Part 3: Annotated Bibliography
Integrated Guidance Model

1. Upland Landuse

Angermeier, P.L., Wheeler, A.P., and Rosenberger, A.E. 2004. A conceptual framework for assessing impacts of roads on aquatic biota. Fisheries. 29(12): 19-29.
A review and development of a two-dimensional framework to organize impacts of roads on aquatic biota. One dimension recognizes three phases of road development, each with distinctive ranges of spatial and temporal scales. The second dimension recognizes five classes of environmental impacts associated with road development.

Atasoy, M., Palmquist, R.B., and Phaneuf, D.J. 2006. Estimating the effects of urban residential development on water quality using microdata. J. Environ. Manage. 79(4): 399-408.
Both the density of residential land use and the rate of land conversion have a negative impact on water quality. The impacts of these non-point sources are found to be larger in magnitude than those from urban point sources.

Bayen, S., Kee Lee, H., and Philip Obbard, J. 2007. Exposure and response of aquacultured oysters, *Crassostrea gigas*, to marine contaminants. Environ. Res. 103(3): 375-382.
Low growth rates in oysters exposed to polluted waters, and significant differences in the burden of persistent organic pollutants (POPs) were discovered. On a positive note, the effects of pollution on oysters were found to be reversible.

Bilkovic, D.M., Roggero, M., Hershner, C.H., and Havens, K.H. 2006. Influence of land use on macrobenthic communities in nearshore estuarine habitats. Estuaries Coasts. 29(6B): 1185-1195.
For biotic indices applied in the nearshore, the highest scores were associated with forested watersheds (W-value, B-IBI sub(N)). Ecological thresholds were identified with nonparametric change- point analysis, which indicated a significant reduction in B-IBI sub(N) and W- value scores when the amount of developed shoreline exceeded 10% and developed watershed exceeded 12%, respectively.

Bosch, D.J., Lohani, V.K., Dymond, R.L., Kibler, D.F., and Stephenson, K. 2003. Hydrological and fiscal impacts of residential development: Virginia case study. J. Water Resour. Plann. Manage. 129(2): 107-114.
Low density development has the greatest hydrological impact due to highest per capita impervious area. Higher density settlements reduce hydrological impacts but bear a high cost to local governments in reduced property tax revenues.

Boward, D., Kazyak, P., Stranko, S., Hurd, M., Prochaska, A., and Environmental Protection Agency, Washington, DC (USA). Office of Research and Development. 1999.

From the mountains to the sea: The state of Maryland's freshwater streams. U.S. Environmental Protection Agency, Center for Environmental Research Information Cincinnati, OH 45268 (USA).
The report describes the impact of urbanization on fish and benthic macroinvertebrate communities (using indices of biotic integrity), herpetofauna, and stream temperatures. The report also describes the extent of physical habitat degradation, including riparian buffer conditions. Other topics include acidification; nutrient enrichment; biodiversity; introduced fish; and rare, threatened, and endangered fish species.

Brooks, R.P., D.H. Wardrop, K.W. Thornton, D. Whigham, C. Hershner, M.M. Brinson and J.S. Shortle, eds. 2006. Integration of ecological and socioeconomic indicators for estuaries and watersheds of the Atlantic Slope. Final Report to U.S. Environmental Protection Agency STAR Program, Agreement R-82868401, Washington, DC. Prepared by the Atlantic Slope Consortium, University Park, PA. 96pp.+ attachments (CD).

Burcher, C.L., and Benfield, E.F. 2006. Physical and biological responses of streams to suburbanization of historically agricultural watersheds. J. N. Am. Benthol. Soc. 25(2): 356-369.
Stormflow total suspended solids were significantly lower and substrate inorganic matter content was significantly higher in streams influenced by suburban development. Fish taxa richness and the density of nonguarding fishes were significantly higher in sites in suburban watersheds than in sites in agricultural watersheds. Biotic assemblages at sites in suburban watersheds were distinct from those at sites in agricultural watersheds. Suburbanization near historically agricultural southern Appalachian streams induces subtle changes to inorganic sediment dynamics, substrate composition, and fish and macroinvertebrate assemblage structure.

Cardoso, P.G., Pardal, M.A., Lilleboe, A.I., Ferreira, S.M., Raffaelli, D., and Marques, J.C. 2004. Dynamic changes in seagrass assemblages under eutrophication and implications for recovery. J. Exp. Mar. Biol. Ecol. 302(2): 233-248.
Eutrophication related modifications include a decrease in species diversity along the *eutrophication gradient, an increase in detritivores and a decline in herbivores together with a significant increase in small deposit-feeding polychaetes. In the long term, sustained eutrophication of this estuary is expected to lead to complete replacement of seagrass habitat by unvegetated coarser sediments, occasionally covered by green macroalgal blooms and dominated by opportunistic invertebrate taxa.*

Carpenter, S.R., Benson, B.J., Biggs, R., Chipman, J.W., Foley, J.A., Golding, S.A., Hammer, R.B., Hanson, P.C., Johnson, P., Kamarainen, A.M., Kratz, T.K., Lathrop, R.C., McMahon, K.D., Provencher, B., Rusak, J.A., Solomon, C.T., Stanley, E.H., Turner, M.G., Zanden, M., Wu, C., and Yuan, H. 2007. Understanding regional change: A comparison of two lake districts. BioScience, Vol. 57(4): 323.
We compared long-term change in two lake districts, one in a forested rural setting and the other in an urbanizing agricultural region, using lakes as sentinel ecosystems. Biotic changes such as habitat loss, species invasions, and poorer fishing were prevalent in the rural region, and lake hydrology and biogeochemistry responded to climate trends and

landscape position. Similar biotic changes occurred in the urbanizing agricultural region, where human-caused changes in hydrology and biogeochemistry had conspicuous effects.

DeLuca, W. V., C. E. Studds, L. L. Rockwood, and P. P. Marra. 2004. Influence of land us on the integrity of marsh bird communities of the Chesapeake Bay, USA. Wetlands 24:837-847.

Dougherty, M., Dymond, R.L., Grizzard, T.J.,Jr, Godrej, A.N., Zipper, C.E., and Randolph, J. 2006. Quantifying long-term NPS pollutant flux in an urbanizing watershed. J. Environ. Eng. 132(4): 547-554.
Compared an urbanized watershed in D.C with 3 mixed Ag-forested watersheds. The urbanized watershed had higher annual NPS sediment and nutrient fluxes linked to increased soil disturbance from urban construction and increased storm volumes resulting from increased mean impervious percent. Higher NPS pollutant fluxes during the growing season, indicate a seasonal impact of replacing vegetated cover with impervious surface.

Dow, C.L., Arscott, D.B., and Newbold, J.D. 2006. Relating major ions and nutrients to watershed conditions across a mixed-use, water-supply watershed. J. N. Am. Benthol. Soc. 25(4): 887-911.
Anthropogenic land uses primarily defined ion and nutrient baseflow chemistry patterns at regional and watershed levels. Individual analyses indicated no dominant watershed-scale landscape attribute that could be used to predict instream inorganic chemistry concentrations, and no single ion or nutrient was identified as the best indicator of a given anthropogenic land use.

Dukes, M.D., and Evans, R.O. 2006. Impact of agriculture on water quality in the North Carolina middle coastal plain. J. Irrig. Drain. Eng. 132(3): 250-262.
Nutrient and sediment concentrations increased along the streams draining the agricultural lands. Surface water was impacted dramatically by seepage from an anaerobic swine wastewater lagoon.

Fisher, T.R., Hagy, J.D.,III, Boynton, W.R., and Williams, M.R. 2006. Cultural eutrophication in the Choptank and Patuxent estuaries of Chesapeake Bay. Limnol. Oceanogr. 51(1): 435-447.
Hydrochemical modeling and land-use yield coefficients suggest that current input rates are 4- 20 times higher for N and P than under forested conditions existing 350 yr ago. Sewage is a major cause of increased nutrients in the Patuxent; agricultural inputs dominate in the Choptank. These loading have caused (1) increased nutrients, phytoplankton, and turbidity; (2) decreased submerged grasses due to higher turbidity and epiphyton shading; and (3) bottom-water hypoxia due to respiration of excess organic matter.

Gage, M.S., Spivak, A., and Paradise, C.J. 2004. Effects of land use and disturbance on benthic insects in headwater streams draining small watersheds north of Charlotte, NC. Southeast. Nat. 3(2): 345-358.
Increasing development north of Charlotte, NC, threatens aquatic life in streams by reducing riparian zones and increasing runoff. Runoff, sedimentation from erosion, and poor construction practices are principal sources of pollution. Sensitive taxa were found in streams with extensively forested watersheds, but were nonexistent in extensively developed watersheds. Disturbances occurring in streams caused declines in diversity, often eliminating sensitive taxa.

Gray, M.J., and Smith, L. 2005. Influence of land use on postmetamorphic body size of playa lake amphibians. J. Wildl. Manage. 69(2): 515-524.
Agricultural land use may indirectly affect the body size of amphibians by altering the hydroperiods of nearby wetlands and influencing amphibian densities—both factors which can limit the larval and post-metamorphic growth rates of amphibians. Thus, if cultivation of landscapes surrounding wetlands negatively influences post-metamorphic body size of amphibians, restoration of native grasslands surrounding playa wetlands may help prevent local amphibian declines.

Groffman, P.M., Dorsey, A.M. and Mayer, P.M. 2005. N processing within geomorphic structures in urban streams. J. N. Am. Benthol. Soc. 24(3): 613-625.
Denitrification potential was highest in organic debris dams and organic-rich gravelbars—structures with high organic matter content. Organic debris dams in suburban streams had higher denitrification than debris dams in the forested reference stream, likely because of higherNO3− concentrations in suburban streams. However, such denitrifying structures as organic debris dams may be difficult to maintain in urban streams because of high storm flows and downstream displacement.

Hagen, E.M., Webster, J.R., and Benfield, E.F. 2006. Are leaf breakdown rates a useful measure of stream integrity along an agricultural landuse gradient? J. N. Am. Benthol. Soc. 25(2): 330-343.
Leaf breakdown rates were related to landuse category (forested, light agriculture, moderate agriculture, and heavy agriculture) but did not differ significantly. Nutrient concentration, temperature, and sedimentation increased, and dissolved O2 decreased along the landuse gradient from forest to heavy agriculture.

Henning, L.A. and W.D. Edge. 2003. Riparian bird community structure in Portland, Oregon: Habitat, urbanization, and spatial scale patterns. The Condor 105:288-302.

Inwood, S.E., Tank, J.L., and Bernot, M.J. 2005. Patterns of denitrification associated with land use in 9midwestern headwater streams. J. N. Am. Benthol. Soc. 24(2): 227-245.
The effects of land use on the relationships among denitrification, NO sub (3) super (-)-N, dissolved organic C (DOC),and other environmental parameters were examined in 9 headwater streams (3 each in forested, agricultural, and urban-dominated sub-watersheds). Agricultural streams had high concentrations of NO sub(3)super(-)-N, DOC, soluble reactive P, and NH sub(4) super(+)-N, whereas forested streams had the

lowest concentrations of these nutrients, and urban streams generally exhibited intermediate concentrations. Sediment denitrification rates were highest in agricultural streams and lowest in forested streams throughout the study period. Despite higher denitrification rates in agricultural and urban streams compared to forested streams, sediment denitrification removed a smaller proportion of the stream NO sub(3) super(-)-N load in agricultural and urban streams relative to forested streams.

Jennings, M.J., Emmons, E.E., Hatzenbeler, G.R., Edwards, C., and Bozek, M.A. 2003. Is littoral habitat affected by residential development and land use in watersheds of Wisconsin lakes? Lake Reserv. Manage. 19(3): 272-279.
Looked at differences in nearshore littoral zone habitat among lakes with different amounts of residential development and different patterns of watershed land use. Quantity of woody debris, emergent vegetation and floating vegetation decreased at developed sites and in lakes with greater cumulative lakeshore development density. Littoral sediments contained more fine particles at developed sites and in lakes with greater development density. Sediment composition, quantity of vegetation, and woody debris were weakly associated with differences in watershed land use. Cumulative changes to watersheds and riparian zones are associated with measurable differences in littoral habitat that may not be detectable at smaller scales.

Kaushal, S.S., Lewis, W.M., Jr, and McCutchan, J.H., Jr. 2006. Land use change and nitrogen enrichment of a rocky mountain watershed. Ecol. Appl. 16(1): 299-312.
The biotic capacity of headwater ecosystems to assimilate increases in inorganic N from residential development may be insufficient to prevent nitrogen enrichment over considerable distances and multiple aquatic ecosystems downstream. Nitrogen enrichment was studied in a Rocky Mountain watershed undergoing rapid expansion of population and residential development. From a watershed perspective, total loading of N to the Blue River catchment from septic and municipal wastewater (2 kg times ha super(-1) times yr super(-1)) is currently less than the amount from background atmospheric sources (3 kg times ha super(-1) times yr super(-1)).

Kimbrough, K.L., and Dickhut, R.M. 2006. Assessment of polycyclic aromatic hydrocarbon input to urban wetlands in relation to adjacent land use. Mar. Pollut. Bull. 52(11): 1355-1363.
The relationship between polycyclic aromatic hydrocarbons (PAHs) in wetland surface sediments and adjacent land use was assessed in the Elizabeth River, VA. Wetlands adjacent to parking lots and petroleum industrial sites exhibited the highest PAH concentrations of all wetlands examined. Overall, commercial land uses had the highest PAH concentrations and automotive sources dominated (52- 69%) PAH input to wetland surface sediments irrespective of adjacent land use.

Kratzer, E.B., Jackson, J.K., Arscott, D.B., Aufdenkampe, A.K., Dow, C.L., Kaplan, L.A., Newbold, J.D., and Sweeney, B.W. 2006. Macroinvertebrate distribution in relation to land use and water chemistry in New York City drinking-water-supply watersheds. J. N. Am. Benthol. Soc. 25(4): 954-976.

Macroinvertebrate communities were examined in conjunction with landuse and water-chemistry variables. Urbanized macroinvertebrate communities varied primarily with specific conductance, population density, and agricultural and urban land use, but communities were not classified as impaired along these gradients. In other areas, conditions ranged from forested to urban, and distinctive communities were associated with point-source discharges, road density, and lake outlets, resulting in impaired macroinvertebrate communities.

Kuehl, S., Alexander, C., Carter, L., Gerald, L., Gerber, T., Harris, C., McNinch, J., Orpin, A., Pratson, L., Syvitski, J., and Walsh, J.P. 2006. Understanding sediment transfer from land to ocean. EOS Trans. Am. Geophys. Union. 87(29): 281.
No abstract?

Leithold, E.L., Perkey, D.W., Blair, N.E., and Creamer, T.N. 2005. Sedimentation and carbon burial on the northern California continental shelf: The signatures of land-use change. Cont. Shelf Res. 25(3): 349-371.
The burial of organic carbon (OC) on continental margins is strongly coupled to the supply and accumulation of inorganic mineral particles. The record reveals a 6-11-fold increase in the rate of sediment accumulation on the mid-shelf beginning about 1955, and a concomitant decrease in grain size and increase in flood-layer preservation. At the same time, the age of buried wood fragments abruptly decreased and their stable carbon isotopic composition became enriched in super(13)C. It is argued that these changes can be explained largely as the result of altered land use in the Eel watershed. Increases in mass wasting and input of bedrock material following the onset of intensive industrial logging in the Eel watershed may have resulted in a lower loading of terrestrial plant OC in the clay fraction deposited after.

Lerberg, S. B., A. F. Holland, and D. M. Sanger. 2000. Responses of tidal creek macrobenthic communities to the effects of watershed development. Estuaries 23:838-853.

Lever, M.A. and Valiela, I. 2005. Response of microphytobenthic biomass to experimental nutrient enrichment and grazer exclusion at different land-derived nitrogen loads. Mar. Ecol. Prog. Ser. 294: 117-129.
Effects of eutrophication on the relative importance of nutrients and macroherbivores as controls of microphytobenthic standing crop show that nitrogen + phosphorus addition increased sediment chlorophyll alpha (chl alpha) content (herein used as a proxy for biomass) by a similar magnitude across estuaries. Grazer exclusion also increased chl a, but to a different extent across estuaries: the magnitude of the response increased with increasing nitrogen loading rates. We found no interactions between nutrients and grazing.

Limburg, K. E., and R. E. Schmidt. 1990. Patterns of fish spawning in Hudson River tributaries: response to an urban gradient? Ecology 71:1238-1245.

Locke, B.A., Cherry, D.S., Zipper, C.E., and Currie, R.J. 2006. Land use influences and ecotoxicological ratings for upper clinch river tributaries in Virginia. Arch. Environ. Contam. Toxicol. 51(2): 197-205.
The Clinch River system; all tributary watersheds are predominately forested, but agricultural, mining, and developed land uses (urban, transportation) are also present. ETRs indicated that the tributaries draining mining-influenced watersheds had greater potential impact on the mainstem than those draining agricultural or forested watersheds, and the presence of developed land uses had no significant relationship with ETRs.

Lussier, S.M., Enser, R.W., Dasilva, S.N., and Charpentier, M. 2006. Effects of habitat disturbance from residential development on breeding bird communities in riparian corridors. Environ. Manage. 38(3): 504-521.
This study assessed the relationship among land use, riparian vegetation, and avian populations at two spatial scales. Bird guilds were correlated with riparian vegetation metrics, percent impervious surface, and percent residential land use, revealing patterns of breeding bird distribution. The number of intolerant species predominated below 12% residential development and 3% impervious surface, whereas tolerant species predominated above these levels.

Mallin, M.A., Johnson, V.L., Ensign, S.H., and MacPherson, T.A. 2006. Factors contributing to hypoxia in rivers, lakes and streams; eutrophication of freshwater and marine ecosystems. Limnol. Oceanogr. 51(1): 690-701.
No Abstract?

Meyer, J.L., Paul, M.J., and Taulbee, W.K. 2005. Stream ecosystem function in urbanizing landscapes. J. N. Am. Benthol. Soc. 24(3): 602-612.
Ecologists have described an urban stream syndrome with attributes such as elevated nutrients and contaminants, increased hydrologic flashiness, and altered biotic assemblages. Both NH4 and soluble reactive P uptake velocities decreased as indicators of urbanization (i.e., % of catchment covered by high-intensity urban development) increased. The amount of fine benthic organic matter (FBOM) also decreased with increasing urbanization, and uptake velocities were directly related to FBOM. Uptake velocities were not related to ecosystem metabolism (gross primary production [GPP], community respiration [CR], or net ecosystem production). Measures of ecosystem function responded differently to urbanization: ecosystem metabolism was not correlated with indicators of urbanization, although breakdown rate of Acer barbatum leaves was positively correlated and nutrient uptake velocities were negatively correlated with indicators of urbanization. Elevated nutrient concentrations associated with urbanization are usually attributed to increased inputs from point and non-point sources; our results indicate that concentrations also may be elevated because of reduced rates of nutrient removal.

Paul, M. J. and J. L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32:333-365.

Moore, A.A., and Palmer, M.A. 2005. Invertebrate biodiversity in agricultural and urban headwater streams: Implications for conservation and management. Ecological Applications: A Publication of the Ecological Society of America. 15(4): 1169-1177.
No Abstract?

Nelson, P.A., Smith, J.A., and Miller, A.J. 2006. Evolution of channel morphology and hydrologic response in an urbanizing drainage basin. Earth Surf. Process. Landforms. 31(9): 1063-1079.
The Dead Run catchment in Baltimore County, Maryland, has undergone intense urbanization since the late 1950s. Trend analyses of discharge records in Dead Run show that urban development and stormwater control measures have had significant impacts on the hydrologic response of the catchment.

Nerbonne, B.A., and Vondracek, B. 2001. Effects of local land use on physical habitat, benthic macroinvertebrates, and fish in the whitewater river, Minnesota, USA. Environ. Manage. 28(1): 87-99.
Best management practices (BMPs) have been developed to address soil loss and the resulting sedimentation of streams, but information is lacking regarding their benefits to stream biota. We compared instream physical habitat and invertebrate and fish assemblages from farms with BMP to those from farms with conventional agricultural practices. Sites were classified by upland land use (BMP or conventional practices) and riparian management (grass, grazed, or wooded buffer). Physical habitat characteristics differed across buffer types, but not upland land use, using an analysis of covariance, with buffer width and stream as covariates. Stream sites along grass buffers generally had significantly lower percent fines, embeddedness, and exposed streambank soil, but higher percent cover and overhanging vegetation when compared with sites that had grazed or wooded buffers.

Opperman, J.J., Lohse, K.A., Brooks, C., Kelly, N.M., and Merenlender, A.M. 2005. Influence of land use on fine sediment in salmonid spawning gravels within the Russian River basin, California. Can. J. Fish. Aquat. Sci. 62(12): 2740-2751.
Relationships between land use or land cover and embeddedness, a measure of fine sediment in spawning gravels, were examined at multiple scales. Agricultural and urban land uses and road density were positively associated with embeddedness, while the opposite was true for forest cover. Land use within a more restricted riparian corridor generally did not relate to embeddedness, suggesting that reach-scale riparian protection or restoration will have little influence on levels of fine sediment.

Price, K., and Leigh, D.S. 2006. Comparative water quality of lightly- and moderately-impacted streams in the southern Blue Ridge Mountains, USA. Environ. Monit. Assess. 120(1-3): 269-300.
For less-developed regions like the Blue Ridge Mountains, data are limited that link basin-scale land use with stream quality. Two pairs of lightly-impacted (90-100% forested) and moderately-impacted (70-80% forested) sub-basins were identified for comparison. Statistically significantly higher mean values of suspended and dissolved

solids, nitrate, specific conductivity, turbidity, and temperature were observed in the moderately impacted streams versus the lightly impacted streams in both pairs, while dissolved oxygen levels were lower in the moderately-impacted streams. No significant differences were demonstrated in orthophosphate or ammonium concentration. However, the demonstration that moderate reductions in forest cover are associated with stream water quality degradation carries important implications for stream management in this rapidly developing mountainous region.

Rodriguez, W., August, P.V., Wang, Y., Paul, J.F., Gold, A., and Rubinstein, N. 2007. Empirical relationships between land use/cover and estuarine condition in the northeastern United States. Landscape Ecol. 22(3): 403-417.
Patterns of coastal urban and agriculture gradients were measured and their relationship with indicators of estuarine condition was modeled statistically. Moderate (0.4 < | r | < 0.7) to strong (| r | greater than or equal to 0.7) linear associations were found between total urban area and measures of estuarine condition. Within regions, total urban area was positively associated with Silver (r = 0.59), Cadmium (r = 0.65), and Mercury (r = 0.47) in Cape Cod, and inversely related to DO (r = -0.65) in the Hudson/Raritan region. Total area of agriculture showed a moderate association with Arsenic in Cape Cod, but no other associations were found in the other two regions.

Roy, A.H., Freeman, M.C., Freeman, B.J., Wenger, S.J., Ensign, W.E., and Meyer, J.L. 2005. Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams. J. N. Am. Benthol. Soc. 24(3): 656-678.
Stream biota in urban and suburban settings are thought to be impaired by altered hydrology; however, it is unknown what aspects of the hydrograph alter fish assemblage structure and which fishes are most vulnerable to hydrologic alterations in small streams. Increased imperviousness was positively correlated with the frequency of storm events and rates of the rising and falling limb of the hydrograph (i.e., storm "flashiness") during most seasons. Increased duration of low flows associated with imperviousness only occurred during the autumn low-flow period, and this measure corresponded with increased richness of lentic tolerant species. Altered storm flows in summer and autumn were related to decreased richness of endemic, cosmopolitan, and sensitive fish species, and decreased abundance of lentic tolerant species. Species predicted to be sensitive to urbanization, based on specific life-history or habitat requirements, also were related to stormflow variables and% fine bed sediment in riffles. Overall, hydrologic variables explained 22 to 66% of the variation in fish assemblage richness and abundance.

Scheuerell, M.D and D.E Schindler. 2004. Lakeshore residential development alters the spatial distribution of fishes. Ecosystems 7(1): 98-106.

Scott, D., Harvey, J., Alexander, R., and Schwarz, G. 2007. Dominance of organic nitrogen from headwater streams to large rivers across the conterminous United States. Global Biogeochem Cycles. 21(1).
We find that organic nitrogen is the dominant nitrogen pool within rivers across most of the United States and is significant even in basins with high anthropogenic sources of nitrogen.

Simon, N.S., Bricker, O.P., Newell, W., McCoy, J., and Morawe, R. 2005. The distribution of phosphorus in popes creek, VA, and in the Pocomoke River, MD: Two watersheds with different land management practices in the Chesapeake Bay basin. Water, Air, Soil Pollut. 164(1-4): 189-204.
This paper compares phosphorus (P) concentrations in sediments from two watersheds, one with (Pocomoke), and one without (Popes Creek), intensive animal agriculture. Concentrations of total P and P extracted with 1N HCl are significantly larger in main-stem bottom sediments from the Pocomoke River than in main-stem bottom sediments from Popes Creek.

Smith, C.M., and Wachob, D.G. 2006. Trends associated with residential development in riparian breeding bird habitat along the Snake River in Jackson Hole, WY, USA: Implications for conservation planning. Biol. Conserv. 128(4): 431-446.
Throughout North America, bird population declines may be attributable to loss of habitat on the breeding grounds. They determined the effects of housing densities on avian community parameters, guilds, individual species distributions, and environmental variables. Landscape-level features were most affected by residential development and trends associated with increasing housing densities, such as anthropogenic habitat fragmentation primarily structured local bird communities. Overall species richness and diversity declined with increasing residential development. Neotropical migrant species were most negatively impacted and consistently declined in proportional representation on forested plots as residential development densities increased. Food generalists, ground gleaners, and avian nest predators all increased with increasing residential development.

Smith, S.V., D.P. Swaney, L. Talaue-McManus, J.D. Bartley, P.T. Sandhei, C.J. McLaughlin, V.C. Dupra, C.J. Crossland, R.W. Buddemeier, B.A. Maxwell and F. Wulff. 2003. Humans, hydrology, and the distribution of inorganic nutrient loading to the ocean. Bioscience 53(3):235-245.

Snyder, C.D., Young, J.A., Villella, R., and Lemarie, D.P. 2003. Influences of upland and riparian land use patterns on stream biotic integrity. Landscape Ecol. 18(7): 647-664.
We found that index of biological integrity (IBI) scores were strongly associated with extent of urban land use in individual catchments. Sites that received ratings of poor or very poor based on IBI scores had > 7% of urban land use in their respective catchments. Habitat correlations suggested that urban land use disrupted flow regime, reduced water quality, and altered stream channels. In contrast, we found no meaningful relationship between agricultural land use and IBI at either whole-catchment or riparian scales. Urban land use was more disruptive to biological integrity in catchments with steeper channel slopes.

Torbick, N.M., Qi, J., Roloff, G.J., and Jan Stevenson, R. 2006. Investigating impacts of land-use land cover change on wetlands in the Muskegon river watershed, Michigan, USA. Wetlands, Vol. 26, no. 4. 26(4): 1103-1113.
No Abstract?

Ulseth, A.J., and Hershey, A.E. 2005. Natural abundances of stable isotopes trace anthropogenic N and C in an urban stream. J. N. Am. Benthol. Soc. 24(2): 270-289.
Important ecological services of low-order streams are greatly affected by urbanization. Thus, specific influences of point sources of N could be distinguished in food web components. Nonpoint sources and stormwater influenced seston delta super (15)N during storm events, but these sources could not be distinguished in consumers by using natural abundances of stable isotopes.

Walsh, C.J.,Roy, A.H., Feminella, J.W., Ottingham, P.D., Groffman, P.M., and Morgan, R.P. 2005. The urban stream syndrome: Current knowledge and the search for a cure. J. N. Am. Benthol. Soc. 24(3): 706-723.
Symptoms of the urban stream syndrome include a flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology, and reduced biotic richness, within creased dominance of tolerant species. Most impacts can be ascribed to a few major large-scale sources, primarily urban stormwater runoff delivered to streams by hydraulically efficient drainage systems. Other stressors, such as combined or sanitary sewer overflows, wastewater treatment plant effluents, and legacy pollutants (long-lived pollutants from earlier land uses) can obscure the effects of stormwater runoff. Most research on urban impacts to streams has concentrated on correlations between instream ecological metrics and total catchment imperviousness. Recent research shows that some of the variance in such relationships can be explained by the distance between the stream reach and urban land, or by the hydraulic efficiency of stormwater drainage.

Wang, L., J. Lyons and P. Kanehl. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22:6-12.

2. Riparian Landuse

Riparian Land Use - Water Quality

Correll, D.L. 1997. Buffer Zones and water quality protection: general principles. Pages 7-20 In: Buffer Zones: Their Processes and Potential in Water Protection. The Proceedings of the International Conference on Buffer Zones September 1996. Edited by N.E. Haycock et al.
This paper is a review of world literature on riparian buffer zones with emphasis on streams and water quality. One of the conclusions was that grass or dense herbaceous vegetation is most effective at removing or trapping particulates from surface flow but only if there is sheet flow. Woody vegetation may be more effective at removing nitrate from groundwater due to the availability of organic carbon deep in the soil for microbial denitrification. For effective nitrate and acidity removal, groundwater must move at a slow speed and at a shallow depth to be intercepted by root zone.

Hefting, M.M., R. Bobbink, M.P. Janssens. 2006. Spatial Variation in Denitrification and N20 emission in relation to nitrate removal efficiency in a N-stressed riparian buffer zone. Ecosystems. 9(4): 550-563.
Riparian zone management that has as its goal an increase of the denitrification activity in buffers is worthy from the perspective of water quality improvement; however, the risk of N_2O emission remains inevitable. Simultaneous minimization of N_2O emissions is only possible if riparian zone management is combined with source-directed measures designed to drastically reduce the nitrate concentration in agricultural runoff.

Henry, M., H. Stevens, & K.W. Cummins. 1999. Effects of Long-Term Disturbance on Riparian Vegetation and In-Stream Characteristics. Journal of Freshwater Ecology. 14(1): 1-18.
This paper evaluated the influence of riparian disturbance on 26 stream variables in six Pennsylvania tributaries. Their primary conclusion was that anthropogenic disturbance destabilized stream ecosystem function. Specifically, agricultural land uses caused detrital processing rates to be less predictable than in forested streams. Mature woodland streams had more stable channel substrates and populations of intolerant species. Disturbed sites tended to have more silt and higher populations of Gammurus sp. Land use in particular had a great effect on detritus processing and storage.

Klapproth, J.C. & J.E. Johnson. 2000. Understanding the Science behind Riparian Buffers: Effects on Water Quality. Virginia Cooperative Extension Publication 420-151.
This is one paper in a series that summarizes the current scientific understanding of riparian buffers in Virginia. Streams in the coastal plain of Virginia particularly benefit from forested riparian buffers due to low-gradient topography and shallow aquifers that allows for effective sediment and nutrient removal. Both grass and forested buffers are effective for sediment removal, forested buffers also offer greater resistance during heavy floods. Buffer widths of 50-100 feet are recommended for sediment trapping. The ability of buffers to remove nutrients is highly variable and is tied to soils and hydrology.

Mayer, P.M., S.K. Reynolds, Jr., M.D. McCutchen and T.J. Canfield. Riparian Buffer Width, Vegetative Cover, and Nitrogen Removal Effectiveness: A Review of Current Science and Regulations. EPA/600/R-05/118. Cincinnati, OH, U.S. Environmental Protection Agency, 2006
Identifies causation & trends in the relationship between buffer width & nitrogen removal capacity extracted from peer-reviewed studies with empirical data on buffer effectiveness. Their main conclusions were that buffer widths of 10-50 m are effective nutrient filters, narrower buffers (5-6 m) may still reduce subsurface nitrate by up to 80%, but buffer widths > 50 m are the most effective. Also, vegetation characteristics did not determine level of pollutant removal, soil type, ground and surface water flow patterns & subsurface biogeochemistry were more determining than vegetation type or width.

Lowrance, R. & J.M. Sheridan. 2005. Surface Runoff Water Quality in a Managed Three Zone Riparian Buffer. J. Environ. Qual. 34: 1851-1859.

This study measured surface runoff volumes and nutrient concentrations and loads in a 3-zone riparian buffer system consisting of a grass strip at the edge of an agricultural field, a managed forest and an unmanaged forest by the stream. The largest percentage reducing of incoming nutrient load (at least 65% for all nutrients) took place in the grass zone because of the large decrease in flow.

Mankin, K.R., D.M. Ngandu, C.J. Barden, S.L. Hutchinson, W.A. Geyer. 2007. Grass-shrub riparian buffer removal of sediment, phosphorus, and nitrogen from simulated runoff. Journal of the American Water Resources Association. 43(4).
This study assessed the effectiveness of different types of grass-shrub buffers for reducing the pollutant load from agricultural fields in Iowa where farmers more readily accept this type of buffer than forested buffers. Their findings suggest that grass-shrub buffers were very efficient in removing sediments, N, and P with the removal efficiencies strongly linked to infiltration, which is consistent with other studies. They also found that a buffer width of only 8 m provided water quality improvement, particularly if adequate infiltration is achieved.

Palone, R. S. & A.H. Todd (editors). 1997. Chesapeake Bay riparian handbook: a guide for establishing & maintaining forest buffers. USDA Forest Service. NA-TP-02-97. Radnor, PA. Revised 1998.
This comprehensive guide provides information about the function, design, establishment, and management of riparian forest buffers in the Chesapeake Bay watershed. Different land use considerations are included for agriculture, forestry and urban settings. They recommend a flexible buffer width design that incorporates floodplain areas, undevelopable steep slopes, and adjacent wetlands.

Schoonover, J.E., K.W.J. Williard, J.J. Zaczek, J.C. Mangun & A.D. Carver. 2006. Agricultural Sediment Reduction by Giant Cane and Forest Riparian Buffer. Water, Air, and Soil Pollution Vol. 169(1-4): 303-315.
High infiltration rates of riparian soils was primary factor controlling sediment trapping, more than particle settling (i.e. variable sediment concentration, surface deposition) Greatest sediment reduction in forest during fall with leaf litter, no significant reduction of sediment mass during the spring at all, during remainder of year only significant at 6.6m into buffer, cane buffer sediment mass reductions significant by 3.3m during all seasons.

Riparian Land Use - Habitat

Diamond, J.M., D.W. Bressler, V.B. Serveiss. 2002. Assessing relationships between land uses and the decline of native mussels, fish and macroinvertebrates in the Clinch and Powell River Watershed, USA. Environmental Toxicology and Chemistry. 21(6): 1147-1155.
This paper was investigating the cause of mussel population declines in mountain streams of Virginia. Limited analyses in two subwatersheds suggested that urban and agricultural land uses within a specified riparian corridor were more related to mussel species richness and fish IBI than land uses in the entire catchments. Based on land uses

within a riparian corridor of 200 m × 2 km for each biological site in the watershed, fish IBI was inversely related to percent cropland and urban area and positively related to pasture area.

Klapproth, J.C. & J.E. Johnson. 2000. Understanding the Science behind Riparian Buffers: Effects on Plant and Animal Communities. Virginia Cooperative Extension Publication 420-152.
This is one paper in a series that summarizes the current scientific understanding of riparian buffers in Virginia. A review of scientific papers suggests that the vegetation complexity of riparian buffers supports a wide variety of wildlife and the loss of complex structure will reduce overall diversity. Forested riparian buffers adjacent to agricultural fields and in developed settings provide habitat to non-riparian dependent wildlife. Studies of bird communities in intensive agriculture areas suggest that riparian areas are very important habitats. Even narrow forest buffers support songbirds compared to herbaceous riparian vegetation, particularly short distance migrants. They also found variable results and conclusions in the literature regarding the terrestrial corridor function. They also concluded that species diversity & biomass of aquatic benthic communities decrease significantly as forest cover is removed from riparian buffers, primarily due to increased water temperature.

Lee, P., C. Smyth, and S. Boutin. 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. J. Environ. Manag. 70: 165–180.
This review of riparian buffer guidelines compared management trends with ecological recommendations for terrestrial and aquatic species. Buffer widths for most jurisdictions were found to be adequate to protect aquatic biota and habitats but were generally less than recommended for terrestrial communities. Most notably core habitat for medium and large mammals and birds were wider than most current guidelines. Fixed-width buffer requirements to accommodate all possible habitats would potentially require buffers wider than is warranted by local site conditions.

Mahan, C.G. & T.J. O'Connell. 2005. Small Mammal Use of Suburban and Urban Parks in Central Pennsylvania. Northeastern Naturalist. 12(3): 307-314.
This study evaluated the importance of riparian buffers for small mammals in Pennsylvania parks. Mature riparian forest sites contained more small mammal species. Species richness and diversity were lowest in parks containing manicured habitats and surrounded by human-modified landscapes.

Snyder, C.D., J.A. Young, R. Villella, D.P. Lemarie. 2003. Influences of upland and riparian land use patterns on stream biotic integrity. Landscape Ecology 18: 647-664.
This paper evaluated urban, agriculture & forested land use patterns at the riparian-reach scale & riparian-site scale. At the riparian-site scale, 2 of the 3 fish cover measures, LWD & undercut banks, exhibited strong positive correlations with forest land cover and negative associations with agriculture land use. Riffle-pool ratios also positively associated with forest and negatively with agriculture land use. Riparian land use patterns failed to explain a significant amount of the remaining variation in site IBI scores suggesting that forested buffer zones were of little value in mitigating the

deleterious effects of urban land use on fish communities. Efforts to moderate impacts of urban land use by protecting riparian buffers may not be sufficient to maintain biotic integrity.

Teels, B.M., C.A. Rewa, J. Myers. 2006. Aquatic Condition Response to Riparian Buffer Establishment. Wildlife Society Bulletin. 34 (4): 927-935.
This study evaluated the effects of recently established riparian buffers on the aquatic condition of agricultural streams in Northern Virginia. They collected baseline data that indicated influences of different land uses. The baseline IBI scores corresponded negatively to percent cropland and percent pasture and positively to percent nonagricultural land. The IBI also responded negatively to urban land-use patterns, particularly in a rapidly developing watershed where dramatic declines in the visible stream condition (SVAP) and the IBI were observed for both the restored and reference sites.

Van Holt, T., D.M. Murphy, L. Chapman. 2006. Local and Landscape Characteristics in the Great Swamp, New York. Northeastern Naturalist. 13(3): 353-374.
This study used local and landscape models to predict fish assemblages in the Great Swamp, New York region, which was undergoing rapid development. Four different scales were evaluated including reach, segment, network and watershed scales. No single model best predicted fish assemblages. The segment scale (100-m buffer for 1 km upstream) was recommended as the best predictor. They also suggested that forest cover is essential to protect fish assemblages. The percent forest positively influenced percent intolerant species and the IBI metrics for benthic insectivores, terete minnows, and dominant species. Any diminishing of forest land cover in favor of increasing agriculture, residential, or wetland negatively influenced the percent intolerant species.

Wigley, T.B. & M.A. Melchiors. Date? (circa 1995 based on studies conducted 1980-1993) Wildlife Habitat and Communities in Streamside Management Zones: A Literature Review for the Eastern United States. Excerpted from Riparian Ecosystems in the Humid U.S.: Functions, Values and Management.
This paper included a literature review of studies related to buffer width for streamside management zones (SMZ) in forestry settings. One of the main findings was that the corridor function of riparian buffers is variable and it is not clear if SMZs provide this function. They also suggest that the existing database is not adequate for SMZ width policy development and that most of the studies came to conclusions that were not supported by the data.

3. Bank Cover

Chesapeake Bay Program (CBP). 2005. Sediment in the Chesapeake Bay and management issues: tidal erosion processes. Prepared by the Tidal Sediment Task Force of the Sediment Workgroup under the Chesapeake Bay Program, Nutrient Subcommittee, May 2005.
This document provides background information on sediment processes and data to determine the effects of tidal sediment in a watershed and can serve as a general targeting tool for shoreline management and sediment controls that can improve water quality. It also suggests that tidal erosion should be viewed as an integral part of the natural ecosystem processes in the Bay and a necessary component of a properly functioning ecosystem, while also considering that excessive sediment loads can be detrimental to water quality.

Dierks, S. 2007. Not all green space is created equal: the hydrologic benefits of native landscapes. Stormwater, the journal for surface water quality professionals, March/April 2007 8(2).
This paper investigates the transformative effects of native plants and landscapes on soil properties that affect the soil's strength, growing medium capacity, and hydrologic properties. Two case studies were used to demonstrate the impact of native plants on soil properties in agricultural watersheds. Native plants have the capacity to improve structure and infiltration over time in all soils, including clays, but additional research beyond typical runoff studies is needed to quantify these effects.

Easson, G, Yarbrough, LD. 2002. The effects of riparian vegetation on bank stability. Environmental & Engineering Geoscience, 8(4) pp.247-260, Nov 2002.
This investigation quantifies root tensile strength of the sweet gum (Liquidambar styraciflua) in a cohesive, fine-grained, primarily loess-derived fluvial material in northern Mississippi. Estimating root reinforcement and root-soil matrix interactions allows for the determination of whether bank vegetation is beneficial or detrimental. The modeling results showed a contrast between root-reinforced and unreinforced soil. When no root reinforcement existed, the slope failed marginally. When simulated root reinforcement of 20 kPa was applied, the slope was shown to be completely stable.

Hardaway, C.S., Jr. G.R. Thomas, J.B. Glover, J.B. Smithson, M.R. Berman, A.K. Kenne. 1992. Bank erosion study. Special report in Applied Marine Science and Ocean Engineering, No. 319. Virginia Institute of Marine Science. April 1992.
This study analyzed fastland bank erosion along 383 miles of tidal shoreline in the Virginia portion of Chesapeake Bay. The authors discovered that the erosion tends to be greatest where a vegetation cover is absent. Sediment volume loading was considered to be halted where defensive shoreline structures were installed. For the James River, 18% of the shoreline studied was defended with structures between 1985-1990 which reduced the annual estimated nutrient load by 5%.

Klapproth, J.C. & J.E. Johnson. 2000. Understanding the science behind riparian buffers: Effects on water quality. Virginia Cooperative Extension publication 420-151.
This is one paper in a series that summarizes the current scientific understanding of riparian buffers in Virginia. Streams in the coastal plain of Virginia particularly benefit from forested riparian buffers due to low-gradient topography and shallow aquifers that allows for effective sediment and nutrient removal. Both grass and forested buffers are effective for sediment removal, forested buffers also offer greater resistance during heavy floods. Buffer widths of 50-100 feet are recommended for sediment trapping. The ability of buffers to remove nutrients is highly variable and is tied to soils and hydrology.

Langland, M. and T. Cronin, editors. 2003. A summary report of sediment processes in Chesapeake Bay and watershed. U.S. Department of the Interior, U.S. Geological Survey, Water-Resources Investigations Report 03-4123.
This report summarizes the most relevant studies concerning sediment sources, transport and deposition in the Chesapeake Bay watershed and estuary, sediments and relation to water clarity, and provides an extensive list of references for those wanting more information.

National Research Council. 2007. Mitigating shore erosion on sheltered coasts. The National Academies Press, Washington DC. 174 pp.
This report examines the impacts of shoreline management on sheltered coast environments and strategies to minimize potential negative impacts to adjacent or nearby coastal resources. It includes background information about sediment processes and basic physical laws that control erosion, such as conservation of sediment mass and control of sediment fluxes.

Ott, R A. 2000. Factors affecting stream bank and river bank stability, with an emphasis on vegetation influences. An annotated bibliography compiled for the Region III Forest Practices Riparian Management Committee.
This literature review focuses on factors affecting stream bank and riverbank stability in Alaska, with an emphasis on vegetation influences. Vegetation has been shown to stabilize banks of rivers and streams in some systems. It has been suggested that the harvest of riparian timber in interior Alaska can increase riverbank erosion rates. It has also been suggested that timber harvest near watercourses will decrease the supply of large woody debris (LWD) that is recruited into a river through natural erosion processes.

Palace, M.W., J.E. Hannawald, L.C. Linker, and G.W. Shenk. 1998. Chesapeake Bay watershed model applications & calculation of nutrient & sediment loadings - Appendix H: Tracking best management practice nutrient reductions in the Chesapeake Bay. Program report of the modeling subcommittee. August, 1998. Chesapeake Bay Program Office, Annapolis, MD.
This document provides a summary of the methodologies used in tracking nutrient reduction goals for the Chesapeake Bay watershed. Both tidal structural and non-structural erosion controls reduce the nitrogen, phosphorus, and suspended sediment loads by an estimated 75 percent.

Palone, R. S. & A.H. Todd (editors). 1997. Chesapeake Bay riparian handbook: a guide for establishing & maintaining forest buffers. USDA Forest Service. NA-TP-02-97. Radnor, PA. Revised 1998.
This comprehensive guide provides information about the function, design, establishment, and management of riparian forest buffers in the Chesapeake Bay watershed. Different land use considerations are included for agriculture, forestry and urban settings. They recommend a flexible buffer width design that incorporates floodplain areas, undevelopable steep slopes, and adjacent wetlands.

Wynn, T.M., S. Mostaghimi, J.A. Burger, A.A. Harpold, M.B. Henderson, L. Henry. 2004. Variation in root density along stream banks. J. of Environ. Qual. 33(6): 2030-2039.
The purpose of this study was to determine the type and density of vegetation that provides the greatest protection against erosion by determining the density of roots in stream banks of the Appalachian Mountains. Root length density with depth and aboveground vegetation density were measured for both forested and herbaceous sites. The results indicated that forested vegetation may provide better protection against stream bank erosion because it had a significantly higher concentration of fine roots, as compared to herbaceous sites.

4. Bank Stability

Byrne, R.J. C.H. Hobbs, III, M.J. Carron. 1982. Baseline sediment studies to determine distribution, physical properties, sedimentation budgets and rates in the Virginia portion of the Chesapeake Bay. US EPA R806001010, Virginia Institute of Marine Science, Gloucester Point, VA. p.155
This study estimated that shore erosion accounted for 6% of the suspended sediment in the total inorganic sediment budget for the Virginia portion of Chesapeake Bay. The authors also gave a measured value for the sand component from shore erosion as $4.0x10^5$ metric tons per year.

Chesapeake Bay Program (CBP). 2005. Sediment in the Chesapeake Bay and management issues: tidal erosion processes. Prepared by the Tidal Sediment Task Force of the Sediment Workgroup under the Chesapeake Bay Program, Nutrient Subcommittee, May 2005.
This document provides background information on sediment processes and data to determine the effects of tidal sediment in a watershed and can serve as a general targeting tool for shoreline management and sediment controls that can improve water quality. It also suggests that tidal erosion should be viewed as an integral part of the natural ecosystem processes in the Bay and a necessary component of a properly functioning ecosystem, while also considering that excessive sediment loads can be detrimental to water quality.

Davis, J.E., S.T. Maynord, J. McCormick and T.J. Olin. 2000. Shoreline protection and erosion control. In Section 5, Establishing Proper Hydrologic Conditions, Wetlands Engineering Handbook. Compiled by TJ Olin et al, prepared for U.S. Army Corps of Engineers Wetlands Research Program, ERDC/EL TR-WRP-RE-21, March 2000, 719 pp.
This chapter in the wetlands engineering handbook describes methods for erosion control and shoreline protection for created and restored wetland sites. Various causes and mechanisms of erosion and bank failure are described. Erosion protection alternatives and design considerations are also provided.

Hardaway, C.S., Jr. G.R. Thomas, J.B. Glover, J.B. Smithson, M.R. Berman, A.K. Kenne. 1992. Bank erosion study. Special report in Applied Marine Science and Ocean Engineering, No. 319. Virginia Institute of Marine Science. April 1992.
This study analyzed fastland bank erosion along 383 miles of tidal shoreline in the Virginia portion of Chesapeake Bay. The authors discovered that the volume of eroded material was more significant than the erosion rate, which depends on bank height (i.e. high bank with low erosion rate may contribute larger volume than low bank with higher erosion rate.) Sediment volume loading was reduced where defensive shoreline structures were installed. For the James River, 18% of the shoreline studied was defended with structures between 1985-1990, which reduced the annual estimated nutrient load by 5%.

Ibison, N.A., C.W. Frye, J.E. Frye, C.L. Hill, N.H. Burger. 1990. Sediment and nutrient contributions of selected eroding banks of the Chesapeake Bay estuarine system.

Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation, Shoreline Programs Bureau. January 1990.
This study evaluated 14 eroding banks to examine sediment and nutrient inputs from tidal shoreline erosion. They estimated 1.37 million pounds per year of nitrogen and 0.94 million pounds per year of phosphorus is entering the Bay ecosystem through shoreline erosion. This quantity of nitrogen is 5.2% of the "controllable" nonpoint source nitrogen load, as defined by the 1987 Chesapeake Bay Agreement (Chesapeake Executive Council, 1988).

Ibison, N.A., J.C. Baumer, C.L. Hill, N.H. Burger, J.E. Frye. 1992. Eroding bank nutrient verification study for the lower Chesapeake Bay. Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation, Shoreline Programs Bureau. February 1992.
This research verified and expanded a 1990 study by examining 44 additional eroding banks along the lower Chesapeake Bay for grain size, nitrogen & phosphorus loads. The impacts of land use on nutrient loading characteristics were also examined (active farms, fallow farms, wooded and rural residential). They discovered that the mean nutrient loading rates from the previous study were approximately twice those calculated in this study. The reaches sampled had lower erosion rates and eroded soil volumes.

Klapproth, J.C. & J.E. Johnson. 2000. Understanding the science behind riparian buffers: Effects on water quality. Virginia Cooperative Extension publication 420-151.
This is one paper in a series that summarizes the current scientific understanding of riparian buffers in Virginia. Streams in the coastal plain of Virginia particularly benefit from forested riparian buffers due to low-gradient topography and shallow aquifers that allows for effective sediment and nutrient removal. Both grass and forested buffers are effective for sediment removal, forested buffers also offer greater resistance during heavy floods. Buffer widths of 50-100 feet are recommended for sediment trapping. The ability of buffers to remove nutrients is highly variable and is tied to soils and hydrology.

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Ott, R A. 2000. Factors affecting stream bank and river bank stability, with an emphasis on vegetation influences. An annotated bibliography compiled for the Region III Forest Practices Riparian Management Committee.
This literature review focuses on factors affecting stream bank and riverbank stability in Alaska, with an emphasis on vegetation influences. Vegetation has been shown to stabilize banks of rivers and streams in some systems. It has been suggested that the harvest of riparian timber in interior Alaska can increase riverbank erosion rates. It has also been suggested that timber harvest near watercourses will decrease the supply of large woody debris (LWD) that is recruited into a river through natural erosion processes.

US Army Corps of Engineers (USACOE). 1990. Chesapeake Bay shoreline erosion study, feasibility report, October 1990.
The purpose of this study was to evaluate shoreline protection measures that will protect both land and water resources of the Chesapeake Bay from the adverse effects of continued erosion. Both structural and nonstructural solutions and their suitability for different shoreline types were examined. Five demonstration projects were also constructed and monitored for about two years, including two in Maryland and three in Virginia.

Wilson, G V; Periketi, R K; Fox, G A; Dabney, S M; Shields, F D; Cullum, R F Soil properties controlling seepage erosion contributions to stream bank failure**.** Earth Surface Processes and Landforms, vol.32, no.3, pp.447-459, Mar 2007
The objective of this study was to determine the impact of soil properties on seepage erosion and the resulting stream bank failure along the banks of a deeply incised stream in northern Mississippi. It was suggested that the USDA-ARS Stream bank Stability model demonstrated the increase in instability of banks due to undercutting by seepage erosion, but failed to account for the sediment loss due to sapping for stable banks and overestimated the sediment loads for failed banks.

Wynn, T.M., S. Mostaghimi, J.A. Burger, A.A. Harpold, M.B. Henderson, L. Henry. 2004. Variation in root density along stream banks. J. of Environ. Qual. 33(6): 2030-2039.
The purpose of this study was to determine the type and density of vegetation that provides the greatest protection against erosion by determining the density of roots in stream banks of the Appalachian Mountains. Root length density with depth and aboveground vegetation density were measured for both forested and herbaceous sites. The results indicated that forested vegetation might provide better protection against stream bank erosion because it had a significantly higher concentration of fine roots, as compared to herbaceous sites.

5. Shoreline Resources

Marshes - Water Quality

Bricker S. B. 1996. Retention of sediment and metals by Narragansett Bay subtidal and marsh environments; an update; Transport and accumulation processes of contaminants in estuarine and coastal waters. The Science of the Total Environment. 179: 27-46.
Study of Narragansett Bay suggests that salt marshes retain virtually all incoming sediment.

Christiansen T. 1999. Sediment deposition on a tidal salt marsh. Thesis Publ. Date: 1998, 134 pp University of Virginia, Charlottesville, VA, USA
Student thesis suggests that Spartina alterniflora has a significant dampening effect on the turbulence of the flow, promoting deposition of suspended particles. Again concludes that more sediment is deposited on marsh edge than interior, with 27% sediment deposited on the marsh surface by storms; the rest deposited during normal high spring tides.

Davis J. L., B. Nowicki, and C. Wigand. 2004. Denitrification in fringing salt marshes of Narragansett Bay, Rhode Island, USA. Wetlands. 24:870-878.
Results of this field survey show the potential of New England fringe salt marshes to intercept and transform land-derived nitrogen loads, but calls for a better understanding of the natural and anthropogenic factors controlling denitrification and net N losses.

Fisher J., M. C. Acreman. 2004. Wetland nutrient removal: a review of the evidence. Hydrology and Earth System Sciences. 8:673-685.
Survey of data from 57 wetlands from around the world showed that the majority of wetlands reduced nutrient loading Marshes were also shown to be slightly more effective at nutrient reduction than riparian zones.

Gleason M. L., D. A. Elmer, N. C. Pien, and J. S. Fisher. 1979. Effects of stem density upon sediment retention by salt marsh cord grass, Spartina alterniflora Loisel. Estuaries. 2(4), 271-273.
Greatest accretion of sediment results from higher density low marsh.

Kaplan W., I. Valiela, and M. Teal. 1979. Denitrification in a salt marsh ecosystem. Limnology and Oceanography. 24:726-734.
Seasonal denitrification measured in Great Sippewissett Marsh, Mass. The rate of denitrification was related to temperature and was highest in the wettest habitats. 60 % of denitrification occurred in the creek bottoms. Suggest greater rates of dentrification than fixation, indicating a significant source of atmospheric nitrogen. Upshot for water quality is less nitrogen in the water column.

MacCrimmon H. R. 1980. Nutrient and sediment retention in a temperate marsh ecosystem. Internationale Revue der Gesamten Hydrobiologie. 65:719-744.

11-month study of a marsh to determine its retention capability for incoming nitrogen, phosphorus, silica, and suspended solids from the Wye River, Ont., agricultural watershed. Results indicated that the marsh is a substantial reservoir for nutrients, sediments.

Morse, J.L., P. Megonigal, and M.R. Walbridge. 2004. Sediment nutrient accumulation and nutrient availability in two tidal freshwater marshes along the Mattaponi River, Virginia, USA. Biogeochem. 69: 175-206.
Sediment accumulation is greater in downstream, channelward marsh edge as opposed to upstream or interior marsh because of close proximity to turbid water.

Neubauer S. C., I. C. Anderson, J. A. Constantine, and S. A. Kuehl. 2002. Sediment deposition and accretion in a Mid-Atlantic (U.S.A.) tidal freshwater marsh. Estuarine, Coastal and Shelf Science. 54:713-727.
A study of sediment deposition and accretion rates in a fresh marsh indicated that deposition was greatest at the creek margin rather than in marsh interior. Seems to indicate most sediment comes from water column and not from upland sources. Also concluded the deposition was not from resuspension/erosion of existing marsh but was from outside sources. Rapid mineralization rates contributed to a decrease in accretion relative to deposition, with the remainder resulting from erosion.

Oviatt C. A., S. W. Nixon. 1975. Sediment resuspension and deposition in Narragansett Bay. Estuar.Coast.Mar.Sci. 3:201-217.
Study concluded that sediment activity increase as the sampling points moved from the head to the mouth of the estuary. Although organics of deposited materials decreased from head to mouth of estuary. most deposited material was from resuspension of bottom sediments rather than fresh inputs from the water column. This seems to indicate the importance of the upper reaches of estuaries (tidal creeks) for trapping organic laden sediments.

van Proosdij D., R. G. D. Davidson-Arnott, and J. Ollerhead. 2006. Controls on spatial patterns of sediment deposition across a macro-tidal salt marsh surface over single tidal cycles. Estuarine, Coastal and Shelf Science. 69:64-86.
A field study examining the spatial patterns of sediment deposition across a salt marsh surface in the Bay of Fundy. Describes the area around the mean high water level as a transition zone for processes of sediment transport and deposition, with most deposition taking place around this region. Somewhat limited in direct application to local Virginia marshes because of the huge difference in tide range.

Reddy K. R., P. M. Gale. 1994. Wetland processes and water quality: a symposium overview. Journal of Environmental Quality. 23:875-877.
Review paper states that wetlands act as buffer between upland and aquatic areas and protect aquatic systems from upland environments through sedimentation and filtration of runoff providing environments for nutrient assimilation.

Marshes - Habitat

Erwin R. M. 1995. The ecology of cormorants: Some research needs and recommendations. Colonial Waterbirds. 1:240-246.
Review of the significance of Cormorants (Phalacrocorax auritus) in coastal systems and the need for more research.

Erwin R. M., G. M. Haramis, D. G. Krementz, and S. L. Funderburk. 1993. Resource protection for waterbirds in Chesapeake Bay. Environmental Management. 17:613-619.
Describes waterbird usage in the Bay and need for more focus on habitat conservation in Bay cleanup efforts. Describes habitat concerns for American black ducks (Anas rubripes), great blue herons (Ardea herodias), and other associated wading birds, wood ducks (Aix sponsa), canvasbacks (Aythya valisineria) and redheads (Aythya americana), and for bald eagles (Haliaeetus leucocephalus)

Erwin R. 1996. Dependence of waterbirds and shorebirds on shallow-water habitats in the mid-Atlantic coastal region: An ecological profile and management recommendations. Estuaries. 19(2A):213-219.
Describes the importance of salt and brackish marsh shallow water areas as habitat for waterbirds (waterfowl, colonially nesting wading and seabirds, ospreys [Pandion haliaetus], and bald eagles [Haliaeetus leucocephalus]) and shorebirds (sandpipers, plovers, and relatives).

Hurd, L. E., G. W. Smedes, et al. (1979). "Ecological Study of a Natural-Population of Diamondback Terrapins (Malaclemys-Terrapin-Terrapin) in a Delaware Salt-Marsh." Estuaries. 2(1): 28-33.
A 2-year study of a population of Diamondback Terrapin in a salt marsh in Delaware. Estimated size of the terrapin population from this study indicates that terrapins may be important components of the marsh food web.

Oviatt C. A., S. W. Nixon. 1973. The demersal fish of Narragansett Bay: an analysis of community structure, distribution and abundance. Estuar.Coast.Mar.Sci. 1:361-378.
Monthly samples of demersal fish resulted in 9000 individuals representing 99 spp Winter flounder, Pseudopleuronectes americanus was most abundant.

Pomeroy L. R.,[1925-], R. G. Wiegert. 1981. The Ecology of a salt marsh / edited by L.R. Pomeroy.
Review of salt marsh ecology and the flora and fauna of the salt marsh.

Smalley, A.E. 1960. Energy flow of a salt marsh grasshopper population. Ecology. 41(4): 672-677.
Classic paper on the energetics of a salt marsh invertebrate at Eugene Odum's Sapelo Island research sites. Often sited in reviews of animals that inhabit salt marshes as Orchelimum is considered a dominant primary consumer in Spartina marshes

Wiegert, R.G. and B.J. Freeman. 1990. Tidal salt marshes of the southeast Atlantic Coast: a community profile. U.S. Fish Widl. Serv., Biol. Rep. 85 (7.29). 70 pp.
This publication series by U.S. Fish and Wildlife Services issues reports on research and inventories, and the effects of land-use on various fish and wildlife resources. This volume by University of Georgia researchers looks at the ecology of tidal marshes in the southeast U.S. Contains lists of vascular plants found in salt marshes as well as invertebrates, fish, reptiles, birds, and mammals that inhabit southeastern salt marshes and in specific community types.

Phragmites - Water Quality

Rooth J. E., J. Court Stevenson, and J. C. Cornwell. 2003. Increased sediment accretion rates following invasion by Phragmites australis: the role of litter. Estuaries. 26:475-483.
"Greater rates of mineral and organic sediment trapping were associated with the P. australis community in both a subsiding creek bank marsh (34 g times m super(-2) times day super(-1) in P. australis vs. 18 g times m super(-2) times day super(-1) in Spartina spp.) and a laterally eroding marsh (24 g times m super(-2) times day super(-1) in P. australis vs. 15 g times m super(-2) times day super(-1) in Spartina spp.). Litter accumulation in P. australis stands is responsible for the higher depositional pattern observed. Additionally, below ground accumulation in P. australis communities (as much as 3 mm in 6 months) appears to substantially increase substrate elevation over relatively short time periods. Thus P. australis may provide resource managers with a strategy of combating sea-level rise and current control measures fail to take this into consideration."

Rooth J. E., J. C. Stevenson. 2000. Sediment deposition patterns in Phragmites australis communities: Implications for coastal areas threatened by rising sea-level. Wetlands Ecology and Management. 8:173-183.
Phragmites was found to enhance rates of marsh accretion and sheds some doubt on the view of Phragmites invasion as a purely undesirable change in the face of sea level rise .Implications for water quality and erosion protection.

Phragmites - Habitat

Able K. W., S. M. Hagan. 2003. Impact of common reed, Phragmites australis, on essential fish habitat: Influence on reproduction, embryological development, and larval abundance of mummichog (*Fundulus heteroclitus*). Estuaries. 26:40-50.
Phragmites invasion in brackish marshes may be having deleterious effects on fish populations and possibly on predators that prey upon F. heteroclitus, and as a result, marsh secondary production.

Able K. W., S. M. Hagan. 2000. Effects of common reed (Phragmites australis) invasion on marsh surface macrofauna: Response of fishes and decapod crustaceans. Estuaries. 23:633-646.

As a result of these observations, with different sampling techniques, it appears there is an overall negative effect of Phragmites on larval and small juvenile fish but less or no effect on larger fish and decapods crustaceans.

Angradi T. R., S. M. Hagan, and K. W. Able. 2001. Vegetation type and the intertidal macroinvertebrate fauna of a brackish marsh: Phragmites vs. Spartina. Wetlands. 21:75-92.
Total macroinvertebrate density, mean taxa richness, stem density, microtopographic relief, density of microhabitats was greater in Spartina. Detrital and above-ground vegetative biomass and water velocity were greater in Phragmites marsh. Difference in invert dominance between the communities. Greater density of intertidal standing-water microhabitats is important as a source of faunal variation between marsh types. Fewer refugia from predators at high tide in Phrag.

Chambers R. M., L. A. Meyerson, and K. Saltonstall. 1999. Expansion of Phragmites australis into tidal wetlands of North America. Aquatic Botany. 64:261-273.
"Rapid spread of Phragmites has been documented in freshwater (<0.5 ppt), oligohaline (0.5-5 ppt) and mesohaline (5-18 ppt) tidal wetlands…A fundamental concern regarding Phragmites expansion, particularly into tidal freshwater wetlands, is the observed reduction in biodiversity as many native species of plants are replaced by a more cosmopolitan species. Commensurate with a shift in habitat type is a reduction in insect, avian and other animal assemblages. Ecosystem services, including support of higher trophic levels, enhancement of water quality and sediment stabilization, however, are not diminished when a tidal wetland becomes dominated by Phragmites, provided that tidal flooding is retained."

Hunter K. L., D. A. Fox, L. M. Brown, and K. W. Able. 2006. Responses of resident marsh fishes to stages of Phragmites australis invasion in three mid Atlantic estuaries. Estuaries and Coasts. 29:487-498.
Patterns studied suggest a decline in habitat function for larval and juvenile F. heteroclitus as invasion progresses.

Jivoff P. R., K. W. Able. 2003. Blue crab, *Callinectes sapidus*, response to the invasive common reed, Phragmites australis: Abundance, size, sex ratio, and molting frequency. Estuaries. 26:B 587-595.
Crabs prefer the marsh surface in Spartina Marshes, so phrag can negatively affect crab usage through different marsh surface. Restoration can have positive influence on marsh crab through change in marsh surface.

Osgood D. T., D. J. Yozzo, R. M. Chambers, D. Jacobson, T. Hoffman, and J. Wnek. 2003. Tidal Hydrology and Habitat Utilization by Resident Nekton in Phragmites and Non-Phragmites Marshes. Estuaries. 26:522-533.
Shrimp and Mummichog greater in Spartina. Large fish effected when Phrag invasion effects flood frequency, water depth.

Robertson T. L., J. S. Weis. 2005. A comparison of epifaunal communities associated with the stems of salt marsh grasses Phragmites Australis and Spartina Alterniflora. Wetlands. 25:1-7.
S. alterniflora stems support more epifaunal animals than P. australis stems overall.

Robertson T. L., J. S. Weis. 2007. Interactions between the grass shrimp *Palaemonetes pugio* and the salt marsh grasses *Phragmites australis* and *Spartina alterniflora*. Biological Invasions. 9:25-30.
Attempted to demonstrate the epifauna differences were due to greater effectiveness of grazing Phragmites. However, found grazing to be proportional. Rules out top-down control of epifauna on Phrag.

Wainright S. C., M. P. Weinstein, K. W. Able, and C. A. Currin. 2000. Relative importance of benthic microalgae, phytoplankton and the detritus of smooth cordgrass Spartina alterniflora and the common reed Phragmites australis to brackish-marsh food webs. Marine Ecology Progress Series. 200:77-91.
Although there were negative effects of invasion on benthic microalgae from shading, the study does indicate that P. australis may contribute to aquatic food webs in tidal marshes.

Weis J. S., P. Weis. 2003. Is the invasion of the common reed, Phragmites australis, into tidal marshes of the eastern US an ecological disaster? Marine Pollution Bulletin. 46:816-820.
Review of studies on Phragmites invasion suggest that Phragmites dominated marshes are comparable to Spartina marshes in benthics and nekton. Some negative effects on Mummichog and epifauna, but overall refutes the idea that Phrag is 'useless' as a habitat and contributor to food webs.

Dunes - Water Quality

Conn C. E., F. P. Day. 1993. Belowground biomass patterns on a coastal barrier island in Virginia. Bulletin of the Torrey Botanical Club. 120:121-127.
Structural attributes of dune plant root systems result in reduced nutrient losses through leaching.

Heyel S. M., F. P. Day. 2006. Long-term residual effects of nitrogen addition on a barrier island dune ecosystem. Journal of the Torrey Botanical Society. 133:297-303.
Belowground reserves of nitrogen from a single fertilization persisted for more than ten years. Suggest that dune plants are efficient at uptake and storage of nutrients given the limitations in the sandy, well drained substrate.

Dunes - Habitat

Engels, W. L. 1942. Vertebrate fauna of North Carolina coastal islands. A study in the dynamics of animal distribution I. Ocracoke Island. American Midland Naturalist. 28(2): 273-304.

Monograph on the geology, climate, ecology of Ocracoke Island and the flora and fauna of the dunes and beaches on the island.

Dunes - Sand Storage

Nordstrom, K.F. and E.L. Lotstein. 1989. Perspectives on resource use of dynamic coastal dunes. The Geographical Review. 79(1): 1-12.
This review discusses the use and management of dunes systems and describes the system as dynamic. Questions the stabilization or control of dunes as diminishing the resource value of dunes as sand reserves.

Beaches - Habitat

Dexter, D.M. 1967. Distribution and niche diversity of Haustoriid Amphipods in North Carolina. Chesapeake Science. 8(3): 187-192.
Review of amphipod fauna of North American Atlantic Coast from Gulf of Saint Lawrence to Florida. Indicates that 91% of interidal beach fauna consists of amphipods in the family haustoriidae.

McLachlan, A. and A. Brown. 2006. 2nd Edition. The Ecology of Sandy Shores.
Gives a global perspective on sand shore environments, with some bias toward South Africa where the most work has been done. Also treats the pacific coast (California) and the N. American Atlantic Coast (Maine) among other locations. Gives the general ecology of sandy shores and the flora and fauna that inhabit them.

Pearse, A.S., H.J. Humm, and G.W. Wharton. 1942. Ecology of sand beaches at Beaufort, N.C. Ecological Monographs. 12(2): 135-190.
A comprehensive ecological survey of the flora and fauna on the beaches around Ft. Macon, N.C. Lists a large number of inverts including Haustoriidae which is again cited as abundant in the surf zone. Also lists fish species found in the near shore as well as bird species foraging in the intertidal beach zone.

6. Shoreline Structures

Seawalls/Bulkheads – Water Quality

Basco, D.R., Bellomo, D.A., Hazelton, J.M., and Jones, B.N. 1997. The influence of seawalls on subaerial beach volumes with receding shorelines. Coast. Eng. 30(3-4): 203-233.
Sandbridge, VA; Do bulkheads increase erosion an adjacent non-bulkheaded shorelines? No, but do affect seasonal variability of sand volume in front of bulkhead.

Bozek, C.M., and Burdick, D.M. 2005. Impacts of seawalls on saltmarsh plant communities in the Great Bay estuary, New Hampshire USA. Wetlands Ecol. Manage. 13(5): 553-568.
How do seawalls impact fringing marshes? Also looks at sediment movement and groundwater flow with bulkheads.

Camfield, F.E., and Briggs, M.J. 1993. Longshore transmission of reflected waves. Journal of Waterway, Port, Coastal and Ocean Engineering (ASCE) JWPED5. p 575-579: 7 ref.
Waves reflected from coastal structures may become trapped by refraction, impacting downshore properties

Dellapenna, T.M., Allison, M., Robb, B., Bronikowski, J.L., Cerf, M., Majzlik, E.J., and Noll, C. 2004. Architecture of barrier island shore face in response to hard structures, beach nourishment, and subsidence; investigations along Galveston and Follet's islands, upper Texas coast. Geological Society of America, south-central section, 38th annual meeting. Abstracts with Programs - Geological Society of America. 36(1): 23.
Compared bulkheads and beach nourishment sites with natural shorelines.

Douglass, S.L. and B.H. Pickel. 1999. "The Tide Doesn't Go Out Anymore"—The Effect of Bulkheads on Urban Bay Shorelines. University of South Alabama, Civil Engineering and Marine Sciences Departments, Mobile. [Online] Available at: http://www.southalabama.edu/cesrp/Tide.htm [January 25, 2006].
Sediment deficit leads to shoreline erosion, when bulkhead is constructed, the erosion continues in front of the bulkhead leading to reduced intertidal areas. Discusses societal impacts and habitat impacts associated with loss of intertidal areas. Seawalls also impact littoral transport by preventing erosion.

El Banna, M.M. 2006. Responses of ras el bar seafloor characteristics to the protective engineering structures, Nile delta, Egypt. Environ. Geol. 49(5): 645-652.
Scouring impacts associated with breakwaters and bulkheads.

Griggs, J.F. and G.B. Tait. 1991. Beach Response to the Presence of a Seawall; Comparison of Field Observations. Contract Report CERC 91-1. U.S. Army Corps of Engineers, Waterways Experiment Station, Vickburg, Mississippi.

Griggs, G.B. 2005. The impacts of coastal armoring. Shore Beach. 73(1): 13-22.
Impacts from coastal hardening along the California coastline.

Kraus, N.C. and W.C. McDougal. 1996. The effects of seawalls on the beach: Part I, An updated literature review. Journal of Coastal Research. 12(3):691-701.

Kraus, N.C. and Heilman, D.J. 1998. Comparison of beach profiles at a seawall and groins, Corpus Christi, Texas. Shore and Beach. 66(2): 4-13.
Very general abstract, need to look at the paper for detail.

Kraus, N.C. and O.H. Pilkey. 1988. The effects of seawalls on the beach. Journal of Coastal Research. Special Issue 4:1-28.

Spalding, V.L. and N.L. Jackson. 2001. Field investigation of the influence of bulkheads on meiofaunal abundance in the foreshore of an estuarine sand beach. Journal of Coastal Research. 17:363-370.

Tait, J.F. and G.B. Griggs. 1990. Beach response to the presence of a seawall: a comparison of field observations. Shore and Beach. 58(2):11-28.
Systematic study of seawall effect on active beach erosion. Looks at seasonal beach changes and the physical processes that impact them.

Weggel, J.R., and Lesnik, J. 2006. Did this seawall cause erosion? Shore Beach. 74(3): 24-25.
No abstract.

Wilber, R.J., and Bush, D.M. 2003. Mesoscale response of a mobile sedimentary shoreline; basis for new directions in coastal management at the community level; Falmouth, MA. Geological Society of America, 2003 annual meeting. Abstracts with Programs - Geological Society of America. 35(6): 469.
Looked at structure impact on sediment movement; a case study.

Seawalls/Bulkheads – Habitat

Bischoff, A., and Humboldt-Universitaet zu Berlin. 2002. Juvenile fish recruitment in the large lowland river Oder: Assessing the role of physical factors and habitat availability. Shaker Verlag GmbH, Aachen.
Sampled juvenile fish assemblages in several different habitats; natural habitat is best.

Bozek, C.M., and Burdick, D.M. 2005. Impacts of seawalls on saltmarsh plant communities in the Great Bay estuary, New Hampshire USA. Wetlands Ecol. Manage. 13(5): 553-568.
How do seawalls impact fringing marshes? Also looks at sediment movement and groundwater flow with bulkheads.

Bulleri, F. 2005. Experimental evaluation of early patterns of colonisation of space on rocky shores and seawalls. Mar. Environ. Res. 60(3): 355-374.
Australia; The different habitat types modify the environment and affect recruitment.

Bulleri, F., Chapman, M.G., and Underwood, A.J. 2005. Intertidal assemblages on seawalls and vertical rocky shores in Sydney harbour, Australia. Austral Ecol. 30(6): 655-667.
Australia, patterns of abundance and variation differ between bulkheads and natural sites.

Bulleri, F. 2005. Role of recruitment in causing differences between intertidal assemblages on seawalls and rocky shores. Mar. Ecol. Prog. Ser. 287: 53-65.
Australia, Intrinsic differences between seawalls and natural shorelines affect recruitment of algae and inverts.

Chapman, M.G. 2006. Intertidal Seawalls as Habitats for Molluscs. J.Molluscan Stud. 72(3): 247-257.
Research has shown that many components of intertidal assemblages live on seawalls, but patterns of abundance and diversity are very variable. Seawalls differ physically from natural shores in a number of ways that are likely to influence distribution and abundances of intertidal molluscs, assemblages varied between tidal heights and among locations, but when data were combined across locations, there were some general patterns. Sessile bivalves (oysters and mussels) and many limpets were found in similar numbers on both habitats, or patterns varied inconsistently. Many coiled snails, in contrast, including whelks and grazing gastropods, plus opisthobranchs, which were either common or relatively sparse on horizontal shores, were not found on seawalls and found in intermediate frequencies on vertical shores. Similarly, common species of molluscs were found in natural and artificial boulder-fields in similar numbers, or patterns were not consistent, although rarer species were not found in these boulder-fields.

Chapman, M.G. 2003. Paucity of mobile species on constructed seawalls: Effects of urbanization on biodiversity. Mar. Ecol. Prog. Ser. 264: 21-29.
Australia, there is a lack of mobile species using seawalls relative to natural shorelines; also a lack of rare species.

Douglass, S.L. and B.H. Pickel. 1999. "The Tide Doesn't Go Out Anymore"—The Effect of Bulkheads on Urban Bay Shorelines. University of South Alabama, Civil Engineering and Marine Sciences Departments, Mobile. [Online] Available at: http://www.southalabama.edu/cesrp/Tide.htm [January 25, 2006].
Sediment deficit leads to shoreline erosion, when bulkhead is constructed, the erosion continues in front of the bulkhead leading to reduced intertidal areas. Discusses societal impacts and habitat impact associated with loss of intertidal areas. Seawalls also impact littoral transport by preventing erosion.

Hendon, J.R., Peterson, M.S., and Comyns, B.H. 2001. Seasonal distribution of gobiids in waters adjacent to estuarine marsh-edge habitats: Assessing the effects of habitat alteration. Proc. Gulf Caribb. Fish. Inst.(52): 428-441.
Lower goby abundance in "altered" marsh habitats compared with natural.

Hendon, J.R., Peterson, M.S., and Comyns, B.H. 2000. Spatio-temporal distribution of larval gobiosoma bosc in waters adjacent to natural and altered marsh-edge habitats of mississippi coastal waters. Bull. Mar. Sci. 66(1): 143-156.
Even altered marsh habitats are important habitats for goby reproduction and life cycle.

Jaramillo, E., Contreras, H., and Bollinger, A. 2002. Beach and faunal response to the construction of a seawall in a sandy beach of south central Chile. J. Coast. Res. 18(3): 523-529.
Found that bulkheads did not impact beach macrofaunal community over the course of the study.

Jennings, M.J., Bozek, M.A., Hatzenbeler, G.R., Emmons, E.E., and Staggs, M.D. 1999. Cumulative effects of incremental shoreline habitat modification on fish assemblages in north temperate lakes. N. Am. J. Fish. Manage. 19(1): 18-27.
Species richness increased with increasing habitat complexity; assemblage structure changed with cumulative effect.

Peterson, M.S., Comyns, B.H., Hendon, J.R., Bond, P.J., and Duff, G.A. 2000. Habitat use by early life-history stages of fishes and crustaceans along a changing estuarine landscape: Differences between natural and altered shoreline sites. Wetlands Ecology and Management. 8: 209-219.
Nekton population was less abundant along bulkhead and riprap shorelines than marsh grass shorelines.

Pilkey, O. and H. Wright. 1988. Seawalls vs. beaches. Journal of Coastal Research SI4:41-64.

Rice, C., Sobocinski, K., and Puget Sound Action Team, Olympia, WA (USA). 2004. Effects of shoreline modification on spawning habitat of surf smelt (hypomesus pretiosus) in Puget Sound, Washington. Puget Sound Action Team, PO Box 40900 Olympia WA 98504 USA.
Higher temperatures were found on unvegetated, armored shorelines compared with natural.

Rice, C.A. 2006. Effects of shoreline modification on a northern Puget Sound beach: Microclimate and embryo mortality in surf smelt (hypomesus pretiosus). Estuaries Coasts. 29(1): 63-71.
Higher temperatures on altered beaches impact smelt egg survival.

Scheuerell, M.D., and Schindler, D.E. 2004. Changes in the spatial distribution of fishes in lakes along a residential development gradient. Ecosystems. 7(1): 98-106.
Shoreline modification is modifying the spatial distribution of aquatic organisms.

Schmude, K.L., Jennings, M.J., Otis, K.J., and Piette, R.R. 1998. Effects of habitat complexity on macroinvertebrate colonization of artificial substrates in north temperate lakes. J. N. Am. Benthol. Soc. 17(1): 73-80.
Riprap shorelines have a larger and more diverse community than bulkheaded shorelines.

Seitz, R.D., Lipcius, R.N., Olmstead, N.H., Seebo, M.S., and Lambert, D.M. 2006. Influence of shallow-water habitats and shoreline development on abundance, biomass,

and diversity of benthic prey and predators in chesapeake bay. Mar. Ecol. Prog. Ser. 326: 11-27.
Benthic abundance and diversity are highest in natural sites, intermediate at riprap sites, and lowest at bulkhead sites, this is also true for blue crabs.

Toft, J. 2005. Benthic macroinvertebrate monitoring at Seahurst Park 2004, pre-construction of seawall removal. Rep. Fish. Res. Inst. Wash. Univ.(0502).
Seawall sites have lower invertebrate density compared to vegetated sites.

Toft, J., and Cordell, J. 2006. Olympic Sculpture Park: Results from pre-construction biological monitoring of shoreline habitats. Rep. Fish. Res. Inst. Wash. Univ (0601) .
Abstract is vague—is this the results of a study or a proposal for a study?

Trial, P.F., Gelwick, F.P., and Webb, M.A. 2001. Effects of shoreline urbanization on littoral fish assemblages. Lake Reserv. Manage. 17(2): 127-138.
Bulkhead communities were different from natural shorelines, while riprap was similar.

Watkinson, D.A., Franzin, W.G., Podemski, C.L., and Department of Fisheries and Oceans Canada, Winnipeg, MB (Canada) Centr. Arctic Reg. 2004. Fish and invertebrate populations of natural, dyked and riprapped banks of the Aassiniboine and Red rivers, Manitoba. 2524.
Fish abundance was higher at armoured than natural shorelines and invertebrate and fish diversity was similar at all sites.

Wolter, C. 2001. Conservation of fish species diversity in navigable waterways. Landscape Urban Plann. 53(1-4): 135-144.
The percent of hardened shoreline was inversely correlated to the number of species, species diversity and the number of intolerant species.

Zito, A.N., Welch, J.M., and Kirby-Smith, W.W. 2004. The impact of avian predation on sea urchins arbacia punctulatan inhabiting a sea wall in Beaufort NC. Ohio J. Sci. 104(1): A-20.
Gulls preferentially prey on sea urchins living on seawalls (compared to what?).

Riprap – Water Quality

Camfield, F.E., and Briggs, M.J. 1993. Longshore transmission of reflected waves. Journal of Waterway, Port, Coastal and Ocean Engineering (ASCE) JWPED5. p 575-579: 7 ref.
Waves reflected from coastal structures may become trapped by refraction, impacting downshore properties

Griggs, G.B. 2005. The impacts of coastal armoring. Shore Beach. 73(1): 13-22.
Impacts from coastal hardening along the California coastline.

Newell, R.I.E. and J. Ott. 1999. Macrobenthic Communities and Eutrophication. Pp. 265-293 in Ecosystems at the Land-Sea Margin: Drainage Basin to Coastal Sea. Coastal and Estuarine Studies, Malone, T.C., A. Malej, L.W. Harding, Jr., N. Smodlaka and R.E. Turner (eds). American Geophysical Union, Washington, DC.

Quigley, J.T. and D.J. Harper (eds.). 2004. Stream bank protection with rip-rap: An evaluation of the effects on fish habitat. Canadian Manuscript Report of Fisheries and Aquatic Sciences Report no. 2701. Canada Department of Fisheries and Oceans, Ottawa, Ontario, Canada. 76 pp.

Wilber, R.J., and Bush, D.M. 2003. Mesoscale response of a mobile sedimentary shoreline; basis for new directions in coastal management at the community level; Falmouth, MA. Geological Society of America, 2003 annual meeting. Abstracts with Programs - Geological Society of America. 35(6): 469.
Looked at structure impact on sediment movement; a case study.

Riprap – Habitat

Angradi, T.R., Schweiger, E.W., Bolgrien, D.W., Ismert, P., and Selle, T. 2004. Bank stabilization, riparian land use and the distribution of large woody debris in a regulated reach of the upper Missouri river, North Dakota, USA. River Res. Appl. 20(7): 829-846.
Riverine; Looked at LWD distribution in areas with and without riprap shorelines; speaks to the environmental impacts of riprap with reduces the abundance of LWD along stabilized shorelines.

Beauchamp, D.A., Byron, E.R., and Wurtsbaugh, W.A. 1994. Summer habitat use by littoral-zone fishes in Lake Tahoe and the effects of shoreline structures. N. Am. J. Fish. Manage. 14(2): 385-394.
Looked at fish communities near piers and "rock-cribs?" and found higher fish abundance in rock-cribs than no crib areas.

Bischoff, A., and Humboldt-Universitaet zu Berlin. 2002. Juvenile fish recruitment in the large lowland river oder: Assessing the role of physical factors and habitat availability. Shaker Verlag GmbH, Aachen.
Sampled juvenile fish assemblages in several different habitats; natural habitat is best.

Burke, R., Lipcius, R., Luckenbach, M., Ross, P.G., Woodward, J., and Schulte, D. 2006. Eastern oyster settlement and early survival on alternative substrates along intertidal marsh, rip rap, and manmade oyster reef. J. Shellfish Res. 25(2): 715.
Oysters recruit and survive less on riprap than natural marsh, but more than on man-made oyster reefs, riprap had the highest recruitment.

Carroll R (2003). Nekton utilization of intertidal fringing salt marsh and revetment hardened shorelines. Masters thesis, The College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, VA

Fringing marsh versus riprap revetment in relation to nekton abundance, biomass and diversity. Significantly greater abundance of most species occurred in fringing marsh which also had higher diversity. Total abundance and biomass were higher in fringing marsh than riprap

Davis, J.L.D., Levin, L.A., and Walther, S.M. 2002. Artificial armored shorelines: Sites for open-coast species in a southern California bay. Mar. Biol. 140(6): 1249-1262.
Riprap communities were more different from natural communities at open coast sites than in protected bays.

Davis, J., Kramer, M., Young-Williams, A., and Hines, A. 2001. Effects of habitat type and size on species composition, nursery function, and refuge quality for an estuarine fish and macroinvertebrate community. Transactions, American Geophysical Union.
Compared riprap to oyster reef, SAV, woody debris and bare sediment; looked at fish and invertebrate; riprap and bare sediment can't substitute for oyster reef, SAV or woody debris.

Garland, R.D., Tiffan, K.F., Rondorf, D.W., and Clark, L.O. 2002. Comparison of subyearling fall chinook salmon's use of riprap revetments and unaltered habitats in Lake Wallula of the Columbia River. N. Am. J. Fish. Manage. 22(4): 1283-1289.
More fish found on natural than altered shorelines.

Hendon, J.R., Peterson, M.S., and Comyns, B.H. 2001. Seasonal distribution of gobiids in waters adjacent to estuarine marsh-edge habitats: Assessing the effects of habitat alteration. Proc. Gulf Caribb. Fish. Inst.(52): 428-441.
Lower goby abundance in "altered" marsh habitats compared with natural.

Hendon, J.R., Peterson, M.S., and Comyns, B.H. 2000. Spatio-temporal distribution of larval G*obiosoma bosc* in waters adjacent to natural and altered marsh-edge habitats of Mississippi coastal waters. Bull. Mar. Sci. 66(1): 143-156.
Even altered marsh habitats area important habitats for goby reproduction and life cycle.

Jennings, M.J., Bozek, M.A., Hatzenbeler, G.R., Emmons, E.E., and Staggs, M.D. 1999. Cumulative effects of incremental shoreline habitat modification on fish assemblages in north temperate lakes. N. Am. J. Fish. Manage. 19(1): 18-27.
Species richness increased with increasing habitat complexity; assemblage structure changed with cumulative effect.

Mueller, O. 2004. Riprap of groynes as habitats for larvae of Ophiogomphus cecilia (odonata: Gomphidae). Libellula. 23(1-2): 45-51.
Riprap is used by O. cecilia as a microhabitat and this is considered unusual.

Peterson, M.S., Comyns, B.H., Hendon, J.R., Bond, P.J., and Duff, G.A. 2000. Habitat use by early life-history stages of fishes and crustaceans along a changing estuarine landscape: Differences between natural and altered shoreline sites. Wetlands Ecology and Management. 8: 209-219.

Nekton population was less abundant along bulkhead and riprap shorelines than marsh grass shorelines.

Scheuerell, M.D., and Schindler, D.E. 2004. Changes in the spatial distribution of fishes in lakes along a residential development gradient. Ecosystems. 7(1): 98-106.
Shoreline modification is modifying the spatial distribution of aquatic organisms.

Schmetterling, D.A., Clancy, C.G., and Brandt, T.M. 2001. Effects of riprap bank reinforcement on stream salmonids in the western United States. Fisheries. 26(7): 6-23.
River bank study; riprap provides some habitat, but not the intricate habitat provided by vegetated shorelines.

Schmude, K.L., Jennings, M.J., Otis, K.J., and Piette, R.R. 1998. Effects of habitat complexity on macroinvertebrate colonization of artificial substrates in north temperate lakes. J. N. Am. Benthol. Soc. 17(1): 73-80.
Riprap shorelines have a larger and more diverse community than bulkheaded shorelines.

Scholle, J., and Schuchardt, B. 1999. Vertical gradients of the macrozoobenthos on riprap embankments of the tidal lower Weser River. Hydrologie Und Wasserbewirtschaftung /Hydrology and Water Resources Management-Germany. 43(2): 60-66.
Compared vertical distribution patterns of benthos on riprap with natural bottom.

Seitz, R.D., Lipcius, R.N., Olmstead, N.H., Seebo, M.S., and Lambert, D.M. 2006. Influence of shallow-water habitats and shoreline development on abundance, biomass, and diversity of benthic prey and predators in Chesapeake Bay. Mar. Ecol. Prog. Ser. 326: 11-27.
Benthic abundance and diversity are highest in natural sites, intermediate at riprap sites, and lowest at bulkhead sites, this is also true for blue crabs.

Stewart, T.W., Shumaker, T.L., and Radzio, T.A. 2003. Linear and nonlinear effects of habitat structure on composition and abundance in the macroinvertebrate community of a large river. Am. Midl. Nat. 149(2): pp.293-305.
Looks at stones as habitat structure; evidence for riprap as habitat?

Toft, JD, Cordell, JR, Simenstad, CA, Stamatiou, LA (2007). Fish Distribution, Abundance, and Behavior along City Shoreline Types in Puget Sound. North Am J Fish Manage 27:465–480
Sampled fish in five main habitat types: cobble beach, sand beach, riprap extending into the intertidal zone, deep riprap extending into the subtidal zone, and the edge of overwater structures. In Puget Sound, Washington.

Toft, J., and Cordell, J. 2006. Olympic Sculpture Park: Results from pre-construction biological monitoring of shoreline habitats. Report # 0601.
Abstract is vague—is this the results of a study or a proposal for a study?

Trial, P.F., Gelwick, F.P., and Webb, M.A. 2001. Effects of shoreline urbanization on littoral fish assemblages. Lake Reserv. Manage. 17(2): 127-138.
Bulkhead communities were different from natural shorelines, while riprap was similar.

Watkinson, D.A., Franzin, W.G., Podemski, C.L., and Department of Fisheries and Oceans Canada, Winnipeg, MB (Canada) Centr. Arctic Reg. 2004. Fish and invertebrate populations of natural, dyked and riprapped banks of the Assiniboine and Red Rivers, Manitoba. 2524.
Fish abundance was higher at armoured than natural shorelines and invertebrate and fish diversity was similar at all sites.

Wolter, C. 2001. Conservation of fish species diversity in navigable waterways. Landscape Urban Plann. 53(1-4): 135-144.
The percent of hardened shoreline was inversely correlated to the number of species, species diversity and the number of intolerant species.

Jetties – Water Quality

Nelson, K.A., Scott, G.I., and Rust, P.F. 2005. A multivariable approach for evaluating major impacts on water quality in Murrells and North inlets, South Carolina. Journal of Shellfish Research, Vol. 24, no. 4. 24(4): 1241-1251.
Urbanization poses a particular threat to the coastal areas of the southeastern United States where uplands surrounding wetlands are still relatively undeveloped compared with other regions. The approach used for this study involved a historical comparison of land use change and fecal coliform bacterial densities on Murrells Inlet (MI) (urbanized site) (n = 2026 samples) and North Inlet (NI) (pristine site) (n =1656 samples), both bar-built estuaries located on the northern coast of South Carolina south of Myrtle Beach. Regression models used the(WQ) parameters and a change in trend term that accounted for both instantaneous and gradual changes in water quality that may arise from a particular environmental intervention. For MI, the 1980 environmental intervention consisted of the construction of a jetty and the conversion from septic tanks to a main sewer line of approximately 92% of all residences. For NI, the 1973 and 1977 interventions were the construction of Baruch Laboratory and urban development of Debidue Island, respectively. For MI, there was a significant decrease in the increasing trend of fecal coliform bacteria and the conversion to the sewage collection system had a beneficial effect on water quality and probably dominated the jetty effect. For NI, the laboratory construction had no overall impact on water quality so background natural sources of bacteria probably masked any small increases from human sources.

Jetties – Habitat

Dolah, R.F.V., Wendt, P.H., Wenner, C.A., Martore, R.M., Sedberry, G.R., and Army Engineer Waterways Exp. Stn., Vicksburg, MS (USA). 1987. Environmental impact research program. Ecological effects of rubble weir jetty construction at Murrells inlet,

south Carolina. Volume 3. Community structure and habitat utilization of fishes and decapods associated with the jetties.
Quarrystone jetties at Murrells Inlet, South Carolina, were studied. The jetties attracted fish species normally associated with reef structures, species commonly found around estuarine inlets, and species that seasonally migrate along the coast. The jetties also serve as nursery habitat for a variety of fish species. More fish captured (recreational fishing) around the jetty structures than in non-jetty areas.

Goren, R., and Benayahu, Y. 1993. Benthic communities on artificial substrates at Elat (Red Sea). Isr. J. Zool. 39(1): 59.
The present study deals with recruitment of benthic communities on the oil jetties underwater constructions at Elat. The vertical pipes of the northern oil jetty have the highest living coverage along the mid-water parts along each pipe. The living coverage is composed of scleractinians, octocorals, sponges, ascidians, and actinians. Size distribution of the most abundant recruits on the pipes clearly shows high abundance of juveniles. The vertical seaward pipes are primarily covered by octocorals.

Hernandez, F.J.,Jr, Shaw, R.F., Cope, J.S., Ditty, J.G., and Farooqi, T. 2001. Do low-salinity, rock jetty habitats serve as nursery areas for pre-settlement larval and juvenile reef fish? Proc.Gulf Caribb. Fish. Inst.(52): 442-454.
This study investigated a coastal rock jetty system as a low-salinity, landward end member of artificial reefs along a transect of three oil and gas platforms extending from the inner continental shelf to the shelf break. Clupeiformes (engraulids and clupeids) comprised approximately 95% and 70% of the total light-trap and pushnet catch, respectively. Reef (or structure-dependent) fish, though not as abundant, included blennies, gobies, eleotrids, sparids, and lutjanids. Significantly lower densities and CPUEs were observed at sampling stations located within the jetty walls versus stations located externally. This result may be related to possible differences in environmental parameters (turbidity, temperature, salinity, and dissolved oxygen) between inner (estuarine) and outer (coastal) sampling stations. Preliminary results indicate that the jetty may serve as a refuge area for pre-settlement reef fish in the absence of other structurally-complex habitat.

Johnson, S.B., and Geller, J.B. 2006. Larval settlement can explain the adult distribution of Mytilus californianus conrad but not of M. galloprovincialis lamarck or M. trossulus gould in moss landing, central California: Evidence from genetic identification of spat. J. Exp. Mar. Biol. Ecol. 328(1): 136-145.
We investigated the spatial distribution of adult and newly settled mussels (Mytilus galloprovincialis Lamarck, Mytilus trossulus Gould and Mytilus californianus Conrad) on the shore at Moss Landing, California to test the hypothesis that adult distributions are a result of settlement patterns. Adult M. californianus were most abundant on a wave-exposed rocky jetty and adults of Blue mussels (M. trossulus and M. galloprovincialis) were more abundant inside the protected Moss Landing harbor.

Kaldy, J.E., Dunton, K.H., and Czerny, A.B. 1995. Variation in macroalgal species composition and abundance on a rock jetty in the northwest Gulf of Mexico. Bot. Mar. 38(6): 519-527.
Seasonal variation in algal species composition and biomass was examined on a rock jetty at Port Mansfield, Texas.). Over 30 algal species were collected during the study period, with the overall species composition dominated by rhodophytes, especially Bryocladia spp., Gelidium crinale/Pterocladia bartlettii complex, Hypnea spp., Centroceras clavulatum and Polysiphonia spp. All sites exhibited greater than 50% similarity of algal species, indicating a relatively homogeneous algal distribution. Red algae accounted for 94% of the average annual biomass compared to 5% for green algae and 1% for brown algae. The high biomass of algae recorded on the north jetty at Port Mansfield indicates that these plants represent a substantial food and habitat resource to marine animals, both invertebrates and vertebrates, which is available year-round.

Rader, W.L. 1998. Faunal list of shelled marine mollusks inhabiting the northern jetty, marina Del Rey, Los Angeles County, California. Festivus. 30(10): 105-112.
Over a seven-year period, at irregular intervals during wintertime low tides, 75 species of shelled marine mollusks living along the western end of the northern jetty at the southern tip of the Marina Peninsula, Los Angeles County, were recorded. A pronounced ecological zonation was noted among the inhabitants, both upon the jetty and within the ecological habitats at its base, and certain species were found to be characteristic of each habitat. A faunal list documenting all taxa that were recorded during this study was assembled.

Renaud, M.L., Carpenter, J.A., Williams, J.A., and Manzella-Tirpak, S.A. 1995. Activities of juvenile green turtles, Chelonia mydas, at a jettied pass in south Texas. Fish. Bull. 93(3): 586-593.
Texas nearshore and inshore waters are important habitats for juvenile and subadult sea turtles. Recent tracking and mark-recapture studies on green turtles indicate that jetties and channel entrances along the south Texas coast serve as summer developmental habitats for this species. Turtles using jetties and channel entrances could interact with human activities, such as channel dredging, shrimping, and recreational fishing and boating. We hypothesized that juvenile green turtles select jetty habitat over other habitats within Brazos-Santiago Pass.

Sullivan, M. 1984. Community structure of epiphytic diatoms from the gulf coast of Florida, U.S.A. Otto Koeltz, Koenigstein.
Epiphytic diatoms were collected on 13 March 1981 and 10 March 1982 from macrophytic algae (Cladophora sp. and Microcoleus lyngbyaceus) on a submerged jetty rock and an immediately adjacent seagrass bed (Syringodium filiforme and Thalassia testudinum) in Fred Howard Park on the Gulf Coast of Florida. The jetty samples were dominated by Synedra barbatula, Licmophora dalmatica, and Achnanthes brevipes var. intermedia, while the most abundant seagrass epiphytes were Cocconeis scutellum var. parva, Amphora tenuissima, and Mastogloia crucicula. Besides sharing no dominant taxa in common, structural similarity between the jetty and seagrass samples as

quantified by the SIMI index was very low and ranged from 0.012 to 0.152. This pronounced dissimilarity in the epiphytic diatom communities of the jetty and seagrass beds was independent of whether diversity (H' & S) was high or low in the former habitat.

Witten, A.L., and Bulkley, R.V. 1975. A study of the effects of stream channelization and bank stabilization on warmwater sport fish in Iowa. Subproject no. 2. A study of the impact of selected bank stabilization structures on game fish and associated organisms. Fish and Wildlife Service Office of Biological Services Report 76/12, May, 1975.116 p, 7 Fig, 15 Tab, 23 Ref.
Four types of stream bank stabilization structures (revetments, retards, permeable jetties, impermeable jetties) were studied to determine their impact upon game fish habitat. Permeable jetties and retards deepened the channel near the structures 7 to 110% greater than the maximum depth in control sections. No other significant differences in either physical parameters or in mean body length or abundance of game fish were found between structured and non-structured stream sections. Rock revetments and impermeable jetties fostered the growth of some invertebrates, primarily mayflies and caddis flies. Revetments, which presented the most rock surface for invertebrate colonization, had the greatest impact on invertebrate abundance. A long rock jetty, extending far enough into the stream to produce a scour hole, would combine most of the advantages noted in the structures studied. For habitat improvement, rock was superior to steel as a construction material, and structures which cause the formation of scour holes superior to those that do not deepen the stream.

Breakwaters – Water Quality

Allen, H.H., R.L. Lazor and J.W. Webb. 1990. Stabilization and development of marsh lands. Beneficial Uses of Dredged Material. Pp. 101-112 in Proceedings of the Gulf Coast Regional Workshop, April 26-28, 1988, Galveston, Texas. Technical Report D-90-3. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

Cuadrado, D.G., Gomez, E.A., and Ginsberg, S.S. 2005. Tidal and longshore sediment transport associated to a coastal structure. Estuar. Coast. Shelf Sci. 62(1-2): 291-300.
Found different modes of sediment transportation on the 2 ends of a breakwater.

Dickson, W.S., Herbers, T.H.C., and Thornton, E.B. 1995. Wave reflection from breakwater. J. Waterway Port Coast. Ocean Eng. 121(5): 262-269.
Large amplitude waves are dissipated more than lower energy waves across a breakwater structure.

El Banna, M.M. 2006. Responses of Ras el bar seafloor characteristics to the protective engineering structures, Nile Delta, Egypt. Environ. Geol. 49(5): 645-652.
Scouring impacts associated with breakwater and bulkhead structures.

Newell, R.I.E. and E.W. Koch. 2004. Modeling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. Estuaries 27:793-806.

Pranesh, M., Venugopalan, P., and Marine Technology Soc., Manoa, HI (USA). Hawaii Sect. 1984. Ocean structure-shoreline interaction.
Predictions of shoreline change due to construction of a detached shoreline structure.

Ranasinghe, R., and Turner, I.L. 2006. Shoreline response to submerged structures: A review. Coastal Engineering. 53: 65-79.
Review of the impact of submerged breakwaters on local sediment transport.

Rennie, T.H. 1990. Using new work and maintenance material for marsh creation in the Galveston District. Beneficial Uses of Dredged Material. Pp. 184-187 in Proceedings of the Gulf Coast Regional Workshop, April 26-28, 1988, Galveston, Texas. Technical Report D-90-3. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

Rice, D.W., T.A. Dean, F.R. Jacobsen and A.M. Barnett. 1989. Transplanting giant kelp Macrocystis pyrifera in Los Angeles Harbor: productivity of the kelp population. Bulletin of Marine Science. 44:1070

Breakwaters – Habitat

Airoldi, L., M. Abbiati, M.W. Beck, S.J. Hawkins, P.R. Jonsson, D. Martin, P.S. Moschella, A. Sundelof, R.C. Thompson and P. Aberg. 2005. An ecological perspective on the development and design of low-crested and other hard coastal defense structures. Coastal Engineering. 52:1073-1087.
Consequences of breakwaters can be seen on a local scale, as disruption of surrounding soft-bottom environments and introduction of new artificial hard-bottom habitats, with consequent changes to the native assemblages of the areas. Proliferation of coastal defense structures can also have critical impacts on regional species diversity, removing isolating barriers, favoring the spread of nonnative species and increasing habitat heterogeneity. Advice is provided to meet specific management goals, which include mitigating specific impacts on the environment, such as minimizing changes to surrounding sediments, spread of exotic species or growth of nuisance species, and/or enhancing specific natural resources, for example enhancing fish recruitment or promoting diversity. The DELOS project points out that the downstream effects of defense structures on coastal processes and regional-scale impacts on biodiversity necessitate planning and management at a regional (large coastline) scale.

Allen, H.H., R.L. Lazor and J.W. Webb. 1990. Stabilization and development of marsh lands. Beneficial Uses of Dredged Material. Pp. 101-112 in Proceedings of the Gulf Coast Regional Workshop, April 26-28, 1988, Galveston, Texas. Technical Report D-90-3. U.S. Army Corps of Engineers, Waterways Experiment Station, Vickburg, Mississippi.

Lincoln Smith, M.P., C.A. Hair and J.D. Bell. 1994. Man-made rock breakwaters as fish habitats: comparisons between breakwaters and natural reefs within an embayment in southeastern Australia. Bulletin of Marine Science. 55:1344.

Moschella, P.S., M. Abbiati, P. Åberg, L. Airoldi, J.M. Anderson, F. Bacchiocchi, F. Bulleri, G.E. Dinesen, M. Frost, E. Gacia, L. Granhag, P.R. Jonsson, M.P. Satta, A. Sundelöf, R.C. Thompson and S.J. Hawkins. 2005. Low-crested coastal defense structures as artificial habitats for marine life: using ecological criteria in design. Coastal Engineering. 52:1053-1071.
Analysis of the effects of breakwaters on the surrounding intertidal and subtidal infaunal assemblages and mobile fauna. Changes in sediment and infauna seem to be inevitable and usually tend to induce negative changes, particularly on the landward side and in the presence of additional structures or after beach nourishment. The presence of species either coming from the new hard bottoms or associated to physical disturbances is viewed as a negative impact, while the potential nursery role is a positive one.

Newell, R.I.E. and E.W. Koch. 2004. Modeling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. Estuaries. 27:793-806.

Rennie, T.H. 1990. Using new work and maintenance material for marsh creation in the Galveston District. Beneficial Uses of Dredged Material. Pp. 184-187 in Proceedings of the Gulf Coast Regional Workshop, April 26-28, 1988, Galveston, Texas. Technical Report D-90-3. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

Rice, D.W., T.A. Dean, F.R. Jacobsen and A.M. Barnett. 1989. Transplanting giant kelp Macrocystis pyrifera in Los Angeles Harbor: productivity of the kelp population. Bulletin of Marine Science. 44:1070

Stephens, J. and D. Pondella. 2002. Larval productivity of a mature artificial reef: the ichthyoplankton of King Harbor, California, 1974-1997. ICES Journal of Marine Science. 59:S51-S58.

Stephens, J., P.A. Morris, D. Pondella, T.A. Koonce and G.A. Jordan. 1994. Overview of the dynamics of an urban artificial reef fish assemblage in King Harbor, California, USA, 1974-1991: a recruitment driven system. Bulletin of Marine Science. 55:1224-1239.

U.S. Army Corps of Engineers (USACE), State of Maryland and Commonwealth of Virginia. 1990. Chesapeake Bay Shoreline Erosion Study. U.S. Army Corps of Engineers, Baltimore District, Maryland.

Misc and Debris – Water Quality

Day, K.E., Holtze, K.E., Metcalfe-Smith, J.L., Bishop, C.T., and Dutka, B.J. 1993. Toxicity of leachate from automobile tires to aquatic biota. Chemosphere. 27(4): 665-675.
A laboratory study was conducted to determine if automobile tires immersed in fresh water leach chemicals which are toxic to aquatic biota. Three tire types were examined - tires obtained from a floating tire breakwater; road-worn tires from the same vehicle; and new tires. Overlying water from both new and used tires was lethal to rainbow trout (Oncorhynchus mykiss) but leachate from used tires was more toxic. In addition, leachate remained relatively toxic to rainbow trout over time (8 d for new and 32 d for used) after tires were removed from the aquaria indicating that the chemicals responsible for toxicity degrade slowly and are non-volatile. No toxicity to cladocerans or fathead minnows was observed with these same leachates. Tires from a floating tire breakwater which had been installed for several (10) years did not release chemicals which were toxic to any species tested. Concentrated (10X) leachate from tires immersed for 25 d in water inhibited bioluminescence in the marine bacterium, Photobacterium phosphoreum , the enzyme, beta -galactosidase, in mutant Escherichia coli and the enzyme, NADH-coenzyme Q reductase, in the inner membrane of mitochondria.

Evans, J.J. 1997. Rubber tire leachates in the aquatic environment. Reviews of Environmental Contamination and Toxicology. 151: 67-115.
This review discusses the background of scrap tires discarded in the environment, including tire composition, adverse environmental effects, threats to public health and safety, and solid waste management. A review of the available information on chemical characterization of tire leachate from tire storage facilities, manufacturing, usage in recycling applications, and toxicity exposure studies, of vegetation surveys from waste tire areas and reviews of mammalian tire product toxicity, and of toxicity, mutagenicity, and carcinogenicity of tire exposure in experimental aquatic animals, microbes, and organelles is presented.

Evans, J.J., Shoemaker, C.A., and Klesius, P.H. 2000. In vivo and in vitro effects of benzothiazole on Sheepshead minnow (Cyprinodon variegatus). Mar. Environ. Res. 50(1-5): 257-261.
Benzothiazole, a common chemical associated with tire manufacturing and industrial wastewater, is a principal component of both fresh water and estuarine tire leachate, a neurotoxicant to larval sheepshead minnows (Cyprinodon variegatus) in in vivo estuarine studies. Fish mortality occurred after 5 days of exposure. Significant decreases in larval growth were noted at all concentrations. Histologically, gills had cellular alterations but the central nervous system lacked the severe cellular damage seen in previous tire leachate exposure studies.

Evans, J. 1998. Toxicity of shredded tire leachate to Sheepshead minnow (Cyprinodon variegatus): A morphological and cytological evaluation.
Analyses of larval sheepshead minnows (C. variegatus) exposed to sequential shredded tire leachate extractions at 5, 15 and 25 ppt salinities indicated that tire leachate acted as a central nervous system neurotoxin. Lesions and decreases in DNA synthesis were most severe after 1 and 2 days of exposure to 2 and 3 day post hatch larvae.

Hartwell, S.I., Jordahl, D.M., and Dawson, C.E.O. 2000. The effect of salinity on tire leachate toxicity. Water, Air, Soil Pollut. 121(1-4): 119-131.
The toxicity of leachates decreased with increasing salinity up to 15 ppt, with no significant change at higher salinities. Tire leachates are probably a greater threat to freshwater habitats than brackish or marine habitats, but bioaccumulation of persistent organic contaminants from tires is an unknown.

Li, W., Seifert, M., Xu, Y., and Hock, B. 2006. Assessment of estrogenic activity of leachate from automobile tires with two in vitro bioassays. Fresenius Environ. Bull. 15(1): 74-79.
This study examined whether automobile tires immersed in fresh water can leach chemicals that display estrogenic activity. All tire leachates obviously showed estrogenic activity, which was increased with duration of immersion. As tire leachates contain estrogenic compounds, they could be important pollution sources, potentially harmful to wildlife and human health. Thus, use of shredded tires as road fill or in landfill sites should arouse our attention.

Nelson, S.M., Mueller, G., and Hemphill, D.C. 1994. Identification of tire leachate toxicants and a risk assessment of water quality effects using tire reefs in canals. Bull. Environ. Contam. Toxicol. 52(4): 574-581.
Due to the paucity of literature on the effects of fire reefs on water quality, a study was conducted using Toxicity Identification Evaluation procedures as designed by the EPA. Three series of analyses utilizing plugs cut from tires and whole tires were performed. Tire leachate was taken from tire plugs and utilized for toxicity evaluation. Meanwhile, a different set of plug leachate was assessed for possible bioconcentrated organic contaminants. The whole tires were applied in depuration studies.

Stephensen, E., Adolfsson-Erici, M., Celander, M., Hulander, M., Parkkonen, J., Hegelund, T., Sturve, J., Hasselberg, L., Bengtsson, M., and Foerlin, L. 2003. Biomarker responses and chemical analyses in fish indicate leakage of polycyclic aromatic hydrocarbons and other compounds from car tire rubber. Environ. Toxicol. Chem. 22(12): 2926-2931.
This study focused on sublethal effects of tire leacheate (PAH). We kept rainbow trout (Oncorhynchus mykiss) in tanks with two types of tires: a tire containing HA oils in the tread or a tire free of HA oils in the tread. After 1 d of exposure, an induction of cytochrome P4501A1 (CYP1A1) was evident in both exposed groups. After two weeks of exposure, EROD activity and CYP1A1 mRNA were still high in fish exposed to leachate from HA oil-containing tire, whereas the effect was somewhat lower in fish exposed to leachate from HA oil-free tread tire. Compounds in the tire leachates also affected antioxidant parameters. Total glutathione concentration in liver as well as hepatic glutathione reductase, glutathione S-transferase, and glucose-6-phosphate dehydrogenase activities were markedly elevated after two weeks of exposure in both groups. The responses were greater in the group exposed to leachate from HA oil-free tread tire. Vitellogenin measurements did not indicate leakage of estrogenic compounds from the tires. Chemical analyses of bile from exposed fish revealed the presence of

hydroxylated PAH as well as aromatic nitrogen compounds indicating uptake of these compounds by the fish.

Wik, A., and Dave, G. 2006. Acute toxicity of leachates of tire wear material to Daphnia magna - variability and toxic components. Chemosphere. 64(10): 1777-1784.
Large amounts of tire rubber are deposited along the roads due to tread wear. Several compounds may leach from the rubber and cause toxicity to aquatic organisms. UV exposure of the filtered tire leachates caused no significant increase in toxicity. The acute toxicity of tire wear for Daphnia magna was found to be -40 times a predicted environmental concentration based on reports on the concentration of a tire component found in environmental samples, which emphasizes the need for a more extensive risk assessment of tire wear for the environment.

7. Marinas, Docks, Boatramps

An, Y.J., D.H. Kampbell, & G.W. Sewell. 2002. Water quality at five marinas in Lake Texoma as related to methyl tert-butyl ether (MTBE). Environmental Pollution. 118(3):331-336.
Concentrations of a gasoline additive (suggesting gasoline spillage) were greatest at boat docks, then fuel pumping facilities, at 5 reservoirs. Suggested importance of gasoline spillage at boat motor start-up, as well as spillage during fueling.

Barbaro, R.D., B.J. Carroll, L.B. Tebo, & L.C. Walters. 1969. Bacteriological water quality of several recreational areas in the Ross Barnett Reservoir. J. Pollution Control Federation. 41(7):1330-1339.
Ref. by Chmura & Ross 1978. Higher fc in marina waters than in nonmarina waters.

British Waterways Board. 1983. Waterway ecology and the design of recreational craft. Inland Waterways Amenity Advisory Council, London, England.
Ref. by USEPA 2001. Boats can cause bank erosion, therefore effect WQ.

Brown, C.L. & R. Clark. 1968. Observations on dredging and dissolved oxygen in a tidal waterway. Water Resources Research. 4(6):1381-1384.
Ref. by Chmura & Ross 1978. DO temporarily decreased 16-33% during dredging of a tidal waterway, due to oxidation of resuspended sediments & decreased light for photosynthesis.

Cassin, J., K. Smith & K. Frenke. 1971. Sanitary implications of small boat pollution in an Atlantic estuary. Environmental Letters. 2(2):59-63.
Ref. by Chmura & Ross 1978. FC increased in water column & shellfish in direct relation to boat numbers, in estuarine area on NY coast.

Chen, K.Y., F.R. Bowerman, & M. Petridis. 1972. Environmental impact of storm drain on a semi-enclosed coastal water. Preprint of the 8th Annual Conference of the Marine Technology Society. (Sea-Grant Library abstract SCU-R-72-003).

Ref. by Chmura & Ross 1978. Heavy metals settled out of stormwater within short distance of discharge, but storm drain discharge had little direct effect on marina WQ. Marina breakwaters accumulated organic debris, depleting DO in bottom water.

Chesworth, J.C., M.E. Donkin, & M.T. Brown. 2004. The interactive effects of the antifouling herbicides Irgarol 1051 and Diuron on the seagrass Zostera marina. Aquatic Toxicology. 66(3):293-305.
Antifouling herbicides applied to boats to prevent algae growth are shown to have the potential to adversely affect seagrass growth.

Chmura, G.L. & N.W. Ross. 1978. The environmental impacts of marinas and their boats: A literature review with management considerations. Marine Advisory Service, Univ. of R.I., Narragansett.
Fairly extensive lit. review. As ref. by USEPA 2001: boat operation increases turbidity.

Faust, M.A. 1982. Contribution of pleasure boats to fecal coliform bacteria concentrations in the Rhode River estuary, Maryland, USA. The Science of the Total Environment. 25(2):255-262.
FC increased over a holiday weekend due to increased boat traffic.

Fisher, J.S., R.R. Perdue, M.F. Overton, M.D. Sobsey, & B.L. Sill. 1987. Comparison of water quality at two recreational marinas during a peak-use period. UNC Sea Grant College Prog. Raleigh, NC.
Ref. by USEPA, 2001. Boats were source of fc in areas w/high boat density & poor flushing.

Fufari, S.A. & J.L. Verber. 1969. Boat waste survey, Potter Cove, Rhode Island, summer 1968. Northeast Marine Health Services Lab., U.S. Public Health Svc. Davisville, RI. 27pp.
Ref. by Chmura & Ross 1978. Sampled water, shellfish, sediment in RI tidal cove, found that primary source of fc was boat waste.

Grovhoug, J.G., P.F. Seligman, G. Vafa, & R.L. Fransham. 1986. Baseline measurements of butyltin in US harbors and estuaries. In Proceedings Oceans 86, Vol.4 Organotin Symposium, Inst. of Electrical & Electronics Engineers, Inc. NY. pp.1283-1288.
Ref by USEPA, 2001. Toxic levels of butyltin found in marina waters.

Hall, L.W., Jr., M.J. Lenkevich, W.S. Hall, A.E. Pinkney, and S.T. Bushong. 1987. Evaluation of butyltin compounds in Maryland waters of Chesapeake Bay. Marine Pollution Bulletin. 18(2):78-83.
Ref. by USEPA, 2001. Toxic concentrations of dissolved copper found at CBay marinas.

Hertler, H., J. Spotila, & D.A. Kreeger. 2004. Effects of houseboats on organisms of the La Parguera Reserve, Puerto Rico. Environmental Monitoring and Assessment. 98:391-407.

Houseboats, at moorings that allowed 360 deg. swing, did not adversely impact seagrass growth. Proximity to new development on shoreline did appear to affect seagrass growth, possibly due to runoff. Houseboats, w/o antifouling paint, acted as artificial structures providing habitat for many types of organisms.

Jensen, H.F., M. Holmer, & I. Dahlof. 2004. Effects of tributyltin (TBT) on the seagrass *Ruppia maritima*. Marine Pollution Bulletin. 49(7-8):564-573.
Denmark. Net photosynthetic activity decreased up to 60%, relative growth rate –25% lower in TBT-contaminated sediments.

Kirby-Smith, W.W. & N.M. White. 2006. Bacterial contamination associated with estuarine shoreline development. J. of Applied Microbiology. 100: 648-657.
Compared fecal colif. along developed, undeveloped, and marina/cmty pier shorelines. Found highest fc at older developed shoreline, then new developed shl., then large marina. Suggest upland runoff more impt. source of fc than boats. Extent of circulation/flushing deemed important. Suggest that oyster gardeners not eat oysters they raise, due to likely high fc. Implications for shellfish closure areas.

Marcus, J.M., G.R. Swearingen, A.D. Williams, & D.D. Heizer. 1988. Polynuclear aromatic hydrocarbons and heavy metals concentrations in sediments at coastal South Carolina marinas. Archives of Environmental Contamination and Toxicology. 17:103-113.
Ref. by USEPA, 2001. Petroleum HCs in high concen. in marinas, but lower in sed. of well-flushed marinas.

McGee, Beth L., Christian E. Schlekat, Daniel M. Boward, and Terry L. Wade. 1995. Sediment contamination and biological effects in a Chesapeake Bay marina. Ecotoxicology. 4(1):39-59.
Found PAHs, copper, TBT elevated in marina sediments. Benthic infauna reflected environmental degradation within marina basin. Marina basin design limited flushing & contaminant export.

McMahon, P.J.T. 1989. The impact of marinas on water quality. Water Science & Technology. 21(2):39-43.
Ref. by USEPA, 2001. Higher levels of metals near maintenance area drains & fuel docks.

Mastran, T.A., A.M. Dietrich, & D.L. Gallagher, & T.J. Grizzard. 1994. Distribution of polyaromatic hydrocarbons in the water column and sediments of a drinking water reservoir with respect to boating activity. Water Research. 28(11):2353-2366.
Found PAHs in water column and sediment correlated with boating activity. Greater in marinas than nonmarina sites. Urban runoff and atmospheric deposition also contributed PAHs.

Milliken, A.S. & V. Lee. 1990. Pollution impacts from recreational boating: A bibliography and summary review. Rhode Island Sea Grant Publications, URI Bay Campus, Narragansett, RI.
Good lit. review.

Nixon, S.W., C.A. Oviatt, & S.L. Northby. 1973. Ecology of small boat marinas. Marine Tech. Rpt. Series No. 5, Univ. of R.I., Kingston, RI.
Rhode Island. Compared marina basin to saltmarsh cove. Found no differences in several factors. Copper levels higher in marina. Fouling communities in marinas exerted signif. oxygen demand. Fouling communities appeared to be impt. food source for fish. Atl. menhaden seldom found in marina. But sport fish more abundant in marina areas.

NCDEM. 1990. North Carolina coastal marinas: Water quality assessment. Report No. 90-01. North Carolina Division of Environmental Management. Raleigh, NC.
Cited in USEPA, 2001. Found lower DO in marinas compared to adjacent water bodies. Copper most common metal found in toxic concentrations in marina waters. PAHs. Boats source of fc in areas w/high boat density & poor flushing. Petroleum HCs in high concen. in marinas, but lower in sed. of well-flushed marinas.

NCDEM. 1991. Coastal marinas: Field survey of contaminants and literature review. Report No. 91-03. North Carolina Division of Environmental Management, Raleigh, NC.
Ref. by USEPA, 2001. Copper most common toxic metal in marina waters. Higher levels of metals near maintenance area drains & fuel docks.

Nixon, S.W., C.A. Oviatt, & S.L. Northby. 1973. Ecology of small boat marinas. Univ. of R.I. Marine Tech.Rpt. No.5. Narragansett, RI. 20pp.
Ref. by Chmura & Ross 1978. Fouling communities on piers & other structures contribute to biological productivity (supplement food), but may not replace pre-existing salt marsh condition. Copper found in high levels in water, sediment, & fouling communities in marinas.

Reish, D.J. 1961. A study of benthic fauna in a recently constructed boat harbor in southern California. Ecology. 42(1):84-91.
Ref. by Chmura & Ross 1978. In a marina newly dredged in part from upland, found that colonization with benthic community similar to those in nearby similar soft sediments occurred within 1 yr. of dredging.

USEPA. 1974. Assessing effects on water quality by boating activity. USEPA, National Environmental Research Ctr, Cincinnati, OH.
Ref. by USEPA, 2001. Boat propwash increases turbidity/susp.sed.

USEPA. 1985. Coastal Marinas Assessment Handbook. USEPA Region IV. EPA 904/6-85-132.

USEPA. 2001. National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating. USEPA Office of Water. EPA 841-B-01-005.
Most recent summary, but most recent reference cited is 1992. Good summary of pollutant types and impacts.

Voudrias, E.A. 1981. Influence of marinas on hydrocarbons in sediments of two estuarine creeks. VIMS M.A. Thesis.

Voudrias, E.A., & C.L. Smith. 1986. Hydrocarbon pollution from marinas in estuarine sediments. In Estuarine, Coastal, and Shelf Science. 22:271-284.
Ref. by USEPA, 2001. Petroleum HCs in high concen. in marinas, but lower in sed. of well-flushed marinas.

Young, D.R. & T.C. Hessen. 1974. Inputs and distributions of chlorinated hydrocarbons in three southern California harbors. p.51-67 In Proceedings of the 4th Annural Technical Conference on Estuaries of the Pacific Northwest, March 14-15, 1974. Oregon Expt. Sta. Circular No. 50, Corvallis, OR.
Ref. by Chmura & Ross 1978. Copper higher in mussels taken from boat harbors.

Young, D.R. & D.J. McDermott, T.C. Hessen & T.K. Jan. 1975. Pollutant inputs and distributions off southern California. p.424-439 In Church, T.M. (ed.). Marine chemistry in the coastal environment. ACS Symposium Series 18, American Chemical Society, Wash. DC. 710pp.
Ref. by Chmura & Ross 1978. Copper higher in mussels taken from boat harbors.

8. Subaqueous Resources

SAV – Water Quality

Cerco, C. F. and K. Moore. (2001) System-Wide Submerged Aquatic Vegetation Model for Chesapeake Bay. Estuaries. 24(4):522-534.
A predictive model of submerged aquatic vegetation (SAV) biomass is coupled to a eutrophication model of Chesapeake Bay. Domain of the model includes the mainstem of the bay as well as tidal portions of major embayments and tributaries. Three SAV communities are modeled: ZOSTERA, RUPPIA, and FRESHWATER. Sensitivity analysis to reductions in nutrient and solids loads indicates nutrient controls will enhance abundance primarily in areas that presently support SAV.

Churchill, A. C., A. E. Cok and M. I. Riner. (1978) Stabilization of subtidal sediments by the transplantation of the seagrass Zostera marina L. NYSSGP; Albany, NY (USA). 46p. Report Series NY Sea Grant Institute.
The seagrass Zostera marina has potential for stabilizing unconsolidated sediments, esp dredge spoils.

Fonseca, M. S. and J. A. Calahan. (1992) A preliminary evaluation of wave attenuation by four species of seagrass. Estuar.Coast.Shelf Sci. 35(6):565-576.
Seagrasses are able to modify current flow and sediment composition. Percent wave energy reduction per meter of seagrass bed equaled 40% when the length of these seagrasses was similar to the water depth. Seagrasses are approximately equal to saltmarshes in reducing wave energy on a unit distance basis, but only when water depth is scaled to plant size. When seagrass beds occur as broad, shallow meadows, the influence of seagrasses on wave energy will be substantial.

Gambi, M. C., A. R. M. Nowell and P. A. Jumars. (1990) Flume observations on flow dynamics in Zostera marina (eelgrass) beds. Marine ecology progress series. 61(1-2):159-169.
Flow dynamics in Zostera marina (eelgrass) were studied in a large seawater flume. Mean velocity increased above the canopy, while within the bed water speed dropped distinctly below the canopy-water interface. Depending on shoot density, water speed was from 2 to 10 times lower under the canopy than upstream of the seagrass bed.

Lilleboe, A. I., M. R. Flindt, M. A. Pardal and J. C. Marques. (2006) The Effect of Zostera noltii, Spartina maritima and Scirpus maritimus on Sediment Pore-water Profiles in a Temperate Intertidal Estuary. Hydrobiologia. 555:(1)175-183.
Sediment profiles of loss on ignition (LOI) showed an increase of the organic matter contents from sand-flat, to Zostera, Spartina, mud-flat and Scirpus. These results suggest that there is an intense mobility of nutrients in the sediment, showing a day-night variation of nutrient concentrations in the pore-water. In the plants' rhizosphere, the day-night variation of nutrients seemed dependent on plant biomass and penetration of the roots. Additionally, coupling between plant and sediment seems to be a species-specific process. The top 10 cm of the sediment in the Spartina salt marsh and in the Zostera beds may contribute to the efflux of nutrients during the night period, especially phosphate.

Madsen, J. D., P. A. Chambers, W. F. James, E. W. Koch and D. F. Westlake. (2001) The interaction between water movement, sediment dynamics and submersed macrophytes. Hydrobiologia. 444(1-3):71-84.
This review defines known relationships and identifies areas that need additional research on the complex interactions among submersed macrophytes, water movement, and sediment dynamics. Water movement has a significant effect on macrophyte growth; in turn, macrophyte beds reduce current velocities both within and adjacent to the beds, resulting in increased sedimentation and reduced turbidity. Additionally, macrophytes affect the distribution, composition and particle size of sediments in both freshwater and marine environments. Therefore, establishment and persistence of macrophytes in both marine and freshwater environments provide important ecosystem services, including: (1) improving water quality; and (2) stabilizing sediments, reducing sediment resuspension, erosion and turbidity.

Newell, R. and Evamaria W. Koch. (2004) Modeling Seagrass Density and Distribution in Response to Changes in Turbidity Stemming from Bivalve Filtration and Seagrass Sediment Stabilization. Estuaries. 27(5):793-806.
Development of a simple model to calculate how changes in the balance between sediment sources (wave-induced resuspension) and sinks (bivalve filtration, sedimentation within seagrass beds) regulate turbidity. The model predicted that eastern oysters reduced suspended sediment concentrations by nearly an order of magnitude. Hard clams and seagrass were less effective. Our model predicted that restoration of eastern oysters has the potential to reduce turbidity in shallow estuaries, such as Chesapeake Bay, and facilitate ongoing efforts to restore seagrasses.

Paling, E. I., M. Van Keulen, K. D. Wheeler, J. Phillips and R. Dyhrberg. (2003) Influence of spacing on mechanically transplanted seagrass survival in a high energy wave regime. Restor.Ecol. 11(1):56-61.
This study indicates that the ability of seagrasses to influence sediment would appear to vary with the prevailing hydrodynamic regime and that a reappraisal of the notion that all seagrass communities trap sediment is necessary.

Peterson, C. H., R. A. Luettich Jr, F. Micheli and G. A. Skilleter. (2004) Attenuation of water flow inside seagrass canopies of differing structure. Mar.Ecol.Prog.Ser. 26:881-92.
A model of the effects of seagrass habitat structure on mean flow within and above the canopy. The field data demonstrated greater flow reductions inside the canopy with increasing vegetation density.

SAV – Habitat

Cardoso, P. G., D. Raffaelli and M. A. Pardal. (2007) Seagrass beds and intertidal invertebrates: an experimental test of the role of habitat structure. Hydrobiologia. 575(1):221-230.
Evidence of the importance of habitat structure for invertebrate community composition and dynamics. Seagrass beds enhanced survival of snails due to protection from avian or fish predators which can have a significant effect on population structure and hence biomass and productivity of key species in this system.

Castellanos, D. L. and L. P. Rozas. (2001) Nekton Use of Submerged Aquatic Vegetation, Marsh, and Shallow Unvegetated Bottom in the Atchafalaya River Delta, a Louisiana Tidal Freshwater Ecosystem. Estuaries. 24(2):184-197.
Vegetated areas generally supported much higher nekton densities than unvegetated sites, and may be important nursery areas for blue crabs and other estuarine species.

Dealteris, J. T., B. D. Kilpatrick and R. B. Rheault. (2004). A comparative evaluation of the habitat value of shellfish aquaculture gear, submerged aquatic vegetation and a non-vegetated seabed. J.Shellfish Res. 23(3):867-874.
Comparison of the habitat value of modified rack and bag, shellfish aquaculture gear (SAG) used for the grow-out phase of the American oyster, Crassostrea virginica,

submerged aquatic vegetation (SAV), Zostera marina, and a shallow nonvegetated seabed (NVSB). The physical structure of the SAG habitat protects juvenile fish from predators and provides substrate for sessile invertebrates that serve as forage for fish and invertebrates. Therefore, we conclude that shellfish aquaculture gear has substantially greater habitat value than a shallow nonvegetated seabed, and has habitat value at least equal to and possibly superior to submerged aquatic vegetation.

Glancy, T. P., T. K. Frazer, C. E. Cichra and W. J. Lindberg. (2003). Comparative Patterns of Occupancy by Decapod Crustaceans in Seagrass, Oyster, and Marsh-edge Habitats in a Northeast Gulf of Mexico Estuary. Estuaries. 26(5):1291-1301.
Decapod crustacean assemblages associated with oyster reef were distinct from seagrass and marsh-edge habitats (which were similar).

Goldberg, R., B. Phelan, J. Pereira, S. Hagan, P. Clark, A. Bejda, A. Calabrese, A. Studholme and K. W. Able. (2002). Variability in Habitat Use by Young-of-the-Year Winter Flounder, *Pseudopleuronectes americanus*, in Three Northeastern U.S. Estuaries. Estuaries. 25(2):215-226.
YOY winter flounder were found in higher densities in unvegetated areas adjacent to eelgrass. The exception was in the Hammonasset River in 1995 when densities were higher in eelgrass. We conclude that the type of habitat most important to YOY winter flounder varies among estuaries and as a result, care should be taken in defining EFH, based only on limited spatial and temporal sampling.

Harris, L. A., B. Buckley, S. W. Nixon and B. T. Allen. (2004). Experimental studies of predation by bluefish *Pomatomus saltatrix* in varying densities of seagrass and macroalgae. Mar.Ecol.Prog.Ser. 28:1233-239.
Eelgrass significantly increased the survivorship of silversides, tautog and cunner at very low shoot densities. Experiments using macroalgae did not result in significantly different survival rates. This information increases our understanding of the relative value of eelgrass habitat to fish stocks.

Horinouchi M. (2007). Distribution patterns of benthic juvenile gobies in and around seagrass habitats: effectiveness of seagrass shelter against predators. Estuar.Coast.Shelf Sci. 72:(4)657-664.
Differences in juvenile abundance are likely due to differences in food availability not predator exclusion by SAV.

Hosack, G., D. Armstrong, B. Dumbauld, J. Ruesink, B. Semmens and I. Fleming. (2004). The effect of *Zostera marina* and *Crassostrea gigas* culture on intertidal communities in a Northeast Pacific estuary. J.Shellfish Res. 23(2):655.
In Pacific Northwest estuaries, commercial oysters are often cultivated at the same tidal elevation as seagrass meadows, and thus management decisions concerning resource use require insight into their comparative value. Meiofauna densities were more than seven times higher in structured habitats and composition was significantly affected by habitat.

Leduc, D., P. K. Probert, R. D. Frew and C. L. Hurd. (2006). Macroinvertebrate diet in intertidal seagrass and sandflat communities: a study using C, N, and S stable isotopes. N.Z.J.Mar.Freshw.Res. 40:(4)615-629.
Z. capricorni was a potentially important contributor (24-99%) to the diet of most consumers sampled at the seagrass site, whereas microphytobenthos dominated the diet of the same consumers at the sandflat site.

Lipcius, R.N., Rochelle D. Seitz, Michael S. Seebo and Duamed Colon-Carrion. (2005). Density, abundance and survival of the blue crab in seagrass and unstructured salt marsh nurseries of Chesapeake Bay. J.Exp.Mar.Biol.Ecol. 319(1-2):69-80.
Juvenile blue crab density was nearly an order of magnitude lower in mudflats and sandflats than in SAV habitats; density was lowest in DCM. We conclude that shallow subtidal mud and sand flats near upriver salt marshes and in marsh coves are vital nursery grounds for the blue crab, and thus warrant conservation and restoration efforts at the level provided to SAV.

Phelan, B. A., R. Goldberg, A. J. Bejda, J. Pereira, S. Hagan, P. Clark, A. L. Studholme, A. Calabrese and K. W. Able. (2000). Estuarine and habitat-related differences in growth rates of young-of-the-year winter flounder (*Pseudopleuronectes americanus*) and tautog (*Tautoga onitis*) in three northeastern US estuaries. J.Exp.Mar.Biol.Ecol. 147:(1)1-28.
Comparisons across nominal habitats within and among estuaries did not show any one habitat with consistently higher growth, and growth was relatively independent of whether a habitat was vegetated or adjacent to vegetation.

Reid, Carolyn Cristine. (2004). The effects of submerged aquatic vegetation as habitat on the survivorship of clams: Field surveys in St. Mary's River, Maryland and laboratory predation experiments (*Callinectes sapidus, Mya arenaria*). Masters Abst.Int. 4241204
Greater predation pressure on clams in lower SAV biomass may be causing differences in clam abundance since SAV presence significantly reduced predation. Habitat studies tracking behavior revealed crabs spent more time in vegetation but consumed more clams outside SAV.

Stevenson, J. C. and N. M. Confer. (1978). Summary of Available Information on Chesapeake Bay Submerged Vegetation. Fish and Wildlife Service 747 ref.
A review of impacts which may contribute to the reduction of SAV in the Chesapeake Bay.

Stockhausen, W. T. and R. N. Lipcius. (2003). Simulated effects of seagrass loss and restoration on settlement and recruitment of blue crab postlarvae and juveniles in the York River, Chesapeake Bay. Bull.Mar.Sci. 72(2):409-422.
Seagrass meadows provide important settlement habitat, food and refuge for postlarvae and young juveniles of the blue crab, Callinectes sapidus. This is a model of the impacts of SAV losses or creation on blue crab settling.

Thayer, G.W., MS Fonseca and W. Judson Kenworthy. (1985). Restoration of seagrass meadows for enhancement of nearshore productivity. Int. Symp. on Utilization of Coastal Ecosystems: Planning, Pollution, and Productivity, Rio Grande, RS (Brazil), 21 Nov 1982
Eelgrass exhibited an exponential growth and coverage rate and attained densities comparable to natural meadows. Bottom coverage rate, carbon fixation, detrital production and faunal recruitment are enhanced by seagrass restoration, helping to maintain nearshore productivity.

Valesini, F. J., I. C. Potter and K. R. Clarke. (2004). To what extent are the fish compositions at nearshore sites along a heterogeneous coast related to habitat type? Estuar.Coast.Shelf Sci. 60(4):737-754.
Extents of the differences in the fish compositions among the various habitat types parallel those in the environmental data for the corresponding habitat types.

Van Montfrans, J., C. H. Ryer and R. J. Orth. (2003). Substrate selection by blue crab Callinectes sapidus megalopae and first juvenile instars. Mar.Ecol.Prog.Ser. 260:209-217.
The initial non-random distribution of blue crabs in Chesapeake Bay may be deterministic and due to habitat-selection behavior by megalopae. Selection for seagrass assures the greatest likelihood of maximal survival and accelerated growth.

Oysters/Bivalves – Water Quality

Campbell, M. (2005). The use of oyster reef restoration as a method of erosion control. J.Shellfish Res. 24(1):318.
The design of a structure that would aid in oyster reef restoration in the shape of a submerged breakwater, termed an "oysterbreak," is designed to stimulate the growth of biologic structures in a wave dissipating shape. In the same way native oyster reefs can form immense structures that protect shorelines and coastal communities from storms, this structure would provide the same function.

Heck Jr., K. L., J. Cebrian and S. P. Powers. (2005). Ecosystem services provided by oyster reefs: An experimental assessment. J.Shellfish Res. 24(1):323.
Experimental assessment of many of the key expectations associated with oyster reef restoration. Specifically, we are assessing whether there are differences in water clarity, nutrient dynamics, benthic primary and secondary production, and nursery value for fish and mobile invertebrates that are associated with the presence of experimentally planted oyster reefs.

Newell, R. and Evamaria W. Koch. (2004). Modeling Seagrass Density and Distribution in Response to Changes in Turbidity Stemming from Bivalve Filtration and Seagrass Sediment Stabilization. Estuaries. 27(5):793-806.
Development of a simple model to calculate how changes in the balance between sediment sources (wave-induced resuspension) and sinks (bivalve filtration, sedimentation within seagrass beds) regulate turbidity. The model predicted that eastern

oysters reduced suspended sediment concentrations by nearly an order of magnitude. Hard clams and seagrass were less effective. Our model predicted that restoration of eastern oysters has the potential to reduce turbidity in shallow estuaries, such as Chesapeake Bay, and facilitate ongoing efforts to restore seagrasses.

Piazza, B., J. Plunket, J. Supan and M. La Peyre. (2003). Using created oyster reefs as a sustainable coastal protection and restoration tool. J.Shellfish Res. 22(1):349.
The value of reefs for protecting shorelines was determined by tracking shoreline position and adjacent marsh health (vegetation biomass, redox, sediment accretion) at paired cultched and non-cultched sites. Reef sustainability was determined by measuring recruitment and survival of oyster spat. Fisheries value of the reef was quantified by sampling nekton. Fish community usage of cultched and non-cultched sites was similar. Shoreline retreat appears to be slightly higher in high energy, non-cultched sites. Minimal movement and reworking of shell through two tropical storm events showed that reefs were stable.

Piazza, Bryan P., Patrick D. Banks and Megan K. La Peyre. (2005). The Potential for Created Oyster Shell Reefs as a Sustainable Shoreline Protection Strategy in Louisiana. Restor.Ecol. 13(3):499-506.
Shoreline retreat was reduced in cultched low-energy shorelines as compared to the control low-energy shorelines (analysis of variance; $p < 0.001$) but was not significantly different between cultched and noncultched sites in high-energy environments. Recruitment and growth rates of oyster spat suggested potential reef sustainability over time. Small fringing reefs may be a useful tool in protecting shorelines in low-energy environments. However, their usefulness may be limited in high-energy environments.

Ruesink, J. L., B. E. Feist, C. J. Harvey, J. S. Hong, A. C. Trimble and L. M. Wisehart. (2006). Changes in productivity associated with four introduced species: ecosystem transformation of a 'pristine' estuary. Mar.Ecol.Prog.Ser. 311:203-215.
The introduction of non-native species can lead to higher local richness. The replacement of native oysters in Willapa Bay by 2 new bivalve species has increased secondary production of harvested suspension feeders by 250% over peak historic values. These changes in production are also associated with altered detritus, water filtration, and biogenic habitat. Because other stressors are largely absent from Willapa Bay, the addition of particular exotic species has dramatically enhanced system production, while fundamentally reshaping the ecological character of the estuary. These strong ecological impacts of introduced species have rarely been measured at whole- ecosystem scales, and they occur in part because new species occupy habitats where similar native species were not present.

Oysters/Bivalves – Habitat

Burke, R., R. Lipcius, M. Luckenbach, P. G. Ross, J. Woodward and D. Schulte. (2006). Eastern oyster settlement and early survival on alternative substrates along intertidal marsh, rip rap, and manmade oyster reef. J.Shellfish Res. 25(2):715.

Surveys within the Lynnhaven Bay system indicate that artificial oyster shell reefs created in the early 1990s are producing poor to marginal oyster densities relative to densities on nearby granite and concrete riprap, and on oyster clusters along marsh-fringed shores. Overall, replicates showed a distinct recruitment/early survival pattern between sites: marsh > rip rap > artificial oyster reef. We therefore propose that granite may be a favorable oyster reef construction material, since it appears to enhance oyster settlement and early post-settlement survival. Additional biological benefits may accrue from granite reefs as community structure develops on the reefs.

Heck Jr., K. L., J. Cebrian and S. P. Powers. (2005). Ecosystem services provided by oyster reefs: An experimental assessment. J.Shellfish Res. 24(1):323.
Experimental assessment of many of the key expectations associated with oyster reef restoration. Specifically, we are assessing whether there are differences in water clarity, nutrient dynamics, benthic primary and secondary production, and nursery value for fish and mobile invertebrates that are associated with the presence of experimentally planted oyster reefs.

Hosack, G., D. Armstrong, B. Dumbauld, J. Ruesink, B. Semmens and I. Fleming. (2004). The effect of Zostera marina and Crassostrea gigas culture on intertidal communities in a Northeast Pacific estuary. J.Shellfish Res. 23(2):655.
Intertidal habitat structure created by seagrass and oysters is broadly considered to play an important role in the shaping of many biologic communites. Meiofauna densities were more than seven times higher in structured habitats, and composition was significantly affected by habitat.

Meyer, D. L. and E. C. Townsend. (2000). Faunal Utilization of Created Intertidal Eastern Oyster (Crassostrea virginica) Reefs in the Southeastern United States. Estuaries. 23(1):34-45.
Oyster cultch was added to the lower intertidal marsh-sandflat fringe of three previously created Spartina alterniflora salt marshes. Eastern oyster (Crassostrea virginica) settlement at one site of created reef exceeded that of the adjacent natural reefs within 9 mo of reef creation. The created reefs also had a higher number of molluscan, fish, and decapod species than the adjacent natural reefs. Created oyster reefs can quickly acquire functional ecological attributes of their natural counterparts.

Piazza, B., J. Plunket, J. Supan and M. La Peyre. (2003). Using created oyster reefs as a sustainable coastal protection and restoration tool. J.Shellfish Res. 22(1):349.
The value of reefs for protecting shorelines was determined by tracking shoreline position and adjacent marsh health (vegetation biomass, redox, sediment accretion) at paired cultched and non-cultched sites. Reef sustainability was determined by measuring recruitment and survival of oyster spat. Fisheries value of the reef was quantified by sampling nekton. Fish community usage of cultched and non-cultched sites was similar. Shoreline retreat appears to be slightly higher in high energy, non-cultched sites. Minimal movement and reworking of shell through two tropical storm events showed that reefs were stable.

Rodney, W. and K. T. Paynter. (2005). Benthic macrofaunal assemblages on restored and unrestored eastern oyster (Crassostrea virginica) reefs in Chesapeake Bay: Implications for finfish species. J.Shellfish Res. 24(1):335.
Motile macrofaunal density was an order of magnitude higher on restored reefs, epifaunal density was more than twice as high on restored reefs, and sessile macrofaunal density was two orders of magnitude higher on restored reefs. Since reef macrofauna include many important fish prey species, oyster reef restoration has the potential to augment energy transfer to higher trophic levels by increasing fish prey densities and fish foraging efficiency.

Rodney, William S. and Kennedy T. Paynter. (2006). Comparisons of macrofaunal assemblages on restored and non-restored oyster reefs in mesohaline regions of Chesapeake Bay in Maryland. J.Exp.Mar.Biol.Ecol. 335(1):39-51.
Density of macrofauna was an order of magnitude higher on restored reefs, epifaunal density was more than twice as high on restored reefs and sessile macrofaunal density was two orders of magnitude higher on restored reefs. Mean amphipod density was 20 times higher on restored plots and densities of xanthid crabs and demersal fish were both four times greater on restored plots. Two out of four functional feeding groups: suspension feeders and carnivore/omnivores, were more abundant on restored plots. Since reef macrofauna include many important fish prey species, oyster reef restoration may have the potential to augment fish production by increasing fish prey densities and fish foraging efficiency.

Seaman, William. (2007). Artificial habitats and the restoration of degraded marine ecosystems and fisheries. Hydrobiologia. 580(1):143-155.
A review of habitat restoration. Principles of ecological restoration are summarized, from planning through to evaluation. Alternate approaches to facilitate ecological recovery include land-use and ecosystem management and determining levels of human population, consumption and pollution.

Zeug, S. C., V. R. Shervette, D. J. Hoeinghaus and S. E. Davis. (2007). Nekton assemblage structure in natural and created marsh-edge habitats of the Guadalupe Estuary, Texas, USA. Estuar.Coast.Shelf Sci. 71(3-4):457-466.
We conclude that lower substrate complexity (specifically oyster) and soil organic content in the created marsh reduced measures of nekton similarity and recommend that these features be addressed in future restoration efforts.

Aquaculture – Water Quality

Rheault, R. B.. (2006). Ecological services rendered by cultured eastern oysters. J.Shellfish Res. 25(2):766.
It has been shown that wild and cultured oysters provide many ecological services that benefit both the environment and wild oyster stocks. (Shumway et al. 2003, Newell 2004, 2002) The services rendered by commercial oyster aquaculture include: removal of nutrients (both by harvest and enhanced bacterial deni-trification); improving water clarity and water quality by enhancing sedimentation; adding larvae to the wild;

sequestering tons of carbon and creating a structurally diverse habitat for other marine organisms.

Ruesink, J. L., B. E. Feist, C. J. Harvey, J. S. Hong, A. C. Trimble and L. M. Wisehart. (2006). Changes in productivity associated with four introduced species: ecosystem transformation of a 'pristine' estuary. Mar.Ecol.Prog.Ser. 311:203-215.
The introduction of non-native species can lead to higher local richness. The replacement of native oysters in Willapa Bay by 2 new bivalve species has increased secondary production of harvested suspension feeders by 250% over peak historic values. These changes in production are also associated with altered detritus, water filtration, and biogenic habitat. Because other stressors are largely absent from Willapa Bay, the addition of particular exotic species has dramatically enhanced system production, while fundamentally reshaping the ecological character of the estuary. These strong ecological impacts of introduced species have rarely been measured at whole- ecosystem scales, and they occur in part because new species occupy habitats where similar native species were not present.

Tallis, H., J. Ruesink, B. Dumbauld, S. Hacker and L. Wisehart. (2006). Eelgrass responds to oysters and grow-out methods in an aquaculture setting. J.Shellfish Res. 25(2):782.
Aquaculture has been shown to have negative impacts on eel-grass. We argue that the magnitude of tradeoffs between aquaculture and biodiversity depends on the ecological details of the production system. We found lower eelgrass density in all aquaculture systems relative to uncultivated areas in 2002-2004. Dredged beds had the lowest eelgrass densities (similar to 50% < uncultivated) while hand picked and long line beds were intermediate. Additionally, eelgrass density declined with oyster density in cultivated beds, although oysters were sparsely planted (similar to 20% cover).

Vaudrey, J., T. Getchis and B. Britton. (2006). Assessing impacts of shellfish aquaculture on eelgrass populations in eastern Long Island Sound. J.Shellfish Res. 25(2):785.
Bivalve aquaculture, specifically the utilization of submerged cultivation and depuration gear such as cages, has been implicated as a potential source of negative impacts to eelgrass populations. However, shellfish aqua-culture gear has also been shown to provide an equivalent or greater degree of ecosystem services as submerged aquatic vegetation such as eelgrass. Preliminary results suggest an increase in eelgrass growth rate, measured as sheath length. No treatment effect was seen for water column properties, sediment % organics, or benthic microalgae concentrations.

Aquaculture – Habitat

Dealteris, J. T., B. D. Kilpatrick and R. B. Rheault. (2004). A comparative evaluation of the habitat value of shellfish aquaculture gear, submerged aquatic vegetation and a non-vegetated seabed. J.Shellfish Res. 23(3:)867-874.
Comparison of the habitat value of modified rack and bag, shellfish aquaculture gear (SAG) used for the grow-out phase of the American oyster, Crassostrea virginica, submerged aquatic vegetation (SAV), Zostera marina, and a shallow nonvegetated

seabed (NVSB). The physical structure of the SAG habitat protects juvenile fish from predators and provides substrate for sessile invertebrates that serve as forage for fish and invertebrates. Therefore, we conclude that shellfish aquaculture gear has substantially greater habitat value than a shallow nonvegetated seabed, and has habitat value at least equal to and possibly superior to submerged aquatic vegetation.

Rheault, R. B.. (2006). Ecological services rendered by cultured eastern oysters. J.Shellfish Res. 25(2):766.
It has been shown that wild and cultured oysters provide many ecological services that benefit both the environment and wild oyster stocks. (Shumway et al. 2003, Newell 2004, 2002) The services rendered by commercial oyster aquaculture include: removal of nutrients (both by harvest and enhanced bacterial deni-trification); improving water clarity and water quality by enhancing sedimentation; adding larvae to the wild; sequestering tons of carbon and creating a structurally diverse habitat for other marine organisms.

Tallis, H., J. Ruesink, B. Dumbauld, S. Hacker and L. Wisehart. (2006.) Eelgrass responds to oysters and grow-out methods in an aquaculture setting. J.Shellfish Res. 25(2):782.
Aquaculture has been shown to have negative impacts on eel-grass. We argue that the magnitude of tradeoffs between aquaculture and biodiversity depends on the ecological details of the production system. We found lower eelgrass density in all aquaculture systems relative to uncultivated areas in 2002-2004. Dredged beds had the lowest eelgrass densities (similar to 50% < uncultivated) while hand picked and long line beds were intermediate. Additionally, eelgrass density declined with oyster density in cultivated beds, although oysters were sparsely planted (similar to 20% cover).

Vaudrey, J., T. Getchis and B. Britton. (2006). Assessing impacts of shellfish aquaculture on eelgrass populations in eastern Long Island Sound. J.Shellfish Res. 25(2):785.
Bivalve aquaculture, specifically the utilization of submerged cultivation and depuration gear such as cages, has been implicated as a potential source of negative impacts to eelgrass populations. However, shellfish aqua-culture gear has also been shown to provide an equivalent or greater degree of ecosystem services as submerged aquatic vegetation such as eelgrass. Preliminary results suggest an increase in eelgrass growth rate, measured as sheath length. No treatment effect was seen for water column properties, sediment % organics, or benthic microalgae concentrations.

Wisehart, L. M., S. D. Hacker, B. R. Dumbauld and J. L. Ruesink. (2006). Oyster aquaculture may positively affect eelgrass (Zostera marina L.) through enhanced seed production and germination. J.Shellfish Res. 25(2):792.
Past studies have identified both positive and negative effects of shellfish aquaculture on eelgrass but researchers have yet to address how such activities may affect eelgrass recruitment. We found higher seedling densities in dredged beds than in longlines or eelgrass beds. Germination was highest in the eelgrass beds, where, interestingly, eelgrass removal had a positive effect. Greater recruitment in dredged beds may thus be due to both enhanced seed densities as well as removal of neighboring adults. Together

these studies suggest ground culture practices may positively affect eelgrass recruitment while longlines may have a negative effect.

9. Fetch and Bathymetry

Basco, D.R. and C.S. Shin. 1993. Design wave information for Chesapeake Bay and major tributaries in Virginia. Report No. 93.1. The Coastal Engineering Institute, Old Dominion University, Norfolk, VA. 49 p.
This report discusses the development and application of a wave climate model based upon the Automated Coastal Engineering System (ACES), developed by the Coastal Engineering Research Center of the U.S. Army Corps of Engineers. This model uses historical wind data, generically referred to as hindcasting, to calculate wave climate. This model was used to produce twelve (12) wave energy maps of the Chesapeake Bay and tributary rivers in Virginia. A significant limitation of this model is that is does not consider nearshore wave transformation processes such as shoaling, refraction and wave breaking processes, i.e. water depth. Therefore, the model is intended to indicate boundary conditions to be used in finer resolution, nearshore wave transformation models.

Cooper, N.J. 2005. Wave dissipation across intertidal surfaces in the Wash tidal inlet, eastern England. Journal of Coastal Research. 21(1): 28-40.
A one-year study was conducted by the authors to characterize the role of the intertidal saltmarsh and mudflats in dissipating wave height and energy. Wave measurements were taken along three (3) different topographic transects, perpendicular to the shoreline of the Wash tidal inlet, located in eastern England. Results indicated that on average, the Wash is 83% effective in dissipating wave height and 91% in dissipating wave energy. The authors conclude that shoreline management should move away from the current structural line of defense approach and move towards management of a "deference zone" that consists of both natural and structural elements in the intertidal zone.

Hardaway, C.S. and R. Byrne. 1997. Shoreline management in Chesapeake Bay. Report. College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, VA. 26 p.
In this report, the authors discuss topics such a shoreline evolution, shoreline processes, reach assessment, shoreline management strategies, and shoreline management goals and applied strategies. Under shoreline processes, the authors discuss wave climate and shoreline erosion. Fetch is described as a simple measure of relative wave energy. For their purposes, low energy shorelines have an average fetch of <1 nautical mile (nm); medium energy shorelines have an average fetch of 1-5 nm; and high-energy shorelines have an average fetch of >5 nm. Shallow nearshore depths, such as tidal flats and sand bars are able to attenuate incoming wave energy before reaching the shoreline better than deeper waters. The authors suggest planted marshes as a viable shoreline protection strategy along low-energy shorelines where fetch exposure is <0.5 nm.

Hardaway, C.S., J. Posenau, G.R. Thomas, and J.C. Baumer. 1992. Shoreline Erosion Assessment Software (SEASware) report. College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, VA. 47 p.
The authors used thirteen (13) shoreline parameters to produce the Chesapeake Bay shoreline erosion potential scale (CBSEPS), with categories of low (<2 ft./yr.), intermediate (2-4 ft./yr.), and high (>4 ft./yr.) erosion rates. These metrics include fetch, longest fetch and direction, distance from MHW to 6 ft. contour, shoreline orientation, shoreline geometry, boat wakes, bank height above MHW, bank base composition, shore zone characterization (presence/absence and width of marsh or beach), backshore zone, fastland bank condition, nearshore morphology, an nearshore aquatic vegetation. Each metric was scored, weighted, and then aggregated with all others to derive the shoreline erosion index (SEI). The fetch distances were categorized into seven (7) ranges; 0-0.1 mi., 0.1-0.33 mi., 0.33-1.0 mi., 1-3 mi., 3-10 mi. 10-20 mi., and >20 mi. Distances to the 6 ft. contour were categorized into five (5) ranges; >3000 ft., 2000-3000 ft., 1000-2000 ft., 300-1000 ft. and <300 ft. The authors note that much of the shoreline erosion observed is a direct result of high-energy storm events, which exhibit considerable temporal variability. Consequently, the cumulative erosion potential value (CEPV) depends upon storm frequency, storm type and direction, intensity and duration, and the resulting wind tides, currents and waves. Also, man-made erosion control structures have the ability to modify this erosion potential.

Keddy, P.A. 1982. Quantifying within-lake gradients of wave energy: Interrelationships of wave energy, substrate particle size, and shoreline plants in Axe Lake, Ontario. *Aquatic Botany*. 14: 41-58. (REI methodology)

Knutson, P.L. and M.R. Inskeep. 1982. Shore erosion control with salt marsh vegetation. CETA-82-3. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, VA. 23 p.

Knutson, P.L., R.A. Brochu, W.N. Seelig and M.R. Inskeep. 1982. Wave dampening in Spartina alterniflora marshes. Wetlands. 2: 87-104.
The authors developed a model based on empirical estimates of the fluid drag forces occurring on vertical cylinders, intended to simulate Spartina alterniflora stems, to describe the decay of wave energy in tidal salt marshes. Field experiments were conducted to test and calibrate the empirical model in S. alterniflora marshes on the eastern shore of the Chesapeake Bay in Virginia. The results of the study suggest that marshes create a buffer against shoreline erosion, dissipating 64% of wave energy within the first 2.5 m of marsh, and virtually no wave energy persisting beyond 30 m. Impacts to and the filling of salt marshes, especially S. alterniflora fringe marshes, will adversely affect the stability of the shoreline in many cases.

Knutson, P.L., J.C. Ford, M.R. Inskeep and J. Oyler. 1981. National survey of planted salt marshes (vegetative stabilization and wave stress). Wetlands. 1: 129-157.
The frequency and magnitude of severe wave conditions is largely influenced by local climatological patterns, fetch, and water depth. In a survey of 104 saltmarsh planting

sites (23 in Virginia) from 12 coastal states, the relative stability of the plantings was compared with various metrics comprising wave climate such as fetch, nearshore slope, offshore depth, shoreline configuration, sediment grain size, shoreline orientation with respect to prevailing and storm winds, and boat wakes. The authors found that of these parameters, fetch, shoreline configuration and sediment grain size were the most highly correlated with planting stability. The authors use these three parameters to develop a model, the Vegetative Stabilization Site Evaluation Form, for evaluating the likely success of potential marsh planting sites. Cumulative scores for four metrics (two used for fetch) are characterized into three probabilities for success: 15%, 50% and 100%. This model is appropriate for calculating the likelihood of a successful planting effort, and can be utilized to determine a site's suitability for vegetative treatments in lieu of rock and wooden structures. The authors acknowledge that both fetch and water depth play significant roles in wave climate for a site.

Möller, I. 2006. Quantifying saltmarsh vegetation and its effect on wave height dissipation: Results from a UK East coast saltmarsh. Estuarine, Coastal and Shelf Science. 69: 337-351.
Wave attenuation across any surface is known to vary with relative wave height. This study uses digital imaging to quantify density, height and structure of three (3) macrotidal saltmarshes in Dengie peninsula, Essex, UK. At two (2) of the study sites dominated by Spartina spp., the relative incident wave height (wave height/water depth) exerted a statistically significant positive control on wave attenuation up to a threshold value of 0.55, beyond which no additional wave attenuation was observed. However, variability in wave attenuation was high, and different vegetation characteristics between the three (3) transects did not exert a statistically significant influence on wave attenuation. The authors report that wave attenuation across the three (3) 10 m transects sampled in the study varied from 0.08% in 0.4 m of water depth to 33% in 0.2 m of depth.

Perry, J.E., T.A. Barnard, Jr., J.G. Bradshaw, C.T. Friedrichs, C.T. Havens, P.A. Mason, W.I. Priest, III, G.M. Silberhorn. 2001. Creating tidal salt marshes in the Chesapeake Bay. Journal of Coastal Science. Special Issue No. 27: 170-191.
The authors provide a review of the existing knowledge of tidal salt marsh creation in the Chesapeake Bay, and provide recommendations for the appropriate siting, design, and construction methods. Three case studies are presented along with a discussion of lessons learned and suggestions for improvements for future design and construction. The authors include fetch in their discussion of recommended design and construction methods. They discuss work done by Hardaway et al. (1980, 1981) that suggested that marshes planted on naturally nonvegetated, intertidal flats did poorly if fetch exceeded 1,600 m. Hardaway and Byrne (1997) recommend planting marshes for erosion control on low energy shorelines with fetches of less than 800 m. The vegetative stabilization site evaluation methodology developed by Knutson et al. (1981) is also discussed, which uses average and greatest fetch distances across open water, along with shoreline geometry and sediment grain size to determine the percent success rate of salt marsh creation sites. Using their site evaluation method, Knutson et al. (1982) suggest that a tidal salt marsh with of fetch >3,000 m has only a 44% probability of survival.

Roland, R.M. and S.L. Douglass. 2005. Estimating wave tolerance of Spartina alterniflora in coastal Alabama. Journal of Coastal Research. 21(3): 453-463.
The authors compared two (2) existing methodologies to estimate wave climate and site suitability for marsh creation in coastal Alabama. Nine (9) sites were selected for this study, with and without Spartina alterniflora. The Keddy (1982) wave exposure index, which uses wind-wave hindcasting, and the Knutson et al. (1981) vegetative stabilization site evaluation methods were used to determine wave climate and suitability of the site to sustain a marsh. The results from the Keddy (1982) model indicated that vegetated wetland sites had the smallest hindcast wave heights and nonwetland (intertidal beach) shorelines had the highest. Sites where the marsh was eroding exhibited intermediate hindcast wave heights. The authors caution that although the Keddy (1982) method (or REI) may be an effective tool in some situations, it may be difficult for those wishing to apply the model to determine the appropriateness of their situation, which limits the model as a tool for wave climate evaluation of wetlands. Incorporating water depth, which can limit wave heights, could improve the utility of this model. Likewise, the authors believe it is unclear how the Knutson et al. (1981) method could be applied to the design of created marshes.

Shafer, D.J., R. Roland and S.L. Douglass. 2003. Preliminary evaluation of critical wave energy thresholds at natural and created coastal wetlands. WRP Technical Notes Collection (ERDC TN-WRP-HS-CP-2.2), U.S. Army Engineer Research and Development Center, Vicksburg, MS.
The purpose of this study was to evaluate a shallow-water wave hindcasting method for determining wave energy at natural and created wetland sites in order to identify critical wave climate thresholds for success of created wetlands. In addition, the critical wave heights identified in this study can be used to help design minimally sized defensive structures that are capable of protecting wetland creation sites. The authors developed their hindcast approach to address shortcomings of various wave climate models such as Relative Exposure Index (REI) which is based upon mean annual wind speed, percent frequency that the wind blew from 16 cardinal and subcardinal compass directions, and fetch distance in each of the 16 compass directions. The authors note that the potential effect of water depth is not explicitly accounted for in the REI methodology, and because wave height can decrease as a wave propogates from deep to shallow water, the inability of this methodology to account for the effect of water depth on wave climate reduces the applicability of REI for siting potential wetland planting sites. To overcome this deficiency, the authors generated the nearshore wave climate using wave hindcasting, where wave height, fetch, wind speed, and average water depth data are input to a computer program based on shallow-water wave generation models (WaveGen; Weggel and Douglass, 1985). With no previous studies to help guide the selection of a wave height statisic, the authors arbitrarily selected the 50^{th} and 20^{th} percentile exceedence wetland wave heights in this study for comparison with observed shoreline stabilization and vegetation characteristics. The 50^{th} percentile represents "average" conditions (exceeded 50% of the time) and the 20^{th} percentile represents more extreme conditions. Using a hindcast method to calculate a critical wave height (wave height statistic), the authors found good agreement with the REI model (Keddy, 1982).

van der Wal, D. and K. Pye. 2004. Patterns, rates and possible causes of saltmarsh erosion in the greater Thames area (UK). Geomorphology. 61: 373-391.
The authors describe a number of factors affecting lateral erosion and interior dissection of salt marshes along the greater Thames estuary, among others. Several causes are attributed to this loss such as the filling of wetlands and construction of embankments that have increased tidal range and current velocities. The large amount of erosion experienced during the 1970's is attributed to a change in the wind-wave climate by the authors. The basic methodology employed is an analysis of published and unpublished documentary evidence along with a time series comparison of historical aerial photographs. This information was used to identify changes in mean low and mean high water along with morphological changes to the shoreline, thus allowing for status and trends analysis. The authors suggest erosion within estuaries can result from relatively small waves generated over short fetches and that flats in the UK provide little shoreline protection during storm tides when they are submerged by up to 4m of water.

Williams, P. 2001. Restoring physical processes in tidal wetlands. Journal of Coastal Research. Special Issue No. 27: 149-161.
This paper discusses the development of a methodology for the restoration of physical processes to create and sustain tidal wetland habitat values based on a geomorphic understanding of the natural evolutionary trajectory of restored tidal marshes. The restoration design methodology presented by the authors includes limiting fetch to a maximum of 300 m to insure natural sedimentation of the marsh is not impeded and to allow for vegetation to naturally colonize and maintain the perimeter of the site.