# Management of Small Docks and Piers

# Environmental Impacts and Issues

# Forward—

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# Introduction—

Private docks have been implicated in a number of environmental impacts. Some of these have received scientific investigation and some remain anecdotal. In an attempt to clarify what is known about environmental impacts from docks, NOAA’s National Centers for Coastal Ocean Science convened a workshop in January of 2003. This session brought together scientists and a group of coastal managers from across the country to discuss the environmental impacts of small docks. The results of that workshop may be found in Kelty and Bliven (2003).

The workshop identified four general impacts:

Impacts to vegetation

Impacts from contaminants related to docks

Impacts from associated boating use

Impacts to sediments and substrate

Impacts to wildlife habitat were discussed as part of the topics above, as this is a significant cross-cutting issue.

# Impacts to Vegetation from Small Docks—

Marsh plants and submerged aquatic vegetation (SAV) are ecologically critical as a source of food and nursery habitat for fish, shellfish, amphibians, reptiles, birds and mammals that live in coastal waters or the adjacent marsh and uplands (Weigert *et al.,* 1981; Teal, 1962, 1969; Weinstein, 1996). Vegetated areas also stabilize shoreline and bottom sediments against erosion (Kearney *et al.,* 1983; Teal, 1986) and take up contaminants and excess nutrients from the water and sediments (Vernberg, 1996).

Impacts to plant health and productivity from docks generally occur in one of the following ways:

Short-term construction impacts,

Chronic impacts from shading,

Chronic impacts from storage of floats and boats and associated foot traffic, and

Impacts from boat use (covered later in this module as a separate topic).

## *Short-Term Construction Impacts—*

Activities during construction can destroy plants either above the tide line (*e.g.,* marsh grasses such as *Spartina* or *Distichlis*) or below (*e.g.*, sea grasses such as *Zostera* or *Halodule*) by pulling them from the substrate or destroying their root systems. The peat beds underlying salt marshes can be compacted through the improper use of heavy equipment leading to ponding of saline waters and a resultant loss or changing of marsh vegetation. Although these impacts are seemingly evident, limited research appears to have been done on the long-term effect of these activities.

Setting pilings in sea grass beds may have immediate impacts as well as causing long-term changes. The act of installing pilings destroys any vegetation within the footprint of the pilings. The use of “jetting” with high-pressure hoses typically disturbs adjacent vegetation and sediments—depopulating grasses existing there prior to construction. Once areas are depopulated, the presence of pilings may lessen chances for regrowth. Beal, Schmit, and Williams (1999) suggest that changes in seagrass communities in the vicinity of pilings may be caused by the modification of currents, sediment deposition, attraction of bioturbators, and leaching from chemically treated wood.

Shafer and Robinson (2001) tracked the regrowth of the seagrass *Halodule wrightii* beneath docks in St. Andrew Bay, FL. They noted bare areas from 35–78 inches in diameter around pilings, ”even though the age of these docks varied widely” suggesting that regrowth is affected by the presence of pilings. Use of high pressure jetting produced a six- to seven-foot diameter hole around each piling, which was then backfilled to hold the piling in place. The resultant “halo” might remain for 10 years without seagrass regrowth. The authors found that where piles were installed using low-pressure jetting techniques there was, “little or no sand deposition around the pilings and the remaining seagrasses around the pilings looked healthy and had good growth around the piling.”

Dock construction also impacts marsh grass. Sanger and Holland (2002) noted a barren path through the marsh along each side of a newly constructed dock in North Carolina where vegetation had been almost totally destroyed. However, construction did not appreciably alter the original marsh elevations. Resurveying the site 15 months later, the researchers found that *Spartina. alterniflora* had recolonized the area and substantial recovery had occurred.

## *Chronic Impacts from Shading—*

Both marsh grasses and sea grasses have adapted to living in extended periods of sunlight. Therefore, shading can have significant impacts on the health and productivity of these plants. Figure 1 illustrates some of the potential impacts from dock shading. Two thresholds are shown; the minimum amount of light necessary for the plant to reach full growth, and the minimum amount of light for the plant to sustain itself. Below the first threshold, plants are stunted in growth or grow tall and spindly in an attempt to reach sunlight. Below the second threshold, plants die.

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**Figure 1.** Light Profile under a dock (From Nightengale and Simenstad 2001. Ron Thom, pers. comm.). The graph illustrates how the shading of an east-west oriented dock affects light levels and vegetation growth below a dock in Washington state. The two horizontal lines indicate the light levels necessary for full, unaffected growth of plants (Minimum light needed for full growth) and the amount of light for plants to live (Minimum light for plant maintenance). Note that much of the area beneath the illustrated dock is below the threshold for plant life. Note also that the shading is somewhat offset to the north due to the declination of the sun.

Amount of Light Required by Vegetation—

Susceptibility to shading varies by species, even those occupying similar habitats. For example, in marsh grasses, densities of *Spartina patens* (Salt Meadow Grass or Salt Hay Grass) and *Distichlis spicata* (Spike Grass or Salt Grass) are more sensitive than *Spartina alterniflora* (Smooth Cordgrass or Saltwater Coordgrass) (Kearney *et al.* 1983).

Light levels necessary for plants to sustain themselves generally range between 12–25 percent of ambient light, depending on the species. Specifically for seagrasses, a National Marine Fisheries Service (NMFS) Technical Memorandum reports that “the light requirements of temperate and tropical seagrasses are very similar” requiring “at least 15 to 25% of the incident light just for maintenance” (Kenworthy and Haunert, 1991). Light requirements are presumably higher to allow full growth but there has been limited research that provides specific percentages.

NMFS’ summary report is supported by studies on individual seagrass species. For example, Shaefer and Robinson (2001) report that light levels of 13–14 percent of mean daily surface irradiance (SI) are necessary for survival of the seagrass *Halodule wrightii*. Shaefer (1999) found that seagrass densities were 40–47 percent less in areas shaded at levels of 16–19 percent SI. Burdick and Short (1999) observed similar trends in the eelgrass, *Zostera marina,* which required light levels of at least 15 percent of surface irradiance for survival and approximately 50–60 percent for healthy beds.

## Direct Impacts of Shading—

As we have already demonstrated, marsh and submerged aquatic vegetation need adequate light levels to survive and flourish. Therefore shading from docks can have significant implications for this vegetation. Recent studies have shown that shoot density, biomass, and overall plant growth may be reduced by dock shading (Sanger and Holland, 2002; McGuire, 1990; Burdick and Short, 1999). In some instances, researchers found an increase in the height of marsh grasses found under docks, possibly due to etiolation. (Etiolation is a condition in which plants growing in reduced light levels elongate much more rapidly than normal as a means of reaching light. It is characterized by long weak stems and small leaves.)

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**Figure 2.** Eelgrass density was significantly lower under and near docks than at sites removed from the dock by various distances (Burdick and Short, 1999).

Impacts due to shading also appear in fresh waters. Garrison *et al.* (2005) investigated shading impacts on submerged vegetation and relationships to fish and invertebrate habitats. They found significant shading under docks “with a corresponding reduction in aquatic plant abundance” in Wisconsin lakes. By placing unbaited minnow traps below piers and within nearby, control vegetated zones, the researchers also found decreased numbers of macroinvertebrates and vertebrates as well as changes in species composition.

Wilson (2002), working in fresh-tidal waters in Connecticut, found that not only did shading have impacts on existing submerged aquatic vegetation but it also adversely affected its ability to regenerate after being mechanically disturbed. (Wilson manually clipped the submerged vegetation in his research but suggests that similar effects would be found from disturbance by boat propellers.)

Geographic Area Affected by Shading—

It is clear that shading from docks can have an adverse impact on the underlying vegetation but one of the questions coastal managers grapple with most is how much total marsh grass or seagrass with be affected by docks, and will the addition of more docks have a significant impact on the total amount of vegetation present. Sanger and Holland (2002) compared the area of marsh affected by docks to the total area within specific creek systems and also estimated the amount of marsh affected by docks through out coastal South Carolina. Based on the number of docks present in 1999, they estimated that docks reduced *S. alterniflora* densities by 0.03–0.72 percent within their study sites. When they projected to a total possible build-out of similarly sized docks in the creek systems, Sanger and Holland calculated that docks would cause a 0.18–5.45 percent decrease in marsh grass. Finally, Sanger and Holland applied this approach to the projected build-out of docks for all eight coastal counties by the year 2010. They estimated that a reduction in marsh density of between 0.03–1.98 percent could be attributed to dock impacts.

Smith and Mezich (1999, in Shafer 2001) note that up to 50 acres of seagrass beds had been negatively impacted in the early 1990s by single-family docks in the Palm Beach County, Florida. Studies in Georgia (Alexander and Robinson, 2004) suggested a maximum estimate of 4–6 percent of the marsh around Wilmington Island could be shaded if full build-out should occur under the provisions of current state laws.

It should be noted that the significance of these shading impacts to the coastal ecosystem as a whole varies by region and the amount of salt marsh or seagrasses present. In areas where coastal vegetation is already severely reduced or otherwise impacted (*e.g.,* New England and Florida) affected areas as a percentage of the entire marsh system could be higher than those reported for South Carolina and Georgia.

## Indirect Impacts of Shading—

Changes in vegetation density and hardiness may lead to increasing sediment erosion and resuspension, and increased undercutting of the marsh shoreline near the dock because robust healthy marsh and seagrass vegetation is no longer present to hold the sediments in place (Burdick and Short 1999).

Burdick and Short (1999) also found that shading of eelgrass beds can lead to fragmentation, thereby disrupting wildlife habitat. The work of Garrison *et al.* (2005) mentioned previously showed that the loss of vegetation due to shading by docks reduced fish and large invertebrate abundance and altered species composition in Wisconsin lakes.

A subsequent effect of the shading by docks in Connecticut was reported to be accelerated soil erosion beneath structures passing over *S. alterniflora* at the edge of the marsh (Kearny *et al.* 1983).

## Factors that Affect Shading—

Kearney *et al*. (1983) studied impacts to marsh grasses from walkways/docks from “all the structures” within Connecticut’s major salt marsh regions, collecting data on vegetation density and height beneath and adjacent to the structures, and the physical dimensions of the docks (width, height, plank width, and spacing between planking—they did not include orientation). They found that dock height was the only statistically significant variable; docks less than 12–16 inches above the marsh shaded out all vegetation in every study site. Any impacts from dock width, plank width, and plank spacing were not statistically significant. However, it should be noted that a National Marine Fisheries Service study that assessed dock impacts on marsh grass vegetation in Connecticut, Rhode Island, and Massachusetts cast some doubt on the methodology and statistical analyses of Kearney *et al* (1983) (Colligan and Collins, 1995).

In a field study conducted in Waquoit Bay, Falmouth/Mashpee and Nantucket Harbor (all in Massachusetts), Burdick and Short (1999) found that dock height was not the only factor influencing shading impacts on eelgrass beds but that the orientation of the dock and dock width also played significant roles. According to their data, North-South orientated docks had less impact than East-West orientated ones.

While orientation may be an important factor in northern latitudes, it may not play a significant role in lower latitudes. Sanger and Holland (2002) assessed impacts on *S. alterniflora* from 32 docks in the Charleston, SC area*.* The structures represented a range of lengths, orientations, and ages. They found no significant difference in reduction in *S. alterniflora* density due to shading between North-South oriented docks and those with an East-West orientation.

The National Marine Fisheries Service suggests that spacing between decking planks on the order of an inch or two has little effect on shading impacts, particularly in northern latitudes (Michael Ludwig, NMFS, Personal Communication, 2003). There appears, however, to have been little systematic research on this topic.

In summary, it appears that dock height and width are significant factors that contribute to shading impacts on vegetation. However, but it is still unclear whether orientation and spacing between decking boards have measurable impacts. There appear to be differences in these impacts between northern and southern latitudes.

## Models to Predict Shading—

McGuire (1990) measured the effects of shading by open pile structures on *S. alterniflora*

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| --- | --- |
| Concentrations of CCA Wood TreatmentsRecommended for Various Uses | |
| Retentions *(lbs./cu.ft.)* | Uses/Exposures |
| 0.10 – 0.25  0.21 – 0.41  0.31– 0.61  2.50 | Above ground  Soil & Freshwater use  Permanent Wood Foundation  Saltwater use |

s) than sand (Luoma and Davis, 1983). Field studies by Weis *et al.* (1992, 1998) found elevated concentrations of metals in fine sediments adjacent to (within 1 meter) bulkheads (solid walls of treated lumber, as opposed to dock pilings) constructed of CCA-treated material. The distance at which elevated levels could be found varied according to the sediment types. At most test sites, the impacts were limited to one meter from the structure. In some other sites where fine-grained sediments were predominant, the elevated levels could be found out to approximately 10 meters (Weis *et al.*, 1998).

Elevated concentrations of metals from CCA-treated wood can be found in organisms living on treated pilings and in the areas near to the pilings (Wendt *et al.*, 1996; Weis and Weis, 1996). In sediments with higher contaminant levels, species richness was depressed (Weis and Weis,1998).

Snails in the laboratory fed marine algae gathered from CCA-treated pilings became inactive in 3-4 weeks; they initially curled up inside their shells and then died (Weis *et al.*, 1991). A field study of oysters living on CCA-treated wooden bulkheads showed that they were smaller than control populations and had taken up measurable levels of copper (Weis *et al.* 1993). When copper concentrations are high enough, the oysters’ digestive glands shrink, leading to death. Wendt *et al.,* (1996), however, evaluated uptake of metals by white shrimp, mud snails and two species of fish (mummichogs and red drum) and found no increase in mortality in individuals placed adjacent to 5–12 month old docks for 96 hours. As noted previously, 99% of all leaching occurs within the first three months; the 5–12-month age of the docks in Wendt *et al.’s* study is outside the period when significant leaching occurs.

Factors involved in impacts to biota appears to include sediment type (mentioned above), amount of CCA-treated material (piers vs. bulkheads), length of time the CCA-treated material has been immersed in marine waters (more than or less than 3 months), and the flushing rate of the water body. In an unpublished “gray literature” study prepared for the New Jersey Department of Environmental Protection, Weis and Weis (1998) looked at sediments and shellfish in the Navesink-Shrewsbury River system (NJ) in relation to distance from docks constructed with CCA-treated materials. They found that concentrations of metals in sediments adjacent to pilings at their test sites “were generally not significantly elevated … it appears that leachates from pilings, in reasonably flushed areas have negligible ecological effects, while those from bulkheads, particularly new ones and ones in poorly flushed regions, have demonstrated, clear-cut, ecological effects.” Sanger and Holland (2002) report that, “it is unlikely that the bioaccumulation of dock leachates by marine biota is having or is likely to have an impact on living resources in South Carolina estuaries and tidal creeks.” Reasons given are that approximately 99% of the leaching takes place in the first three months after installation, that the size of the area around the dock that might be affected is small, and high rates of tidal flushing will dilute and flush any accumulations in the water column.

While Weis *et al.* (1991) noted mortality in snails fed algae grown on CCA-treated wood in laboratory tanks, there have been, thus far, no reports of the transfer of metals from the CCA treatment up the food chain to higher predators (P. Weiss in Kelty and Bliven, 2003).

As of 2004, pressure-treated lumber intended for residential and recreational (including docks in freshwater) is no longer treated with CCA. (CCA-treated materials are still used in marine waters.) Alternative treated wood intended for freshwater applications include: Alkaline Copper Quat (ACQ) and Copper Azole (CA, “Wolmanized”®). These are not recommended for marine use.

To summarize, issues to consider in management decisions relating to CCA-treated materials include:

the area of exposed surface of CCA-treated materials (bulkheads have greater surface exposed to water than dock pilings so have a greater potential to leach contaminants into the environment),

the age of the materials used (most leaching occurs within the first 90 days,

the types of sediments in the area (fine-grained sediments with high organic content take up more contaminants than larger grained sediments), and

the flow of water through the system.

Despite these research efforts however, a tidal flushing threshold for contaminant impacts has not been identified, and data do not exist to evaluate the importance of dilution in high flow areas with different benthic community composition.

# *Impacts from Flotation Materials—*

Plastic, non-enclosed foam billets are occasionally used as floatation material for docks. Sometimes referred to by the tradename Styrofoam or “beadboard.” Open-cell foam absorbs water over time and reduces flotation support. More importantly to environmental effects, it breaks down easily into small beads that are virtually indestructible. Pieces of these billets may litter the shoreline or be ingested by wildlife. It may choke air-breathing species or take up considerable space in the digestive tract of species that ingest it, lessening their ability to take up nutrients. Use of this material as dock flotation has been banned in many jurisdictions (Burns, 1999).

*Impacts from Painting and Seasonal Upkeep—*

Painting, staining, scraping or other seasonal maintenance to docks can introduce contaminants into the water column. To avoid potential pollution caused by this type of dock maintenance activity, the Maine State Planning Office (1997) discourages painting and staining, suggesting that “all coatings pose a local environmental threat, damage floatation materials, and have only minimal effect on a structure’s longevity.”

*Impacts from Fuel Leakage—*

Fueling that takes place at small docks generally consists of pouring fuel from a portable tank into an outboard engine’s fuel tank—often with the engine attached to the stern of the boat directly over the water. This offers the opportunity for spillage or overflows. Poorly designed or maintained engines also may discharge fuel during operation. Petroleum products in marine waters can have significant impacts to be discussed further in the following section on boating impacts.

**Impacts of Small Docks on Sediments and Sedimentation—**

During a permit review or planning exercise, coastal managers sometimes hear concerns that small, pile supported docks may cause changes to sediments topography and composition in the vicinity of the structure. This may be attributed to erosion, increased sedimentation, or resuspension and movement of specific particulate sizes or types. Generally, one of the following three mechanisms are suggested:

Changes in water movement due to pilings redirecting water flow or speeding movement around the pile resulting in scour,

Disruption of sediments during piling installation,

Suspension of sediments as floats or boats attached to docks touch or approach the bottom at low tides and lift sediments as they rise with the tide (“pumping”).

# *Altering currents—*

Structures placed in moving water have the capability to disrupt the water’s flow. Piles may cause increased flow rates immediately around their base leading to scour and erosion. They may also lead to a general slowing of flow over the area of the dock, resulting in settling out of sediments carried by the current. The resulting changes in sediments caused by scour or deposition may affect fish shellfish or habitat.

There appears to be very little in the way of research results available on the impacts on sedimentation from small pile supported structures. What research has been reported was done in open ocean settings, not in embayments, and most focused on the morphological changes to adjacent shorelines and bottom topography—no information was located on the nature of sediment type change, if any, over time in the vicinity of pile-supported piers.

What literature was located was done in the 1970s. Noble (1978) assessed the impacts of 20 piers—all situated within the Southern California Bight. These piers ranged from 625–2,500 feet in length and 15–300 feet in width—far larger than the small recreational facilities under consideration here. All of the piers studied had pile spacing greater that 4 times the diameter of the piles. Noble found that these piers “had a negligible effect” on sedimentation and erosion of adjacent shorelines. He notes that his results support prior findings of Johnson (1973) and Evert and DeWall (1975).

Miller *et al.,* (1983), researching the impacts of an 1,840-foot long, 20-foot wide pier near Duck, NC on the Atlantic coast found that the pier produced a permanent trough under the pier reaching a maximum depth of 9.9 feet. Scour around individual pilings was noted to be on the order of 3.3 feet in depth. The pilings in this case are 30 and 36 inches in diameter spaced 15 feet on center across the pier and 40 feet on center along its length.

In an engineering study related to Lagoon Pond on Martha’s Vineyard, MA, Poole (1987) suggests that, “At a wind angle of 90º to a 50-foot pier with 5 pilings on each side [diameter of pilings not noted–ed.] can [sic] produce eddy currents and flow friction 2 times the diameter of the pilings—minimally. This means…a 30 percent reduction in flow. The area or parallel shoreline affected by the flow reduction would be a factor of 2 to 3 times the pier length. Properties within 100 feet to 150 feet of a 50–foot pier could be subjected to wrack algae accumulation, sand deposition and shellfish population changes.” This evaluation cites no research results and appears to be based on predictive engineering calculations.

# *Disruption during pile installation—*

Anecdotal evidence suggests that the method of piling installation can produce changes in sediment type and bottom morphology in the vicinity of a dock (Ziencina, 2002 pers. com.) Jetting of pilings (jetting uses a high pressure water pump to blow a deep hole in the bottom. The piling is set into the hole and sand packs back around the piling) tends to cause greater disruption than driving piles with a drop hammer. Jetting suspends sediments and can disrupt adjacent vegetation resulting in bare areas around pilings that are subject to scour. Shaefer (2001) found bare areas with a diameter of 35–78 inches around pilings in St. Andrew Bay, FL. Using a low pressure pump to produce a starter hole and subsequent insertion of a sharpened pile with a drop hammer in a sandy area “reduces the physical removal and disturbance” of seagrasses in the area of the piling and results in little to no sand deposition around the pilings (Shaefer, 2001)

# *Pumping of sediments from floats or docks resting on or near the bottom—*

Observational evidence indicates that changes in sediments occur when floats or boats are allowed to settle on the bottom at low tide (Ziencina, 2002, pers. com.). As the floats rise they create a suction that resuspends sediments—the sediment is “pumped” into resuspension. Additionally wave refraction in a downward direction may also resuspend some sediments (Ludwig, 2003, pers. com.).

**Impacts from Boating Uses Associated with Small Docks—**

Most small docks are associated with boat traffic. Being situated at the interface between land and water, at least a portion of each dock is in the intertidal zone and extends into or through shallow areas. In many cases this can lead to environmental impacts. Because docks are in the shallowest areas of an embayment and are the location where refueling may take place and engines are started and stopped, impacts are apt to be particularly significant. Propeller scarring of vegetation and “prop dredging” of sediments are perhaps the most visible impacts in the shallow waters adjacent to docks.

In 1994, a workshop on the impacts of boating was held at the Woods Hole Oceanographic Institution (Crawford *et al*., 1998). A number of potential boating-related impacts were discussed although no differentiation was made between general boating activities and those taking place in the vicinity of docks. While noting that there were adverse impacts, the presentations revealed that there were limited quantitative data available that could be used as the basis for management decisions—although it was agreed that sufficient data exist to “substantiate the inference that recreational … motor boat traffic is far from a benign influence on aquatic and marine environments.” A second symposium on the topic, “Impacts of Small Motorized Watercraft on Shallow Aquatic Systems” was held in 2000 at Rutgers University. The results of this symposium were published in Kennish (2002).

Both workshops identified several issues of concern regarding boating activity including:

Impacts to submerged aquatic vegetation,

Contamination from fuel discharges,

Erosion on shorelines, and

Resuspension of bottom sediments and turbidity.

# *Impacts on submerged vegetation—*

Boat propellers can directly damage submerged aquatic vegetation in shallow waters (Phillips, 1960; Thayer *et al.,* 1975; Zieman, 1976; Eleuteruis, 1987; Kruer, 1998; Burdick and Short, 1999); impacts that may take years to heal. *Thallasia sp.,* for example,can take four to six years to recolonize a prop scar (Kruer, 1998). Damage to the plants and their rhizome system





**Figure 3.**  Prop scarring in Waquoit Bay Massachusetts. From Crawford (2002)

often leads to both reduced wildlife habitat and destabilized sediments. Zieman (1976) reported that most propeller scarring takes place in water less that 1 meter (3.3 feet) in depth. Research in and around Corpus Christi Bay found that 39 percent of the seagrass meadows were either moderately (5–20 percent) or heavily (<20 percent) scarred based on the percentage of the area of the beds compared with the area of the propeller scars (Dunton and Schonberg, 2002).

*Contamination from fuel discharges—*

Outboard motors have long been associated with polluting of waterways. Milliken and Lee (1990) provide a good summary of the early literature. Two-cycle engines release up to 20 percent unburned fuel along with exhaust gases (Moore, 1998). Moore (1998) compared the polycyclic aromatic hydrocarbon (PAH), a carcinogenic organic molecule found in petroleum products, output from a two-cycle outboard engine with that from a four-cycle engine. The tests were run in tanks containing fresh water. The two-cycle motor discharged five times as much PAH as the four-cycle engine based on levels in the tanks. Most of this difference was due to a reduction in discharge of 2- and 3-ring compounds in the four-cycle. However, he found little difference between the levels of discharge of 4- and 5-ring compounds—those generally related to chronic toxicity. Albers (2002) notes that PAH concentrations in the water column are “usually several orders of magnitude below levels that are acutely toxic,” but those in sediments may be much higher.

Even when PAHs are found in coastal waters it is difficult to relate them directly to small dock use. Sanger and Holland (2002) looked at PAH levels in tidal creeks in South Carolina but were not able to distinguish PAHs from dock-related activities from other anthropogenic sources. Additionally, it is difficult to differentiate between general recreational boat use and that associated with small docks (Sanger, in Kelty and Bliven, 2003)

*Shoreline erosion—*

Boat wakes, which lap at the shoreline, can contribute to increased shore erosion (Zabawa *et al.* 1980; Camfield *et al.* 1980; Hagerty *et al.*, 1981). Most of these relate to boats moving at or near maximum speed through waterways. If boats are moving at a speed slow enough to avoid leaving a wake, there will not be shoreline erosion. There was little found in the literature that pertained specifically to boats maneuvering near docks or landing areas

*Resuspension of bottom sediments and turbidity—*

Running a motorized boat through shallow waters produces two distinct types of wake (Crawford, 1998):

The primary wake (or bow wake) that is related to water displacement by the boat that moves out to the side and can cause bank erosion, and

The secondary wake (or prop wash) related to engine and propeller effects that moves behind the boat and down and causes sediment resuspension and damage to submerged aquatic vegetation.

The secondary wake does not fan out as does the surface wake and consequently has localized impacts. Hartge (1998) compared prop-driven boats with those that were water-jet propelled and noted no major differences between the amount of resuspension of sediments; he did note that slow-moving, heavy laden boats caused more turbidity than lighter, faster moving boats. Modern planning hulls (hulls designed to climb towards the surface of the water as power is applied, thus reducing the amount of wetted hull surface and reducing the friction or drag) also have a far lesser impact on bottom sediments (Crawford, 1998; Hartge, 1998). Secondary wake impacts are difficult to quantify accurately because they vary widely from boat to boat and based on environmental conditions. Propeller thrust characteristics are highly variable depending on:

Propeller size,

Thrust angle,

Clearance over bottom,

Engine power,

Hull shape,

Operating conditions (*e.g.,* speed, state of the tide, weather, number of passengers, and

Operator choices. (Crawford in Kelty and Bliven, 2003).

Despite the ongoing research described above, there has been limited progress in finding quantifiable, predictable impacts from boating uses. This led Crawford (in Kelty and Bliven, 2003) to offer the following conclusions.

Using sediment resuspension to assess impacts is not recommended because of the wide range of factors involved.

Small-scale measurements of wave impacts are too variable; the broader the scale the better.

It is difficult to ascribe generic impacts to an activity like boating that has such a wide range of variables.

More research is needed—however the research is expensive and very time consuming.

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