CALIFORNIA COASTAL COMMISSION
45 FREMONT, SUITE 2000
SAN FRANCISCO, CA 94105-2219
VOICE AND TDD (415) 904-5200
FAX (415) 904-5400

MEMORANDUM

FROM: John Dixon, Ph.D.
Ecologist

TO: Alison Dettmer

SUBJECT: Effects of Oyster Mariculture on the Natural Resources in Drake's Estero

DATE: September 11, 2007

Habitat Characteristics of Drake's Estero

Drake's Estero is a shallow tidal estuary with four inland branching bays (Figures 1 & 2). A fifth bay to the west, Estero de Limantour, is somewhat isolated but its mouth is also inside the sand spit that shelters these areas from the open ocean and, to some degree, it is functionally a part of Drake's Estero. Anima (1990) categorizes Drake's Estero as a "coastal lagoon" because there is relatively little freshwater influence. Salinity throughout the estuary is generally similar to that on the open coast. At higher high tide, the lagoon system (including Estero de Limantour) covers about 2323 ac (9.4 km^2) of which some 1186 ac (4.8 km^2) are intertidal. The subtidal portions of the Estero are shallow, generally less than 6.5 ft (2 m). The deepest areas (23-26 ft; 7-8 m) are at the entrance and within a portion of the main channel. There is very little natural hard substrate present. The dominant substrates are silty sands and muds.

Large areas of subtidal sand and mud currently support eelgrass. Eelgrass (*Zostera marina*) is one of about 50 species of seagrasses, a polyphyletic group of specialized flowering plants that have evolved adaptations to live and reproduce in the marine environment. They are distinct from the algae that are the most common photosynthetic organisms in the oceans. Like other seagrasses, eelgrass provides important habitat for large numbers of species of invertebrates and fish (Phillips 1984). Thirty-five species of fish have been observed within eelgrass beds in either Drakes Estero or Estero de Limantour (Wechsler 1996). Eelgrass is often described as "nursery habitat" because of its importance to the juvenile life stages of many species. It also provides foraging habitat for many species of birds, including black brant (*Branta bernicla nigricans*) for which eelgrass itself is a preferred food (Ganter 2000). Eelgrass also has important indirect effects on community organization by stabilizing the substrate and affecting nutrient cycling (Phillips 1984). A demonstration of the importance of eelgrass habitats occurred in the 1930s when disease destroyed 90% to 100% of beds of eelgrass in various locations in the north Atlantic. This was followed by a precipitous decline in many fish and invertebrate species, including commercial species, which caused significant economic hardship (Stauffer 1937; Cottam & Munroe 1954; Phillips 1984). Coincident with the loss of eelgrass, the overwintering population of brant in the Netherlands dropped two orders of magnitude to about 100 individuals. This natural catastrophe has been largely forgotten by all but eelgrass specialists. However, a widespread appreciation of the critical ecological functions of eelgrass is re-emerging as seagrass habitats are again in decline, now being imperiled by the intensive development of the world's coastlines (Orth et al. 2006).

Like most species, eelgrass waxes and wanes in local abundance and spatial distribution over time (e.g., Griffin 1997). Where appropriate data are available, the best estimate of suitable habitat is generally the cumulative distribution of eelgrass over some long period. In 1990 when Anima mapped eelgrass in Drake's Estero, it was mostly confined to the central portion of the estero. Today, there are also significant eelgrass beds in Schooner Bay and Home Bay (personal observations on July 17, 2007 and aerial photograph in NPS 2007) and probably in other areas. Brown and Becker (2007) estimate that there are currently 740 acres[1] of eelgrass in Drake's Estero, of which 355 acres have dense cover and 385 acres have patchy cover. Obviously the appropriate habitat is more extensive than would have been estimated by the distribution of eelgrass in 1990. Since there apparently are few estimates of eelgrass distribution in Drake's Estero, all areas of appropriate substrate and depth should be considered potential eelgrass habitat.

Drake's Estero is relatively pristine. Water quality is high with little evidence of herbicides or pesticides and human activities within the watershed (mostly grazing) do not appear to have resulted in high levels of sediment inputs (Anima 1990). There are few roads or buildings in the area. Within the estero itself, the only development is related to oyster mariculture. Drake's Estero is part of Point Reyes National Seashore and has received special congressional designation as "wilderness[2]" (NPS 2007). Drakes Estero is particularly important for shorebirds and waterfowl. Thousands of birds are regularly present and during the winter the number of individuals occurring in Drakes Estero and Estero de Limantour are thought to be around 20,000 (Hickey et al. 2003). Drake's Estero (including Estero de Limantour) has been designated a site of regional importance by the Western Hemisphere Shorebird Reserve Network. Drake's Estero is also of regional significance for harbor seals. Twenty percent of the mainland breeding population in California utilizes the Point Reyes coast (Allen et al. 2004). Within this important area, Drake's Estero is one of the primary pupping sites. In 2006, Drake's Estero supported the largest number of harbor seals and contributed the largest number of pups within Point Reyes (Manna et al. 2006). The significance to fish of eelgrass and other estuarine habitats within Drake's Estero was recognized by the Pacific Fisheries Management Council when it designated those habitats as "Essential

[1] No methods were described in this Trip Report (Brown & Becker 2007), so this should be considered a preliminary estimate until a formal report is available.

[2] Estero de Limantour is currently designated "wilderness" (and a California State Ecological Reserve) and Drake's Estero is "potential wilderness" due to the nonconforming mariculture operation. The 1972 agreement that "grandfathered" the mariculture operation for 40 years expires in 2012, at which time Drake's Estero will be eligible for full "wilderness" status.

Fish Habitat" and a "Habitat Area of Particular Concern[3]" under the Magnuson-Stevens Fishery Conservation and Management Act (http://www.pcouncil.org/facts/habitat.pdf).

Oyster mariculture in Drake's Estero

Oysters have been grown in Drake's Estero since about 1930 (Anima 1990). The processing facility is located close to the shore in the upper northeast section of Schooner Bay. Currently, there are at least four methods of cultivation employed. Oysters are grown suspended from wooden racks, on the bottom in plastic mesh bags individually scattered in a haphazard fashion on intertidal flats, on the bottom in plastic mesh bags tethered in lines on intertidal flats, and in buoyed plastic mesh bags that are tethered in lines on intertidal flats but that float when the area is inundated by the tide. Each of these culture techniques has the potential for negative environmental impacts.

Bottom bag culture is generally restricted to intertidal areas and so avoids the eelgrass beds which grow from rhizomes in the subtidal sediments. However, some of the individual bags have found their way into the adjacent eelgrass. I suspect that this is an accidental result of placing the bags by dropping them from a boat at high tide. It is also possible that some bags have been moved by waves or currents. Regardless of how they arrived, these bags should be removed from the eelgrass beds because they preempt habitat. The bags that are left on the intertidal flats probably add nutrients to the sediments and isolate the sediment from the water column. Taken together, these factors probably result in anaerobic conditions developing closer to the surface[4], which would likely result in changes to the composition of the infaunal community. To my knowledge, this hypothesis remains untested. I have found no studies of the effects of bottom bags on infauna. A potentially more serious environmental impact of bottom bags is the preemption of shorebird foraging habitat. In Tomales Bay, oyster mariculture is avoided by western sandpipers and dunlins but preferentially utilized by willets (Kelley et al. 1996). Overall, the abundance of foraging shorebirds is reduced in Tomales Bay by the mariculture operation. However, Kelley et al (1996) did not distinguish the effects of bottom bag culture and culture in bags on raised racks. Although a reduction in shorebird foraging opportunities is a potentially serious environmental impact of oyster bottom culture, the significance of such an impact will be directly related to the proportion of foraging habitat that is preempted. An estimation of that proportion would help in the assessment of the significance of the environmental impact. If the proportion of the suitable intertidal foraging habitat that is covered by bottom bags is relatively small, then the impact is probably not very significant. The effects of bottom bag culture on harbor seals is potentially much more serious. Some of the bags are being placed on intertidal flats which have been documented to be haul-out sites for harbor seals (Allen 2007). The bags preempt space and create barriers to

[3] "Habitat Area of Particular Concern" refers to the subset of Essential Fish Habitat which is rare, particularly susceptible to human-induced degradation, especially ecologically important, or located in an environmentally stressed area.

[4] When I disturbed the substrate by tugging on bottom bags that were scattered on the intertidal flat at Bull Point, there was a strong hydrogen sulfide odor released, which indicates shallow reducing conditions.

movement and are a locus of disturbance when they are placed, maintained, and retrieved.

Oyster culture within eelgrass beds generally has deleterious effects (Everett, et al. 1995; De Casabianca, et al. 1997; Griffin 1997; Rumrill and Poulton 2004; Bertin & Chamillon 2006). These are related to preemption of space, changes in currents that result in either scour or sedimentation, shading, biodeposition that may result in increased sedimentation and eutrophication, and physical disturbance of the substrate (e.g., trampling & propeller scarring) related to routine mariculture activities. The type and severity of mariculture impacts are related to the type of culture technique (e.g., ground culture[5], bottom bag culture or rack culture), the depth distribution of eelgrass relative to optimal mariculture habitat, the spatial extent of the mariculture manipulations, the biomass of cultured oysters, and the hydrological characteristics of the site.

At Drake's Estero, only rack culture using suspended lines is intentionally located in eelgrass beds. The most obvious effect of the oyster culture is that eelgrass tends to be excluded from the footprint of the racks (Wechsler 2004, Brown & Becker 2007, NPS 2007[6], pers. obs. July 17, 2007). National Park Service personnel counted 89 culture racks in eelgrass beds and found no eelgrass under the 62 useable racks and no eelgrass under 20 of the 27 dilapidated racks (Brown & Becker 2007). The total area under active and abandoned oyster racks where eelgrass is excluded is estimated to be about 8 acres (Brown & Becker 2007). Eelgrass is very sensitive to light levels (Backman & Barilotti 1976; Burdick & Short 1999) and the lack of eelgrass within the footprint of culture racks is probably a result of shading. Depending on their orientation relative to currents oyster racks can also cause scouring or increases in sedimentation (Forrest & Creese 2006), either of which could also reduce eelgrass abundance. However, regardless of mechanism, there is less eelgrass present today than there would be in the absence of the oyster racks.

Eelgrass is also impacted by the boat traffic associated with the oyster operation. The deep channel in Schooner Bay is thought to be caused by scour from regular boat use associated with the oyster operation (Anima 1990). In the absence of frequent motor boat activity this channel would probably be shallow and winding, as is the case elsewhere in the estero, and portions of what is now channel would be shallow flats that could support eelgrass. Propeller scarring in seagrass beds is a well-known phenomenon that is of increasing concern in heavily populated areas (Sargent et al.

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[5] Ground culture differs from bottom bag culture in that shells with oyster spawn (cultch) are scattered directly on the substrate and are not confined.

[6] NPS (2007) incorrectly cites Elliott-Fisk et al. (2005) as also noting a lack of eelgrass under mariculture racks. In fact, the latter state that, "We found the oyster racks to have no pronounced impacts on the eelgrass beds, which existed both under and away from the racks as an incredibly rich habitat type." Elliott-Fisk et al. is largely a summary of the research that was conducted by several U.C. Davis graduate students, including Wechsler. Since the quoted passage directly contradicts the findings of Wechsler (2004) and recent observations, it was probably simply a mistake by the author of that section. In any event, the current presence or absence of eelgrass under culture racks is a simple matter of fact that can be easily verified.

1995; Madley et al. 2004). In shallow water, propellers and propeller wash tear up the sea grass canopy but also displace rhizomes and leave bare areas (Zieman 1976). Even in Drake's Estero where boating activity is relatively low, the cumulative effects of propeller scarring may be significant because it may take years for scars to recover (Dawes et al. 1997). The direct impacts on eelgrass are obvious and the area affected could be determined from aerial imagery. There may also be indirect impacts to organisms that depend upon the eelgrass for habitat. The patchy disturbance to the seagrass bed affects different species in different ways, with motile swimming species being less affected than more sedentary species (Bell et al. 2002; Uhrin & Holmquist 2003). Although the community effects of propeller scarring in Drake's Estero are difficult to quantify, it is clear that they constitute a negative impact.

Biodeposition is a phenomenon that can have deleterious effects by increasing sedimentation and nutrients. Oysters feed by filtering materials that are suspended in the water column. This includes plankton, particulate organic matter, and inorganic particles. Oysters do not ingest filtered inorganic particles. Both organic residue from the digestive tract and rejected inorganic particles are bound in a mucus matrix and ejected (Newell et al. 2005). The former are termed feces and the latter are called pseudofeces since they have not passed through the digestive system. If the concentration of suspended particles is so high that the filtering rate exceeds the processing rate, oysters will reject plankton and particulate organic matter in addition to the indigestible inorganic particles and the pseudofeces will then have a relatively high organic content. The strings of feces and pseudofeces are much larger than the constituent materials and settle around seven times as fast as unbound suspended particles (Haven & Morales-Alamo 1966). Where oyster culture is intense and tidal flushing is low, biodeposition has been shown to have very serious deleterious effects (Ito & Imai 1955; De Casabianca 1997; Bertin & Chaumillon 2006). However, in Drake's Estero there is good tidal flushing and individual rack areas are fairly small. Therefore, at current levels of oyster production it seems unlikely that biodeposition would result in significant environmental impacts to eelgrass or to the local infauna. According to Elliott-Fisk et al. (2005), Harbin-Ireland (2004) found little difference in the number of infaunal taxa or individuals under the racks and at various distances up to 50 m away. Nor was there a significant difference in the concentration of organic materials in the sediments. Qualitatively, however, the effect of oyster culture is to remove plankton, particulate organic matter, and inorganic particles from the water column, process them, and deposit them on the bottom. Whether this is a positive or negative ecological effect depends on the context. In Drake's Estero where water quality is good and where millions of bivalves may not have been present historically (although the history of native oysters is probably unknown), the effects of oyster culture on natural ecological processes is probably negative but not easily measured.

A salient effect of oyster mariculture is to introduce hard substrates to areas where they are naturally rare. The oyster racks, the oyster cultch, and the cultured oysters all provide surfaces that can be colonized by sedentary "fouling" organisms. The novel surfaces associated with pilings and floats are particularly attractive to non-indigenous species (Glasby et al. 2007). Where both natural reefs and pilings are present, the latter are disproportionately colonized by the exotics. In Drake's Estero, one such species is the tunicate identified as *Didemnum* species A (Bullard et al. 2007; NPS 2007). This invasive species is common on oysters and has also colonized patches of intertidal mudstone. Although *Didemnum* is unlikely to become a pest in Drake's Estero due to the lack of appropriate substrate, the oyster racks and oysters provide a continuing source of larvae that can colonize other areas.

The oyster racks themselves are constructed of lumber that was pressure treated with a wood preservative. Prior to 2003, the preservative used was almost always chromated copper arsenate. This chemical compound is highly toxic to marine organisms (Weis & Weis 1996). It is designed to be very persistent in wood and retention studies show little change in concentration over time at the parts-per-hundred level. However, aquatic organisms are affected at a parts-per-million level and the chemicals do leach at this level, although the rate of leaching decreases with time (Weis et al. 1992). The leached toxic compounds are taken up and concentrated by marine organisms and accumulate in sediments (Weis & Weis 1992; Weis & Weis 1996). The most toxic element for aquatic organisms is the copper, which has even been found at elevated levels in oysters growing on structures constructed of treated wood (Weis et al. 1993).

Oyster racks and the suspended strings of oysters with their attached fouling organisms also create a physical habitat that is not naturally present and that might alter the species composition and abundance of the local fish community. Such structures provide habitat and may also simply act as fish aggregating devices. Wechsler (2004) attempted to assess the effects of the oyster racks on the fish community. However, his fishing methods prevented him from sampling within the footprint of the oyster rack itself. Trawls were conducted within eelgrass 1 to 2 m from the racks. Gill nets were attached to the racks and may provide a better indication of the community actually associated with the racks, but the data were not separated by fishing method. The results indicated no differences in the number of species or number of individuals next to the racks, 75 m distant, and in Estero de Limantour.[7]

A potentially very significant environmental impact associated with oyster culture is disturbance of foraging birds and disturbance of harbor seals. Disturbance may exclude birds from feeding or roosting areas, increase energy demands both by increasing metabolic rate before flight and causing them to take flight, and reduce feeding efficiency and feeding time (Stillman et al. 2007). Similarly, both pedestrian and boat activity can result in physiological and behavioral changes in harbor seals. Disturbance that causes seals to leave the shore and enter the water is particularly serious, especially when pups are present (Suryan & Harvey 1999). Such disturbance increases energy requirements by decreasing the haul-out period, creates a trampling risk for pups, and increases the chances of pup abandonment. The significance of disturbance varies with tidal height, frequency, distance, and season. At higher tides most habitat will be inundated and the effects of human activities will be less consequential. Obviously, more frequent disturbance will have more serious consequences. The

[7] The analysis of variance resulted in tiny F-values which were incorrectly associated with a P-value of 0.01. However, Wechsler appropriately described his results as statistically not significant.

closer the source of disturbance, the more likely it will have a negative effect on behavior. For example, in Washington, it was found that of all cases of harbor seal harassment from boat operation, none took place at distances >260 m, 25% occurred at a distance of 200-260 m, 50% at a distance of 100-200m, and 25% at a distance of <100 m (Suryan & Harvey 1999). The seasons of greatest concern are probably the spring and fall migratory periods and winter for birds and the breeding and pupping season (March – June) for harbor seals. In Drake's Estero, both human presence and boat operation are potential sources of disturbance to birds and harbor seals. For example, an oyster operation boat was observed to disturb 90 hauled out harbor seals, of which 7 adults and 7 pups flushed into the water, and around 300 black brant, which were flushed from an eelgrass bed where they were feeding (Allen 2007).

Summary and Recommendations

Oyster mariculture in Drake's Estero causes a number of environmental impacts. Those that are most significant are the preemption of space by culture racks that results in the loss of about 8 acres of eelgrass, the damage to eelgrass beds by boating (propeller scars and channel scour), the provision of suitable habitat for exotic fouling species by placing mariculture infrastructure in the estero, the placement of bottom culture bags on harbor seal haul-out areas, and disturbance to harbor seals and birds from pedestrians and boats. Some impacts are not mitigable, but the negative effects of others can be significantly reduced. I suggest that the following mitigation measures be implemented:

1. Oyster mariculture should not occur on tidal flats that are harbor seal haul-out and pupping sites.
2. Boat operation and other human activities should stay a safe distance away from haul-out areas. Data suggest that an adequate buffer would be between 100 and 200 meters, depending on the type of disturbance (Allen et al. 1984; Suryan & Harvey 1999; Johnson & Acevedo-Gutierrez 2007).
3. Boat routes to culture areas should be marked and traffic confined to those defined lanes. This would reduce both impacts to eelgrass and disturbance to wildlife.
4. No bottom culture should take place in eelgrass habitat and bottom bags that are currently in eelgrass habitat should be removed.
5. No new structures should be added and discarded materials and culture racks that are no longer used should be removed. These materials provide habitat for non-indigenous species and the racks are constructed of lumber that contains toxic compounds.
6. No aquaculture organisms from other areas or aquaculture materials, including shell, that have been used in the marine environment elsewhere should be placed in Drake's Estero.
7. To the extent feasible, mariculture operations should be spatially consolidated.

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Figure 1. Drake's Estero and Estero de Limantour. Google Earth photograph.

Figure 2. Schematic showing significant features of Drake's Estero (From Anima 1990). The Johnson's Oyster Company is now Drakes Bay Oyster Farm.