Mangroves: An Annotated Bibliography

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The following summative annotated bibliography was prepared to address current knowledge of the effects of mangroves, primarily red mangrove (*Rhizophora mangle)*, on stream mouth estuary structure, function, and water quality in Hawai`i. There is a paucity of research specifically addressing the relationship between mangroves and water quality in Hawai`i; however, water quality is addressed indirectly in mangrove studies conducted throughout their native range (Figure 1). It may not be prudent to extrapolate mangrove ecosystem services documented in other regions to Hawai`i because mangroves are not native to Hawai`i. Studies reviewed in this document that were conducted in Hawai`i were highlighted in green; those studies conducted in Hawai`i that specifically addressed mangroves were highlighted in blue. The remaining studies address mangroves throughout their range and are not highlighted. To date we have reviewed over 80 journal articles and technical report and additional literature is continually added to our database. None of the literature specifically addresses ecosystem services of mangrove wetlands in Hawai`i.

Global Distribution of Mangroves

Approximately 50 species of mangroves occur in tropical and subtropical environments, worldwide (Figure 1). Mangroves inhabit the intertidal zone of coastal environments with low wave energy. Mangroves are, for the most part, considered native species throughout their range except in Hawai`i and some parts of Polynesia. Woodroffe (1987) provides the distribution of mangrove taxa throughout Polynesia; Chimner et al. (2006) and D'iorio et al. (2007) use GIS to determine the extent and expansion of red mangroves on O`ahu and Molokai.

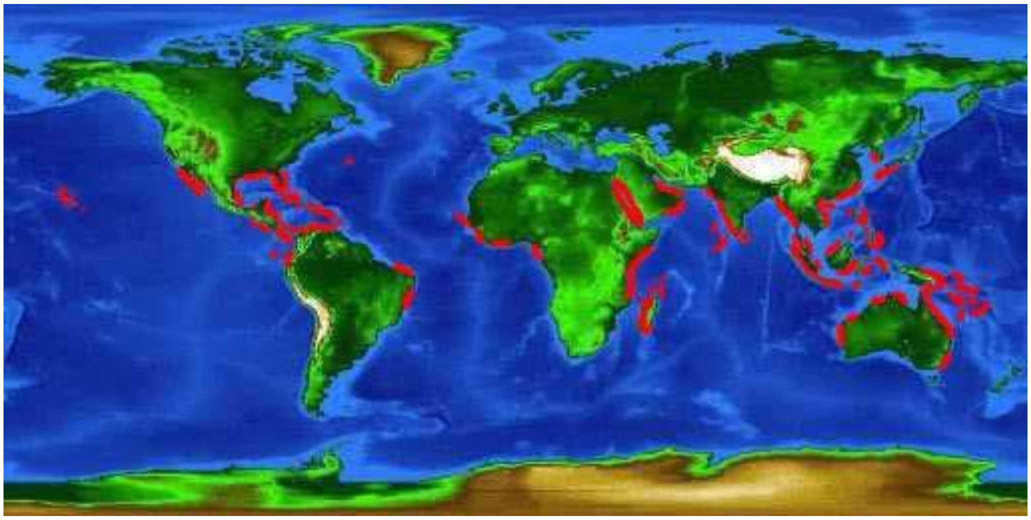

Figure 1. Mangrove Distribution Worldwide.
(http://www.flmnh.ufl.edu/fish/southflorida/mangrove/distribution.html)

Mangrove Ecosystem Services

The Millennium Ecosystem Assessment (MEA 2005) suggests that ecosystems provide a plethora of direct and indirect services to humanity (Figure 2). MEA did not distinguish between services provided by native and alien mangrove ecosystems. Mangrove wetlands, outside of Hawai`i, have been attributed a wide range of ecosystem services from improving water quality to supporting cultural values (Vo et al. 2012). In their native range, mangrove habitats are ecologically and geologically valuable coastal resources that harbor a great diversity of organisms, filter dissolved and particulate materials crossing the land-sea interface, and stabilize and protect eroding coastlines (Lugo and Snedaker 1974). The service of protecting coastlines was illustrated when coastal areas fringed by mangroves during the 2005 Asian tsunami exhibited less damage than cleared regions (Danielsen et al. 2006; Cochard et al. 2008).

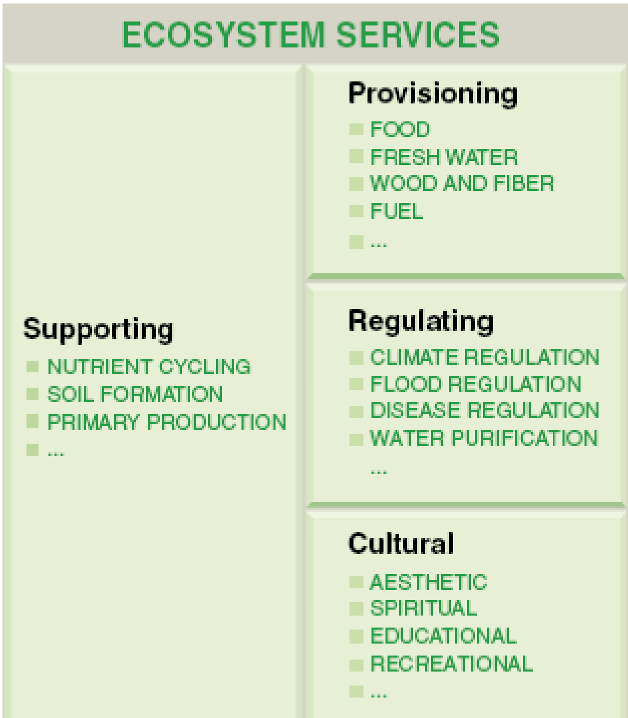

Figure 2. Ecosystem Services (MEA 2005)

The role of mangrove and seagrass ecosystems in buffering near shore coral habitats from land-based influences remains a topic of great debate even in their native range (Davis, Lierman and Wozniak 2009). Mangrove wetlands are generally considered to be net exporters of organic materials (Lee 1995); however, leaf litter from mangrove trees can also accumulate in tide pools and potentially lead to anoxic conditions through organic matter breakdown (Fronda et al.2008). McLeod et al (2011) suggest mangrove wetlands along with their marine corollaries, sea grass beds and salt marshes, are disproportionately important in sequestering carbon in comparison with other marine habitats.

Mangroves in Hawai`i

Mangroves were introduced to Hawai`i on the island of Molokai in the early 1900s to stabilize mudflats and reduce erosion (Allen 1998, Allen et al. 2000), one of many ecosystem services attributed to mangroves in their native ranges. After mangroves arrived they colonized tidal flats, riverbanks, fishponds, canals, protected reefs, embayments, lagoons and other low energy coastlines (Chimmer et al. 2006). Reportedly, their invasion and reduction of prime foraging and nesting habitat of four endangered waterbird species and overgrowth onto native Hawaiian archaeological sites e.g. fishponds has been especially problematic and costly to resource managers (Cox and Allen 1999).

Mangroves are unique in Hawai'i in that they are considered an alien, invasive species, commonly referred to as the "invasive marine weed tree" (http://www.malamaopuna.org/waiopae.php). The exotic red mangrove, *Rhizophora mangle*, has altered hydrological inputs, organic matter dynamics, sedimentation patterns, and invertebrate food webs along invaded Hawaiian coastlines as well as increased numbers of exotic invertebrates (D'Iorio 2003, Demopoulos et al. 2007, Demopoulos and Smith 2010, Sweetman et al. 2010). Many, although not all of these examples of effects of mangroves in Hawai`i, are considered ecosystem services in other parts of the world. It is unknown whether mangroves provide the same ecosystem services in Hawai`i as they do throughout the native range.

Differences in structure and function of mangroves are reflected in differences in their environmental setting, including the hydrological regime (Lei 2010). Ewel et al (1998) suggest that ecosystem services are dependent on the type of mangrove forest: fringe, riverine, and basin. Fringe mangroves primarily provide shoreline protection. Riverine forests, tuypically the most productive of the three types of forests, support animal and plant productivity, perhaps resulting from high nutrient concentrations associated with sediment trapping in this environmental setting. Basin forests serve as nutrient sinks for both natural and anthropogenically enhanced ecosystem processes (Ewel et al. 1998).

He`eia stream mangroves most closely resemble riverine mangrove wetlands and they may support high nutrient sediment concentrations, but are not necessarily nutrient sinks. Moreover, it is not clear whether non-native mangroves or the ecosystems occurring in Hawai`i prior to the arrival of mangroves provided greater ecosystem services. McKenzie and Kryss (2013) investigated the effect of mangroves on tide pool fish assemblages and found no significant differences among tide pools with mangroves, where mangroves had been removed, and control tide pools (mangroves were never established) in their ability to support native fish. Even in their native range, the role of mangroves in the fate of nutrients in sub-tropical estuaries is poorly understood (Twilley, Chen and Koch 1996).

Conclusions and Recommendations

Considering the dearth of data evaluating the effect of mangroves on water quality in streams and estuaries in Hawai`i, it is prudent to address management options at the next larger scale. In other words, evaluate management options at the ecosystem or in Hawai`i's case the watershed scale. The Ecological Society of America defines ecosystem management as "management driven by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem composition, structure, and function" (Norman et al. 1996). Others emphasize that sociopolitical, economic and cultural aspects of systems must also inform ecosystem management. An understanding of the linkages between social/cultural needs and ecosystem services in coastal zones has been largely absent in the scientific literature (Karrasch et al. 2014; Balvanera et al. 2012) although fully embraced by the Hawaiian community. The He`eia watershed, a NOAA Sentinel Site, has been nominated as a National Estuarine Research Reserve, and has active stewardship from multiple groups occurring throughout the watershed, provides a unique opportunity to not only inform ecosystem management in Hawai`i but to evaluate the role of mangroves on Hawai`i's coastlines.

In light of our review of the literature and our understanding of the current understanding of the role mangroves play in the He`eia watershed, it is our recommendation that the proposed project to remove mangroves from the mouth of He`eia stream be supported for the following reasons. These reasons are all founded in principles of ecosystem management and ecological engineering that attempt to integrate services of nature and humanity to the benefit of both. These reasons are not necessarily listed in order of importance.

1. In other regions, mangroves have been shown to affect hydrologic properties, e.g. stream flow. This suggests that stream flow and tidal mixing are likely diminished in the He`eia stream mouth. Restricted flow may reduce dissolved oxygen in surface water and sediment in areas where mangrove litter accumulates. Although the effects of anoxic conditions on habitat quality and nutrient cycling can be assessed, the effects are not clearly understood in Hawai`i's stream mouth estuaries. Flash floods, associated with winter rains, likely diminish the potential for riverine mangrove systems in Hawai`i to serve as a long term nutrient sink.
2. Mangrove negatively affect Hawaiian cultural resources. Paepae o He`eia is currently removing mangroves from and restoring the wall of a historical Hawai`ian fishpond. This wall constitutes one bank of the mouth of He`eia stream extending to the long bridge on Kamehameha highway. Moreover, Kākoʻo ʻŌiwi is removing mangroves on the mauka side of the long bridge on Kamehameha highway as they work with The Nature Conservancy and other organizations to restore the wetlands mauka of the bridge. Kākoʻo ʻŌiwi's efforts include not only reestablishing lo`i (taro patches) but investigating the role of lo`i in sediment and nutrient retention. The He`eia community is working together towards a goal of enhancing the ecological and cultural function of the He`eia watershed. The proposed project could be an important part of this effort. The full effect of these efforts will unlikely be realized if the proposed project does not move forward and mature mangroves remain in He`eia stream mouth providing a source of propagules for future reestablishment.
3. It is known that mangroves have established on mudflats in Hawai`i, including the mouth of He`eia stream and have reduced habitat for endangered waterbirds.

It is important to recognize that our recommendation is specific to the He`eia watershed; we are not recommending large scale removal of mangroves be undertaken in other Hawaiian systems. Our recommendation takes into account the many current efforts of a wide range of stakeholders to restore and enhance ecological and cultural function within the He`eia watershed. The stakeholders within the watershed are committed to removing mangroves to enhance cultural, aesthetic, recreational and natural services. The stakeholders include not only Hui O Koolaupoko, Hui ku Maoli Ola, He`eia State Park, Paepae o He`eia, Hawai`i Department of Health and Hawai`i Pacific University but also include Kākoʻo ʻŌiwi, University of Hawai`i, US Fish and Wildlife Service, National Oceanic and Atmospheric Administration. Although the role of mangroves in water quality is still debated, the reasons provided above overwhelm this uncertainty. If this project does not go forward, an opportunity to use He`eia stream mouth as a pilot project for adaptative ecosystem management of mangroves and an effort to understand the ecosystem services or disservices mangroves provide in Hawai`i will be lost.

Annotated Bibliography

1. **Ake-Castillo, J.A., Vazquez, G. and Lopez-Portillo, J. 2006. Litterfall and decomposition of *Rhizophora mangle, L.* in a coastal lagoon in the southern Gulf of Mexico. *Hydrobiologia* 559: 101-111**.

   Litter production and decomposition rates of *Rhizophora mangle* were studied in a mangrove estuary in Mexico. The authors reported seasonal peaks in litter production and decomposition that were similar to those found by other researchers in other regions.

2. **Alfaro, A. C. 2010. Effects of mangrove removal on benthic communities and sediment characteristics at Mangawhai Harbour, northern New Zealand. – ICES Journal of Marine Science 67: 1087–1104.**

   Mature mangrove habitats had less total abundance and fewer taxa than all the other habitats sampled and were dominated by pulmonate snails (*Amphibola crenata*) and mud crabs (*Helice crassa*). Mangrove eradication was followed by immediate changes in the sediment from a muddy to sandier environment, which favored an overall increase in the abundance of crabs, snails, and bivalves.

3. **Allen, J. A. 1998. Mangroves as alien species: the case of Hawai`i. *Global Ecology and Biogeography Letters*, 7, 61-71.**

   Mangroves were introduced in 1902 to stabilize coastal mud flats. At least two other associated species have established self- maintaining populations in Hawai`i (*Bruguiera gymnorrhiza* and *Conocarpus erectus*). Mangroves have reduced habitat quality for native birds, and have also proved to be problematic economically, damaging drainage systems and archaeological sites. It is important to note that coastal wetlands were altered before the introduction of mangroves and therefore mangroves may not be directly responsible for the eradication of native flora. Mangroves have been shown to stabilize sediment, improve water quality, serve as a nutrient sink, export organic matter, and provide coastal protection; however, in still water, mangroves may increase leaf litter, reduce water quality, and result in lower oxygen levels.

4. **Allen, J.A., K.W. Krauss, H.C. Duke, D.R. Herbst, O. Bjorkman and C. Shih. 2000. Bruguiera species in Hawai`i: Systematic considerations and ecological implications. Pacific Science 54:331-343.**

   Rhizophora mangle, *Bruguiera gymnorrhiza*, *Conocarpus erectus*, *and B. parviflora* along with at least one related mangrove species were introduced to Hawai`i. *R. mangle* is the most common species. The author's provide an overview of two introduced mangrove species in Hawai`i, *Bruguiera gymnorrhiza* (aka *B. sexangula*) and *B. parviflora*.

5. **Allen, J. A. and K.W. Krauss. 2006. Influence of propagule flotation longevity and light availability on establishment of introduced mangrove species in Hawai`i. Pacific Science 60:367-376.**

   Establishment of *Rhizophora mangle* and *Brubuiera sexangula* were compared with respect to propagule flotation longevity and light availability. Factors other than flotation ability are responsible for the failure of *B. sexangula* to become on established on islands other than Oahu.

6. **Alongi, D.M. 2002. Present state and future of the world's mangrove forests. Environmental Conservation 29:331-349**

   Mangrove deforestation is directly related to human population and is a concern throughout mangrove's natural range. Mangroves are a valuable ecological and economic resource. They are important nursery grounds and breeding sites for birds, fish, crustaceans, shellfish, reptiles and mammals; a renewable source of wood; accumulation sites for sediment, contaminants, carbon and nutrients; and offer protection against coastal erosion.

7. **Aumann, C.A., L.A. Eby, and W.F. Faban. 2006. How transient patches affect population dynamics: the case of hypoxia and blue crabs. Ecological Monographs 76:415-438.**

   Aumann et al. modelled the interactive effects of hypoxic extent v. static and transient patches, hypoxic extent vs. pray abundance and hypoxic extent vs. cannibalism in blue crabs. They found static and transient patches of hypoxia resulted in different mechanisms for changes in population dynamics. Static patches resulted in populations limited by egg production and recruitment. Transient patches led to populations limited by cannibalism. The authors report from existing literature that the maximum amount of total estuarine hypoxia is 40% to 60 % during the summer. The median time the deepest areas remain continuously hypoxis is ~ 9 days (See Selberg et al. 2001, Buzzelli et al. 2002)

8. Patricia Balvanera, María Uriarte, Lucía Almeida-Leñero, Alice Altesor, Fabrice DeClerck, Toby Gardner, Jefferson Hall, Antonio Lara, Pedro Laterra, Marielos Peña-Claros, Dalva M. Silva Matos, Adrian L. Vogl, Luz Piedad Romero-Duque, Luis Felipe Arreola, Ángela Piedad Caro-Borrero, Federico Gallego, Meha Jain, Christian Little, Rafael de Oliveira Xavier, José M. Paruelo, Jesús Emilio Peinado, *et al. Ecosystem Services*, *Volume 2*, *December 2012*, *Pages 56-70*

9. **Barbier, E. B. 2000. Valuing the environment as input: review of applications to mangrove-fishery linkages. *Ecological Economics*, 35, 47-61.**

   Barbier discusses the extent of input of mangroves to fisheries based on the forests functioning as breeding grounds and nurseries and presents two methods for valuation of the environment as an input to the economy. He shares a case study from southern Thailand and another from Mexico.

10. **Barletta, M., U. Saint-Paul, A. Barletta-Bergan, W. Ekau, and D. Schories. 2000. Spatial and temporal distribution of *Myrophis punctatus* (Ophichthidae) and associated fish fauna in a northern Brazilian intertidal mangrove forest. Hydrobiologia 426:65-74.**

    Fish total density was 2.8 ind m^{-2} and total biomass 17.4 g m^{-2}. Fish densities did not differ among areas; however, fish biomass differed significantly in time and space.

11. **Barletta, M., A. Barletta-Bergan, U. Saint-Paul, and G. Hubolds. 2005. The role of salinity in structuring the fish assemblages in a tropical estuary. Journal of Fish Biology 66:45-72.**

    Mean fish density and biomass for the Caete´ River estuary channel was 0.25 individuals m^{-2} and 0 .9 g m^{-2}, respectively. The number of species, total density and total biomass differed significantly between areas and seasons. For the most important species, the mean density of differed significantly between seasons while the meandensity of other species did not.

12. **Beck, M.W., K.L.Heck, K.W. Able, D.L Childers, D.B. Eggleston, B.M.Gillanders, B. Halpern, C.G. Hays, K. Hoshino, T.J. Minello, R.J. Orth, P.F. Sheridan and M.P. Weinstein. 2001. The identification, conservation, and management of estuaries and marine nurseries for fish and invertebrates. *Bioscience*. 51(8): 633-641.**

    This article explores the nursery-role as an ecological concept as it applies to coastal aquatic habitats including estuaries and mangroves. The authors state that there is a lack of studies examining the movement of juveniles from “nursery” habitat to “adult” habitats. The authors describe a nursery habitat as “any habitat that makes a greater than average contribution to the recruitment of adults”. The authors suggest that the nursery-habitat distinction should be based on four factors: density, growth, survival and movement. Authors state that a more quantitative and accurate distinction of nursery habitats can help to better value and manage coastal areas.

13. **Blaber, S.J.M, and T.G. Blaber. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. Journal of Fish Biology 17:143-163**

    The purpose of this study was to identify factors influencing the distribution of juveniles, particularly the species which enter estuaries in Australia. Four habitats were sampled. Salinity, temperature and turbidity were evaluated. Salinity and temperature were not important to most species. All species preferred shallow water. Turbidity was the most important factor for juveniles entering the estuary. The authors suggest that many species are attracted to shallow turbid areas rather than simply estuaries.

14. **Blasco, F., P. Saenger, and E. Janodet. 1996. Mangroves as indicators of coastal change. Catena 27:167-178.**

Minor variations in hydrological and tidal regimes cause mangrove mortality. Each species exists in a narrow range of salinity in water and soil and inundation regime. These conclusions were drawn from data reported at several locations including Guiana, Gambia, Cote d'Ivoire, Kenya, India and Bangladesh.

15. **Borja, A., S.B. Bricker, D. M. Dauer, N.T. Demetriades, J.G. Ferreira, A.T. Forbes, P. Hutchings, X. Jia, r. Kenchington. 2008. Overview of integrative tools and methods in assessing ecological integrity in estuarine and coastal systems worldwide. Marine Pollution Bulletin. 56: 1519-1537.**

    This article highlights the advantages of an ecosystem-based approach (EBA) for assessment of coastal and estuarine habitats. Low level of dissolved oxygen is characterized as a "secondary symptom" of euthrophication.

16. **Boswell, K.M., Wilson, M.P. and Wilson, C.A. 2007. Hydroacoustics as a tool for assessing fish biomass and size distribution associated with discrete shallow water estuarine habitats in Louisiana. *Estuaries and Coasts*. 40(4): 607-617.**

    The authors compare biomass data obtained by bioacoustics methods to gill-net and trawl capture methods. Results showed higher biomass of the ecosystem in lower salinity areas than in higher salinity areas. The results also show similar data when collected with each of the three methods but that the acoustic method has a lower rate of larger fish that may be too close to the substrate to accurately measure with acoustics. This article supports the use of hydroacoustics for assessing fish distribution in shallow (>5m) water habitats.

17. **Bowman, H.H.M. 1917. Ecology and physiology of the red mangrove. Proceedings of the American Philosophical Society. 56:589-672.**

    Bowman investigated the growth habits of the mangroves, the character of the bottoms on which they grew, the depth relations, tidal effects, flowering and fruiting conditions, growth rates, growth habits, water densities, dimensions of roots and aerial structures, heights of trees and general distribution around Key West, Florida.

18. **Brasher, A.M.D. 2003. Impacts of human disturbances on biotic communities in Hawaiian streams. *BioScience*, 53, 1052-1060.**

    Brasher reports that increasing human populations on tropical islands are introducing nonnative species, diverting water, modifying stream channels, and reducing flow in natural rivers. Although he reports that this has resulted in lower water quality and degraded physical habitats for many native stream species no water quality data is provided except for water temperature in four urban and three forested streams. Brasher suggested species richness and diversity are higher in degraded streams; however, no statistical analyses were conducted to support this claim. A trend in a reported decrease invertebrate abundance in urbanized streams shows a more easily discernible pattern.

19. Brasher, A.M.D. and Wolff, R. H. 2004. Relations between land use and organochlorine pesticides, PCBs and Semi-volatile compours in streambed sediment and fish on the island of Oahu, Hawai`i. Arch. Environ. Contam. Toxicol. 46:385-398.

Data were collected from 27 sites around the island of Oahu (representing urban, agricultural, mixed, and forested land use). Of the 28 organochlorine compounds analyzed in the fish, 14 were detected during this study. Nineteen of the 31 organochlorine compounds and 40 of the 65 SVOCs were detected in the sediment. Urban sites had the highest number of detections and tended to have the highest concentrations of pesticides. Although addressing contaminants in water, sediment and fish in Hawaiian streams the authors did not correlate their finding to the presence or absence of mangroves.

20. Brasher, A.M.D., Wolff, R. H. and Luton, C. D. 2004. Associations among land-use, habitat characteristics, and invertebrate community structure in nine streams on the island of Oahu, Hawai`i. *USGS Water-Resources Investigators Report*, 1-48.

This paper describes the advantages of sampling macroinvertebrates for bioassessment and biomonitoring. The study spanned over 10 sites in 9 streams on Oahu during summers of 1999-2001. They determined associations between land use, habitat characteristics (physical and chemical), and benthic invertebrate community structure. The paper describes the physiography and climate of Oahu, and then goes on to talk about drainage basin and streamflow characteristics. They categorize land-use into urban, agricultural, or forested and discuss the physical and chemical effects of altered stream reaches. They discuss native species and the introduction of nonnative species. They chose sites based on dominant land-use. Invertebrate samples were collected following standard NAWQA protocols using a modified Surber sampler/Slack sampler in “richest targeted habitat” (i.e. riffles). A D-frame kick net was used to collect qualitative samples from all available habitats at each site. Habitat characteristics classification and water quality also followed standard NAWQA protocols. Streamflow, temperature, discharge, and water chemistry were measured at each site. Bank angle, erosion, and canopy cover were measured along perpendicular transects to the stream flow. Aspect, wetted perimeter, depth, velocity, and substrate size were also recorded. Depth and velocity were measured at the microhabitat of each sample. They used a multivariate and nonparametric analyses and diversity indices. Diptera and Trichoptera were the dominant insect groups (ratio).

21. Buzzelli, C. P., R. A. Luettich, Jr., S. P. Powers, C. H. Peterson, J. E. McNinch, J. L. Pinckey, and H. W. Paerl. 2002. Estimating the spatial extent of bottom-water hypoxia and habitat degradation in a shallow estuary. Marine Ecology Progress Series 230:103-112.

Salinity stratification and water temperature explained respectively 30 and 23% of the variance in bottom-water DO concentrations in a shallow Neuse River estuary in North Carolina.

22. **Carter, M. R., Burns, L. A. and Cavinder, T. R. 1973. Ecosystems analysis of the big cypress swamp and estuaries. *USEPA*, 1-479**

    Extensive techniques/methods for community metabolism/productivity of mangrove forest. Compared with Golley, Lugo, Miller, and Snedaker data to compare different mangrove ecosystems in Florida and Puerto Rico.

23. **Chen, R. and Twilley, R.R. 1999. A simulation model of organic matter and nutrient accumulation in mangrove wetland soils. *Biogeochemistry*. 44:93-118.**

    This study uses sediment cores to evaluate organic matter decomposition and accumulation as well as the levels of carbon, nitrogen and phosphorus in mangroves soils for Red Mangroves, *Rhizophora mangle* in Florida. This article reviews and lists many published formulas for quantifying the sediment nutrient content and decay rates for leaf litter, wood debris and soil decomposition. There are also several figures included that list the parameters used for the NUMAN model which is an accepted model for studying coastal sediment. Concentrations of organic matter increased from the estuary “downstream” locations of samples collected to the “upstream” region whereas the bulk density of organic materials were highest in the “downstream” areas and lowest in the “upstream” areas.

24. **Chesney, E.J., Baltz, D.M., and Thomas, R.G. 2000. Louisiana estuarine and coastal fisheries and habitats: perspectives from a fish’s eye view. *Ecological Applications*. 10(2): 350-366.**

    This paper is essentially a literature review. Though this study focuses on Louisiana marshes and fisheries, it provides meaningful insight about some of the abiotic factors that may affect nekton and general ecology in coastal systems. Authors discuss turbidity effects on fishery productivity and that microtidal systems may enhance the nursery function of estuaries by harboring nekton. Author discusses both benefits and detriments to hypoxic environments to estuarine systems.

25. **Chimner, R. A., Fry, B., Kaneshiro, M. Y. and Cormier, N. 2006. Current extent and historical expansion of introduced mangroves on Oahu, Hawai`i. *Pacific Science*, 60, 377-384.**

    Chimner et al. use GIS to assess mangrove cover and the rate at which mangroves have expanded on Oahu from 1951 – 2001. Mangroves colonized tidal flats, riverbanks, fishponds, canals, protected reefs, embayments, lagoons and other low energy coastlines.

26. Cochard, R, S. L. Ranamukhaarachchi, G. P. Shivakoti, O V. Shipinb, P. J. Edwards, and K T. Seeland. 2008. The 2004 tsunami in Aceh and Southern Thailand: A review on coastal ecosystems, wave hazards and vulnerability. Perspectives in Plant Ecology, Evolution and Systematics 10:3–40.

    The authors review the role of coastal ecosystems in mitigating sea wave hazards.

27. Cox, E.F. and J.A. Allen. 1999. Stand structure and productivity of the introduced *Rhizophora mangle* in Hawai`i. Estuaries 22:276-284.

Mangroves throughout the tropics are valued for their ecosystems services, only in Hawai`i are they considered to have negative impacts. They invade and reduce prime foraging and nesting habitat for four endangered waterbird species and they overgrow native Hawaiian archaeological sites (fishponds). This study documents the overall productivity and propagule production of a small stand of the alien R. mangle on the Mokapu peninsula. The authors report density, dbh, above ground biomass, and leaf damage.

28. Crowder, L.B. and Eby, L.A. 2004. Effects of hypoxic disturbances on an estuarine nekton assemblage across multiple scales. *Estuaries*. 27(2): 342-351

Hypoxia was defined as less than or equal to 2.0mg/liter dissolved oxygen concentration. Authors trawled in the study area subsampling stations that were 0.5-0.75 meters apart and would randomly subsample about 32 stations per day. All fish caught in the trawl were identified and counted. Temperature, salinity, conductivity, depth and dissolved oxygen were collected before and after trawls using a CTD. Partial Mantel tests were used to calculate correlations between variables of assemblage structure and environmental variables. At times, low levels of dissolved oxygen covered 60% of the study area but these areas were typically in deeper waters and tended to fluctuate with seasons. Species richness and diversity was highest in deeper waters when the estuary was well-oxygenated but seemed to aggregate in shallow waters when hypoxic conditions were present, with lower species richness and diversity overall during hypoxic times. These seemed to only be small-spatial-scale trends and were only evident at the station-level and not study-area level. Authors state that changes in distributions associated with hypoxia may have population level effects such as decreased growth rates for juvenile fish and also may cause a larger than normal overlap between predator and prey species.

29. Cuddihy, L. W. and C.P. Stone. 1990. Alteration of native Hawaiian vegetation: effects of humans, their activities and introductions. Honolulu, HI: University of Hawai`i, Cooperative National Park Resources Studies Unit.

A detailed explanation of how Hawaiian coastal vegetation has been altered for millennia, beginning with the Polynesian settlement around 400 A.D. and into the European settlement. Plant and animal introductions are traced back to their origin and their effect on the land is examined.

30. Danielsen, F. M.K. Sorensen, M.F. Olwig, V Selvam, F. Parish, N.D. Burgess, T. Hiraishi, V. M. Karungaran, M.S. Rasmussen, L.B. Hansen, A.Quarto, and N. Suryadiputra. 2005. The Asian Tsunami: A Protective Role for Coastal Vegetation. Science 310:643

The authors report the protective role of coastal vegetation in ameliorating the impacts of the ocean waves by reducing amplitude and energy.

31. Davis, S.E., D. Lirman, and J.R. Wozniak. 2009. Nitrogen and phosphorus exchange among tropical coastal ecosystems. In: Ecological Connectivity Among Tropical Coastal Ecosystems, Nagelkerken**, Ivan. editor. Springer; 2010 edition.**

The role mangrove and seagrass ecosystems play in buffering nearshore coral habitats from land-based influences remains a topic of great debate. The author's discuss N and P water column concentrations and system-level exchanges (i.e., water-mediated fluxes and nutrient loading) from the literature. N and P concentrations in mangroves reported in the literature are provided.

32. Demopoulos, A.W.J. 2004. Aliens in paradise: a comparative assessment of introduced and native mangrove benthic community composition, food-web structure and litter-fall production. Dissertation

Mangrove benthic community ecology was compared between a native mangrove forest in Micronesia and the introduced mangrove forest in Hawai`i. Demoupoulos suggests that the few native detritivores in Hawai`i rely on mangrove leaves. Furthermore, introduced mangrove forests in Hawai`i export a greater proportion of the litter when compared to native mangrove forests in Puerto Rico. She suggest this may be a consequence of stand age and as Hawai`i's mangrove stands age they may more closely resemble native mangrove forests elsewhere.

33. Demopoulos, A.W.J., Fry, B., and Smith, C.R. 2007. Food web structure in exotic and native mangroves: a Hawai`i- Puerto Rice comparison. *Oecologia*. 153:675-686.

The authors use stable isotope analysis to examine the food web structure of detritivores in native and non-native mangrove estuaries. The data from sediment analysis show that detritivores in non-native mangrove habitats do not seem to feed on detritus from mangroves. Authors state that non-native mangrove detritus is poorly utilized by invertebrates in this ecosystem and this may be due to the poor nutritional value or to the high levels of tannin. The authors suggest that the reduced use of mangrove detritus as a food source may be a function of forest age.

34. Demopoulos, A.W., and C.R. Smith. 2010. Invasive mangroves alter macrofaunal community structure and facilitate opportunistic exotics. Marine Ecology Progress Series 404:51-67.

Mangrove sites, one on Oahu and one on Molokai were compared to nearby sandflats considered "control" sites. These control sites are questionably comparable to the mangrove sites. This study investigated habitat parameters (sediments) and macrofaunal community structure. Systems with mangroves were compared to sandflat controls. Higher densities of non-native macrofauna were found in mangroves; however, mangrove habitats had higher macrofaunal species richness and diversity. Introduced mangroves altered benthic community construct compared to sand flats.

35. **D'iorio, M., Jupiter, S. D., Cochran, S. A. and Potts, D. C. 2007. Optimizing Remote Sensing and GIS Tools for Mapping and Managing the Distribution of an Invasive Mangrove (Rhizophora mangle) on South Molokai, Hawai`i. Marine Geodesy, 30,125-144.**

This paper compares the accuracy of different techniques for mapping mangrove distributions and outlines the advantages and disadvantages of each. The introduction provides useful and important background information about the role of the Red Mangrove in Hawai`i.

36. Department of Land and Natural Resources. 2010. Oahu coastal stream mouth map book. University of Hawai`i.

Describes the stream mouth estuaries on Oahu. Provides background, site descriptions, maps and imagery.

37. Dorenbosch, M. 2006. Connectivity between fish assemblages of seagrass beds, mangroves, and coral reefs. *Radboud University Nijmegen*, 219 pp.

This book is a compilation of M. Dorenbosch's work, all of which were papers published in peer-reviewed journals.

38. Dorenbosch M, van Riel MC, Nagelkerken I, and van der Velde G. (2004) **The relationship of reef fish densities to the proximity of mangrove and seagrass nurseries. Estuarine Coastal and Shelf Science 2004 60:37-48.**

The authors investigated the relationship of reef fish densities to the proximity of mangrove and seagrass nurseries. They found results differed by species.

39. Dorenbosch, M., Verberk, W., Nagelkerken, I. and van der Velde, G. 2007. Influence of habitat configuration on connectivity between fish assemblages of Caribbean seagrass beds, mangroves, and coral reefs. *Marine Ecology Progress Series*, 334, 103-116.

This study uses underwater visual census to determine juvenile fish usage of mangrove habitats in relation to reef location. They also examine fish assemblages on reefs with varying proximity to mangroves. It was found that habitat configuration in relation to the reef was related to fish community structure, diversity, and fish density and size. Accessibility and complexity of the mangrove habitats played a role in these data. Many fish species that utilize mangrove nurseries were at reduced densities on reefs further than 9 km away.

40. **Englund, R.A. 2002. The Loss of Native Biodiversity and Continuing Nonindigenous Species Introductions in Freshwater, Estuarine and Wetland Communities of Pearl Harbor, Oahu, Hawaiian Islands. *Estuaries*. 25(3): 418-430.**

    This study was performed with samples from Pearl Harbor. The author details several methods for catching invertebrates and fishes in estuarine communities. The author used a combination of several methods including aerial sweep nets, aquatic dip nets, gill nets, seines and benthic samplers. Benthic communities in soft-sediment were sampled using a dredge and then sieved. The study found a non-significant trend in the number of native species increased as salinity increased.

41. **Englund, R. A., Arakaki, K., Preston, D. J., Coles, S. L. and Eldredge, L. G. 2000. Nonindigenous freshwater and estuarine species introductions and their potential to affect sportfishing in the lower stream and estuarine regions of the south and west shores of Oahu, Hawai`i. *Hawai`i Biological Survey*, 2000-002, 1-133**

    Discusses the impact of introduced species in Hawai`i and provides descriptions of introduced aquatic and estuarine species that were collected during the study on the south and west shores of Oahu. The authors provide thorough site descriptions of 24 streams, with many containing mangroves. It was found that several introduced species, even recent introductions, were associated with mangrove habitats on Oahu.

42. **Englund, R. A. and Godwin, L. S. 2002. Non-insect aquatic invertebrate surveys of four windward Oahu stream systems impacted by the Waiahole Ditch. *Hawai`i Biological Survey*, 2003-13, 1-41.**

    The report determines community composition after a disturbance. This is an old disturbance, and thus the purpose was to establish a new baseline.

43. **Englund, R. A., Imada, C., Preston, D. J. and Arakaki, K. 2003. Kane'ohe Bay, O'ahu stream estuary studies. *Hawai`i Biological Survey*, 2003-13, 1-41.**

    Ten streams were sampled for riparian vegetation including mangroves, stream substrate, and habitat condition for native aquatic organisms. Insects, fish, crustaceans, amphibians, and reptiles were sampled at each site. A list of species that were found is provided along with their geographic status.

44. **Englund, R. A., Wright, M. G. and Polhemus, D. A. 2007. Aquatic insect taxa as indicators of aquatic species richness, habitat disturbance, and invasive species impacts in Hawaiian streams. *Bishop Museum Bulletin in Cultural and Environmental Studies*, 3, 2007-232.**

    The study explains why the IBI is not sufficient in Hawai`i. They also determine the efficacy of using indicator, flagship, and umbrella species. The author's do not address mangroves.

45. Ewel, K.C., Twilley, R.R., and Ong, J.E., 1998, Different kinds of mangrove forests provide different goods and services: Global Ecololgy & Biogeographical Letters 7, p. 83-94.

Ewel et al. discuss the varying ecosystem services provided by fringing, riverine, and basin mangrove forests.

46. Field, C. B., Osborn, J. G., Hoffman, L. L., Polsenberg, J. F., Ackerly D. D., Berry, J. A., Bjorkman, O., Held, A., Matson, P. A. and Mooney, H. A. 1998. Mangrove biodiversity and ecosystem function. *Global Ecology and Biogeography Letters*, 7, 3-14.

Discusses how a mangrove forest may influence biodiversity, biogeochemical processes, ecology, and even anthropogenic activities of that habitat.

47. Fondo, E. N. and Martens, E. E. 1998. Effects of mangrove deforestation on macrofaunal densities, Gazi Bay, Kenya. *Mangroves and Salt Marshes*, 2, 75-83.

Crabs are the dominant macrofauna in mangrove forests and feed on leaf litter. To assess the differences in macrofauna distribution and abundance, areas of natural mangroves were compared with deforested areas in Gazi Bay on the south coast of Kenya. Two transects in the two areas were laid out and epifauna were sampled using an aluminum drop trap. Crabs were excavated from their burrows. Infauna were collected by obtaining sediment using a shovel. Processing of macroinvertebrate methods are clearly outlined. A chi-square test was used to assess the difference between the two areas and a Pearsons relation coefficient was used to relate macrofaunal densities and environmental properties. A significant difference was found in the distribution of epifauna and infauna in the two areas. Higher densities of epifauna were present in the natural mangrove forest, however infauna densities did not change significantly. It was concluded that community composition in mangrove forests changes in relation to vegetation cover and substratum.

48. Fry, B. and K.C. Ewel. 2003. Using stable isotopes in mangrove fisheries research - a review and outlook. Isotopes in Environmental and Health Studies 39:191–196

Fry and Ewel reported findings that reflect a lack of mangrove importance in local foodwebs and that production of benthic algae at the Puerto Rico site was estimated to equal mangrove production

49. Fronda, R., M. Lane-Kamahele and B. Harry. 2008. Removal of alien red mangrove from Kaloko-Honokohau National Historical Park. Pacific Cooperative Studies Unit Technical Report 162, University of Hawai`i at Manoa, Department of Botany, Honolulu, HI.

Frondo et al. summarize efforts to remove *Rhizophora mangle* from Kaloko-Honokohau. The focus is on methods for removal and maintenance requirements. Removal efforts are driven by protecting Honokohau fish pond. The author's do not address physico-chemical or biological responses to mangrove presence or removal.

50. Fry, B. and Cormier, N. 2011. Chemical ecology of Red Mangroves, Rhizophora Mangle, in Hawai`i. Pacific Science 65:219-234.

The authors sampled mangroves on dry leeward coasts of southern Molokaʻi and Oʻahu during 2001 – 2002 for 14 leaf variables including stable carbon and nitrogen isotopes (δ13C, δ15N), macronutrients (C, N, P), trace elements (B, Mn,Fe, Cu, Zn), and cations (Na, Mg, K, Ca). Modelling indicated two times higher productivity for mangroves in urban versus rural settings, with rural mangroves more limited by low N and P nutrients and high-nutrient urban mangroves more limited by freshwater inputs and salt stress.

51. Golley, F. B., Odum, H. T., Wilson, R. F. 1962. The structure and metabolism of a Puerto Rican red mangrove forest in May. *Ecology*, 43, 9-19.

This paper provides important background information, including habitat range and description and biology of the native Red Mangrove.

***52.* Gurtz, M.E. 1994. Design of biological components of the National Water-Quality Assessment Program, in Loeb, S.L., and Spacie, Anne, eds.*, Biological monitoring of aquatic systems: Boca Raton, Lewis Publishers, CRC Press, Inc*. 187–215.**

Describes the program and methods used by USGS to determine the condition and trends of water resources nationwide.

53. Higashi, G. R. and Nishimoto, R. T. 2007. The point quadrat method: a rapid assessment of Hawaiian streams. *Bishop Museum Bulletin in Cultural and Environmental Studies*, 3, 305-312.

Describes the point quadrat method used by DAR to count stream fish and invertebrates. The database contains this data since 1960. The paper claims the technique to be the best method for this data collection and provides efficient and accurate data, however human error, visibility, and environmental conditions seem to be major sources of error. If this method is used, conditions should be kept constant, however this would limit sampling days.

54. Kairo, J. G., Dahdouh-Guebas, F., Bosire, J. and Koedam, N. 2001. Restoration and management of mangrove systems – a lesson for and from the East African region. *South African Journal of Botany*, 67, 383-389.

Describes the extent of mangroves and their importance worldwide. Shrimp ponds are a major threat to mangrove forests in east Africa. Extensive mangrove planting and management has occurred in India and Malaysia to exploit the trees for wood products. They have also been managed for integrated fish culture, eco-tourism, and erosion control. A table describes the value of mangroves at the community, national, and global levels. Cites a source (Ellison 2000) that reviews the literature on mangrove plantation establishments with mixed success of restoration efforts. Discusses the advantages and disadvantages of two approaches to mangrove forest restoration. A table describes what parameters should be monitored following restoration. It was found that faunal composition and diversity changed following restoration efforts in Kenya.

55. **Kido, M. H. 2008. A persistent species assemblage structure along a Hawaiian stream from catchment-to-sea. *Environ Biol Fish,* 82, 223-235.**

Describes the consistent zonation of species in one river over a 6 year period.

56. **King, R., Turner, C., Dacles, T., Solandt, J. L. and Raines, P. unpublished. The mangrove communities of Danjugan Island, Cauayan, Negros Occidental, Philippines. Submitted to Silliman Journal.**

King describes the role of the native Red Mangrove in the Philippines. It was found that fish and shrimp near shore yields were directly correlated with relative densities of mangroves.

57. **Kobayashi. D.R. 1989. Fine-scale distribution of larval fishes: patterns and processes adjacent to coral reefs in Kaneohe Bay, Hawai`i. Marine Biology 100:285-293.**

Kobayashi reported greater larval fish densities near reefs, adult fish habitats, than away from reefs. He suggests that larger scale students may under estimate the importance of near shore larvae.

58. **Levin, L. A., Boesch, D. F., Covich, A., Dahm, C., Erseus, C., Ewel, K. C., Kneib, R. T., Moldenke, A., Palmer, M. A., Snelgrove, P., Strayer, D. and Weslawski, J. M. 2001. The function of marine critical transition zones and the importance of sediment biodiversity. *Ecosystems*, 4, 430-451.**

Estuaries are critical transition zones (CTZ) that provide ecological functions such as decomposition, nutrient cycling and production, and regulation of nutrients, water, particles, and organisms. Sediment-associated biota are essential to these processes, and are classified into functional groups. Among these groups are benthic invertebrates. Threats to CTZs include pollution, eutrophication, species introductions, overfishing, habitat alteration, and climate change. Diversity is typically low in CTZ sediments, indicating that any shift in diversity is significant. The authors describe the flow of organic matter from mangrove forests to the coastal ocean and input into the detrital food web. Table 1 describes ecosystem functions in CTZs and potential functional groups driving the processes. Discusses several ecological roles of mangrove forests and the overall web they contribute to. Discusses benthic invertebrate composition of mangrove forests and zonation of mangrove species. The authors also call for further research into possible effects of the invasive mangrove.

59. **Lewis, R. R. III 2005. Ecological engineering for successful management and restoration of mangrove forests. *Ecological Engineering*, 24, 403-418.**

Mangrove wetlands are often temporarily used to collect eroded soil and raise intertidal areas to usable terrestrial agricultural uses. Previous research has documented the general principle that mangrove forests worldwide exist largely in a raised and sloped platform above mean sea level, and inundated at approximately 30%, or less of the time by tidal waters.

60. Lugo, A. E. and Snedaker, S. C. 1974. The ecology of mangroves. *Annual Review of Ecology and Systematics*. 39-64.

This paper summarizes findings of other studies for leaf litter and describes its importance in the ecosystem and the factors affecting it. They mention the role of invertebrates as decomposers and describe the functional role of mangroves as import of terrestrial inorganic compounds and export of organic products to the sea. Several studies are mentioned that measure community metabolism via carbon dioxide exchange in an ecosystem and is used to compare ecosystems. Can measure p. 48 (Golley, Odum, Wilson)?

61. MacCaughey, V. 1917. The mangrove in the Hawaiian islands. *The Hawaiian Forester and Agriculturalist*, 14, 361-366.

Dated 1917, the author describes the Hawaiian coasts as lacking arborescent vegetation and claims that the perfectly suited environment would benefit from the introduction of mangroves. The paper mentions what may have been the first tree in Hawai`i and the first seeds brought over. It also provides detailed biology and facts about the mangrove.

62. Maciolek, J.A. and Timbol, A.S. 1982. Environmental features and macrofauna of Kahana Estuary, Oahu, *Hawai`i. Bulletin of Marine Science*. 31(3):712-722.

This paper discusses a study done from May 1969-May 1971 with weekly sampling in Kahana Bay. Authors also used a 5X2m seine net to sample biodiversity. Water quality measurements and catch descriptions are discussed. The results show large differences in dissolved oxygen levels during the day and night samples, showing significantly lower nocturnal DO levels. Occurrence of at least 18 species of fish only present as juveniles supports the idea of Hawaiian estuaries are nursery habitats.

63. Macnae, W. and Kalk, M. 1962. The ecology of the mangrove swamps of Inhaca Island, Mozambique. *J. Ecol.*, 50, 19-34.

Describes the zonation of fauna in a native mangrove forest. This native ecological system can be compared to Hawaiian mangroves non-native system.

64. MacKenzie, R.A. and C.L. Kryss. 2013. Impacts of exotic mangroves and chemical eradication of mangroves on tide pool fish assemblages. Marine Ecology Progress Series 472: 219–237,

Data suggest that exotic mangroves in Hawai`i are not having an adverse effect on native fish assemblages in tide pools, and may actually provide nursery habitat for native and exotic fish.

65. Millennium Ecosystem Assessment (MEA), 2005. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.

This report assessed the consequences of ecosystem change for human well-being and established the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. The assessment focused on the linkages between ecosystems and human well-being and, in particular, on "ecosystem services."

66. Miller, P. C. 1972. Bioclimate, leaf temperature, and primary production in red mangrove canopies in south Florida. *Ecology*, 53, 22-45.

Miller discusses the ecology of a native mangrove forest in Florida. This native ecological system can be compared to Hawaiian mangroves non-native system.

67. Mumby P. J., Edwards, A. J., Arias-Gonzalez, J. E., Lindeman, K. C., Blackwell, P. G., Gall, A., Gorczynska, M. I., Harborne, A. R., Pescod, C. L., Renken, H., Wabnitz, C. C. C. and Llewellyn, G. 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Letters to Nature*, 427, 533-536.

This report presents the biomass (kg km^{-2}) for several species of fish on patch, shallow, and Montastraea reefs with scarce and rich mangroves. The purpose of this report is to illustrate the decline in fish species after mangrove deforestation.

68. Nagelkerken, I., Blaber, S. J. M., Bouillon, S., Green, P., Haywood, M., Kirton, L. G., Meynecke, J. –O., Pawlik, J., Penrose, H. M., Sasekumar, A. and Somerfield, P. J. 2008. The habitat function of mangroves for terrestrial and marine fauna: a review. Aquatic Botany, 89, 155-185.

This paper describes the food web and habitats in a mangrove forest. They suggest that the distribution of infauna may be due to physical parameters such as tannin levels, anoxic conditions, or amount of leaf litter.

69. Nagelkerken, I., Roberts, C. M., A.N., van der Velde, G., Dorenbosch, M., van Riel, M. C., Cocheret de la Moriniere, E. and Nienhuis, P. H. 2002. How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale. *Marine Ecology Progress Series*, 244, 299-305.

This study compares densities of Caribbean reef fishes on coral reefs with and without mangroves. They use the fish count method in the estuaries and coral reefs. The species counted were based previous literature documenting those that are known to be dependent on nurseries. It was found that these fish species had lower densities on reefs that were further from mangroves.

70. **Nelson, W. G., Brock, R., Lee, H., Lamberson, J. O. and Cole, F. 2007. Condition of estuaries and bays of Hawai`i for 2002: a statistical summary. *US Environmental Protection Agency*, EPA 620-R-07/001**

The program uses habitat indicators such as salinity, pH, and temperature and benthic condition indicators such as infaunal species composition, abundance, and richness.

71. Norman L. Christensen, Ann M. Bartuska, James H. Brown, Stephen Carpenter, Carla D'Antonio, Rober Francis, Jerry F. Franklin, James A. MacMahon, Reed F. Noss, David J. Parsons, Charles H. Peterson, Monica G. Turner, and Robert G. Woodmansee 1996. The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecological Applications 6:665–691.

72. **Odum, W.E., McIvor, C.C., 1990, Mangroves, *in* Myers, R.L., and Ewel, J.J., eds., Ecosystems of Florida: Chapter 15, p. 517-548.**

73. **Oki, D. S. and Brasher, A. M. D. 2003. Environmental setting and implications for water quality and aquatic biota, Oahu, Hawai`i. *U.S. Geological Survey Water-Resources Investigations Report*, 03-4156, 98**

74. **Parham, J. E. 2005. Survey techniques for freshwater streams on oceanic islands: important design considerations for the PABITRA project. *Pacific Science*, 59, 283-289.**

Essentially this paper emphasizes the importance of including spatial scales in a scoring system, an aspect that the IBI ignores.

75. **Parrish, J. D. 1989. Fish communities of interacting shallow-water habitats in tropical oceanic regions. *Marine Ecology Progress Series*, 58, 143-160.**

Parrish discusses how mangroves influence reef fishes by serving as a habitat in their juvenile stages.

76. **Onuf, C.P., Teal, J.M. and Valiela, I. 1977. Interactions of nutrients, plant growth and herbivory in a mangrove ecosystem. *Ecology*. 58:514-526.**

This study reports mangrove growth rates and herbivory in areas with greater nutrient availability in a Florida mangrove wetland. Increased nutrient availability was attributed to bird rookeries.

77. **Rivera-Monroy, V. H., Torres, L. A., Bahamon, N., Newmark, F. and Twilley, R. R. 1999. The potential use of mangrove forests as nitrogen sinks of shrimp aquaculture pond effluents: the role of denitrification. *Journal of the World Aquaculture Society*, 30, 12-26.**

Rivera-Monroy et al. document reductions in all forms of nitrogen in shrimp aquaculture pond effluent after diversion through a mangrove wetland on the Caribbean coast of Columbia.

78. **Rivera-Monroy, V.H., J. W. Day , R.R. Twilley, F. Vera-Herrera and C. Coronado-Molina. 1995. Flux of Nitrogen and Sediment in a Fringe Mangrove Forest in Terminos Lagoon, Mexico**

There was a net import of dissolved inorganic nitrogen (NH~ and NO~+NO~) from the creek and basin forest, while particulate (PN) and dissolved organic nitrogen (DON) were exported to the creek and basin forest. The tidal creek was the principal source of NH^{-4} (0.53 g m^{-2} $year^{-1}$) and NO_3+NO_2 (0.08 g m^{-2} $year^{-1}$) to the fringe forest, while the basin forest was the main source of total suspended sediments (TSS; 210 g m- a year- 1). Net export of PN occurred from the fringe forest to the tidal creek (0.52 g m --2 year- i) while less PN was exported to the basin forest (0-0.6 g m - 2 year- 1).

79. **Ronnback, P. 1999. The ecological basis for economic value of seafood production supported by mangrove ecosystems. *Ecological Economics*, 29, 235-252.**

Ronback evaluates the indirect value of mangroves in seafood production using literature values from the literature.

80. **Rozas, L. P. and Minello, T.J. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: a review of sampling design with focus on gear selection. *Estuaries* 20(1): 199-213**

This article discusses details on methods for evaluating fish distribution and density in estuaries. It offers very useful information on selecting sampling areas, setting sample sizes and the advantages/ disadvantages of different commonly used gear. The article also has a well-organized chart displaying these features.

81. **Siple, M. C. and Donahue, M. J. 2013. Invasive mangrove removal and recovery: food web effects across a chronosequence. *Journal of Experimental Marine Biology and Ecology*, 448, 128-135.**

Investigates infaunal community structure, crab abundance, and response to predator exclusion in the presence of mangroves and after their removal at Heeia fishpond. Following removal, it was found that there was an increase in infaunal abundance and suspension feeding worms and a decrease in sub-surface deposit feeders, while crab abundance remained unchanged. Crabs did not exert top-down influence on infaunal communities before or after removal. A canonical correspondence analysis was used to compare species with environmental variables including temperature, pH, salinity, substrate, turbidity, and chlorophyll. However the assumption that the data fits a chi-square distribution was not addressed. It was concluded that recovery following mangrove removal is gradual and not determined by top-down pressure.

82. **Smith, P. T. 1996. Physical and chemical characteristics of sediments from prawn farms and mangrove habitats on the Clarence River, Australia. *Aquaculture*, 146, 47-83.**

Smith provides comparisons in sediment N and P compounds between native mangrove wetlands and prawn farms. N and P concentrations were lower in native mangrove wetlands than prawn farms. These concentrations should be compared to N and P concentrations in Hawai`i's mangrove wetlands.

83. **Sweetman, A. K., Middelburg, J. J., Berle, A. M., Bernardino, A. F., Schander, C., Demopoulous, A. W. J. and Smith, C. R. 2010. Impacts of exotic mangrove forests and mangrove deforestation on carbon remineralization and ecosystem functioning in marine sediments. *Biogeosciences*, 7, 2129-2145.**

To evaluate how mangrove invasion and removal can modify benthic carbon cycling processes and ecosystem functioning, the authors used stable-isotopically labelled algae as a tracer to quantify benthic respiration and C-flow through macrofauna and bacteria in sediments collected from (1) an invasive mangrove forest, (2) deforested mangrove sites 2 and 6 years after removal of above-sediment mangrove biomass, and (3) two mangrove-free, control sites in the Hawaiian coastal zone. Sediment oxygen consumption (SOC) rates were significantly greater in the mangrove and mangrove removal site experiments than in controls and were significantly correlated with total benthic (macrofauna and bacteria) biomass and sedimentary mangrove biomass (SMB). Bacteria dominated C processing in exotic mangrove wetlands whereas macrofauna were more important in mangrove removal and control sites. Mean faunal abundance and short term C-uptake rates in sediments from both removal sites were significantly higher than in control cores, which collectively suggest that community structure and short-term C-cycling dynamics in habitats where mangroves have been cleared can remain fundamentally different from un-invaded mudflat sediments for at least 6-yrs following above-sediment mangrove removal. In summary, invasion by mangroves can lead to large shifts in benthic ecosystem function, with sediment metabolism, benthic community structure and short-term C-remineralization dynamics being affected for years following invader removal.

84. **Thom, B. G. 1967. Mangrove ecology and deltaic geomorphology: Tabasco, Mexico. *J. Ecol.*, 55, 301-343**

Thom reviews studies that have demonstrated the importance of the physiographic-ecological relationship along alluvial coasts and the establishment of mangroves. Frequency of inundation and salinity are two important hydrographic factors which are frequently cited as having significant effect on mangrove distribution.

85. **Trott, L. A. and Alongi, D. M. 2000. The impact of shrimp pond effluent on water quality and phytoplankton biomass in a tropical mangrove estuary.** ***Marine Pollution Bulletin*****, 40, 947-951.**

Trott and Alongi evaluated water quality in a mangrove estuary in Australia subject to shrimp pond effluent. Chlorophyll a, dissolved oxygen (DO), biological oxygen demand (BOD), pH, and salinity at the discharge site in the receiving estuary were significantly higher than in the two control estuaries. There were no significant differences between the impacted and control estuaries in total suspended solids (TSS) and dissolved nutrient concentrations.

86. **Twilley, R.R. and R. Chen. 1996. Biogeochemistry and Forest Development of Mangrove Wetlands in Southwest Florida: Implications to Nutrient Dynamics of Florida Bay. http://www.aoml.noaa.gov/flbay/mang96.html**

87. **Vannote, E. Mishall, G. W., Cummins, K. W., Sedell, J. R. and Cushing, C. E. 1980. The river continuum concept.** ***Canadian Journal of Fisheries and Aquatic Sciences*****, 37, 130-137**.

This paper describes the physical variables and consequent biotic factors as a gradient from headwaters to the mouth of a stream. The authors present a model of macroinvertebrate community structure, dominant food sources, and ecosystem productivity along this gradient. At the mouth, the most dominant functional feeding group is collectors, given that FPOM is the major food source. Additionally, high order streams should have a P:R ratio less than 1 caused by turbidity and depth. Estuarine ecosystems may diverge from this prediction slightly.

88. **Victor, S., Golbuu, Y., Wolanski, E., and Richmond, R.H. 2004. Fine sediment trapping in two mangrove-fringed estuaries exposed to contrasting land-use intensity, Palau, Micronesia.** ***Wetlands Ecology and Management*****. 12:277-283.**

This study compares the fine sediment levels in two mangroves: one with and one without heavy land-use and coastal development. Study finds that although the mangroves seem to trap equal amounts of sediment, much more sediment is suspended and present in the estuary adjacent to extensive human activity. The study also concludes that sediment catchment of mangroves is a function of the tidal flux and not of sedimentation present in the rivers. The authors stress the importance of proper land-use management to limit estuary sedimentation and protect coral reefs.

89. Vo, Q.T., C. Kuenzer, Q.M. Vo, F. Moder, and N. Opelt. 2012. Review of valuation methods for mangrove ecosystem services. Ecological Indicators 23:431-446

The authors provide a thorough review of the literature to identify ecological economic methods that are amenable to valuing non-market ecosystem services provided by mangroves.

90. Walsh, G.E. 1967. An ecological study of a Hawaiian mangrove swamp, in: Lauff, G.H. (Ed.) (1967). *Estuaries. American Association for the Advancement of Science Publication*, 83, 420-431

This paper provides background information about the ecology of the mangrove and describes some of its functions such as retaining sediment and serving as a nutrient sink.

91. **Weigner, T.N., Mead, L.H. and Molloy, S.L. 2013. A comparison of water quality between low- and high-flow river conditions in a tropical estuary, Hilo Bay, HI. *Estuaries and Coasts* 36:319-333**.

This article compares water quality and nutrient conditions in Hilo Bay and two rivers during low-flow river conditions and high-flow river conditions. Also described are the methods used to collect and analyze the water samples for the study. Nitrogen compounds (specifically DON) seemed to have the largest differences between low- and high-flow river conditions. Biological parameters such as changes in Chlorophyll α and bacterial abundance were also measured and evaluated.

92. Woodroffe, C. D. 1987. Pacific Island mangroves: distribution and environmental settings. *Pacific Science*, 41, 166-186.

Woodroffe provides an over view of mangrove species in the Pacific Islands. Table 1 indicates number of species (and hybrids) recorded in characteristic mangrove genera as reported in the literature. He also differentiates between environmental settings that support mangroves (Table 2).

TABLE 1

THE DISTRIBUTION OF TAXA (NUMBER OF SPECIES AND HYBRIDS) IN THE CHARACTERISTIC MANGROVE GENERA IN THE PACIFIC

	MANGROVE GENERA													
	Rhizophora	*Bruguiera*	*Ceriops*	*Avicennia*	*Aegiceras*	*Xylocarpus*	*Lumnitzera*	*Camptostemon*	*Aegialitis*	*Osbornia*	*Sonneratia*	*Scyphiphora*	*Nypa*	*Tot.*
New Guinea	4	6	2	5	1	3	2	1	1	1	3		1	30
Solomon Islands	4	3	1	3	1	1	1			1	2	1	1	19
Vanuatu	3	2	1	1		1	1				2			11
New Caledonia	5	1	1	1			2				1			11
Fiji	3	1				2	1							7
Tonga	3	1				2	1							7
Samoa	2	1				1								4
Tuvalu	1						1							2
Kiribati	1	1					1				1			4
Nauru		1												1
Palau and Yap	2	1	1	1		1	1				1	1	1	10
Guam	2	1		1		1	1						1	7
Saipan		1					1							2
Truk, Ponape and Kusaie	2	1				1	1				1		1	7
Marshall Islands	1	1					1				1			4
New Zealand				1										1

TABLE 2

ENVIRONMENTAL SETTINGS IN WHICH MANGROVES OCCUR AND THOSE RECORDED IN THE PACIFIC

	ENVIRONMENTAL SETTING (AFTER THOM 1982, 1984)	CHARACTERISTICS OF SETTING	PACIFIC ISLAND MANGROVE EQUIVALENT (THIS STUDY)
Terrigenous			
Setting I	River-dominated allochthonous	Deltaic/estuarine, microtidal	Deltaic/estuarine mangrove swamps
Setting II	Tide-dominated allochthonous	Deltaic/estuarine, macrotidal	—
Setting III	Wave-dominated barrier lagoon (autochthonous)	Barrier islands and spits, high wave energy	—
Setting IV	Composite river and wave dominated	Deltaic and lagoonal	—
Setting V	Drowned bedrock valley	Bedrock embayment	Embayment/harbor/lagoon mangroves
Carbonate			
Setting VI	Carbonate platform	Over lime mud on broad platforms	—
Setting VII	Sand/shingle barrier	In lee of rampart	Reef flat mangroves
Setting VIII	Quaternary reef top	Over reef flat or fossil reefal environments	
	—	—	Inland mangroves and depressions