

The Ecological Role of Shellfish Aquaculture in West Coast Estuaries

Aquaculture influences the estuarine system in three primary ways 1) physical structure – aquaculture introduces the cultured organisms themselves, in many cases a physical anchoring structure, and also generally involves a harvesting or removal process all of which alter the physical habitat; 2) food web - bivalves are filter feeders which remove food from the overlying water or the substrate and themselves may be food for other organisms and 3) material processes - bivalves process food and produce wastes and they themselves are added to and removed from the environment. Clearly, these processes are all linked, but this review focuses primarily on the influence of shellfish (and primarily oyster) aquaculture on physical structure in West Coast US estuaries.

Structured Habitat

Numerous studies have been conducted on the role of bivalves as habitat for fish and invertebrates in both estuarine and marine systems, but most of these have concentrated on the role of natural assemblages of oysters or mussels (). Most clams are infaunal of course and so their burrows and siphons are the only physical structure added to the sediment. Mussels and oysters generally form large concentrations or even reefs as native organisms or when allowed to grow on their own in estuaries. These have been shown to provide substantial cover and refugia from predation as well as a hard substratum for attachment of both algae and invertebrates in studies around the world. Fewer studies however, have been conducted on shellfish aquaculture sites and the majority of those have focused on suspended culture systems. In West coast estuaries, the dominant shellfish culture activities are 1) oyster culture which has evolved from harvest and cultivation of the native species (*Ostreola conchaphila*) to the introduction and extensive cultivation of the Pacific oyster (*Crassostrea gigas*) 2) clam culture which has evolved from harvest of native species to either enhancement of these native species (especially geoducks) or introduction and enhancement of the Manilla clam (*Tapes phillipinarum*) and 3) mussel culture which involves enhancement and sometimes replacement of native mussel species. Oysters and mussels are not generally left to form reef structures but instead either suspended on structures or spread out on the substrate where they are allowed to grow. Clams are generally planted in the substrate but usually at higher densities than might occur naturally and culture activities also often involve the addition of netting or other structures (like geoduck tubes) to prevent predation. Thus it is important to recognize that shellfish often form a three dimensional structured habitat that was not necessarily present in these estuaries prior to their cultivation and usually replaces either open sand, mud, gravel and cobble, or in some cases other more structured habitat formed by native or non-native vegetation like algae and eelgrass growing on these substrates. Like structure created by the bivalves, vegetated three dimensional structure, particularly seagrasses have been shown to be very important habitat for numerous organisms in estuaries around the world and are thus often the focus of habitat comparisons and impact studies. Seagrass as habitat in West Coast estuaries is less studied, as are the factors that control its abundance. Though clearly important as habitat for some species, data suggest that not only the number of species that utilize seagrass,

but also the limiting factors that control seagrass abundance may differ from those observed elsewhere and also differ between systems.

Shellfish

Ground cultured oysters and shell placed in the intertidal portion of West Coast estuaries has been shown to provide equal or better habitat than eelgrass for juvenile 0+ Dungeness crab and both of these structures provide much better habitat than open unstructured mud or sand habitats where these small prey do not find adequate protection from predators including fish and larger crab (Eggleston and Armstrong 1995; Feldman et al. 2000). Older age classes of Dungeness crab (1+ and 2+ animals) however favor open unstructured littoral habitats for foraging and do not necessarily utilize structured habitat (Holsman et al 2006).

Ground cultured oysters provide habitat for an equally diverse community of macro-infauna as eelgrass in Willapa Bay and presumably other West Coast estuaries (Ferraro and Cole 2004, Ferraro and Cole in press). This is presumably due to the presence of oysters which can be considered ecosystem engineers and is the reason that these communities were more diverse than those found in the presence of other engineers like burrowing mud and ghost shrimp. Trianni (1996) and Rumrill and Poulton (2004) found higher benthic infaunal abundance and diversity in eelgrass than in oyster culture habitats in Humboldt Bay, California (the former study comparing dredge harvested on bottom oyster culture and the latter long-line oyster culture with eelgrass). Dumbauld et al. 2001 showed that the primary result of treating burrowing shrimp dominated tideflats with the pesticide carbaryl, was to remove the effect of bioturbation of the sediments caused by these engineers and then replace this with a three dimensional architecture by planting oysters.

Habitat structure created by oysters and eelgrass also influences the diversity and composition of epibenthic meiofauna communities including harpacticoid copepods known to be important prey items for juvenile salmonids and other fish. Meiofauna densities were higher in both eelgrass and oyster habitats than over open mudflat dominated by burrowing shrimp in Willapa Bay, Washington (Hosack et al. in press). Finally, one study suggests that microbes are generally more abundant in siltier sediments and that aerobic microbes are less abundant when oysters are grown on these substrates, presumably due to the contribution of feces and pseudofeces (Richardson et al. submitted).

Larger mobile fish and crab are less strongly associated with habitat though individual species displayed some trends in Willapa Bay (e.g. rock crab *Cancer productus* were more abundant in oyster aquaculture and tube snouts *Aulorhynchus flavidus* in eelgrass; Hosack et al. in press). Data from Humboldt Bay suggest that fish abundance and diversity was influenced by structure there and the fish community was most diverse and abundant in oyster longline followed by eelgrass and open mud (Pinnix et al 2006). Nonetheless, these organisms may instead be responding to both larger structures as refuge from predation (as these researchers also found most differences during daytime

catches) and to larger estuarine landscape scale habitat features (eelgrass corridors along channel edges) in both estuaries.

Estuaries function as nursery habitats for juvenile salmon providing both refuge from predators and trophic resources. Larger juvenile chinook salmon smolts preferred the structure of eelgrass as a refuge in the laboratory over oysters or open sand substrate when a mock predator was introduced. No habitat preference was noted in field collections of these fish in these habitats within Willapa Bay, nor in their diet composition which appeared to be related more to landscape scale features (Hosack et al 2006).

Eelgrass

At tidal elevations that can support eelgrass, studies in west coast estuaries suggest that eelgrass is less dense in oyster aquaculture beds than in nearby eelgrass meadows (Wadell 1964; Simenstad and Fresh 1995; Rumrill and Poulton 2004; Pregnall 1993, Tallis et al. in review). However, eelgrass is generally present on all aquaculture beds at this tidal elevation and these studies do not evaluate historical records to indicate either loss or gains in eelgrass habitat over time, nor whether eelgrass would have been there otherwise. There is clear evidence from Willapa Bay for example that suggests the practice of applying the pesticide carbaryl to remove burrowing shrimp from intertidal areas enhances the presence of eelgrass (Dumbauld and Wyllie-Echeverria 2003). With the exception of changes in practices like switching from on-bottom culture to off-bottom culture in some locations, the press (oyster addition) and pulse (planting and harvest operations) disturbances of oyster culture have not changed materially for decades (Ruesink et al. 2006), so there is no reason eelgrass would necessarily be worse off now than in the past. Indeed, there is scientific evidence that native eelgrass fluctuates with environmental conditions (Thom et al 2003) and compelling anecdotal evidence that it has been expanding its distribution in Willapa Bay and other West coast open coast estuaries.

Disturbance by aquaculture ranges from simple space competition between oysters and eelgrass (i.e. a spot on the tidelflat occupied by an oyster or other shellfish cannot also be occupied by an eelgrass shoot) to removal of entire plants and rhizomes via harvest with mechanical dredge implements (Tallis et al. in review). Surveys document that the magnitude of negative impact varies, but follows an expected gradient from dredge harvest > widely spaced long-lines > narrow spaced longlines > hand picked beds for oyster aquaculture.

Recovery time after disturbance is difficult to define but varies with disturbance size, disturbance intensity, and sediment characteristics (Tallis et al., in review). Timing of disturbance is also likely a factor, but results from small-scale (5x5 m) eelgrass removal experiments, experimental dredging, and dredged beds tracked over time in Willapa Bay suggest that 2 years is a reasonable estimate (Tallis et al. in review). This is also true for disturbance caused by harvest of geoduck clams in South Puget Sound (Ruesink et al. in prep).

Eelgrass growth can be influenced by numerous factors including light and nutrients. The importance of these factors differs by location. Thus in some areas outside the Pacific Northwest, nutrients may be limiting and shellfish can provide these via pseudofeces and feces (Reucsh and Williams 1994, Peterson et al 1987, Peterson and Heck 1999, Peterson and Heck 2001). It could occur in some areas of Puget Sound and elsewhere along the West Coast, but in Willapa Bay, Washington where studies have recently been conducted nutrients do not appear to limit eelgrass growth so it is similar in both aquaculture beds and nearby eelgrass meadows (Tallis et al. in review). Light however does seem to limit growth in PNW estuaries and thus eelgrass may even shade itself when dense. Thus eelgrass grew faster in ground cultured oyster beds in Willapa Bay. While growth was faster, overall production was still lower due to reduced eelgrass density.

Eelgrass can recover via lateral rhizome spread or via sexual reproduction and seed dispersal. Seedlings reached highest density on dredged oyster beds in Willapa Bay, due to a combination of high seed production and successful growth after germination (Wisehart et al. in review). In Willapa Bay, eelgrass increases in density in spring due to a combination of branching and seed germination. Shoot densities drop seasonally by about 40% in autumn, as flowering shoots die and light limitation sets in (Wisehart et al., in prep).

Landscape Ecology and Information Needs

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