Overwater Structures and Marine Habitats

Bibliography

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Background & Scope

The Protected Resources Division of the National Marine Fisheries Service's (NMFS) West Coast Region is editing the effects analysis portion of an existing Essential Fish Habitat (EFH) programmatic consultation for overwater structures between NMFS and the United States Army Corps of Engineers. To that end, a literature search was requested from the NOAA Central Library. This literature search covered the effects of anthropogenic change and overwater structures on marine habitats and their processes, especially EFH. The literature found is presented here in this bibliography.

This bibliography presents all literature in alphabetical order by author. It covers the years 2010-2021 and primarily includes peer-reviewed academic literature, reports by state and federal governments, and dissertations.

Sources Reviewed

Along with a web search for relevant grey literature materials, the following databases were used to identify sources: Dimensions, Lens.org, Clarivate Analytics' Web of Science, Wiley Online Library, Science Direct, Google Scholar, ProQuest's Aquatic Science and Fisheries Abstracts, and JSTOR. Only English language materials were considered.

References

Able, K. W., & Grothues, T. M. (2018). Essential Fish Habitat for Nearshore Sentinel Species of Fishes and Crabs in Heavily Urbanized New York Harbor. *Urban Naturalist,* 16, 1-25. Retrieved from https://www.eaglehill.us/URNAonline/articles/URNA-16/04-Able.shtml

Our objective was to evaluate nearshore fish and crab habitat use and quality in New York Harbor, a heavily urbanized area. We determined Essential Fish Habitat at several levels (abundance, reproduction, growth, survival, and habitat fidelity) for specific sentinel species of estuarine fishes (*Fundulus heteroclitus* [Mummichog], *Fundulus majalis* [Striped Killifish], *Menidia menidia* [Atlantic Silverside]) and *Callinectes sapidus* (Blue Crab). “Heavily altered” and “altered” shorelines at different sites typically had a steep slope and fabricated break on the upland side with very little or no vegetation; other “naturalized” shallow shorelines had gradually sloping mudflats or beaches with some intertidal and supratidal vegetation. Resident species (Mummichog, Striped Killifish) completed their life cycle along these shallow beaches and marsh shorelines, as evidenced by collections that included all size classes from newly hatched larvae to gravid adults. Mark–recapture efforts involving Mummichog demonstrated minimal dispersal, suggesting that all habitat needs were met in these limited shallow areas. The non-resident, but frequent users of these shorelines either migrated in to reproduce, grow, and survive (e.g., Atlantic Silverside) or grew from settlement from the plankton and survived to juveniles (e.g., Blue Crab). Given these findings, even small and potentially fractured restoration projects that seek to restore shallow, naturalized habitat with marsh features should be encouraged in this and other heavily urbanized estuaries.

Able, K. W., Grothues, T. M., & Kemp, I. M. (2013). Fine-scale distribution of pelagic fishes relative to a large urban pier. *Marine Ecology Progress Series,* 476, 185-198. https://doi.org/10.3354/meps10151

Intense shading under large piers is known to negatively affect benthic fishes. However, effects on pelagic fishes are poorly known. We employed the equivalent of acoustic video, dual frequency identification sonar (DIDSON), under a kayak to evaluate the response of pelagic fishes at a large (351 x 255 m) urban pier (Pier 40) in Hudson River. A repeated measures design (322 occupations) sampled 3 transects each across both the northern and southern open water-pier edge-under pier continuum during the day and night from June 2009 to September 2010. Over 22 000 individual fish, ranging from small schooling forage species (e. g. *Anchoa mitchilli*, *Menidia menidia*) to large predators *(Morone saxatilis, Pomatomus saltatrix*) were detected with DIDSON and verified with conventional sampling nets. Small (<250 mm) schooling pelagic fishes avoided areas under the pier where light is dramatically reduced during both day and night (when municipal lights illuminate the water away from the pier). Less abundant large (>250 mm) predatory fish responded somewhat differently from small schooling fish in that large predatory fish were slightly more abundant under the pier than in open water, but only from the edge extending to 5 m under the pier where there was still some light. Beyond that, abundance declined sharply. Together, these observations indicate that areas under large piers are suboptimal habitats for many of the abundant pelagic fishes, a pattern similar to that for benthic fishes.

Airoldi, L., Turon, X., Perkol-Finkel, S., Rius, M., & Keller, R. (2015). Corridors for aliens but not for natives: effects of marine urban sprawl at a regional scale. *Diversity and Distributions,* 21(7), 755-768. https://doi.org/10.1111/ddi.12301

Aim: The global sprawl of marine hard infrastructure (e.g. breakwaters, sea walls and jetties) can extensively modify coastal seascapes, but the knowledge of such impacts remains limited to local scales. We examined the regional-scale effects of marine artificial habitats on the distribution and abundance of assemblages of ascidians, a key group of ecosystem engineer species in benthic fouling systems. Location Five hundred kilometers of coastline in the North Adriatic Sea. Methods: We sampled a variety of natural reefs, marine infrastructures and marinas, and tested hypotheses about the role of habitat type and location in influencing the relative distribution and abundance of both native and nonindigenous species. Results: Assemblages differed significantly between natural and artificial habitats and among different types of artificial habitats. Non-indigenous species were 2–3 times more abundant on infrastructures built along sedimentary coastlines than on natural rocky reefs or infrastructures built close to rocky coastlines. Conversely, native species were twice as abundant on natural reefs than on nearby infrastructures and were scarce to virtually absent on infrastructures built along sedimentary coasts. The species composition of assemblages in artificial habitats was more similar to that of marinas than of natural reefs, independently of their location. Main conclusions: Our results show that marine infrastructures along sandy shores disproportionally favour non-indigenous over native hard bottom species, affecting their spread at regional scales. This is particularly concerning for coastal areas that have low natural densities of rocky reef habitats. We discuss design and management options to improve the quality as habitat of marine infrastructures and to favour their preferential use by native species over nonindigenous ones.

Balouskus, R. G., & Targett, T. E. (2012). Egg Deposition by Atlantic Silverside, *Menidia menidia*: Substrate Utilization and Comparison of Natural and Altered Shoreline Type. *Estuaries and Coasts,* 35(4), 1100-1109. https://doi.org/10.1007/s12237-012-9495-x

Egg deposition by the intertidal spawning fish Atlantic silverside (*Menidia menidia*) was compared among six shoreline types (*Spartina alterniflora, Phragmites australis*, sandy beach, riprap, riprap-sill, and bulkhead) and various substrates. In spring 2010, M. menidia egg density was measured daily near Roosevelt Inlet, Delaware Bay, USA. Over 3,000,000 eggs were collected during 50 sampling days. Eggs were deposited at all six shoreline types, with > 93 % of eggs collected from S. alterniflora shorelines. Choice of substrate for egg attachment was similar across shoreline types with > 91 % of eggs collected from filaments of the green alga *Enteromorpha spp*., a disproportionately high utilization rate in comparison with *Enteromorpha spp*.'s relative coverage. This study demonstrates that *S. alterniflora* shoreline, in association with *Enteromorpha spp*., is the preferred spawning habitat for *M. menidia* and that hardened shorelines and shorelines inhabited by *P. australis* support substantially reduced egg densities.

Balouskus, R. G., & Targett, T. E. (2016). Fish and Blue Crab Density along a Riprap-Sill-Hardened Shoreline: Comparisons with Spartina Marsh and Riprap. *Transactions of the American Fisheries Society,* 145(4), 766-773. https://doi.org/10.1080/00028487.2016.1172508

Wetland managers have historically considered riprap-sill structures (a type of "living shoreline" consisting of a rock sill that is placed low in the intertidal zone, with native vegetation planted between the sill and the shore) to be more ecologically sound than the riprap that is traditionally applied for shoreline stabilization in estuaries. However, little research has been conducted to compare the macrofauna associated with riprap-sill and riprap-hardened shorelines. Density and diversity of fish and blue crabs *Callinectes sapidus* were compared via weekly sampling along a riprap-sill shoreline, a riprap shoreline, and a shoreline fringed with smooth cordgrass *Spartina alterniflora* marsh in the Delaware Coastal Bays during summer 2010. Seining was conducted to quantitatively sample the shore zone and shallow subtidal regions, and minnow traps were used to determine the presence or absence of fishes in the mid-to upper-intertidal zone of each shoreline type. Temporally persistent differences in macrofaunal density and diversity were evident among the three shoreline types. In terms of fish density and diversity metrics, riprap-sill was more similar to the smooth cordgrass shoreline than to the traditional riprap shoreline. These results provide evidence for the biological advantage of riprap-sill over traditional riprap as a shoreline modification structure; spatial confirmation by further studies at different locations is warranted.

Barboza, C. A. M., Mattos, G., Soares-Gomes, A., Zalmon, I. R., & Costa, L. L. (2021). Low Densities of the Ghost Crab *Ocypode quadrata* Related to Large Scale Human Modification of Sandy Shores. *Frontiers in Marine Science,* 8. https://doi.org/10.3389/fmars.2021.589542

Sandy beaches are the most common ecosystems of coastal regions and provide direct and indirect essential services for millions of people, such as coastal protection, fishing, tourism, and recreational activities. However, the natural habitats of sandy shores are being modified at rates never experienced before, making beaches key monitoring sites of marine ecosystems worldwide. The ghost crab species *Ocypode quadrata* is the most conspicuous crustacean of sandy beaches along the Western Atlantic coast and has been successfully used as an indicator of anthropogenic disturbance and environmental variability. To investigate the potential role of a "triple whammy" [(1) urbanization; (2) use of resources; (3) decreasing resilience] on the most common bioindicator of sandy shores, we compiled a dataset including 214 records of burrows density from 94 microtidal sandy beach sectors covering a range of over 65 degrees of latitude. The response of burrows density to synergetic effects of human modification of natural systems and environmental changes was investigated using linear models. We used the cumulative Human Modification (HMc) index, a standardized geographic projection of changes of natural systems, as a predictor of urbanization, industrialization and use of resources. The predictor wave energy, tidal range and temperature (sea surface and air) were included as potential effects of climate changes. Literature review showed records mainly concentrated at sub-tropical and temperate regions. HMc values were clearly negatively related to burrows density, thereby supporting an effect of modification of natural habitat at large spatial scale. Sea surface temperature and air temperature were positive related with density and the lack of a general pattern of the relationship between burrows density, interactions between wave energy and tide range, supported unclear patterns reported at regional scales. Finally, we argue that ghost crabs are valuable targets for protection actions on sandy beaches that can benefit coexisting species and provide natural habitat conservation.

Bone, E. K., Reid, D. J., Thurman, M., Newton, R., Levinton, J. S., & Strayer, D. L. (2015). *Development of protocols to assess the relative habitat values of urban shorelines in the New York–New Jersey Harbor Estuary.* Prepared for the Hudson River Foundation and New York – New Jersey Harbor & Estuary Program, New York. Retrieved from http://hdl.handle.net/11343/251876

Habitat complexity is reduced when natural estuarine shorelines are replaced with concrete seawalls in highly urbanized regions. There is growing interest and investment in rehabilitating urbanized shorelines by adding physical habitat complexity to encourage establishment of diverse and resilient ecological communities. This is challenging, as multiple factors in addition to habitat availability operate across large scales to constrain ecosystem rehabilitation in urban estuaries. Design and management of shorelines to enhance their habitat and other ecological values should be based on using scientifically rigorous information to facilitate effective and efficient use of limited resources. This study was the initial step in the development of a protocol to provide a standardized and ecologically meaningful assessment of the relative habitat values of urban shorelines varying in physical habitat complexity across New York-New Jersey Harbor.

We developed a novel device with multiple colonization surfaces of standard dimensions, and a preliminary protocol manual to guide personnel in the construction and use of the device. In the subtidal zone of hard shorelines in the Harbor, mobile and sessile communities colonized mesh netting and hard settlement plates, respectively. Across all shorelines, mobile amphipods and encrusting algae were common, whilst isopods, shrimps, crabs and ascidians were common in some locations. Subtidal communities differed more between locations than between shorelines, varying in physical complexity, within locations. Increased habitat complexity did not consistently favor any particular taxonomic group across shorelines, but there were notable differences in community structure between concrete seawall and riprap revetment shorelines in some locations. However, some components of the original colonization devices were not durable enough and loss of replicate samples prevented meaningful comparisons across all shoreline types.

Colonization devices were redesigned with stronger outer caging made from vinyl-coated steel, more secure settlement plate attachment and greater weight for anchorage to hard shorelines. Redesigned devices were successfully deployed on a hard shoreline subject to high water movement.

Intertidal surveys using quadrats, subtidal photoquadrat surveys, bivalve surveys using scouring pads and fish surveys using minnow traps were trialed, but did not provide additional useful information for comparing the relative habitat values of hard shorelines in New York-New Jersey Harbor. The colonization device and associated measurements of abiotic variables should be refined, and they show promise for facilitating standardized assessments that could inform the future design and management of hard estuarine shorelines in the Harbor.

Briand, M. J., Letourneur, Y., Bonnet, X., Wafo, E., Fauvel, T., Brischoux, F., . . . Bustamante, P. (2014). Spatial variability of metallic and organic contamination of anguilliform fish in New Caledonia. *Environmental Science and Pollution Research,* 21(6), 4576-4591. https://doi.org/10.1007/s11356-013-2327-0

New Caledonia is one of the main hot spots of biodiversity on the planet. Large amounts of contaminants are discharged into the lagoon as a result of increasing anthropogenic activities such as intense mining, urbanization, and industrialization. Concentrations of 14 trace elements and 26 persistent organic pollutants (POPs: PCBs and pesticides) were measured in the muscles of two

anguilliform fish species, over a coast to barrier reef gradient in two lagoon areas differently exposed to anthropic disturbances. This study emphasizes the high trace element contamination status of anguilliform fish and also highlights slight but perceptible organic pollution. The contamination extends throughout the lagoon, from coast to barrier reef, even in areas remote from emission points. High levels of trace elements, especially those linked to mining activities (i.e., Co, Cr, Fe, Mn, and Ni), were detected in coastal sites. Furthermore, the large dispersion of most POPs throughout the entire lagoon poses the question of their potential toxicity on marine organisms from numerous habitats. Our results underline the need for long-term monitoring of various contaminants over large spatial and time scales.

Bulleri, F., & Chapman, M. G. (2010). The introduction of coastal infrastructure as a driver of change in marine environments. *Journal of Applied Ecology,* 47(1), 26-35. https://doi.org/10.1111/j.1365-2664.2009.01751.x

1. Coastal landscapes are being transformed as a consequence of the increasing demand for urban infrastructure to sustain commercial, residential and tourist activities. A variety of man-made structures, such as breakwaters, jetties and seawalls have thus become ubiquitous features of intertidal and shallow subtidal habitats. This transformation will accelerate in response to the exponential growth of human populations and to global changes, such as sea-level rise and increased frequency of extreme meteorological events (e.g. storms). Here, we provide a critical overview of the major ecological effects of increasing infrastructure to marine habitats, we identify future research directions for advancing our understanding of marine urban ecosystems and we highlight how alternative management options might mitigate their impacts.

2. Urban infrastructure supports different epibiota and associated assemblages and does not function as surrogate of natural rocky habitats. Its introduction in the intertidal zone or in near-shore waters can cause fragmentation and loss of natural habitats. Furthermore, the provision of novel habitat (hard substrata) along sedimentary shores can alter local and regional biodiversity by modifying natural patterns of dispersal of species, or by facilitating the establishment and spread of exotic species.

3. Attempts to use ecological criteria to solve problems of urban infrastructure are promising. Incorporating natural elements of habitat (e.g. wetland vegetation; seagrass) into shoreline stabilization can reduce ecological impacts, without impinging on its efficacy in halting erosion. Likewise, improving the ecological value of artificial structures by adding features of habitat that are generally missing from such structures (e.g. rock-pools) can contribute to mitigation of the detrimental effects of urbanization on biodiversity. Management of anthropogenic disturbances (e.g. maintenance works; harvesting) to artificial habitat is, however, necessary if such attempts are to be successful.

4. Synthesis and applications. Increasing our understanding of the ecological functioning of marine habitats created by urban infrastructure and incorporating ecological criteria into coastal engineering are crucial for preserving biodiversity in the face of the growth of human populations in coastal areas and of forecasted global changes. Achieving this goal will need strong collaboration between engineers, managers and ecologists.

Cordell, J. R., Toft, J. D., Munsch, S. H., & Goff, M. (2017). Benches, Beaches, and Bumps: How Habitat Monitoring and Experimental Science Can Inform Urban Seawall Design. In *Living Shorelines: The Science and Management of Nature-Based Coastal Protection.* D. M. Bilkovic, M. M. Mitchell, M. K. La Peyre, & J. D. Toft (Eds.), (pp. 421-438). New York: CRC Press Retrieved from https://www.taylorfrancis.com/chapters/edit/10.1201/9781315151465-25/benches-beaches-bumps-jeffery-cordell-jason-toft-stuart-munsch-maureen-goff

This chapter reviews habitat impacts of seawalls and how these impacts can be mitigated and present a case study of Seattle's seawall habitat improvements. It indicates that benches, beaches, and "bumps" added to Seattle's seawall can have beneficial effects. The ecology of intertidal areas is driven by the physical environment, which is modified by shoreline armoring. Important differences between seawalls and natural rocky intertidal shorelines include habitat heterogeneity and complexity that tend to be lacking on seawalls. When the Seattle Art Museum's Olympic Sculpture Park opened in 2007, it included two major enhancements intended to benefit juvenile salmon: a ~290-m-long habitat bench projecting from the base of the seawall with sediment simulating more natural conditions than those found along most of Seattle's waterfront and a ~100-m-long pocket beach excavated from a stretch of riprap-armored shoreline and surfaced with pebbles and cobbles. Habitat improvements along extremely urbanized shorelines are obviously constrained by human uses and the infrastructure needs of a city.

Crooks, J. A., Chang, A. L., & Ruiz, G. M. (2010). Aquatic pollution increases the relative success of invasive species. *Biological Invasions,* 13(1), 165-176. https://doi.org/10.1007/s10530-010-9799-3

Although individual ecosystems vary greatly in the degree to which they have been invaded by exotic species, it has remained difficult to isolate mechanisms influencing invader success. One largely anecdotal observation is that polluted or degraded areas will accumulate more invaders than less-impacted sites. However, the role of abiotic factors alone in influencing invisibility has been difficult to isolate, often because the supply of potential invaders is confounded with conditions thought to increase vulnerability to invasion. Here, we conducted a field experiment to test how the assemblages of exotic versus native marine invertebrates changed during community assembly under different exposure levels of a common pollutant, copper. The experiment was conducted by deploying fouling panels in a Randomized Block Design in San Francisco Bay. Panels were periodically removed, placed into buckets with differing copper concentrations, and returned to the field after 3 days. This design allowed propagule availability to the plates to be statistically independent of short-term copper exposure. The results demonstrate that copper caused significant differences in community structure. Average native species richness was significantly affected by copper exposure, but average exotic richness was not. The total native species pool within treatments exhibited a greater than 40% decline within increasing copper, while the exotic species pool did not change significantly. These results confirm that anthropogenic alteration of abiotic factors influences invader success, indicating that management strategies to reduce invader impacts should include both efforts to improve environmental conditions as well as reduce invader supply.

Dethier, M. N., Raymond, W. W., McBride, A. N., Toft, J. D., Cordell, J. R., Ogston, A. S., . . . Berry, H. D. (2016). Multiscale impacts of armoring on Salish Sea shorelines: Evidence for cumulative and threshold effects. *Estuarine Coastal and Shelf Science,* 175, 106-117. https://doi.org/10.1016/j.ecss.2016.03.033

Shoreline armoring is widespread in many parts of the protected inland waters of the Pacific Northwest, U.S.A., but impacts on physical and biological features of local nearshore ecosystems have only recently begun to be documented. Armoring marine shorelines can alter natural processes at multiple spatial and temporal scales; some, such as starving the beach of sediments by blocking input from upland bluffs may take decades to become visible, while others such as placement loss of armoring construction are immediate. We quantified a range of geomorphic and biological parameters at paired, nearby armored and unarmored beaches throughout the inland waters of Washington State to test what conditions and parameters are associated with armoring. We gathered identical datasets at a total of 65 pairs of beaches: 6 in South Puget Sound, 23 in Central Puget Sound, and 36 pairs North of Puget Sound proper. At this broad scale, demonstrating differences attributable to armoring is challenging given the high natural variability in measured parameters among beaches and regions. However, we found that armoring was consistently associated with reductions in beach width, riparian vegetation, numbers of accumulated logs, and amounts and types of beach wrack and associated invertebrates. Armoring-related patterns at lower beach elevations (further vertically from armoring) were progressively harder to detect. For some parameters, such as accumulated logs, there was a distinct threshold in armoring elevation that was associated with increased impacts. This large dataset for the first time allowed us to identify cumulative impacts that appear when increasing proportions of shorelines are armored. At large spatial and temporal scales, armoring much of a sediment drift cell may result in reduction of the finer grain-size fractions on beaches, including those used by spawning forage fish. Overall we have shown that local impacts of shoreline armoring can scale-up to have cumulative and threshold effects - these should be considered when managing impacts to public resources along the coast.

Deudero, S. (2016, 2016). *CIESM Congress Session: Marine artificial habitats.* Paper presented at the 41st CIESM Congress Proceedings, Monte Carlo. Retrieved from http://ciesm.org/online/archives/abstracts/pdf/41/CIESM_Congress_Volume_41.pdf

Moderator's Synthesis is the following: There is a worldwide increase in adding new artificial structure and substrates linked to a wide array of human activities ranging from aquaculture, energy derived structures (gas and oil platforms, offshore wind parks), coastal urbanization and recreational activities, maritime activities (harbors, marine litter…) The session contributions covered mostly the artificial approach of increasing biomass of fishes gathered by attraction towards new substrates. The concept of mimicking the natural substrates, either in size and materials was presented as promising management units that can minimize impacts of artificial habitats related with diving activities and eco-tourism in Crete (contribution from Doumas et al.). Evaluating spatial and temporal aggregations of fishes around gas platforms is more effectively performed by a combination of methodologies: underwater visual census, camera records and hydroacustics (contribution from Gaetani et al). In the same regard, fish community structure reveals changes in fish abundance and size around the largest artificial reefs of the Mediterranean (contribution from Ozgul & Lok). Similarly, analysing the home range and movement patterns of resident species (*Scorpaena scrofa* and *S. porcus*) can be achieved with fine-scale radiotracking (contribution from Ozgul & Lok). Future concerns deal with jumping from the traditional 'fisheries approach' (i.e. artificial reefs, fish aggregation devices FADS…) towards innovative approaches

such as the design of eco-structures, biofoulings, regulations of dumping at sea, materials for foundations and artificial structures, marine litter as a new substrate, along with the consideration of accumulative effects. Several questions arose in the debate, especially with regard to selection criteria for habitat deployment, habitat restoration with artificial reefs, links with conservation and along with recruitment processes linked to marine corridors, stepping stones and marine litter.

Doi, H., Chang, K. H., Ando, T., Imai, H., & Nakano, S. (2010). Shoreline bank construction modifies benthic-pelagic coupling of food webs. *Ecological Engineering,* 36(4), 601-604. https://doi.org/10.1016/j.ecoleng.2009.12.017

Management of the food web is important in maintaining ecosystem functions: however, the studies to assess anthropogenic impact on food web structures are very limited. Recently, shoreline development is considered to impact the littoral zone of lakes through loss of littoral habitats. Shoreline engineering would consequently modify the food web structure and coupling between benthic and pelagic habitats. Thus, we investigated whether lakeshore modification would change benthic-pelagic coupling by large-mouth bass in 15 ponds, which differed in the proportion of concrete bank modification. We performed isotope mixing models to estimate benthic contribution to the fish species and tested the relationships with environmental factors including proportion of bank modification by general linear models. These results showed that the benthic contribution to largemouth bass was strongly related to the proportion of anthropogenic shoreline modification, while for bluegill sunfish, the benthic contribution was not changed with anthropogenic shoreline modification. Therefore, anthropogenic modification of shoreline strongly modified the food webs in ponds through the littoral habitat modification. The results suggested that we should pay attention to the anthropogenic impact on food web structures to maintain ecosystems.

Dumont, C. P., Harris, L. G., & Gaymer, C. F. (2011). Anthropogenic structures as a spatial refuge from predation for the invasive bryozoan *Bugula neritina*. *Marine Ecology Progress Series,* 427, 95-103. https://doi.org/10.3354/meps09040

Anthropogenic structures may play an important role in the marine invasion process by providing novel artificial habitats, often out of the reach of common benthic predators. A survey of piers in northern-central Chile revealed a change in the epibenthic assemblage on pilings at different distances from a rocky shore with abundant grazers and predators. Pilings on soft sediment, away from the rocky shore, were heavily colonized by the invasive bryozoan *Bugula neritina*. We therefore hypothesized that benthic predators may forage on pilings located on rocky bottom whereas pilings on soft sediment benefit from the absence of generalist benthic predators which do not occur on soft sediment. We examined piling communities using cages directly attached to pilings, where we included or excluded the sea urchin *Tetrapygus niger* and the rock shrimp *Rhyncocinetes typus*. Resultant communities differed substantially; a high percentage of bare space occurred in the presence of sea urchins, while turf algae dominated in the presence of shrimp. Both sea urchins and shrimp suppressed the colonization of the invasive *B. neritina* and, when acting together, totally prevented its recruitment. In contrast, invasive bryozoans colonized 95% of the available substratum in cages where predators were excluded. Our results show the important role of benthic generalist predators in limiting the

establishment and spread of non-native species on anthropogenic structures. Further, this study highlights the unprecedented role of shrimp grazing in structuring hard-bottom communities.

Ehinger, S., Abernathy, L., Bhuthimethee, M., Corum, L., Price, D., & Quan, J. *Puget Sound Nearshore "Conservation Calculator" User Guide.* National Marine Fisheries Service, Retrieved from http://media.fisheries.noaa.gov.s3.amazonaws.com/2020-11/Calculator%20User%20Guide%2011-17-20%20V1_jmc.pdf

This "conservation calculator" is a user-friendly tool that simplifies the complex application of the Habitat Equivalency Analysis (HEA) and Nearshore Habitat Values Model (NHVM). The goal of the conservation calculator is to quantify the habitat impacts from a proposed re-development/development projects and the habitat benefits from restoration projects in terms of a common habitat currency.

Elizabeth Alter, S., Tariq, L., Creed, J. K., & Megafu, E. (2021). Evolutionary responses of marine organisms to urbanized seascapes. *Evolutionary Applications,* 14(1), 210-232. https://doi.org/10.1111/eva.13048

Many of the world's major cities are located in coastal zones, resulting in urban and industrial impacts on adjacent marine ecosystems. These pressures, which include pollutants, sewage, runoff and debris, temperature increases, hardened shorelines/structures, and light and acoustic pollution, have resulted in new evolutionary landscapes for coastal marine organisms. Marine environmental changes influenced by urbanization may create new selective regimes or may influence neutral evolution via impacts on gene flow or partitioning of genetic diversity across seascapes. While some urban selective pressures, such as hardened surfaces, are similar to those experienced by terrestrial species, others, such as oxidative stress, are specific to aquatic environments. Moreover, spatial and temporal scales of evolutionary responses may differ in the ocean due to the spatial extent of selective pressures and greater capacity for dispersal/gene flow. Here, we present a conceptual framework and synthesis of current research on evolutionary responses of marine organisms to urban pressures. We review urban impacts on genetic diversity and gene flow and examine evidence that marine species are adapting, or are predicted to adapt, to urbanization over rapid evolutionary time frames. Our findings indicate that in the majority of studies, urban stressors are correlated with reduced genetic diversity. Genetic structure is often increased in urbanized settings, but artificial structures can also act as stepping stones for some hard-surface specialists, promoting range expansion. Most evidence for rapid adaptation to urban stressors comes from studies of heritable tolerance to pollutants in a relatively small number of species; however, the majority of marine ecotoxicology studies do not test directly for heritability. Finally, we highlight current gaps in our understanding of evolutionary processes in marine urban environments and present a framework for future research to address these gaps.

Gianni, F., Bartolini, F., Airoldi, L., & Mangialajo, L. (2018). Reduction of herbivorous fish pressure can facilitate focal algal species forestation on artificial structures. *Marine Environmental Research,* 138, 102-109. https://doi.org/10.1016/j.marenvres.2018.04.007

Coastal areas have been transformed worldwide by urbanization, so that artificial structures are now widespread. Current coastal development locally depletes many native marine species, while offering limited possibilities for their expansion. Eco-engineering interventions intend to identify ways to facilitate the presence of focal species and their associated functions on artificial habitats. An important but overlooked factor controlling restoration operations is overgrazing by herbivores. The aim of this study was to quantify the effects of different potential feeders on *Cystoseira amentacea*, a native canopy-forming alga of the Mediterranean infralittoral fringe, and test whether manipulation of grazing pressure can facilitate the human-guided installation of this focal species on coastal structures. Results of laboratory tests and field experiments revealed that Sarpa salpa, the only strictly native herbivorous fish in the Western Mediterranean Sea, can be a very effective grazer of *C. amentacea* in artificial habitats, up to as far as the infralittoral fringe, which is generally considered less accessible to fishes. *S. salpa* can limit the success of forestation operations in artificial novel habitats, causing up to 90% of *Cystoseira* loss after a few days. Other grazers, such as limpets and crabs, had only a moderate impact. Future engineering operations,intended to perform forestation of canopy-forming algae on artificial structures, should consider relevant biotic factors, such as fish overgrazing, identifying cost-effective techniques to limit their impact, as is the usual practice in restoration programmes on land.

Gladstone, W., & Courtenay, G. (2014). Impacts of docks on seagrass and effects of management practices to ameliorate these impacts. *Estuarine Coastal and Shelf Science,* 136, 53-60. https://doi.org/10.1016/j.ecss.2013.10.023

Seagrasses have high conservation and human-use values, but around the world they are being damaged by human activities. Compared to the larger spatial scale at which some human activities affect estuaries and their seagrasses (e.g. catchment disturbance, dredging, pollution, trawling), recreational boating and infrastructure of moorings and docks act at smaller scales. However, the cumulative effects contribute to stresses acting on seagrass beds. This study assessed the effects of docks on the native seagrass *Zostera muelleri subsp. capricorni* in an estuary in south-east Australia and of current management practices designed to reduce dock impacts on this seagrass. A field survey found that seagrass biomass was significantly reduced below docks, and the effects were not influenced by dock orientation. Management practices requiring the use of a mesh decking to provide greater light penetration reduced, but did not eliminate, the reduction in seagrass biomass caused by docks. A modified beyond BACI experiment provided evidence for a causal link between the installation of wooden or mesh docks and reductions in biomass of seagrass. The reduction in biomass was apparent 6 mo after dock installation, and by 26 mo seagrass biomass had declined by at least 90%. Faced with increasing coastal populations, increases in recreational use, and continued pressures from other human activities, alternative management practices that further minimize the effects of docks are needed.

Grothues, T. M., & Able, K. W. (2020). Shoreline infrastructure degradation and increasing littoral naturalization accommodates juvenile fish and crab assemblages in heavily urbanized Upper New York Harbor. *Restoration Ecology,* 28(4), 947-959. https://doi.org/10.1111/rec.13163

Many estuarine shorelines are influenced by urbanization. Extensive shoreline modification in Upper New York Harbor (UNYH) included port development, landfilling marshes, and armoring. Recent sedimentation in constructed shipping terminal embayments, abandonment of shoreline structure maintenance, subsequent recruitment of upland and intertidal vegetation, and restoration projects have naturalized some shorelines in this urban setting. We determined the species composition and relative abundance of fishes and crabs in shallow shoreline habitats in constructed embayments of UNYH with seine sampling to determine the potential for restoring similar isolated shallow water sites as functional habitats. Twenty-seven identified species of fishes and crabs, including seasonally transient and resident marsh species, were represented in samples dominated by *Menidia menidia*, but marsh resident and coastal ocean species were also periodically abundant. Differences in assemblage structure among the sampled embayments as measured by principal components analysis were weak despite some differences in the slope and colonization of vegetation along shorelines. The mere presence of shallow shorelines was sufficient to recruit numerous species. Assemblage differences relative to a nearby relatively unaltered estuary revealed a lack of southern, warm affiliated species reflecting a natural clinal gradient. Marsh resident species dominated in UNYH, but not as strongly as at the reference estuary. Together with a previously published evaluation of life cycle connectivity for several sentinel species, this study shows that even small, isolated projects seeking to restore shallow shorelines add value to the estuarine landscape and are worth pursuing.

Grothues, T. M., Rackovan, J. L., & Able, K. W. (2016). Modification of nektonic fish distribution by piers and pile fields in an urban estuary. *Journal of Experimental Marine Biology and Ecology,* 485, 47-56. https://doi.org/10.1016/j.jembe.2016.08.004

Large urban piers degrade habitat value for several estuarine benthic fish species by shading, but their effects on mobile nektonic species is less well understood due to sampling challenges. Dual Frequency Identification Sonar (DIDSON) allowed equal access to sampling in the water column of structured shaded and unshaded vs. open environments in both dark and light conditions by methods similar to video but without light. Sampling (n = 228, 5-min transects) occurred under and around four large municipal piers of varying dimensions in the Hudson River estuary during day and night from summer and fall in 2007-2009. The distribution of small (5-25 cm in length) and large (25-850 cm) fishes were analyzed separately in recognition of functional guild differences. Small fishes occupied open water, shaded under-pier, and un-decked relict piling habitats, but were significantly more abundant during the day in open unshaded water than under adjacent piers or in piling habitats. Small fish occurred under 3 of 4 piers of varying size and configuration at 10-20% of the median abundances of adjacent open water. However, while schools were rare under piers they could be very large, so that abundance greatly exceeded mean open water abundance variance so as to preclude confidence in differences among piers. The differences among habitats were not significant at night, and the difference among piers was also not significant at night. School membership for small fish appeared to mitigate adverse effects of shading and may influence scaling of their response to shading and could therefore influence pier design. Large (>25 cm) predatory fish were uncommon but responded similarly to habitat effects as did small fish. Habitats did not segregate fish by guild as small forage fish co-occurred in 65.8% of samples with large piscivores. Studies that provide species-specific and mechanistic interpretation of dynamic

habitat use as well as further quantification of scaling effects could improve our understanding of how fishes respond to piers and other structures on urban shorelines.

Hammond, M., Bond, T., Prince, J., Hovey, R. K., & McLean, D. L. (2020). An assessment of change to fish and benthic communities following installation of an artificial reef. *Regional Studies in Marine Science,* 39, 101408-. https://doi.org/10.1016/j.rsma.2020.101408

Artificial reefs are frequently installed to provide additional habitat that enhances recreational activities such as diving and fishing. This study assessed changes to habitats, macroinvertebrates and fish after installation of an artificial reef, deployed to influence the marine community and create a more appealing dive trial at Port Coogee, Western Australia. This was achieved by comparing the communities at three control sites to the impact site (artificial reef) before installation and at increased time intervals after installation (3, 11 and 20 months). Across the sampling period and at the impacted site the cover of brown turfing algae increased significantly by 87%. Relative to previous monitoring 18 new species of macroinvertebrate and on average 138 more individuals were detected during post reef surveys. Both the species richness and abundance of fish tended to increase at all sites over the duration of the survey. Although this result was not significant, the final sampling period detected 14 more species and on average 31 more individuals than the previous sampling period. The colonisation of these structures and the progression of the marine community at this site provides valuable insight into the potential function of engineered artificial reefs.

Heerhartz, S. M., & Toft, J. D. (2015). Movement patterns and feeding behavior of juvenile salmon (*Oncorhynchus spp.*) along armored and unarmored estuarine shorelines. *Environmental Biology of Fishes,* 98(6), 1501-1511. https://doi.org/10.1007/s10641-015-0377-5

Estuarine nearshore environments are important habitats for many organisms, including juveniles of several Pacific salmon species (*Oncorhynchus spp.*). These habitats provide shallow water and high prey productivity, but are increasingly modified by anthropogenic activity including shoreline armoring, which disrupts connectivity between aquatic and terrestrial realms and artificially steepens the shore. Such effects may have adverse consequences for juvenile salmon, particularly Chinook (*O. tshawytscha*) and chum (*O. nerka*), which are known to rely on shallow, productive nearshore habitats for foraging and refuge from predators during their outmigration from natal streams to the sea. We developed snorkel methods to quantify feeding rates, movement rates, and path complexity of juvenile salmon along armored and unarmored shorelines in Puget Sound, WA, USA. We found that juvenile salmon had relatively high feeding rates along all shoreline types, but that path straightness and movement rates showed some variation between armored and unarmored sites. Feeding fish swam in more complex paths and were observed in larger schools than non-feeding fish, and path straightness and movement rate were negatively correlated with proportion of time feeding. Feeding behavior, school size, and movement rates also showed variation by species. Shoreline type (armored or unarmored) influenced juvenile salmon distribution, and unarmored shorelines appear to accommodate a greater diversity of movement patterns than armored shorelines. Our results show that juvenile salmon feed at high rates along armored and unarmored estuarine shorelines, thus decreased prey availability or altered prey resources are likely the most detrimental foraging effects of armoring in estuarine nearshore ecosystems.

Heerhartz, S. M., Toft, J. D., Cordell, J. R., Dethier, M. N., & Ogston, A. S. (2015). Shoreline Armoring in an Estuary Constrains Wrack-Associated Invertebrate Communities. *Estuaries and Coasts,* 39(1), 171-188. https://doi.org/10.1007/s12237-015-9983-x

Beach wrack is an organic subsidy that supports high intertidal and supralittoral invertebrate communities in many coastal systems. Beaches fringed with riparian vegetation accumulate wrack from both terrestrial leaf litter and marine algae/seagrasses, forming a reciprocal connection. Previous research has shown that shoreline armoring disrupts this marine-terrestrial connection and alters the amount and composition of beach wrack. We sampled invertebrates associated with beach wrack at 29 paired armored and unarmored beaches in Puget Sound, WA and conducted wrack decomposition experiments. Armored beaches had significantly fewer invertebrates as well as different assemblages. Unarmored assemblages were characterized by talitrid amphipods and dipteran and coleopteran insects (flies and beetles), and were correlated with the amount of beach wrack and logs, the proportion of terrestrial material in the wrack, and the maximum elevation of the beach. Experiments showed that talitrid amphipods and oligochaete worms were positively correlated with wrack decomposition rates. The substantial reduction in high-shore invertebrates at armored beaches represents a decrease in subsidies to secondary consumers in both adjacent terrestrial and nearshore ecosystems. These armoring effects may thus cascade, via altered food webs, to organisms in other environments. Our sampling of multiple armored-unarmored beach pairs allowed us to control for variability of many environmental parameters, improving our ability to identify armoring-related differences, and greatly expanding the scale of inference of previous studies showing the negative effects of armoring on beach fauna.

Heery, E. C., Dafforn, K. A., Smith, J. A., Ushiama, S., & Mayer-Pinto, M. (2018). Not all artificial structures are created equal: Pilings linked to greater ecological and environmental change in sediment communities than seawalls. *Marine Environmental Research,* 142, 286-294. https://doi.org/10.1016/j.marenvres.2018.08.012

Artificial structures are agents of change in marine ecosystems. They add novel habitat for hard-substrate organisms and modify the surrounding environment. Most research to date has focused on the communities living directly on artificial structures, and more research is needed on the potential impacts these structures have on nearby communities and the surrounding environment. We compared the sedimentary habitat surrounding two types of artificial structures (pilings and seawalls) to sediments adjacent to rocky reefs using a combination of traditional sediment analyses, stable isotope analysis, and environmental DNA. Artificial and natural shore sediments were best differentiated by sediment variables strongly associated with flow speed. Pilings sediments had significantly finer grain size, higher organic content, and generally lower C:N ratios than sediments adjacent to the other habitat types, suggesting flow is reduced by pilings. Sedimentary assemblages near pilings were also consistent with those predicted under low-flow conditions, with elevated bacterial colonization and increased relative abundances of small deposit feeders compared with other habitat types. Additionally, lumbrinerid polychaetes in pilings sediments had reduced delta(15)N values, suggesting different detrital resources and fewer trophic linkages compared with lumbrinerids in other habitats. Woody detritus was greater adjacent to seawalls than to natural rocky shores or pilings. Our findings suggest that artificial structures have the potential to influence adjacent soft sediments through changes to sediment properties that affect infaunal and microbial communities, as well as trophic linkages for some consumers. We hypothesize that this is due to a combination of altered flow, differing detrital subsidies, and differing

adjacent land-use among habitat types. Managers should consider the potential for changed sediment properties and ecology when deciding where to build different types of artificial structures. Further manipulative experiments are needed to understand mechanisms of change and help manage the impacts of artificial structures on the seafloor.

Heery, E. C., Oh, R. K. E., Taira, D., Ng, D., Chim, C. K., Hartanto, R. S., . . . Todd, P. A. (2020). Human-engineered hydrodynamic regimes as a driver of cryptic microinvertebrate assemblages on urban artificial shorelines. *Science of the Total Environment,* 725, 138348. https://doi.org/10.1016/j.scitotenv.2020.138348

Urban shorelines undergo substantial hydrodynamic changes as a result of coastal engineering and shoreline armouring that can alter sedimentation, turbidity, and other factors. These changes often coincide with major shifts in the composition and distribution of marine biota, however, rarely are hydrodynamic-mediated factors confirmed experimentally as the mechanism underpinning these shifts. This study first characterized hydrodynamic-related distribution patterns among epilithic and epiphytic microinvertebrates on urban seawalls in Singapore. We found reduced microinvertebrate abundances and distinct microinvertebrate community structure within benthic turf algae in areas where coastal defences had reduced wave energy and increased sediment deposition, among other hydrodynamic-related abiotic changes. Low-exposure areas also had reduced densities of macroinvertebrate grazers and less dense turf algae (lower mass per cm(2)) than adjacent high-exposure areas. Using harpacticoid copepods as a model taxon, we performed a reciprocal transplant experiment to discern between the effects of exposure-related conditions and grazing. Results from the experiment indicate that conditions associated with restricted wave energy from shoreline engineering limit harpacticoid population densities, as transplantation to low-exposure areas led to rapid reductions in abundance. At the same time, we found no effect from grazer exclusion cages, suggesting harpacticoids are minimally impacted by exposure-related gradients in gastropod macrograzer densities over short time scales. Given the key role of intertidal microinvertebrates, particularly harpacticoids, in nearshore food webs, we postulate that human-engineered hydrodynamic regimes are an important factor shaping marine ecosystem functioning in urban areas.

Henderson, C. J., Gilby, B. L., Schlacher, T. A., Connolly, R. M., Sheaves, M., Maxwell, P. S., . . . Olds, A. D. (2019). Landscape transformation alters functional diversity in coastal seascapes. *Ecography,* 43(1), 138-148. https://doi.org/10.1111/ecog.04504

The ecological impacts of landscape modification and urbanisation have transformed the composition of plant and animal assemblages, and altered the condition of ecosystems globally. Landscape transformation influences the spatial distribution of species and ecological functions by selecting for generalist species with wide ecological niches, which can adapt to opportunities in highly-modified environments. These effects of landscape modification can shape functional diversity on land, but it is not clear whether they have similar functional consequences in the sea. We used estuaries as a model system to test how landscape transformation alters functional diversity in coastal seascapes, and measured how variation in level of urbanisation, catchment modification and habitat loss influenced fish diversity across thirty-nine estuaries in eastern Australia. Fish were surveyed with baited remote underwater video stations and functional diversity was indexed with three metrics that describe

variation in the functional traits and niche space of assemblages. The extent of landscape transformation in the catchment of each estuary was associated with variation in the functional diversity of estuarine fish assemblages. These effects were, however, not what we expected as functional diversity was highest in modified estuaries that supported a large area of both urban and grazing land in their catchments, were bordered by a small area of natural terrestrial vegetation and that contained a moderate area of mangroves. Zoobenthivores and omnivores dominated assemblages in highly-modified estuaries, and piscivorous fishes were common in natural waterways. Our results demonstrate, that the modification and urbanisation of ecosystems on land can alter functional diversity in the sea. Intense landscape transformation appears to select for abundant generalists with wide trophic niches, and against species with specialised diets, and we suggest that these changes might have fundamental consequences for ecosystem functioning in estuaries, and other highly modified seascapes.

Iacarella, J. C., Adamczyk, E., Bowen, D., Chalifour, L., Eger, A., Heath, W., . . . Baum, J. K. (2018). Anthropogenic disturbance homogenizes seagrass fish communities. *Global Change Biology,* 24(5), 1904-1918. https://doi.org/10.1111/gcb.14090

Anthropogenic activities have led to the biotic homogenization of many ecological communities, yet in coastal systems this phenomenon remains understudied. In particular, activities that locally affect marine habitat-forming foundation species may perturb habitat and promote species with generalist, opportunistic traits, in turn affecting spatial patterns of biodiversity. Here, we quantified fish diversity in seagrass communities across 89 sites spanning 6° latitude along the Pacific coast of Canada, to test the hypothesis that anthropogenic disturbances homogenize (i.e., lower beta-diversity) assemblages within coastal ecosystems. We test for patterns of biotic homogenization at sites within different anthropogenic disturbance categories (low, medium, and high) at two spatial scales (within and across regions) using both abundance- and incidence-based beta-diversity metrics. Our models provide clear evidence that fish communities in high anthropogenic disturbance seagrass areas are homogenized relative to those in low disturbance areas. These results were consistent across within-region comparisons using abundance- and incidence-based measures of beta-diversity, and in across-region comparisons using incidence-based measures. Physical and biotic characteristics of seagrass meadows also influenced fish beta-diversity. Biotic habitat characteristics including seagrass biomass and shoot density were more differentiated among high disturbance sites, potentially indicative of a perturbed environment. Indicator species and trait analyses revealed fishes associated with low disturbance sites had characteristics including stenotopy, lower swimming ability, and egg guarding behavior. Our study is the first to show biotic homogenization of fishes across seagrass meadows within areas of relatively high human impact. These results support the importance of targeting conservation efforts in low anthropogenic disturbance areas across land- and seascapes, as well as managing anthropogenic impacts in high activity areas.

Komoroske, L. M., Lewison, R. L., Seminoff, J. A., Deheyn, D. D., & Dutton, P. H. (2011). Pollutants and the health of green sea turtles resident to an urbanized estuary in San Diego, CA. *Chemosphere,* 84(5), 544-552. https://doi.org/10.1016/j.chemosphere.2011.04.023

Rapid expansion of coastal anthropogenic development means that critical foraging and developmental habitats often occur near highly polluted and urbanized environments. Although coastal contamination is widespread, the impact this has on long-lived vertebrates like the green turtle (*Chelonia mydas*) is unclear because traditional experimental methods cannot be applied. We coupled minimally invasive sampling techniques with health assessments to quantify contaminant patterns in a population of green turtles resident to San Diego Bay, CA, a highly urbanized and contaminated estuary. Several chemicals were correlated with turtle size, suggesting possible differences in physiological processes or habitat utilization between life stages. With the exception of mercury, higher concentrations of carapace metals as well as 4,4'-dichlorodiphenyldichloroethylene (DDE) and gamma chlordane in blood plasma relative to other sea turtle studies raises important questions about the chemical risks to turtles resident to San Diego Bay. Mercury concentrations exceeded immune function no-effects thresholds and increased carapace metal loads were correlated with higher levels of multiple health markers. These results indicate immunological and physiological effects studies are needed in this population. Our results give insight into the potential conservation risk contaminants pose to sea turtles inhabiting this contaminated coastal habitat, and highlight the need to better manage and mitigate contaminant exposure in San Diego Bay.

Lawless, A. S., & Seitz, R. D. (2014). Effects of shoreline stabilization and environmental variables on benthic infaunal communities in the Lynnhaven River System of Chesapeake Bay. *Journal of Experimental Marine Biology and Ecology,* 457, 41-50. https://doi.org/10.1016/j.jembe.2014.03.010

Coastlines worldwide are being altered due to shoreline hardening and stabilization and while highly altered systems are subject to change, variability exists in how shoreline hardening affects benthic communities depending on the landscape features of the system and regional production. Oyster reefs have been used to stabilize shorelines and offer a potentially positive effect on shoreline communities. In a field survey, we used 29 sites throughout the Lynnhaven River System, a highly developed yet productive subestuary of Chesapeake Bay, to determine effects of shoreline type (natural marsh, oyster shell reef, rip-rap, and bulkhead), sediment characteristics (grain size and total organic carbon and total nitrogen), and predators on benthic infaunal density, biomass, and diversity. An information-theoretic approach was used to determine which of several hypothesized Generalized Linear Models were supported by the data. Shoreline type was the best predictor of benthic infaunal density, with oyster reefs having the highest benthic density and bulkhead the lowest. In contrast, sediment characteristics and predators were the best predictors of benthic infaunal biomass and diversity. The Lynnhaven system is shallow (similar to 2.5 m), and nearly 78% of the shoreline is natural marsh, which promotes high regional benthic productivity that may mask small-scale effects of shoreline stabilization on infauna. Our findings contrast with previous studies in moderately productive systems where altered shorelines had substantial direct effects on the benthos, suggesting that further studies need to take place across various systems among a range of upland usages to help clarify the impact of local shoreline stabilization versus regional watershed usage on benthic communities. Our results highlight that high ecosystem productivity is important for resilience to local shoreline modification.

Lewis, D. M., Troast, B. V., Glomb, J. C., & Cook, G. S. (2020). An Ecological Characterization of Fish Assemblages in Mosquito Lagoon, Florida. *Southeastern Naturalist,* 19(3), 491-510. https://doi.org/10.1656/058.019.0306

Coastal marine ecosystems are increasingly threatened by urbanization, land- based sources of pollution, and climate change. Changes in the environment due to these pressures could lead to shifts in community composition and dynamics. To address this issue, we sampled the fish assemblage of a coastal lagoon to assess species richness, rates of occurrence, and relative abundance. We caught 176,136 individuals representing 87 taxa. We compared our results to the last published survey of the study area conducted during the mid-1990s. Compared to historic data, there have been large shifts in percent occurrence in some economically important taxa, such as *Lagodon rhomboides* (Pinfish) increasing from 4% to 53% and *Anchoa spp.* (anchovies) increasing from 23% to 66%. These findings possibly indicate changes in the fish assemblage, essential fish habitat, or environment over the past 2 decades. As environmental and anthropogenic stressors continue to impact this complex coastal ecosystem, continued monitoring will be critical to detecting and understanding changes in the fish community in Mosquito Lagoon.

Mayer-Pinto, M., Johnston, E. L., Hutchings, P. A., Marzinelli, E. M., Ahyong, S. T., Birch, G., . . . Hedge, L. H. (2015). Sydney Harbour: a review of anthropogenic impacts on the biodiversity and ecosystem function of one of the world's largest natural harbours. *Marine and Freshwater Research,* 66(12), 1088-1105. https://doi.org/10.1071/Mf15157

Sydney Harbour is a hotspot for diversity. However, as with estuaries worldwide, its diversity and functioning faces increasing threats from urbanisation. This is the first synthesis of threats and impacts in Sydney Harbour. In total 200 studies were reviewed: 109 focussed on contamination, 58 on habitat modification, 11 addressed non-indigenous species (NIS) and eight investigated fisheries. Metal concentrations in sediments and seaweeds are among the highest recorded worldwide and organic contamination can also be high. Contamination is associated with increased abundances of opportunistic species, and changes in benthic community structure. The Harbour is also heavily invaded, but invaders' ecological and economic impacts are poorly quantified. Communities within Sydney Harbour are significantly affected by extensive physical modification, with artificial structures supporting more NIS and lower diversity than their natural equivalents. We know little about the effects of fishing on the Harbour's ecology, and although ocean warming along Sydney is among the fastest in the world, we know little about how the ecosystem will respond to warming. The interactive and cumulative effects of stressors on ecosystem functioning and services in the Harbour are largely unknown. Sustainable management of this iconic natural system requires that knowledge gaps are addressed and translated into coherent environmental plans.

McLaughlin, S. M., Leight, A. K., Bricker, S. B., Jacobs, J. M., Messick, G. A., Skelley, S., & Spires, J. E. (2018). *Coastal Ecological Assessment to Support NOAA's Choptank River Complex Habitat Focus Area: Tred Avon River*. NOAA Technical Memorandum NOS NCCOS 251 Oxford, MD https://doi.org/10.25923/k2xr-5n27

The Chesapeake Bay is the largest estuary in the United States with a total of 18,804 kilometers (11,684 miles) of shoreline along the main stem and its tributaries (CBP 2018a). The ecology of the Chesapeake Bay and its watershed are national treasures and provide environmental, economic, social, cultural, recreational, and historical value. The condition of the Chesapeake Bay, however, has degraded over time due to ever increasing pressures of population growth and land development. The conversion of forests and wetlands into agricultural and urban lands and the loss of underwater vegetation has contributed to increased sediment loading and nutrient pollution and to shifts in marine resource harvests and other important ecosystem services. Degradation of the structure and function of the Chesapeake Bay aquatic ecosystem from human actions reduces the Bay's resiliency. The watershed's citizens, county planners, and state managers face major challenges in their efforts to balance land use planning decisions and conservation priorities. In 2014, the Choptank River complex was designated a NOAA Habitat Focus Area (HFA) to serve as a catalyst for the integration of conservation activities related to habitat restoration, science and monitoring, and community engagement in this key watershed of the Chesapeake Bay. The Choptank River complex provides food and critical habitat such as wetlands, oyster reefs, and freshwater streams for many Chesapeake Bay species including commercially important striped bass, blue crabs, and oysters. It supplies valuable seafood and supports agriculture as well as recreational fishing, boating, hunting, and other activities. Continued human population growth and land development has put pressure on the watershed and threatens key habitats for fish and aquatic resources. The location of historic oyster beds in the Choptank watershed led to their designation as protected oyster sanctuaries and the target of reef restoration activities by state and federal partners. In this assessment, we analyzed the impacts of land use on the condition of the aquatic ecosystem in the Tred Avon River, an important tributary of the Choptank River, over the period 2015–2017. The Tred Avon River is a good example of a watershed where multiple types of land use are competing for space and where urbanization is slowly replacing farm fields and forests. This watershed is representative of different land uses, with relatively high development at the headwaters near Easton and at the mouth near the Town of Oxford, as well as agriculture and undeveloped land along the shorelines extending between. Results from our earlier ecological assessments, in which comparisons were made among river systems dominated by a particular land use (agriculture, urban, mixed forest), indicate the signals from land use impacts are stronger upstream than downstream (Leight et al. 2014, 2015). Thus, our approach to the Tred Avon River ecological assessment was targeted to tidal waters in eight selected sub-watersheds representing different dominant land uses. The condition of each of the eight selected sub-watersheds in the Tred Avon River was assessed using a suite of indicators including water quality, benthic habitat condition, benthic community condition, fish community composition, contaminants, and fish health. In our analysis of information collected, we looked for similarities between the conditions found and potential influencing factors such as land use. Overall, our study shows that the Tred Avon River is a tributary in relatively good condition compared to other areas of the Choptank River and the larger Chesapeake Bay. Similarly, the 2017 ShoreRivers Chesapeake Bay report card for the Tred Avon River, based primarily on samples collected in the main stem of the river, is also positive (ShoreRivers 2018). Nevertheless, there are signs of ecosystem degradation in areas affected by rapid growth and development in the region and thus efforts to protect and conserve critical fish habitat and spawning areas must remain a priority. Results show that each of the eight selected sub-watersheds of the Tred Avon River showed some signs of stress and indeed several Chesapeake Bay-wide issues were clearly detected, including excess nutrients, high chlorophyll a concentrations, seasonally

decreased oxygen levels in bottom waters, and poor water clarity. Signs of degradation were particularly evident in the sub-watershed nearest Easton (TA1), the most highly developed location in the assessment, which was impacted by multiple stressors – low dissolved oxygen in bottom waters, the presence of chemical contaminants above low-level NOAA thresholds, high levels of nutrients, high chlorophyll a concentrations, high fecal bacterial counts, and poor water clarity. The fish health assessment index and benthic index of biotic integrity indicators detected significant differences among tributaries within the Tred Avon River, underscoring the utility of these indices and the importance of within–river sampling resolution. In a separate but related study included in this report, we conducted modelling studies to quantify oyster ecosystem services of nutrient removal through filtration by oysters at restored reefs and aquaculture sites in the Tred Avon River and other locations in the Choptank watershed. Encouragingly, we discovered that oyster related nutrient removal ecosystem services can contribute in a positive way to nutrient management in the Tred Avon and Choptank Rivers as oyster tissue has recently been approved as a nutrient Best Management Practice (BMP) in the Chesapeake Bay. Analysis of the indicators of ecosystem condition in the Tred Avon River and their relationship to human activities provides insights into the trade-offs between development on land and the condition of the aquatic ecosystem. This information is critical to striking a balance between supporting the needs of increasing population growth and protecting vital ecosystem services that have benefited generations of communities residing locally or in the larger Chesapeake Bay watershed.

Mercader, M., Blazy, C., Di Pane, J., Devissi, C., Mercière, A., Cheminée, A., . . . Lenfant, P. (2019). Is artificial habitat diversity a key to restoring nurseries for juvenile coastal fish? Ex situ experiments on habitat selection and survival of juvenile seabreams. *Restoration Ecology,* 27(5), 1155-1165. https://doi.org/10.1111/rec.12948

Man-made infrastructures have become ubiquitous components of coastal landscapes, leading to habitat modification that affects the abundance and diversity of marine organisms. Marine coastal fish have a complex life cycle requiring different essential habitats. One of these habitats is known as a nursery, a place where juveniles can settle in large numbers, survive, and grow to contribute to the adult population. Nurseries are mainly found in shallow, sheltered zones and are thus particularly impacted by urbanization, notably by harbors. The vertical featureless structure of docks is very unlikely to be used by juveniles, which need complex habitats to find food and shelter from predators. Recent attempts to rehabilitate the nursery function in such environments by using artificial habitats have proven efficient in increasing juvenile densities. However, nothing is known about the survival of juveniles in these habitats, preventing any conclusions on the effectiveness of this means of restoration from being drawn. Here, we set up tank experiments to test the relationship between habitat preferences and the survival rate of two species of seabream when facing stalk-attacking combers. Habitat choice was consistent with survival results, indicating that artificial habitats might not represent unintended ecological traps for juveniles. However, the artificial habitats' effect on survival was variable between species. Therefore, our results suggest that habitat diversity might be of prime importance to sustain juveniles of different species and stress the need for the development of diverse artificial habitats to counteract the effects of seascape homogenization.

Mercader, M., Merciere, A., Saragoni, G., Cheminee, A., Crec'hriou, R., Pastor, J., . . . Lenfant, P. (2017). Small artificial habitats to enhance the nursery function for juvenile fish in a large commercial port of the Mediterranean. *Ecological Engineering,* 105, 78-86. https://doi.org/10.1016/j.ecoleng.2017.03.022

The concentration of human activities along the shoreline induces high levels of pressure, notably seascape urbanization caused by the proliferation of coastal and marine infrastructures such as ports, harbors, marinas and coastal defense structures. Because they are localized in sheltered and shallow coastal areas, these infrastructures inevitably lead to the loss of natural essential habitats once used as nursery ground by juvenile fish. Some studies have reported the presence of high juvenile densities on breakwaters and jetties suggesting those infrastructures could support the nursery function. However, ports seem unlikely to be used by juveniles due to their vertical and featureless docks. Here we explored the feasibility of using small artificial habitats to enhance the ecological value of ports. We set up a total of 108 artificial habitats in three different locations of the large commercial port of Marseille in the northwestern Mediterranean. We then surveyed juvenile fish on the artificial habitats and control docks on 7 different occasions between June and September 2014. Average species richness and densities were higher on the artificial habitats but displayed high spatial and taxa-specific variations. Hence, small artificial habitats are promising ecological engineering tools to enhance the nursery function inside ports and thus reduce the ecological footprint of those infrastructures.

Midwood, J. D., & Doka, S. E. (2018). *Mapping and Assessing Coastal-Margin Aquatic Habitats in Severn Sound, Lake Huron.* Canadian Technical Report of Fisheries and Aquatic Sciences 3284. Fisheries and Oceans Canada, Ottawa. Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/40737706.pdf

The coastal margin of Severn Sound, Georgian Bay has the most complex shoreline in the Great Lakes region and provides important habitat for a wide variety of species. Presently much of the shoreline is natural, but the coastal margin is increasingly affected by human development, water level fluctuations, and gradual warming of the air and water. To better assess the status of aquatic habitat in the coastal margin of this diverse region we: 1) mapped the extent of submerged aquatic vegetation (SAV) across a range of habitat conditions; 2) collected substrate samples to verify existing side-scan sonar; and 3) tracked dissolved oxygen (DO) and temperature dynamics in key regions. Results suggest that while much of the diversity in aquatic habitat conditions in Severn Sound is largely driven by natural factors, some regions exhibit some detrimental effects from human activities. SAV was abundant across much of the Sound with cover and depth distribution primarily restricted by exposure to wind and wave action (restricts distribution in shallow waters) and natural variation in water clarity due to dissolved organic carbon (primarily restricts the maximum depth of colonization). Sand dominated the majority of substrate samples, except in more protected areas that had higher organic content. Finally, DO profiles were also affected by the level of exposure with more stable DO levels at exposed sites and increasing hourly and daily variability in more protected areas. Extended periods of anoxia were not prevalent, but daily periods of anoxia were common at two of the more protected wetland areas suggesting these events were primarily driven by diurnal cycles in primary production. The results presented in this report can be combined with ongoing efforts by the Severn Sound Environmental Association and University of Windsor to help develop a complete fish habitat suitability model for the coastal margin of Severn Sound.

Morley, S. A., Toft, J. D., & Hanson, K. M. (2012). Ecological Effects of Shoreline Armoring on Intertidal Habitats of a Puget Sound Urban Estuary. *Estuaries and Coasts,* 35(3), 774-784. https://doi.org/10.1007/s12237-012-9481-3

Shoreline armoring is extensive in urban areas worldwide, but the ecological consequences are poorly documented. We mapped shoreline armoring along the Duwamish River estuary (Washington State, USA) and evaluated differences in temperature, invertebrates, and juvenile salmon (*Oncorhynchus spp.*) diet between armored and unarmored intertidal habitats. Mean substrate temperatures were significantly warmer at armored sites, but water temperature similar to unarmored habitats. Epibenthic invertebrate densities were over tenfold greater on unarmored shorelines and taxa richness double that of armored locations. Taxa richness of neuston invertebrates was also higher at unarmored sites, but abundance similar. We did not detect differences in Chinook (*O. tshawytscha*) diet, but observed a higher proportion of benthic prey for chum (*O. keta*) from unarmored sites. Given that over 66% of the Duwamish shoreline is armored--similar to much of south and central Puget Sound--our results underscore the need for further ecological study to address the impacts of estuary armoring.

Morris, R. L., Chapman, M. G., Firth, L. B., & Coleman, R. A. (2017). Increasing habitat complexity on seawalls: Investigating large- and small-scale effects on fish assemblages. *Ecology and Evolution,* 7(22), 9567-9579. https://doi.org/10.1002/ece3.3475

The construction of artificial structures in the marine environment is increasing globally. Eco-engineering aims to mitigate the negative ecological impacts of built infrastructure through designing structures to be multifunctional, benefiting both humans and nature. To date, the focus of eco-engineering has largely been on benefits for benthic invertebrates and algae. Here, the potential effect of eco-engineered habitats designed for benthic species on fish was investigated. Eco-engineered habitats ("flowerpots") were added to an intertidal seawall in Sydney Harbour, Australia. Responses of fish assemblages to the added habitats were quantified at two spatial scales; large (among seawalls) and small (within a seawall). Data were collected during high tide using cameras attached to the seawall to observe pelagic and benthic fish. At the larger spatial scale, herbivores, planktivores, and invertebrate predators were generally more abundant at the seawall with the added flowerpots, although results were temporally variable. At the smaller spatial scale, certain benthic species were more abundant around flowerpots than at the adjacent control areas of seawall, although there was no general pattern of differences in species density and trophic group abundance of pelagic fish between areas of the seawall with or without added habitats. Although we did not find consistent, statistically significant findings throughout our study, the field of research to improve fish habitat within human-use constraints is promising and important, although it is in its early stages (it is experimental and requires a lot of trial and error). To advance this field, it is important to document when effects were detected, and when they were not, so that others can refine the designs or scale of habitat enhancements or their study approaches (e.g., sampling protocols).

Morris, R. L., Porter, A. G., Figueira, W. F., Coleman, R. A., Fobert, E. K., & Ferrari, R. (2018). Fish-smart seawalls: a decision tool for adaptive management of marine infrastructure. *Frontiers in Ecology and the Environment,* 16(5), 278-287. https://doi.org/10.1002/fee.1809

Infrastructure is increasingly being built in marine habitats, with extensive ecological consequences for benthic and fish assemblages alike. The practice of ecological engineering attempts to mitigate the negative impacts of infrastructure through the design of artificial structures that benefit both humans and nature. Although research has primarily focused on the benefits for invertebrates and algae, fish also respond to changes in habitat complexity and benthic biodiversity. We surveyed the scientific literature on natural and artificial reefs to identify key habitat features that fish respond to, and propose a decision tool for ecologists and managers to tailor the structural complexity of marine infrastructure for fish. Inevitably, natural habitats will increasingly be replaced with artificial ones, making ecologically sensitive designs essential for maintaining biodiversity and ecosystem services. Using lessons from natural and artificial reefs, we show that existing and new infrastructure could be designed not only to reduce negative impacts but also to foster positive effects on fish assemblages.

Munsch, S. H., Cordell, J. R., & Toft, J. D. (2015). Effects of seawall armoring on juvenile Pacific salmon diets in an urban estuarine embayment. *Marine Ecology Progress Series,* 535, 213-229. https://doi.org/10.3354/meps11403

An important nursery function of estuaries is providing prey resources for juvenile fish. Shoreline armoring compromises epibenthic and terrestrial prey resources, but it is unclear how this affects fish feeding ecology, particularly in urban landscapes where armoring is common. In this study we sampled prey availability and diets from 3 species of juvenile Pacific salmon (*Oncorhynchus spp.*) in shallow habitats of an extensively armored urban estuary. We compared sites armored by intertidal seawalls with those at small, engineered beaches without armoring. Available prey was different between shoreline types: epibenthic copepods were more abundant and taxonomically diverse at beaches, and barnacles were more abundant at seawall sites. There was no effect of armoring on salmon stomach fullness. Armoring rarely influenced whether salmon selected for or against a prey taxon but did affect diet composition of small (<50 mm) chum salmon (O. keta), which consumed greater abundances of epibenthic copepods at beaches and planktonic copepods at seawall sites. At beaches, these fish selected for epibenthic copepods and against planktonic copepods. At seawall sites, they selected for both epibenthic and planktonic copepods. Armoring did not affect diets of other salmon species or larger chum salmon that had different diets than small chum salmon. Armoring effects on fish diets may depend on differences in prey selection among species and life history stages. Further research is necessary to assess effects of armoring on habitat quality because fish may consume alternative prey when armoring changes the prey field, but it is unclear whether there are energetic costs to the predator.

Munsch, S. H., Cordell, J. R., & Toft, J. D. (2015). Effects of shoreline engineering on shallow subtidal fish and crab communities in an urban estuary: A comparison of armored shorelines and nourished beaches. *Ecological Engineering,* 81, 312-320. https://doi.org/10.1016/j.ecoleng.2015.04.075

Shoreline armoring is common worldwide, yet its ecological effects have only recently been investigated. In this study, we surveyed shallow subtidal fish and crab communities at three sites with

shorelines modified by seawall and riprap armoring and at three beaches with no armoring, all along the urbanized Elliott Bay shoreline of Seattle, WA (USA). Similar to many urban areas there is little natural shoreline remaining in Elliott Bay and beach sites were nourished with sediment that was similar to the historical structure of ambient nearshore habitats. We visually surveyed fish and crabs along scuba dive transects at these sites for eighteen months to quantify the composition of their communities and the association of fish and crabs with substrate types. The community composition and substrate type associations were similar among seawall sites and distinct from those at nourished beaches. Some species were predominantly associated with one substrate type (e.g., sand, riprap) and their densities at each site corresponded to the availability of this substrate type. Our results suggest that hard structures in engineered subtidal habitats may benefit some species that select for these introduced structures despite these structures not occurring historically. It is also clear that the creation of nourished beaches within armored shorelines can maintain different fish and crab communities than those associated with armoring, even in highly urbanized systems. Our study contributes to a growing literature that suggests that shoreline armoring and other types of habitat modifications affect the ecology of nearshore waters and the composition of nearshore communities.

Munsch, S. H., Cordell, J. R., Toft, J. D., & Morgan, E. E. (2014). Effects of Seawalls and Piers on Fish Assemblages and Juvenile Salmon Feeding Behavior. *North American Journal of Fisheries Management,* 34(4), 814-827. https://doi.org/10.1080/02755947.2014.910579

Shoreline modifications, such as seawall armoring and piers, are ubiquitous along developed waterfronts worldwide, and recent research suggests that their ecological effects are primarily negative. We utilized snorkel surveys to quantify the effects of seawalls and piers on fish in nearshore habitats of an urbanized estuary in Puget Sound, Washington. We observed 17 species of fish and 4 species of crab during April-August 2012 at sites modified by seawalls and piers and at reference beach sites with minimal anthropogenic structures. Species assemblages at modified sites were significantly different from those at reference beaches. At modified sites, fish distribution and assemblage structure varied with proximity to the shade cast by piers; overall fish abundances were reduced under piers, and the greatest abundances were observed at high tides in areas directly adjacent to piers. Juvenile Pacific salmon *Oncorhynchus spp.* were the dominant fish species, and piers reduced their presence and feeding, indicating that areas under piers provide less-valuable habitat to salmon species. Piers may interrupt movements of juvenile salmon when they use shallow waters along shorelines to migrate from freshwater to marine habitats, as juvenile salmon tend to avoid shade under piers, especially at high tides. Our results show that shoreline modifications can alter species assemblage structure, thus potentially creating novel combinations and abundances of species, and can reduce habitat function for species that utilize these and similar habitats elsewhere.

Murphy, G. E. P., Wong, M. C., & Lotze, H. K. (2019). A human impact metric for coastal ecosystems with application to seagrass beds in Atlantic Canada. *FACETS,* 4(1), 210-237. https://doi.org/10.1139/facets-2018-0044

Coastal biogenic habitats are vulnerable to human impacts from both terrestrial and marine realms. Yet the broad spatial scale used in current approaches of quantifying anthropogenic stressors is not relevant to the finer scales affecting most coastal habitats. We developed a standardized human impact metric

that includes five bay-scale and four local-scale (0-1 km) terrestrial and marine-based impacts to quantify the magnitude of anthropogenic impacts to coastal bays and nearshore biogenic habitats. We applied this metric to 180 seagrass beds (*Zostera marina*), an important biogenic habitat prioritized for marine protection, in 52 bays across Atlantic Canada. The results show that seagrass beds and coastal bays exist across a wide human impact gradient and provide insight into which are the most and least affected by human threats. Generally, land alteration, nutrient loading, and shellfish aquaculture were higher in the Gulf of St. Lawrence, whereas invasive species and fishing activities were higher along the Atlantic coast. Sixty-four percent of bays were at risk of seagrass decline from nitrogen loading. We also found high within-bay variation in impact intensity, emphasizing the necessity of quantifying impacts at multiple spatial scales. We discuss implications for management and conservation planning, and application to other coastal habitats in Canada and beyond.

Ono, K., Simenstad, C. A., Toft, J. D., Southard, S. L., Sobocinski, K. L., & Borde, A. B. (2010). *Assessing and Mitigating Dock Shading Impacts on the Behavior of Juvenile Pacific Salmon (Oncorhynchus spp.): Can Artificial Light Mitigate the Effects?* WSDOT Research Report WA-RD 755.1. Washington State Department of Transportation, Retrieved from https://www.wsdot.wa.gov/research/reports/fullreports/755.1.pdf

The shadows from large over-water structures built on nearshore habitats in the Puget Sound can reduce prey abundance and disrupt juvenile Pacific salmon (*Oncorhynchus spp.*) migratory behavior with potential consequences on survival rates. As part of an ongoing project to reduce the effects of ferry terminals on juvenile salmon, this study looked at the effectiveness of a fiber optic lighting system at mitigating dock shading impacts on juvenile salmon behavior. The authors conducted intensive visual observations, snorkel surveys, and video filming surveys at the Port Townsend Ferry Terminal (dock) from March through August 2008 and 2009 to test whether migrating salmon reacted to changes in light beneath the terminal and whether evident reactions by the salmon were moderated by the fiber optic lighting system. The authors found that during high tides shoals of juvenile salmon (primarily pink salmon *O. gorbuscha*) were reluctant to swim under the dock and also under the shaded areas. Overall, less than 15 percent of juvenile salmon shoals penetrated under the terminal, and they typically remained within a few meters from the dock. No salmon swam completely under the dock during their observations in the study period. As a consequence of this dock avoidance behavior, ferry terminals likely delay migration for some juvenile salmon (pink salmon) by several hours per dock encounter, during high tide periods, daylight hours and on sunny days. The authors' results also indicated that light transmitted or installed under some old and new terminals could mitigate dock shading impacts on juvenile salmon. However, their experience testing both fiber optic-transmitted natural and in situ artificial (halogen) light suggests that such light mitigation systems will need to (1) be more powerful, (2) be regulated to light only shaded areas, (3) operate on a natural light spectrum, and (4) distribute light over a wide area. The impacts of large over-water structures on juvenile salmon behavior likely alter juvenile salmon migration behavior in shallow nearshore waters, but with an unknown impact to growth and survival. The use of artificial light is a promising mitigation method because fish appeared to respond at a low light level. However, the authors' results were not sufficient to determine whether artificial light could completely mitigate the effects of the dock and eliminate juvenile salmon avoidance behaviors.

Ono, K., & Simenstad School, C. A. (2014). Reducing the effect of overwater structures on migrating juvenile salmon: An experiment with light. *Ecological Engineering,* 71, 180-189. https://doi.org/10.1016/j.ecoleng.2014.07.010

Like many migratory species, anadromous juvenile salmon (*Oncorhynchus spp.*) rely heavily on light perception to orient themselves in space, capture prey, shoal, avoid predators, and migrate along the shoreline to the ocean. However, the continuous demographic expansion along the US West coast has modified many natural coastal environments and has created a new artificial light environment for these species. Among the contributing factors are the construction of large overwater structures such as ferry terminals that have interfered with juvenile salmon migration and behavior by reducing light availability in the salmon migratory pathway. We examined in this study whether the use of an artificial lighting system can mitigate the dock shading impacts on juvenile salmon behavior. A linear mixed effect model was used to analyze changes in individual fish behavior (due to dock shading and artificial lighting) within a shoal. Two different fish movement metrics were examined to characterize the change in behavior: swimming angular variation, and closest distance to the dock. Juvenile salmon avoided penetrating under the dock when strong shadow was present underneath it. Conversely, when artificial light was used to attenuate the dock edge shadow, it was able to mitigate to some extent the effect on juvenile salmon swimming behavior by making them swim closer to the dock with a higher directionality. But when light was used on a non-shaded area, it caused them to stay further away. Light could potentially be used as a method to mitigate dock shading but precautions need to be paid.

Paredes del Puerto, J. M., Paracampo, A. H., García, I. D., Maiztegui, T., Garcia de Souza, J. R., Maroñas, M. E., & Colautti, D. C. (2021). Fish assemblages and water quality in pampean streams (Argentina) along an urbanization gradient. *Hydrobiologia*. https://doi.org/10.1007/s10750-021-04657-z

The Matanza Riachuelo Basin is one of the most polluted watersheds in the world. We assessed the relationships between land use, stream-water quality, and the structure of the fish assemblages on a subbasin scale from data obtained in 44 sampling sites. A gradient of change from the rural upper sector to the urbanized and industrialized lower basin in conjunction with water-quality impoverishment was recorded. Redundancy analysis revealed that dissolved oxygen concentration, heavy metals, detergents, and *Escherichia coli* were the most explanatory variables of that gradient. Fish assemblages manifested the highest richness, abundance, and diversity in the rural areas; in the urbanized and industrialized sectors, the fish community became severely modified, represented only by tolerant species. Multivariate analyses indicated that the fish assemblage structure was highly impacted by water-quality deterioration. The combined study of the impacts of land use on water quality and fish assemblages enabled a detailed diagnosis of the consequent effects on a subbasin scale, thus substantiating the usefulness of fish assemblages as a model for that purpose. Field studies over large-scale gradients of environmental impact are essential for understanding the mechanisms of ecological deterioration and biotic responses as a first step in developing remediation policies.

Pastor, J., Koeck, B., Astruch, P., & Lenfant, P. (2013). Coastal man-made habitats: Potential nurseries for an exploited fish species, *Diplodus sargus* (Linnaeus, 1758). *Fisheries Research,* 148, 74-80. https://doi.org/10.1016/j.fishres.2013.08.014

Human pressure on seashores has induced the installation of many seawalls. Artificial coastal defence structures may be providential for the juveniles of fish species exploited by artisanal fisheries. Focusing on Diplodus sargus, the number of settling juveniles was estimated on artificial structures and on natural rocky shores. The aim is to know if these artificial areas can have a nursery function. Densities of juveniles are from 30 to 109 times greater than those in natural habitats. Artificial coastal defence structures can be regarded as artificial nurseries. However, in the studied case, they also cause the loss of the nursery function of the nearby lagoon. The artificial seawalls at the entrance to the lagoon receive almost all the larvae that would normally enter the lagoon. This study underlines the important role of these artificial habitats in the life cycle of white seabream. They may have a positive impact on maintaining other species exploited by artisanal fisheries.

Paxton, A. B., Taylor, J. C., Peterson, C. H., Fegley, S. R., & Rosman, J. H. (2019). Consistent spatial patterns in multiple trophic levels occur around artificial habitats. *Marine Ecology Progress Series,* 611, 189-202. https://doi.org/10.3354/meps12865

With increasing global rates of urbanization, it is important to understand the ecological functions of artificial structures. One way to assess the ecological functions of such structures is to test whether they function similarly to natural habitats. In marine systems, naturally occurring structured habitats, such as coral reefs and rocky reefs, support aggregations of planktivorous fish, often inducing spatial patterns in prey and predators. Whether similar spatial patterns occur around submerged artificial structures, which often have more abrupt topographies than natural habitats, remains less well understood. We tested whether consistent spatial patterns in planktivorous fish, their prey (zooplankton), and their predators (piscivorous fish) were present around artificial structures. We first documented spatial distributions of these 3 trophic groups around 15 marine artificial structures (shipwrecks) using acoustic surveys and then asked how spatial distributions of each trophic group relate to the others. We found that the center of planktivorous fish aggregations occurred an average of 39 m from habitat edges. Zooplankton prey were detected throughout nearly 25% of surveyed areas around habitats. Piscivorous fish predators concentrated closest to habitats. Further analyses revealed that these patterns sometimes related to environmental factors, such as water current magnitude and direction. Because spatial distributions of planktivorous fish, their prey, and their predators were consistent across sampled artificial structures, our findings suggest that artificial structures influence spatial patterns across adjacent trophic levels. This finding adds to a growing body of evidence that artificial habitats provide important ecological functions.

Rao, A., Boyer, L., & Erickson, K. (2013). *2013 Final Report: Nearshore Eelgrass Inventory: Bowen, Passage and Bowyer Islands.* Islands Trust, Retrieved from http://seagrassconservation.org/wp-content/uploads/2016/02/2013-Metro-Vancouver-Eelgrass-Mapping-Report-Bowen-Passage-Bowyer-Islands.pdf

Land use developments within watersheds have led to a loss of natural estuarine and nearshore marine habitats in British Columbia, which are the receiving waters of land based activities. Agriculture, forestry, and dredging for commercial and residential development have all contributed to the loss (Durance, 2002). The pressure to modify natural marine features and habitat for the development of commercial facilities and residential units within coastal areas is intensifying. To prepare for the increase in

populations on the BC coast and concurrent shoreline developments, it is necessary to identify and quantify nearshore habitats to protect and maintain these valuable environments. This final report on the 2013 nearshore inventory and mapping of native eelgrass, Zostera marina surrounding Bowen, Bowyer and Passage Islands is a summary of the rationale, methodology and findings of this study conducted by SeaChange Marine Conservation Society in partnership with the Islands Trust, Islands Trust Fund and Metro Vancouver. The report also serves as background information for future eelgrass inventories. The goal is to support science-based sound decisions that will affect the natural ecological health of the marine nearshore environments around these islands.

Rehr, A. P., Williams, G. D., Tolimieri, N., & Levin, P. S. (2014). Impacts of Terrestrial and Shoreline Stressors on Eelgrass in Puget Sound: An Expert Elicitation. *Coastal Management,* 42(3), 246-262. https://doi.org/10.1080/08920753.2014.904195

We used expert elicitation to examine potential responses of eelgrass to several restoration strategies in Puget Sound. Restoration strategies included shoreline armor removal and modification, removal and modification of overwater structures, and efforts to improve water clarity via reductions in anthropogenic nutrient and sediment loadings. Expert responses indicated a general belief that reducing stressors would increase eelgrass cover; however, responses varied greatly among stressors. Our analyses revealed that removal of overwater structures, nutrient loading and shoreline armoring will have significantly larger effects on eelgrass recovery than would removal of sediment loading, with removal of overwater structures having the largest effect. We then used a probabilistic model to estimate what actions, singularly or in combination, could yield a large increase in eelgrass cover. Reducing single stressors could, in theory, result in recovery of eelgrass in Puget Sound; however, the magnitude of actions required would be so great that it is likely not practical. In contrast, we identified combinations of smaller reductions of stressors that could achieve significant eelgrass recovery. For example, a 40% reduction in overwater structures, combined with 20% reductions in shoreline armor, and nutrient and sediment loadings, was predicted to be one of the more feasible combinations of actions for meeting the target. The importance of eelgrass to Puget requires prompt input of scientific advice, and this work fills an important knowledge gap in the face of rapidly approaching legislative deadlines. While coded expert opinion of the sort we use here is a weak substitute for data, our work clarifies the current extent of scientific uncertainty that can guide management action in the near term and scientific research in the long term.

Rizzo, L., Musco, L., & Crocetta, F. (2021). Cohabiting with litter: Fish and benthic assemblages in coastal habitats of a heavily urbanized area. *Marine Pollution Bulletin,* 164, 112077. https://doi.org/10.1016/j.marpolbul.2021.112077

Anthropogenic litter negatively impacts the marine environment and threatens biodiversity. At the same time, it represents a suitable substrate for the settlement of sessile species, thus potentially altering composition and structure of soft bottom benthic assemblages. By using a Remotely Operated Vehicle (ROV), we hereby investigated patterns of abundance, distribution, and origin of benthic litter in three subtidal habitats of a heavily urbanized area and tested whether litter distribution related to patterns of fish and mega- and macro-benthic diversity. Litter accumulation mostly occurred on soft bottoms, while rocky substrata were the least affected, albeit being particularly threatened by sea-based pollution. As

expected, the highest biodiversity was observed on rocky bottoms, hosting notable biogenic formations (*Cladocora caespitosa*, *Leptogorgia sarmentosa*) despite the area is historically affected by anthropogenic activities. No correlation was found between biota and marine litter, suggesting that litter does not apparently influence biodiversity and distribution of the investigated assemblages.

Sawyer, A. C., Toft, J. D., & Cordell, J. R. (2020). Seawall as salmon habitat: Eco-engineering improves the distribution and foraging of juvenile Pacific salmon. *Ecological Engineering,* 151. https://doi.org/10.1016/j.ecoleng.2020.105856

Urban nearshore ecosystems are built environments that differ structurally and functionally from the natural ecosystems they replace. Eco-engineering offers the ability to enhance these ecosystems by reducing the impacts of shoreline modification. Recent studies have linked shoreline armoring and pier shade-common features of modified shorelines-to lower foraging rates, altered distribution patterns, and increased predation risk for juvenile salmon. The 2017 replacement of the Elliott Bay seawall in Seattle, WA, USA incorporated novel eco-engineering design elements, including glass light penetrating surfaces (LPS) in overwater structures, an elevated seafloor, and textured substrates in the seawall face to enhance nearshore habitat for juvenile Pacific salmon (*Oncorhynchus spp.*) migrating from natal streams to the ocean. To examine the effectiveness of seawall eco-engineering, we used snorkel surveys to assess changes in juvenile salmon spatial distribution and foraging patterns during peak outmigration (March-August), and measured ambient light penetration before and after seawall replacement. Overall, we found that juvenile salmon were distributed more evenly across a spatial mosaic of habitats following eco-engineering. LPS enhanced ambient light penetration in nearshore under-pier habitats, and juvenile salmon use of these habitats increased concurrently. Salmon densities under piers tended to be greatest at low tides, indicating that light availability may mediate selective habitat use. Feeding rates at sites immediately adjacent to the seawall increased both between and under piers following habitat enhancement. Our findings suggest that the elevated light levels facilitated by LPS, in concert with physical enhancements that provided more complex shallow water habitat, temper the negative effects of pier shade and shoreline armoring on juvenile salmon.

Scyphers, S. B., Gouhier, T. C., Grabowski, J. H., Beck, M. W., Mareska, J., & Powers, S. P. (2015). Natural shorelines promote the stability of fish communities in an urbanized coastal system. *Plos One,* 10(6), e0118580. https://doi.org/10.1371/journal.pone.0118580

Habitat loss and fragmentation are leading causes of species extinctions in terrestrial, aquatic and marine systems. Along coastlines, natural habitats support high biodiversity and valuable ecosystem services but are often replaced with engineered structures for coastal protection or erosion control. We coupled high-resolution shoreline condition data with an eleven-year time series of fish community structure to examine how coastal protection structures impact community stability. Our analyses revealed that the most stable fish communities were nearest natural shorelines. Structurally complex engineered shorelines appeared to promote greater stability than simpler alternatives as communities nearest vertical walls, which are among the most prevalent structures, were most dissimilar from natural shorelines and had the lowest stability. We conclude that conserving and restoring natural habitats is essential for promoting ecological stability. However, in scenarios when natural habitats are

not viable, engineered landscapes designed to mimic the complexity of natural habitats may provide similar ecological functions.

Sedano, F., Navarro-Barranco, C., Guerra-Garcia, J. M., & Espinosa, F. (2020). From sessile to vagile: Understanding the importance of epifauna to assess the environmental impacts of coastal defence structures. *Estuarine Coastal and Shelf Science,* 235, 106616-. https://doi.org/10.1016/j.ecss.2020.106616

Ocean sprawl is leading to the introduction of multiple artificial structures into the marine environment. However, the biota on these novel habitats differ from that on natural hard substrates. Amphipods, despite their ecological importance, are usually overlooked when comparing benthic assemblages on artificial and natural hard substrates. So as to assess the effects of artificial structures on amphipod assemblage and to identify the main factors involved, the amphipod assemblage structure was studied in five different substrates (seawalls, cubes, acropods, rip-raps and natural rock). Abiotic measurements of each substrate (complexity, rock composition, and age) were related to the ecological patterns. Complexity measurements seemed to affect the amphipod community structure, highlighting the need to consider physical complexity in eco-engineering actions. Amphipod assemblages were also affected by the secondary substrate (sessile biota), suggesting that artificial structures are indirectly shaping amphipod assemblages by firstly shaping the sessile biota. Future research should study the same secondary substrates across different artificial structures to separate the direct effects (caused by the artificial structures) from the indirect effects (caused by the sessile biota).

Sedano, F., Navarro-Barranco, C., Guerra-Garcia, J. M., & Espinosa, F. (2020). Understanding the effects of coastal defence structures on marine biota: The role of substrate composition and roughness in structuring sessile, macro- and meiofaunal communities. *Marine Pollution Bulletin,* 157, 111334. https://doi.org/10.1016/j.marpolbul.2020.111334

The increasing deployment of artificial structures into the marine environment is creating new hard substrates that differ from natural ones in physical and biological aspects. However, studies of macrofaunal and meiofaunal communities associated with artificial structures are very limited. Seawalls, cubes, acropods and rip-raps in Algeciras Bay (southern Spain) were each compared with the nearest natural hard substrate and their community structure was related to substrate roughness, composition, carbonates content, crystallinity and age, using db-RDA. The results showed clear differences between substrates for the three community levels (sessile, macro- and meiofauna). Overall, rip-raps were the most similar to natural substrates. Under similar environmental conditions, substrate roughness, composition (only for sessile) and age of the structures seemed to play important roles in structuring those communities. They especially affected the sessile community, initiating strong cascading effects that were detectable at high taxonomic level in the associated fauna.

Seitz, R. D., Knick, K. E., Davenport, T. M., & Saluta, G. G. (2018). Human Influence at the Coast: Upland and Shoreline Stressors Affect Coastal Macrofauna and Are Mediated by Salinity. *Estuaries and Coasts,* 41(1), 114-130. https://doi.org/10.1007/s12237-017-0347-6

Anthropogenic stressors can affect subtidal communities within the land-water interface. Increasing anthropogenic activities, including upland and shoreline development, threaten ecologically important species in these habitats. In this study, we examined the consequences of anthropogenic stressors on benthic macrofaunal communities in 14 subestuaries of Chesapeake Bay. We investigated how subestuary upland use (forested, agricultural, developed land) and shoreline development (riprap and bulkhead compared to marsh and beach) affected density, biomass, and diversity of benthic infauna. Upland and shoreline development were parameters included in the most plausible models among a candidate set compared using corrected Akaike's Information Criterion. For benthic macrofauna, density tended to be lower in subestuaries with developed or mixed compared to forested or agricultural upland use. Benthic biomass was significantly lower in subestuaries with developed compared to forested upland use, and biomass declined exponentially with proportion of near-shore developed land. Benthic density did not differ significantly among natural marsh, beach, and riprap habitats, but tended to be lower adjacent to bulkhead shorelines. Including all subestuaries, there were no differences in diversity by shoreline type. In low salinities, benthic Shannon (H') diversity tended to be higher adjacent to natural marshes compared to the other habitats, and lower adjacent to bulkheads, but the pattern was reversed in high salinities. Sediment characteristics varied by shoreline type and contributed to differences in benthic community structure. Given the changes in the infaunal community with anthropogenic stressors, subestuary upland and shoreline development should be minimized to increase benthic production and subsequent trophic transfer within the food web.

Smith, C. S., Paxton, A. B., Donaher, S. E., Kochan, D. P., Neylan, I. P., Pfeifer, T., . . . Taylor, J. C. (2021). Acoustic camera and net surveys reveal that nursery enhancement at living shorelines may be restricted to the marsh platform. *Ecological Engineering,* 166. https://doi.org/10.1016/j.ecoleng.2021.106232

Rapid human development in coastal areas is introducing significant amounts of novel habitat and leading to widespread habitat simplification. To predict how species will respond to these changes, it is important to understand how organisms interact with novel habitats versus naturally existing habitats. In this study, we used traditional fish sampling gear (fyke nets and minnow traps) and a Dual-Frequency Identification Sonar (DIDSON) to conduct fish surveys along natural and modified estuarine shorelines in North Carolina, USA. The overall objective of our study was to investigate how fish abundance and other community metrics change as a function of shoreline type (natural marsh, living shoreline, or bulkhead), sampling location (marsh platform or the shallow subtidal area offshore of the structure), and time of day (day or night). Using fyke nets, we caught significantly more fish and recorded higher species richness on the marsh platform at living shorelines versus natural marsh shorelines. However, we found no significant differences in fish abundance in the shallow unvegetated habitats seaward of the different shoreline types, which may have been affected by low sampling efficiency and replication when sampled using minnow traps and the DIDSON. Our findings, in conjunction with similar studies, may reflect a localized shoreline effect where the nursery enhancement observed at living shoreline sites is restricted to the living component of the shoreline (i.e., the marsh). Additionally, the preliminary results from our limited daytime versus nighttime DIDSON sampling show no significant differences in fish detections. This contrasts with many previous studies using traditional fish sampling techniques that report

substantially higher fish catches at night. This unexpected finding is worthy of additional research as it may suggest that traditional fish sampling techniques are underestimating fish abundances during the day, perhaps due to visual gear avoidance. Ultimately, a careful consideration of the social and ecological goals of any shoreline stabilization project is needed before choosing a final design; however, maximizing habitat restoration and limiting the use of artificial materials is likely to confer the greatest ecological benefit.

Sobocinski, K. L., Cordell, J. R., & Simenstad, C. A. (2010). Effects of Shoreline Modifications on Supratidal Macroinvertebrate Fauna on Puget Sound, Washington Beaches. *Estuaries and Coasts,* 33(3), 699-711. https://doi.org/10.1007/s12237-009-9262-9

In coastal environments, the supratidal zone bridges marine and terrestrial ecosystems and is important for energy exchange. However, it is also subject to extensive anthropogenic disturbance, such as armoring of shorelines. Shoreline armoring is extensive along many coasts, but the impacts on biota are comparatively unknown. Between 2000 and 2002, paired and synoptic sampling regimes were employed to assess armoring effects on insects and benthic macroinvertebrates in the supratidal zone of Puget Sound beaches. Paired sampling showed natural beach sites had significantly more deposited wrack. Infauna was dominated by oligochaetes and nematodes; talitrid amphipods, insects, and collembolans were significantly more numerous at natural beaches, and crustaceans were more abundant at altered beaches. Insect assemblages were diverse, with taxon richness higher at natural beach sites. In the synoptic sampling, where sites with higher elevation modifications were used, there were fewer differences in invertebrate assemblages between armored and nonarmored sites. The results show that, where shoreline armoring lowers the land-sea interface, benthic infauna and insect assemblages are disrupted. Widespread shoreline modifications may decrease the availability of prey resources for fish and wildlife and decrease the contribution of organic material entering the nearshore ecosystem.

Stefankiv, O., Hall, J. E., Timpane-Padgham, B. L., Nicol, C., Fogel, C., Beechie, T. J., & Pess, G. R. (2019). *Salmon Habitat Status and Trends: Monitoring Protocols*. NWFSC Processed Report ; 2019-03 https://doi.org/10.25923/w8y2-vj33

In 2014 and 2015, we began a habitat status and trend monitoring program for the Puget Sound Chinook, Hood Canal Summer Chum, and Puget Sound Steelhead Evolutionarily Significant Units (ESUs), covering large river, floodplain, delta, and nearshore habitats. The purpose of this monitoring program is to provide consistent habitat data for evaluating trends in the habitat listing factor at each 5-year status review for the listed ESUs. As part of the monitoring program, we developed protocols for delineating floodplain, delta, and nearshore boundaries, and measuring habitat features and calculating monitoring metrics. In 2018 we expanded the monitoring program to the Oregon Coast Coho salmon ESU. Funding was reduced at the end of 2018. In this report, we summarize the protocols for delineating analysis area boundaries, and for measuring habitat features and calculating habitat metrics.

Strayer, D. L., Findlay, S. E. G., Miller, D., Malcom, H. M., Fischer, D. T., & Coote, T. (2012). Biodiversity in Hudson River shore zones: influence of shoreline type and physical structure. *Aquatic Sciences,* 74(3), 597-610. https://doi.org/10.1007/s00027-012-0252-9

The shore zones of the Hudson River, like those of many developed waterways, are highly varied, containing a mix of seminatural and highly engineered shores. Our goal was to document the biodiversity supported by different kinds of shore zones in the Hudson. We chose six common types of shore zones, three of them "natural" (sand, unconsolidated rock, and bedrock), and three of them engineered (riprap, cribbing, and bulkheads). We measured selected physical characteristics (shore zone width, exposure, substrate roughness and grain size, shoreline complexity) of three examples of each of these shore types, and also sampled communities of terrestrial plants, fishes, and aquatic and terrestrial invertebrates. Community composition of most taxa differed across shore types, and frequently differed between wide, sheltered shores and narrow, exposed shores. Alien plant species were especially well represented along engineered shores. Nevertheless, a great deal of variation in biological communities was not explained by our six-class categorization of shore zones or the physical variables that we measured. No single shore type supported the highest values of all kinds of biodiversity, but engineered shore zones (especially cribbing and bulkheads) tended to have less desirable biodiversity characteristics than "natural" shore zones.

Sutherland, T. F., Elner, R. W., & O'Neill, J. D. (2013). Roberts Bank: Ecological crucible of the Fraser River estuary. *Progress in Oceanography,* 115, 171-180. https://doi.org/10.1016/j.pocean.2013.05.018

Roberts Bank, part of the Fraser River delta system on Canada's Pacific coast, is a dynamic estuarine environment supporting important fisheries as well as internationally significant populations of migratory shorebirds. The 8000 ha bank environment comprises a complex of riparian boundaries, intertidal marshes, mud and sand flats, eelgrass meadows, macroalgae and biofilms. Anthropogenic developments (a ferry causeway in 1961 and a port causeway in 1969) have been responsible for changes in tidal flow patterns, tidal elevation, sediment transport and the net expansion of eelgrass beds. The goals of the present study were to (1) directly compare geotechnical properties spanning each side of the coalport causeway, and (2) enhance our understanding of the intercauseway ecosystem under a high-resolution sampling design. Sediment properties (grain size, porosity, organic content, and chlorophyll) and biological communities (eelgrass, macrofauna (0.5-1.0 mm) and meiofauna (0.063-0.5 mm)) were surveyed in 1997 at three stations outside the intercauseway area and three lateral transects spanning the intercauseway tidal flat at tidal heights representing three different habitats: biofilm, *Zostera japonica*, and *Zostera marina*. A fine-silt organic-rich porous deposit was observed on the shoreward north side of the coalport causeway relative to the south counterpart, suggesting that consolidation and erosion processes could likely not keep pace with the deposition of Fraser River silt. High chlorophyll levels were found in the protected shoreward northern border of the ferry causeway where fine sands dominate and higher water transparency exists, owing to the redirection of the silt-laden river plume by the coalport causeway. Principle Components Analysis revealed a positive relationship between these porous, organic-rich sediments and cumacean abundance in all regions where eelgrass was absent, including the north side of the coalport causeway. Further, a positive relationship was found between biofilm components (chlorophyll and silt), polydora, and harpacticoid copepod abundance, which, together with cumaceans, are food for Western Sandpipers, *Calidris mauri*. Finally, 52% of the intercauseway variation was explained by direct correlations between eelgrass

attributes and fauna consisting of bivalves, caprellids, and harpacticoid copepods (root biomass, leaf area index), the latter being prey for juvenile salmon which depend on eelgrass beds as rearing habitat. These habitats are vulnerable to changes in tidal flow patterns, tidal elevation, sediment transport, and water clarity that could be caused by future port development and/or sea level rise in response to climate change.

Szypulski, E. J. (2018). *Ecological Effects of Overwater Structures on Subtidal Kelp, Northern Puget Sound, Washington.* (Master of Science), Central Washington University, Retrieved from https://digitalcommons.cwu.edu/etd/1052/

There are more than 9,000 overwater structures in the Puget Sound casting an estimated 9 km2 of anthropogenic created shade to the seafloor. Subtidal kelp, over 20 species in total, are abundant in the Sound but little data exists on how they are impacted by these overwater structures. The purpose of this research is to quantify various overwater structures' impacts on the productivity and distribution of subtidal kelp beds and to create a subtidal kelp monitoring protocol. Three sets of floating docks and paired controls were sampled twice during the summer of 2017 for subtidal kelp distribution, biomass, photosynthetically active radiation (PAR), substrate, and fish presence. Georeferenced benthic video surveys were conducted along parallel transects to create 1 m grid cell maps encoded for subtidal kelp presence/absence at each site. Wet biomass and morphometric measurements were taken from kelp collected from 30 samples at each site. Light extinction coefficients were calculated using an array of 11 PAR sensors deployed at various depths and distances from each dock and within each paired control site. Substrate samples were analyzed for organic content and particle size distributions. Proportional coverages and densities of subtidal kelp were statistically compared for significant differences between the docks and their paired control sites and were correlated with related environmental conditions using nonparametric tests. Overall, subtidal kelp distribution and productivity were negatively related to dock presence. Significantly less kelp presence by transect was found at every dock site (medians = 0 – 20.4%) than paired controls (medians = 96.2 – 100%), as well as significantly less kelp biomass (dock medians = 0 – 199.6 g; control medians = 282.1 – 565.9 g), while available PAR was found to be less on the north of the docks (means = 26.2 – 193.4 µmol m-2 s-1) than paired controls (means = 58.2 – 219.0 µmol m-2 s-1) in all but one case. PAR appears to be the limiting environmental factor to kelp distribution and productivity while sediment size and percent organics do not appear to play a significant role.

Tabor, R. A., Fresh, K. L., Piaskowski, R. M., Gearns, H. A., & Hayes, D. B. (2011). Habitat Use by Juvenile Chinook Salmon in the Nearshore Areas of Lake Washington: Effects of Depth, Lakeshore Development, Substrate, and Vegetation. *North American Journal of Fisheries Management,* 31(4), 700-713. https://doi.org/10.1080/02755947.2011.611424

Juvenile Chinook salmon *Oncorhynchus tshawytscha* in nearshore areas of Lake Washington, Washington, were studied to determine their depth distribution, substrate associations, and use of overhanging vegetation (OHV) and shoreline armoring. From March to May, juvenile Chinook salmon progressively shifted to deeper waters as they increased in size. At night, they were associated with small substrates, whereas no association with a particular substrate type was detected during daytime. Juveniles were commonly found in open areas or within 5 m of overwater structures (e. g., piers and docks) but were rarely found directly under such structures. The number of juveniles associated with

armored shorelines was lower than expected given the availability of this habitat type. Large numbers of small juveniles often used OHV during the day; however, at night they moved away from cover and occupied open areas with no structure. Larger juveniles did not show a strong affinity to overhead cover. Our results suggest that continued development of the Lake Washington shoreline has the potential to restrict the amount of habitat that is useable by the Chinook salmon. They used shallow shoreline areas with fine substrates (sands and gravels), including both open beaches and areas with riparian vegetation for providing woody debris and OHV. These types of habitat features tend to be reduced as a result of lakeshore development. We hypothesize that habitat use by juvenile Chinook salmon was most likely being driven by predation risk. Habitat changes resulting from shoreline development could therefore potentially increase their vulnerability to predators.

Thom, R. M., Haas, E., Evans, N. R., & Williams, G. D. (2011). Lower Columbia River and Estuary Habitat Restoration Prioritization Framework. *Ecological Restoration,* 29(1), 94-110. https://doi.org/10.3368/er.29.1-2.94

The Restoration Prioritization Framework was designed as a decision-making tool for the Lower Columbia River Estuary Partnership, to help identify the highest-priority sites for restoration. The underlying concepts are derived from regional applications of aquatic restoration theory. The framework uses the conceptual model that physical controlling factors (e.g., light, temperature, hydrology) drive the formation and maintenance of habitats and their ecological functions, and that stressors act on the controlling factors. The framework is two tiered and comprises 1) an overview of the concepts and description of framework tools; 2) a spreadsheet containing detailed data, formulas, and workflow for the actual site prioritization; and 3) a geographic information system (GIS) database containing source and processed geospatial datasets. In Tier I, the framework uses a GIS-based approach to evaluate impacts from a variety of human "stressors" such as diking, agriculture, overwater structures, and flow restrictions. Data processing derives priority scores, which are then relinked to the geographic sites in the GIS. In this manner, all of the data and tools employed can be analyzed and queried in a geospatial context. In addition to the core impact assessment, the framework includes tools to incorporate information on hydrologic connectivity and existing function into the priority screening. Specific restoration project proposals are evaluated in Tier II, using information on cost, expected functional change, site size, and predicted probability of success. Using this framework, the Lower Columbia River Estuary Partnership can screen for impacted areas, prioritize areas based on desired ecological criteria, and evaluate selected projects.

Toft, J. D., Munsch, S. H., Cordell, J. R., Siitari, K., Hare, V. C., Holycross, B. M., . . . Hughes, B. B. (2018). Impact of multiple stressors on juvenile fish in estuaries of the northeast Pacific. *Global Change Biology,* 24(5), 2008-2020. https://doi.org/10.1111/gcb.14055

A key step in identifying global change impacts on species and ecosystems is to quantify effects of multiple stressors. To date, the science of global change has been dominated by regional field studies, experimental manipulation, meta-analyses, conceptual models, reviews, and studies focusing on a single stressor or species over broad spatial and temporal scales. Here, we provide one of the first studies for coastal systems examining multiple stressor effects across broad scales, focused on the nursery function of 20 estuaries spanning 1,600 km of coastline, 25 years of monitoring, and seven fish and invertebrate

species along the northeast Pacific coast. We hypothesized those species most estuarine dependent and negatively impacted by human activities would have lower presence and abundances in estuaries with greater anthropogenic land cover, pollution, and water flow stress. We found significant negative relationships between juveniles of two of seven species (Chinook salmon and English sole) and estuarine stressors. Chinook salmon were less likely to occur and were less abundant in estuaries with greater pollution stress. They were also less abundant in estuaries with greater flow stress, although this relationship was marginally insignificant. English sole were less abundant in estuaries with greater land cover stress. Together, we provide new empirical evidence that effects of stressors on two fish species culminate in detectable trends along the northeast Pacific coast, elevating the need for protection from pollution, land cover, and flow stressors to their habitats. Lack of response among the other five species could be related to differing resistance to specific stressors, type and precision of the stressor metrics, and limitations in catch data across estuaries and habitats. Acquiring improved measurements of impacts to species will guide future management actions, and help predict how estuarine nursery functions can be optimized given anthropogenic stressors and climate change scenarios.

Toft, J. D., Ogston, A. S., Heerhartz, S. M., Cordell, J. R., & Flemer, E. E. (2013). Ecological response and physical stability of habitat enhancements along an urban armored shoreline. *Ecological Engineering,* 57, 97-108. https://doi.org/10.1016/j.ecoleng.2013.04.022

Shoreline armoring is prevalent worldwide and has resulted in substantial habitat alteration in heavily urbanized areas. The biological and physical processes associated with these shorelines have in many cases been compromised, which has led to a recent focus on how to design and implement projects to restore some of the lost or impaired functions, termed enhancement. We describe a multi-year effort testing whether an enhanced site has improved conditions in Seattle, WA, USA, along urban marine shorelines of Puget Sound. The Olympic Sculpture Park opened in January 2007 and included construction of two shallow-water features: a low-terrace habitat bench placed in front of an existing seawall, and a constructed pocket beach that replaced existing riprap. Riparian vegetation was also planted in the uplands replacing impervious surfaces and manicured lawn. We measured the functions of these sites by sampling both before and after enhancements (2005, 2007, and 2009), and comparing to adjacent armored shorelines. Although we are limited in our ability to make generalizations beyond this specific site due to only having one replicate of each shoreline type, the unique aspects of this urban enhancement make it useful as a case study that can apply to other urban systems. Fishes that are dependent on shallow water habitat were a main focus of sampling, specifically outmigrating juvenile salmon (*Oncorhynchus spp.*) and larvae of other species. Terrestrial and aquatic invertebrates were also assessed, both as a metric for habitat quality and as a determinant of available prey resources for juvenile salmon. Physical features of the created habitats were monitored in post-enhancement years to measure their stability. Results showed that shoreline enhancements increased densities of larval fishes and juvenile salmon and measurements of juvenile salmon feeding behavior dependent on the year, and provided habitat for invertebrate assemblages that were different from armored shorelines and had high taxa richness. Physical resilience depended on both natural processes and human activities, demonstrating the need to incorporate anthropogenic use into the management of urban shorelines.

Torre, M. P., & Targett, T. E. (2016). Nekton assemblages along riprap-altered shorelines in Delaware Bay, USA: comparisons with adjacent beach. *Marine Ecology Progress Series,* 548, 209-218. https://doi.org/10.3354/meps11685

Riprap-reinforced shorelines are becoming more prevalent as a result of increasing coastal development and sea level rise. Altered morphology at the land-water interface, associated with riprap shorelines, has the potential to reduce shore-zone habitat quality for associated nekton species. The shore-zone nekton assemblage within a temperate, mid-Atlantic coast, USA, estuary was examined to identify differences in habitat use between sandy beach and riprap shorelines. We found that riprap can have a negative effect on a local scale. Overall nekton density, species richness, and density of dominant species were higher along beach shorelines relative to adjacent riprap, in most instances. Nekton association with shoreline habitat appears to be consistent over the diel cycle. Densities of Atlantic silverside Menidia menidia, striped killifish Fundulus majalis, spot Leiostomus xanthurus, and white perch Morone americana were generally reduced along riprap. In some cases, riprap shorelines also had altered species assemblages. Thus, our findings provide evidence of altered habitat quality for shore-zone nekton associated with shoreline hardening. These impacts were, however, variable spatially and temporally. Further research is needed to identify the biophysical mechanisms associated with riprap shorelines that are most responsible for altered habitat quality.

Valenti, J. L., Grothues, T. M., & Able, K. W. (2017). Estuarine Fish Communities along a Spatial Urbanization Gradient. *Journal of Coastal Research,* 78, 254-268. https://doi.org/10.2112/Si78-017.1

The human population surrounding Barnegat Bay, New Jersey, has increased dramatically in recent decades. Consequently, urbanization (anthropogenic development) of the watershed has occurred, resulting in shoreline hardening and habitat destruction. A resulting gradient of urbanization increases from the southern to the northern portion of the bay's watershed. The objective of this study was to investigate cumulative impacts of urbanization in Barnegat Bay by assessing species composition, abundance, and diversity of fish communities in relation to the large-scale urbanization gradient in the watershed. Otter trawl surveys occurred in April, June, August, and October for 3 years (2012-2014) at 40 sampling sites stratified along the urbanization gradient. The sampling sites included four different representative, subtidal subhabitats: open bay (soft bottom), submerged aquatic vegetation beds, upper marsh creek, and marsh creek mouth. Analyses did not reveal strong differences in fish communities among strata that could be solely attributed to the urbanization gradient. Fish species composition was similar among strata, whereas species abundances and diversity differed among strata. Many of the observed differences in abundance and diversity were attributed to ecological variables unassociated with the urbanization gradient. Further study on potential urbanization effects should include investigations at the species level and at smaller scales.

Vasilas, B., Bowman, J., Rogerson, A., Chirnside, A., & Ritter, W. (2011). Environmental Impact of Long Piers on Tidal Marshes in Maryland-Vegetation, Soil, and Marsh Surface Effects. *Wetlands,* 31(2), 423-431. https://doi.org/10.1007/s13157-011-0152-0

Piers may impact the health of coastal wetlands by altering vegetation, soil organic matter accretion, and sediment deposition or erosion. Permit requests for piers have recently increased in the U.S. leading to concern by environmental regulatory agencies on potential impacts. In response, a project was conducted in Maryland to assess the impacts of long piers on plant communities, soils, and marsh surface characteristics. Twenty sites with piers and 20 control sites were assessed. Control sites and pier sites were similar with respect to soil types, marsh surface characteristics, and plant community composition. Shading consistently reduced vegetation density directly beneath piers and occasionally reduced vegetation density adjacent to piers. Shading favored Spartina alterniflora over Distichlis spicata, and Distichlis spicata over Spartina patens. Distribution of marsh surface components (high marsh, low marsh, mudflats, open water) was unaffected by proximity to piers. Direct evidence of pier effects on erosion or deposition was limited to the immediate vicinity of a few piers. In general, thickness of the organic horizons or that of the root mats was unaffected by proximity to a pier. We concluded that any effects of piers on vegetation or erosion were restricted to the close proximity of the piers.

Verdiell-Cubedo, D., Torralva, M., Andreu-Soler, A., & Oliva-Paterna, F. J. (2012). Effects of Shoreline Urban Modification on Habitat Structure and Fish Community in Littoral Areas of a Mediterranean Coastal Lagoon (Mar Menor, Spain). *Wetlands,* 32(4), 631-641. https://doi.org/10.1007/s13157-012-0296-6

The shallow habitats of coastal lagoons play an invaluable role for fish communities as nursery areas and provide essential habitats for threatened fish species. Shoreline modification is an anthropogenic coastal stressor that can negatively affect aquatic communities through the modification of nearshore habitats. The aim of the present study was to quantify the effects of two types of shoreline conditions on habitat structure and fish community of littoral habitats. Unmodified shorelines adjacent to saltmarshes and recreational beaches in urbanised areas of the Mar Menor coastal lagoon were compared. The results showed that there were significant differences in habitat structure, fish community structure and fish species abundance by shoreline type. Recreational beaches were characterised by higher water depth and homogeneous substrata, while unmodified shorelines showed high substrata heterogeneity and supported well developed meadows of submerged vegetation. The latter shoreline type provided an important nursery habitat for marine species such as *Sparus aurata* and *Liza saliens*, and represented critical habitats for species of conservation concern such as *Aphanius iberus* and *Syngnathus abaster*. Littoral areas adjacent to modified shorelines were dominated by *Pomatoschistus marmoratus*. We suggest that urbanisation has impacted fish assemblages through degradation of habitat structure (loss of complexity and refuge areas).

Warry, F. Y., Reich, P., Cook, P. L. M., Mac Nally, R., & Woodland, R. J. (2018). The role of catchment land use and tidal exchange in structuring estuarine fish assemblages. *Hydrobiologia,* 811(1), 173-191. https://doi.org/10.1007/s10750-017-3487-6

Changes in land use often increase nutrient loading to aquatic ecosystems, affecting primary productivity and water quality, with flow-on effects to consumers. We explored whether fish-assemblage composition, species diversity, and the representation and richness of ecological guilds were associated with catchment land use in 31 estuaries in Victoria, Australia. Fish assemblages were surveyed using fyke and gill nets. Species were assigned to ecological guilds based on salinity associations and their use of estuaries, water column position and trophic characteristics. The Shannon diversity index, representation and richness of several marine-associated species and trophic guilds dominated by marine-associated species were positively related to tidal exchange, indicating the widespread influence of marine connectivity on estuarine fish assemblage and trophic structure. These patterns were driven by adult life stages. The richness and the proportion of demersal species in juvenile assemblages were negatively associated with the proportion of the catchment with land uses expected to elevate nutrient loads (e.g. animal production, horticulture, industry and urbanization). This relationship may reflect shifts in vegetated habitat, resource availability or changes in water quality induced by nutrient enrichment. Juvenile demersal fish show promise as an indicator of the effects of catchment land use on the structure of estuarine fish assemblages.

Wedge, M., Anderson, C. J., & DeVries, D. (2015). Evaluating the Effects of Urban Land Use on the Condition of Resident Salt Marsh Fish. *Estuaries and Coasts,* 38(6), 2355-2365. https://doi.org/10.1007/s12237-015-9942-6

Urbanization can impact coastal fisheries by reducing the quality of important habitats, including salt marshes. Similarly, increased urban land use surrounding tidal creeks can impact the health of fish by changing salinities, altering habitat structure, and increasing exposure to pollution. In this study, we investigated the effects of residential urban land use on the condition of salt marsh resident fish along the northern Gulf of Mexico. Fish were sampled seasonally using minnow traps along salt marshes near the mouth of six second-order tidal creeks (three surrounded by residential development and three surrounded primarily by forest) in Alabama and west Florida. *Fundulus grandis* and *Poecilia latipinna* were the dominant species representing 65 % (n = 3588) and 15 % (n = 777) of the total number of fish caught, respectively. All *F. grandis* and *P. latipinna* were evaluated for mass, length, and length-weight relationship. A subset (745 and 367, respectively) was further analyzed for conditional measures of caloric density and liver somatic index (LSI). The mass per length relationships did not differ between urban and reference creeks for either *F. grandis* or *P. latipinna*; however, reference creeks yielded *F. grandis* and *P. latipinna* that were significantly larger. Further, *F. grandis* and *P. latipinna* had significantly lower LSI and caloric density in urban creeks compared to reference. Both species showed seasonal patterns of conditional measures that were likely related to reproduction and annual fattening cycles. Differences in fish condition between urban and reference creeks may reflect differences in food availability/quality, creek salinity regimes, and salt marsh structure.

Yabsley, N. A., Gilby, B. L., Schlacher, T. A., Henderson, C. J., Connolly, R. M., Maxwell, P. S., & Olds, A. D. (2020). Landscape context and nutrients modify the effects of coastal urbanisation. *Marine Environmental Research,* 158, 104936. https://doi.org/10.1016/j.marenvres.2020.104936

Estuaries are focal points for coastal cities worldwide, their habitats frequently transformed into engineered shorelines abutting waters with elevated nutrients in an urbanised landscape. Here we test for relationships between shoreline armouring and nutrients on the diversity and trophic composition of fish assemblages across 22 estuaries in eastern Australia. Urbanisation was associated with fish diversity and abundance, but there were differences in the effects of shoreline armouring and nutrient level on the trophic composition of fish assemblages. Fish diversity and the abundance of most trophic groups, particularly omnivores, zoobenthivores and detritivores, was greatest in highly urban estuaries. We show that estuarine fish assemblages are associated with urbanisation in more nuanced ways than simple habitat transformation would suggest, but this depends on the broader environmental context. Our findings have wider implications for estuarine conservation and restoration, emphasizing that ecological benefits of habitat measures may depend on both landscape attributes and water quality in urban settings.