

Docks that were sampled included locations from three New England states with a minimum tidal range of 0.3 m and a maximum of 3.0 m (Table 1). The majority of the docks had an east-west orientation (21) though many were oriented north-south (16) and a few were in between (6). Each of the docks provided access to deep water from the upland by means of a fixed structure, and eight had removable floats that intersected eelgrass beds (Figure 3). All but one was constructed primarily of wood, and the majority had wood plank decking. In the 2006 sampling effort, several were found to have alternative deck material consisting of either extruded metal mesh or open-grid fiberglass grating (Figure 4). Although the majority of the fixed docks were approximately 2 m wide, deck width varied considerably (0.8 to 3.7 m), as did length (3.3 to 450 m), and height above the marine bottom (1.2 to 4.85 m). Floating docks had various configurations, but generally extended below the water surface and therefore showed negative values for deck height above the water (Table 1).

Floating docks typically supported poor eelgrass bed quality and exhibited different relationships with some site and dock variables, so these were excluded from the model. Of the 43 docks, 8 were floating and 35 were fixed on pilings. Using the fixed dock subset, we noted some differences when characteristics were averaged by year of sampling. In general, the more recent sampling included docks at sites with greater tidal ranges (as planned), as well as taller docks, many of which were able to support eelgrass beds of better quality under them (Table 2), particularly in Narragansett Bay sites. The latter observation may have been linked to the fact that the Rhode Island has adopted the original dock design model (Burdick and Short 1999) to regulate new dock construction (Chris Powell, RI DFW, personal communication). The RI docks included in this study were predominantly new construction, clearly incorporating design elements recommended by the original dock design model. In Florida, recently constructed docks in five areas with seagrass communities were evaluated for compliance with construction guidelines adopted in 2001 (Shafer et al. 2008). They concluded that greater compliance with guidelines would result in fewer impacts to seagrass under docks. We found that newer docks had significantly greater eelgrass bed quality (Table 3), undoubtedly due to the construction guidelines adhered to in Rhode Island.

Application of Old Model to New Data

We used the old model from Burdick and Short (1999) to predict eelgrass bed quality under the fixed docks visited in 1993 and 2006:

Predicted bed quality = 1.0 + 4.0 * (dock height above marine bottom) – 0.081 (compass bearing) – 1.4 (dock width) **(1)**

To demonstrate the limitations of the original model, we then regressed the observed bed quality from the 35 fixed dock configurations on the bed quality predicted using the old model (Figure 5). The old model fit the data fairly well ($r^2 = 0.57$) and the statistical results were highly significant, with an intercept not different from zero and a slope of 0.62. The slope was significantly less than 1.0, which indicated that eelgrass beds observed under docks in 2006 (especially taller docks) were found to be of poorer quality relative to surrounding beds than the quality predicted from the old model based on our observations in 1993. The results suggested that the model, in its original design, was not applicable to such a wide variety of dock configurations and tidal ranges as were documented in the 2006 observations. Therefore, we set out to develop a new, improved model that would guide varied dock configuration designs to minimize or eliminate impacts to eelgrass over a broader tidal range and geographic area.

Correlation of Dock Variables

A correlation matrix of all the dock and eelgrass variables was made using all observed dock configurations (43) as well as one made using only the fixed docks (35 observations). In general, docks at sites with greater tides were built more sturdily (i.e., thicker decks) and taller than comparable docks at sites with smaller tidal amplitude (Table 3). Floating structures were thicker than fixed docks due to floatation materials and these docks blocked more light. The results for fixed docks (Table 3b) showed that eelgrass bed quality was most highly correlated with the distance between the deck base and mean sea level (r = 0.68). The compass bearing of the dock axis also correlated with eelgrass bed quality (r = -0.42), showing that docks constructed along a north-south axis had reduced impacts to eelgrass under them, as found previously (Burdick and Short 1999, Shaefer 1999), while docks with an east-west axis had the greatest impact on eelgrass.

Results of the DEC Model

Based on information from correlations (Table 3) and stepwise regressions, a new multiple regression model was developed, DEC, that included the dock height above MSL, width, and bearing to predict impacts to eelgrass bed quality associated with specific dock configurations. Using data from 35 fixed structures assessed in 1993 and 2006, the model explained 70% of the variability in eelgrass bed quality under and near the docks ($R^2 = 0.70$; $F=22.8$; $P<0.0001$).

Eelgrass bed quality = 2.8 + 3.83 * (dock height above MSL) – 0.053 (compass bearing) – 0.74 (dock width) **(2)**

Dock height in the DEC model is the distance from deck base to mean sea level (MSL), which is slightly different, but easier to use and apply, than the definition of dock height in the old model. (Dock height had been defined in the previous model as the distance from the base of the deck to the marine bottom, which varies along the length of the dock.) Although the old model explained slightly more of the variability in bed quality (75%) it only included 16 fixed dock structures, all limited to tides of less than 1 m. The DEC model functions for areas with a tidal range of 0 to 3m and is based on 35 structures. The slight reduction in the DEC model's ability to explain variability in eelgrass bed quality is likely due to the fact that the DEC model incorporated considerably more dock data from more variable site conditions and habitats – ultimately making the new model more valuable over a broader geographical area (i.e., all of New England) than the previous version of the model that was based upon a more narrow range of site conditions (i.e., Nantucket and Falmouth, Massachusetts).

Despite broadening geographic range and environmental conditions in development of the DEC model, the expanded data set gives results comparable to the initial one (Table 4). For example, a dock height of 3.3 m above the marine bottom (with a water depth of 0.8 m MSL), would be required to yield a predicted eelgrass bed quality score of 9 in the old model for a dock orientation of 30° and width of 2.0 m. Similarly, a height of 2.5 m above the mean sea level yields the same bed quality, with all other parameters being equal in the new model, and with the depth to the marine bottom at 0.8 meters (MSL), the two models yield the same result.

Impacts of Docks on Eelgrass Beds

For development of the DEC model, a two-way ANOVA analyzed the new data from 22 dock configurations to estimate dock impacts to eelgrass beyond the area directly under the dock itself. Each dock configuration served as a block and eelgrass cover was estimated with a quadrat at three distances (0, 2 and 4 meters) and scored relative to eelgrass cover at the most distant station (8m) where it was assumed that no impacts to eelgrass occurred. The model was highly significant, explaining 80% of the variation in cover, and showed that, on average, one quarter of the reference eelgrass cover was supported under the docks, about 50% reference cover occurred at 2 m from the docks, and almost 75% reference eelgrass cover occurred at 4 m from the docks (Figure 6). Although we did not measure the corresponding reduction in light levels due to shading, the shading effects we observed are consistent with the literature, which suggests that light is the factor limiting seagrass survival and distribution (Kenworthy and Haunert 1991, Dennison et al. 1993, Shafer 1999, Shafer and Robinson 2001, Shafer et al. 2008). Additional work has specifically demonstrated the significance of light to survival of eelgrass in Long Island Sound and Narragansett Bay (Koch and Beer 1996) as well as in Waquoit Bay and Nantucket Harbor (Burdick and Short 1999). Regardless of whether the impacts away from the dock footprint are due to shading, dock construction or boat operation, the impacts from docks to eelgrass in our study were clear, consistent and measurable.

Impacts to eelgrass for each dock were calculated separately and are shown in Table 5. Impact areas are summed to show the total area of eelgrass impacted. The Total Eelgrass Loss (Table 5) is the area in square meters that requires mitigation to compensate for dock impacts. In light of these results, management agencies should carefully consider development of guidance documents for dock requirements, as has been done in Rhode Island and Florida. Furthermore, guidance documents should include a suite of mitigation rules covering area and density requirements as well as success criteria (Short et al. 2002). Such a guidance document should include minimum performance criteria for docks based on dimensional specifications and the predicted outcomes of dock design alternatives on eelgrass resources, all of which can be obtained from the new DEC model (Figure 7). To download the new, updated Dock Eelgrass Calculator, go to: http://marine.unh.edu/jel/faculty/fred2/seagrass-tools.htm

Summary

Shading effects from dock structures on growth and success of seagrasses and salt marshes alike have been ecologically significant enough to motivate regional workshops and conferences that highlight the current knowledge base and state of the science in several regions (see reviews by Smardon 2000, and Bliven 2003). With the exception of the contribution of Burdick and Short (1999), no published studies have developed a model that empirically calculates minimum dock specifications to reduce or eliminate shading effects of docks.

The new DEC model presented here integrates data from twice as many docks as the earlier version. It considers: 1) more variety in dock configuration, dimension, and construction materials; 2) greater tidal ranges, up to 3 m; and 3) a broader geographic area than the old version, with sites from southern Maine to Rhode Island. Finally, the use of mean sea level rather than marine bottom to measure deck height was an important change to more easily and accurately assess impacts to eelgrass at individual sampling stations rather than relying on a depth measure that varies along the length of the dock. The combination of the broadened tidal range, increased geographic area, addition dock variability, and changes in assessment methodology make the resulting DEC model more robust and applicable to a wider range of conditions in which eelgrass can be found throughout New England, representing an overall improvement to the model for dock design. Furthermore, our development of a user interface to input dock specifications makes the DEC model directly valuable to a wide ranging group of potential users, including regulatory, planning and engineering communities as well as property owners.

While the model developed here is designed to minimize dock impacts to eelgrass beds, it is not intended to encourage or promote dock development. The first priority is to avoid construction of docks within eelgrass habitat. The use of an existing dock or development of one community dock (rather than several individual docks) should always be considered. However, when building a dock across eelgrass is unavoidable, designs that minimize or avoid impacts should be used.

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Table 1. Characteristics of docks over or adjacent to eelgrass beds in New England collected in 1993 and 2006. Location ACK = Nantucket, NP = Ninigret Pond, NB = Narragansett Bay, PC = Pepperel Cove, PT = Provincetown, WB = Waquoit Bay and WH = Woods Hole.

Location	Year	Site	Tide Range (m)	Compass Bearing	Fixed	Width (m)	Thickness (cm)	Deck Ht. / MLW	Deck Ht. / Bottom	Deck Ht. / Mean Water	Bed Quality (0-9)
ACK, MA	1993	Brant Pt #1	0.98	20	Yes	6.9	28	1.97	2.86	1.51	1
ACK, MA	1993	Brant Pt #2	0.98	0	Yes	1.35	34	1.71	2.21	1.25	7
ACK, MA	1993	Ch Beach S	0.98	60	Yes	1.25	32	1.18	1.84	0.72	0
ACK, MA	1993	Ch Beach N	0.98	60	Yes	1.8	35	0.89	1.28	0.43	0
ACK, MA	1993	Town Dock	0.98	90	Yes	2.42	30	1.9	3.4	1.44	3
ACK, MA	1993	Town Dock	0.98	90	No	4.8	71	-0.23	1.57	-0.23	1
ACK, MA	1993	Monomey #1	0.98	60	Yes	2	30	2.59	3.24	2.13	5
ACK, MA	1993	Monomey #2	0.98	60	Yes	1.8	35	2.35	2.88	1.89	9
ACK, MA	1993	Hulbert Ave.	0.98	20	Yes	1.52	23	2.12	2.44	1.66	9
NP, RI	1993	Ninigret Pond	0.3	30	No	0.76	50	-0.1	1.19	-0.1	0
WB, MA	1993	Great River #1	0.55	80	Yes	1.8	22	1.45	2.22	1.3	0
WB, MA	1993	Great River #2	0.55	85	Yes	1.45	33	1.18	2.18	1.03	0
WB, MA	1993	Great River #3	0.55	85	No	2.5	100	-0.4	0.77	-0.4	0
WB, MA	1993	Great River #4	0.55	70	Yes	0.73	16	0.72	1.34	0.57	0
WB, MA	1993	Jehu #5a	0.55	40	Yes	1.87	27	0.36	1.09	0.26	0
WB, MA	1993	Jehu #5b	0.55	40	No	3.5	50	-0.09	0.82	-0.09	0
WB, MA	1993	Jehu #6	0.55	85	Yes	1.21	27	0.51	1.49	0.41	0
WB, MA	1993	Jehu #7a	0.55	40	Yes	1.22	23	0.78	1.28	0.68	0
WB, MA	1993	Jehu #7b	0.55	40	Yes	1.02	16	0.7	1.61	0.6	0
WB, MA	1993	Jehu #7c	0.55	40	No	1.83	34	-0.09	1.42	-0.09	2
WH, MA	1993	Town Dock	0.59	40	Yes	1.24	60	1.35	1.79	1.08	5
WH, MA	2006	Penzance PZ1	0.59	5	Yes	1.75	26	1.35	2.77	1.05	7.5
WH, MA	2006	Penzance PZ2	0.59	0	Yes	1.55	23	2.12	3.12	1.82	9
WH, MA	2006	Penzance PZ4	0.59	10	Yes	3.37	33	1.5	2.17	1.2	7
WH, MA	2006	Penzance PZ5	0.59	0	Yes	1.55	36	1.58	2.05	1.28	5
WH, MA	2006	Penzance PZ7	0.59	60	Yes	1.8	28	1.56	2.43	1.26	7.5
WH, MA	2006	Penzance PZ8	0.59	60	Yes	3.6	28	1.51	2.84	1.21	2
NB, RI	2006	RZ1	1.25	80	Yes	1.27	34	3.16	3.96	2.54	6

NB, RI	2006	RZ2	1.25	80	Yes	1.27	34	2.36	4.24	1.74	4.5
NB, RI	2006	RZ3	1.25	80	Yes	1.5	33	1.53	3.99	0.91	3
NB, RI	2006	NC1	1.25	90	Yes	1.4	34	2.44	3.45	1.82	3
NB, RI	2006	NC2	1.25	0	No	2.5	55	-0.15	1.87	-0.15	3
NB, RI	2006	EG1	1.25	85	Yes	0.9	20	1.5	2.1	0.88	2
NB, RI	2006	EG2	1.25	85	No	2.6	95	-0.45	2.05	-0.45	0
NB, RI	2006	BP1	1.25	25	Yes	1.2	33	2.77	3.62	2.15	7
NB, RI	2006	BP2	1.25	25	Yes	1.2	33	1.87	2.92	1.25	6
NB, RI	2006	BP3	1.25	25	Yes	1	33	1.87	3.17	1.25	3
NB, RI	2006	BP4	1.25	25	Yes	4.5	33	1.87	3.17	1.25	0
NB, RI	2006	MZ1	1.25	80	Yes	1.3	33	3.37	4.17	2.75	7
NB, RI	2006	MZ2	1.25	80	Yes	1.3	33	1.64	2.87	1.02	2
PT, MA	2006	CG1	2.99	30	Yes	3.7	45	3.63	3.95	2.14	7
PT, MA	2006	CG3	2.99	30	Yes	3.7	45	3.63	4.4	2.14	8.5
PC, ME	2006	PC1	2.85	4	No	3.66	61	-0.13	0.88	-0.13	0

Table 2. Dock characteristics averaged by collection year for fixed structures; data for floating portions were averaged for both collection years. Means are followed by standard errors.

Collection Year	n	Tide range (m)	Compass bearing (°)	Width (m)	Thickness (cm)	Deck Ht. / MSL (m)	Bed Quality (0-9)
FIXED DOCKS ONLY							
1993	16	0.77 +/-.06	53 +/-7	1.9 +/-.4	29 +/-3	1.06 +/-.14	2.4 +/-.9
2006	19	1.22 +/-.16	46 +/-7	2.0 +/-.3	33 +/-1	1.56 +/-.13	5.1 +/-.6
FLOATING DOCKS ONLY							
Both years	8	1.04 +/-.29	47 +/-13	2.8 +/-.43	65 +/-8	-0.21 +/-.05	0.8 +/-.4

Table 3. Correlation matrices of dock characteristics using data from both floating and fixed docks (A; n=43) and only fixed docks (B; n=35). Underlined values indicate significance at alpha = 0.05 (two-tailed) for A: $|r|>0.301$ and B: $|r|>0.335$.

A. Variable	Year	Tide Range	Bearing	Fixed = 1 Floating =-1	Width	Thickness	Deck Ht./ Bottom	Deck Ht./ MSL	Bed Quality (0-9)
Year	1.000	.475	- .173	.131	.029	.020	.572	.340	.401
Tide Range		1.000	- .124	- .012	.318	.203	.451	.281	.247
Bearing			1.000	.031	- .180	.112	.094	- .022	- .353
Fixed/Float				1.000	- .260	- .741	.531	.738	.384
Width					1.000	.301	.029	- .086	- .114
Thickness						1.000	- .266	- .492	- .194
Deck/Bottom							1.000	.843	.611
Deck/ MSL								1.000	.704
Bed Quality									1.000

B. Variable	Year	Tide Range	Bearing	Width	Thickness	Deck Ht./ Bottom	Deck Ht./ MSL	Bed Quality (0-9)
Year	1.000	.403	- .125	.058	.187	.625	.414	.414
Tide Range		1.000	- .028	.296	.472	.660	.514	.334
Bearing			1.000	- .287	- .105	.092	- .033	- .423
Width				1.000	.165	.235	.184	- .012
Thickness					1.000	.345	.326	- .329
Deck/Bottom						1.000	.822	.521
Deck/ MSL							1.000	.681
Bed Quality								1.000

Table 4. Dock heights (m) needed to support eelgrass based on bed quality using both old and new models with a dock width of 2 meters.

	Compass bearing of the dock long axis				
Eelgrass Bed Quality	0 (N)	30	60	90 (E)	120
OLD MODEL RESULTS – heights (m) from deck base to marine bottom					
9 (equal)	**2.7**	**3.3**	**3.9**	**4.5**	**3.9**
7	**2.2**	**2.8**	**3.4**	**4.0**	**3.4**
5 (1/2)	**1.7**	**2.3**	**2.9**	**3.5**	**2.9**
3	**1.2**	**1.8**	**2.4**	**3.0**	**2.4**
0 (none)	**0.5**	**1.1**	**1.7**	**2.2**	**1.7**
NEW MODEL RESULTS – heights (m) from deck base to mean sea level (MSL)					
9 (equal)	**2.1**	**2.5**	**2.9**	**3.3**	**2.9**
7	**1.5**	**2.0**	**2.4**	**2.8**	**2.4**
5 (1/2)	**1.0**	**1.4**	**1.8**	**2.2**	**1.8**
3	**0.5**	**0.9**	**1.3**	**1.7**	**1.3**
0 (none)	**NA**	**0.1**	**0.5**	**0.9**	**0.5**

Table 5. Area of impacts to eelgrass beds (square meters) from docks found overlying and interrupting meadows in 2006. Location: PC = Pepperel Cove, ME; WH = Woods Hole, MA; PT = Provincetown, MA; and NB = Narragansett Bay, RI. Percent impact under and adjacent to docks were calculated from reductions in eelgrass cover compared to stations furthest removed from impacts of shading and vessel activity. Near impacts were 0-3 meters and Far impacts were 3-5 meters from docks, (except 0-4 m and 4-6 m, respectively, for Provincetown Harbor). *Docks in Pepperel Cove and Woods Hole lacking Near data measured Far impacts at 0-4 m away. Total area is eelgrass habitat impacted due to the dock impact and represents the area requiring mitigation.

		Under Dock		Near (0-3 m)		Far (3-5 m)		**Eelgrass Impacted**
Location	Dock	Area	% Impact	Area	% Impact	Area	% Impact	Total Area
PC	PC1	27.6	100	*		28.8	81	**56.4**
WH	PZ1	97.8	44	*		136.0	20	**233.8**
WH	PZ2	44.4	44	*		64.0	26	**108.4**
WH	PZ4	44.2	89	*		48.0	23	**92.2**
WH	PZ5	42.5	77	*		61.2	41	**103.7**
WH	PZ7	203.0	38	*		280.0	0	**203.0**
WH	PZ8	24.4	99	17.4	71	26.1	17	**67.9**
PT	CG1	808.5	57	630.0	25	1050.0	27	**2488.5**
PT	CG3	1516.9	41	1182.0	28	1970.0	15	**4668.9**
NB	RZ1	56.2	58	68.8	62	103.2	21	**228.2**
NB	RZ2	30.7	92	37.6	83	56.4	68	**124.7**
NB	RZ3	35.7	96	15.2	67	22.8	44	**73.7**
NB	NC1	32.2	75	64.4	53	96.6	11	**193.2**
NB	NC2	27.5	85	24.4	19	36.6	0	**88.5**
NB	EG1	12.8	93	17.6	53	26.4	23	**56.8**
NB	EG2	27.5	100	24.4	61	36.6	0	**88.5**
NB	BP1	46.1	19	57.6	28	86.4	0	**190.1**
NB	BP2	29.1	47	36.4	28	54.6	28	**120.1**
NB	BP3	15.0	100	20.0	63	30.0	0	**65.0**
NB	BP4	19.5	100	12.0	100	18.0	100	**49.5**
NB	MZ1	14.5	43	17.6	68	26.4	50	**58.5**
NB	MZ2	11.9	80	14.4	25	21.6	0	**47.9**

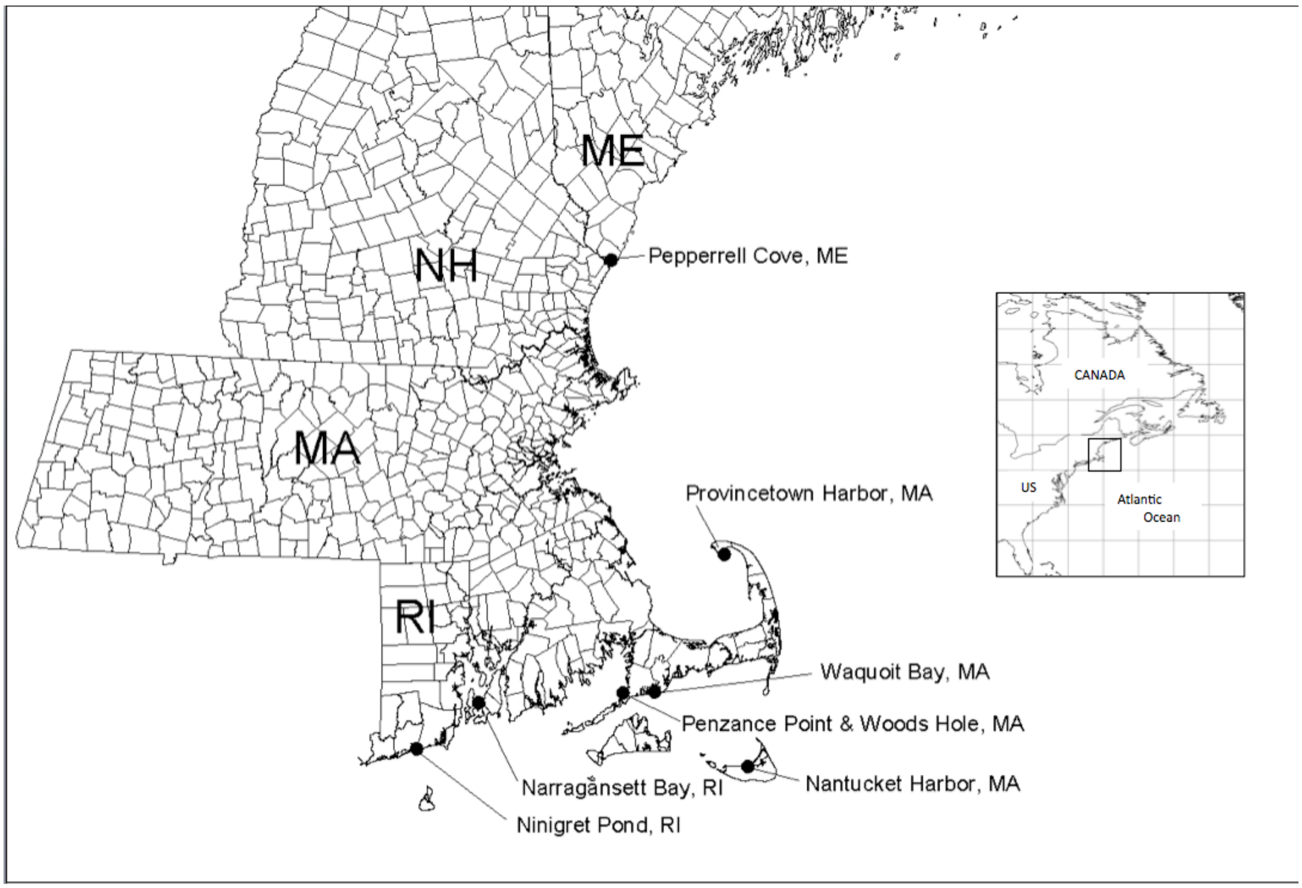


Figure 1: Locations of docks studied in New England. A total of 43 docks were measured in three New England states (MA, ME and RI) during sampling dates in 1993 and 2006.

Figure 2. Schematic of dock: dimensions, eelgrass beds, transect locations and the physical parameters measured in the field. Stations are coded 1 = under dock, 2 = adjacent to dock, 3 = midpoint distance between stations 2 and 4, and 4 = farthest away from dock, outside of impacts from the structure. Note that fixed docks, floats, and associated ramps, when present, are considered separate dock structures. The triangles (T-1, etc.) show sampling positions along the dock.

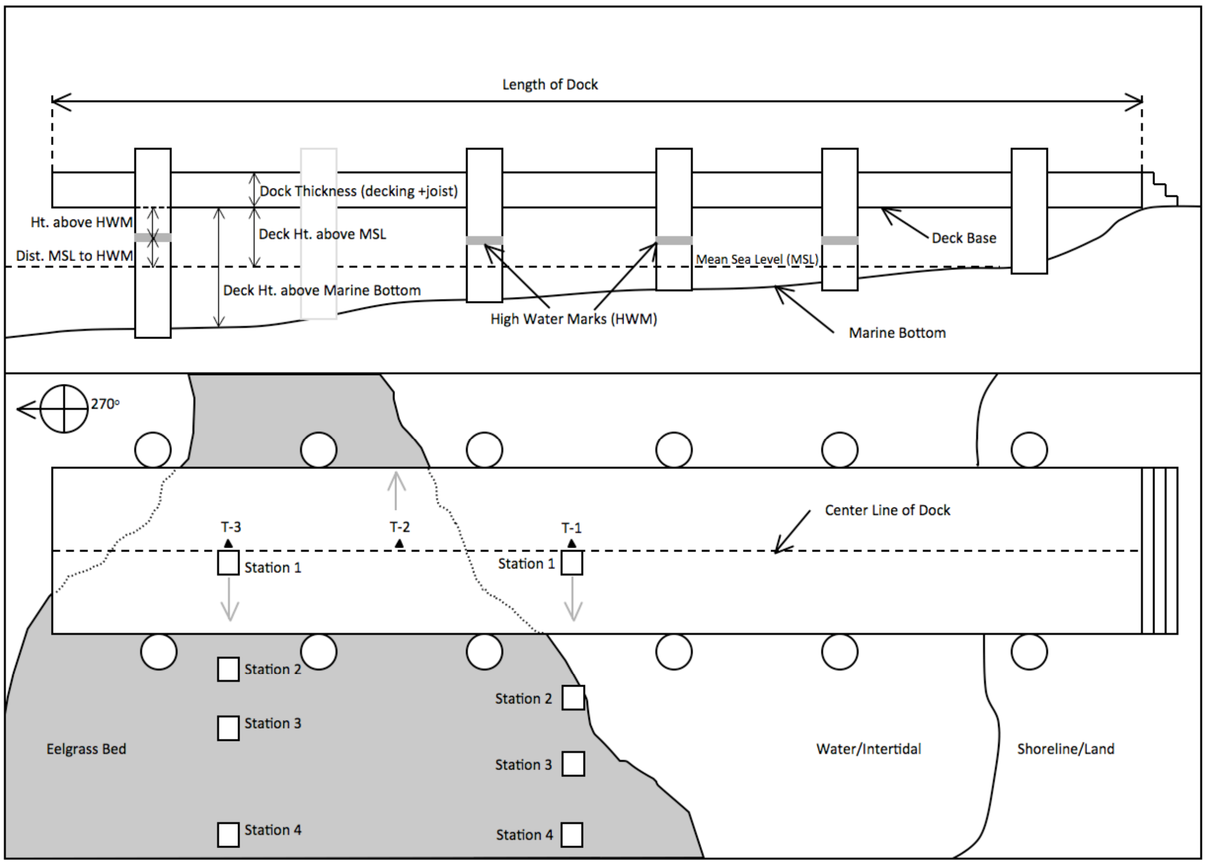
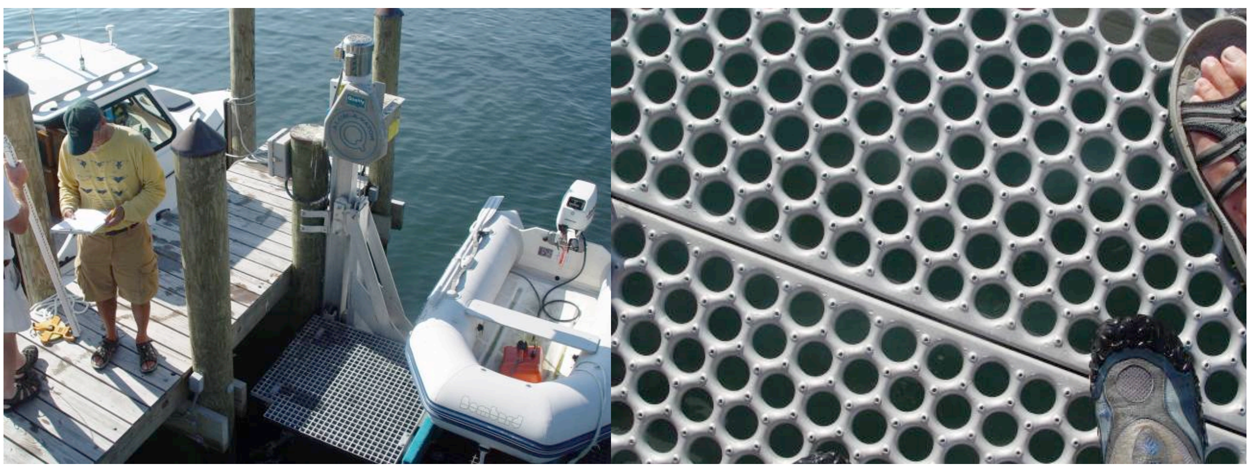


Figure 3. Typical wood-framed docks and floats sampled in this study.

Figure 4. Examples of wood, fiberglass (adjacent to inflatable dingy) and aluminum decking materials.



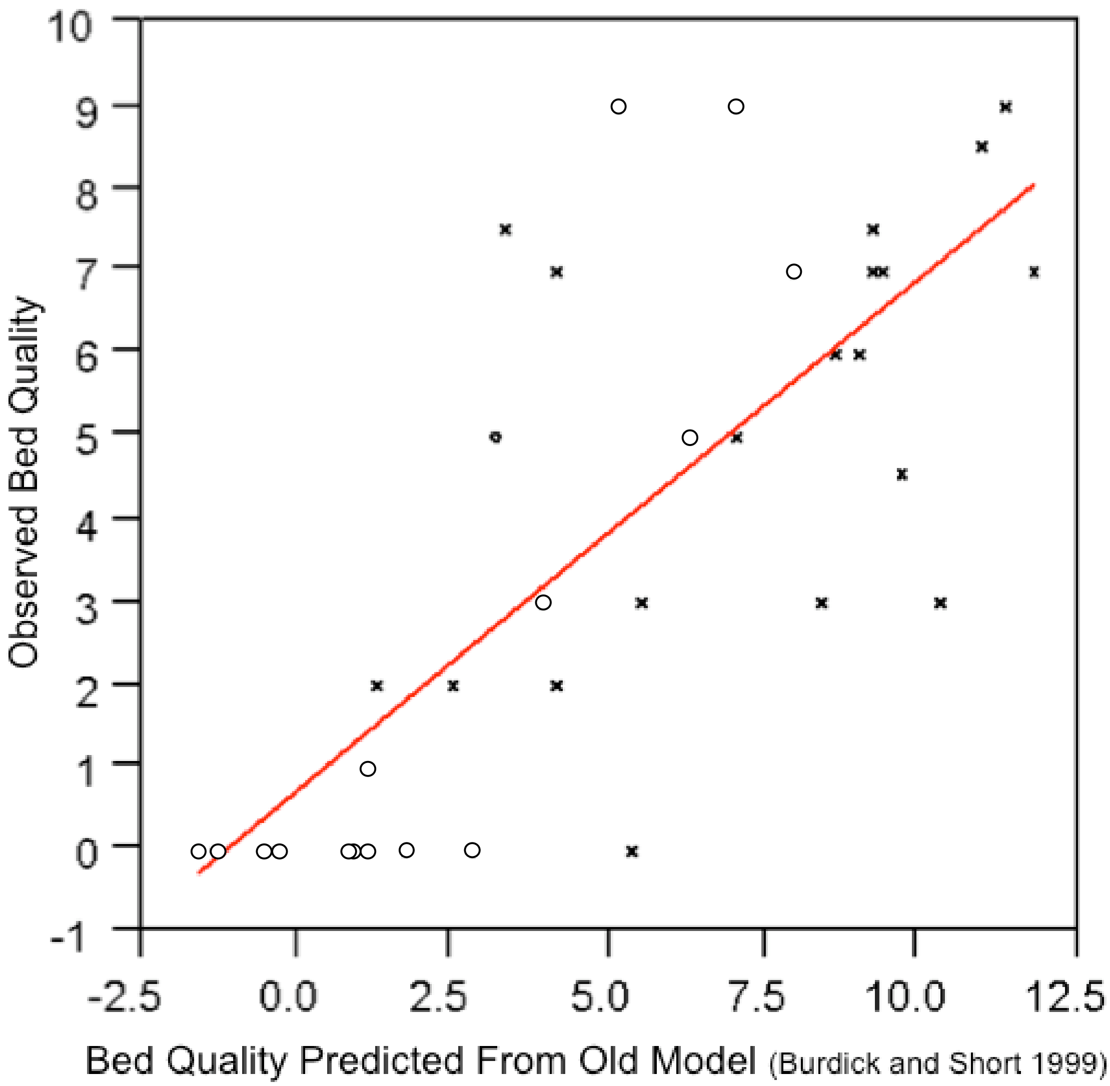


Figure 5. Comparison of 1993 (o) and 2006 (x) observations versus predictions from old model of eelgrass bed quality under fixed docks.

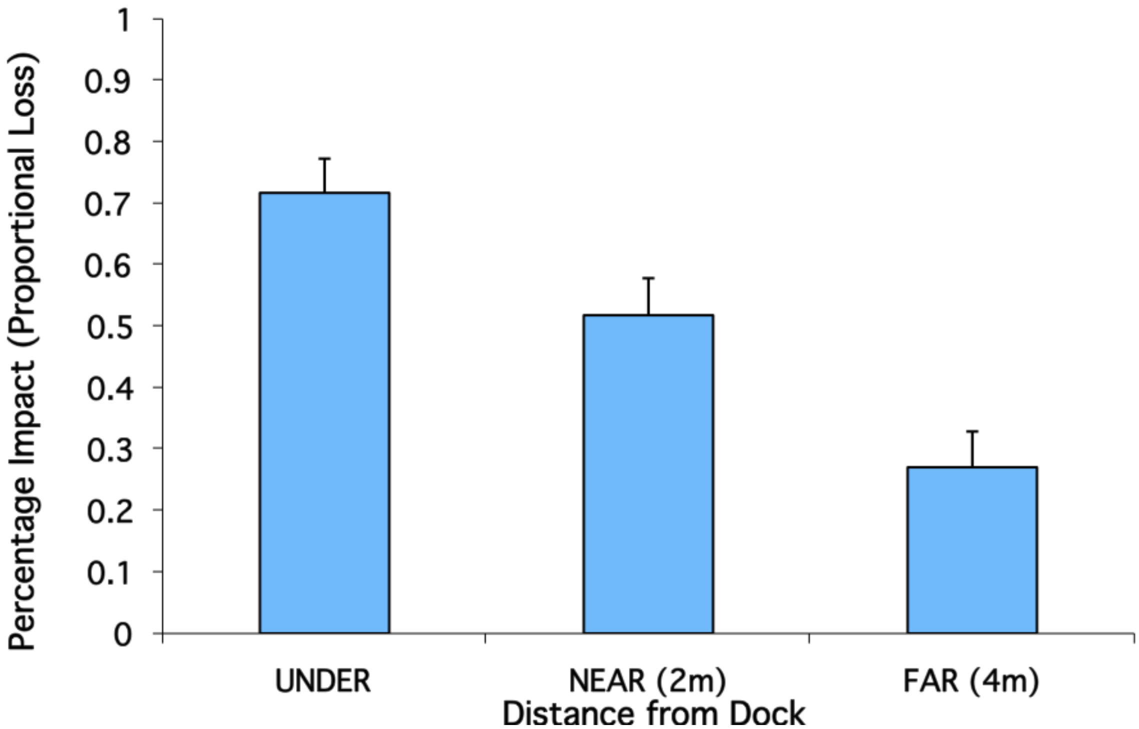


Figure 6. Impacts to eelgrass under and near docks.

Figure 7. DEC, the Dock Eelgrass Calculator in MS Excel.