Shellfish Mariculture in Drakes Estero, Point Reyes National Seashore, California

Committee on Best Practices for Shellfish Mariculture and the Effects of Commercial Activities in Drakes Estero, Pt. Reyes National Seashore, California; National Research Council

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in their review of this report:

Peter Boveng, National Oceanic and Atmospheric Administration, Seattle, WA
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Steve Rumrill, South Slough National Estuarine Research Reserve, Charleston, OR
Sandra Shumway, University of Connecticut, Groton, CT

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by **Dr. Bonnie McCay**, Rutgers University, appointed by the Divison on Earth and Life Studies, and **W.L. Chameides**, Duke University, appointed by the Report Review Committee, who were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

SUMMARY

When Drakes Estero, which lies within the Point Reyes National Seashore (PRNS) about 25 miles northwest of San Francisco, California, was designated by Congress in 1976 as Potential Wilderness, it contained a commercial shellfish (nonnative oyster and clam) mariculture operation. Oyster mariculture began in Drakes Estero with the introduction of the nonnative Pacific oyster (*Crassotrea gigas*) in 1932, after the beds of the native Olympia oyster (*Ostrea lurida*) had been depleted throughout the region by overharvest, and has been conducted continuously from that date forward. Hence, the cultural history of oyster farming predates the designation of Point Reyes as a National Seashore in 1962. Nevertheless, with the approach of the 2012 expiration date of the current National Park Service (NPS) Reservation of Use and Occupancy (RUO) and Special Use Permit (SUP) that allows Drakes Bay Oyster Company (DBOC) to operate within the estero[1], NPS has expressed concern over the scope and intensity of impacts of the shellfish culture operations on the estero's ecosystem. Recent public documents produced by NPS characterizing the impacts of shellfish culturing in Drakes Estero have stimulated public debate over the pending expiration of the RUO and the presentation of scientific information that appeared to justify closing the oyster farm. The increasingly contentious nature of the debate led to the request for this study to help clarify the scientific issues raised with regard to the shellfish mariculture activities in Drakes Estero (See Box 1 for Statement of Task).

Box 1
Statement of Task – Part 1[§]

An ad hoc committee will be formed to produce two reports on shellfish mariculture in coastal areas. In the first report, the committee will assess the scientific basis for the National Park Service (NPS) presentations and the report (including revisions), "Drakes Estero: A Sheltered Wilderness Estuary," on the ecological effects of the Drakes Bay Oyster Company operations on Drakes Estero, Pt. Reyes National Seashore in California. In carrying out its task, the committee will address the following questions:

- What is the body of scientific studies on the impact of the oyster farm on Drakes Estero, and what have they shown?
- What effects can be directly demonstrated by research conducted in Drakes Estero itself?
- What effects can reasonably be inferred from research conducted in similar ecosystems?
- What conclusions can be drawn from the body of scientific studies, and how do they compare with what the NPS presented to the public? Have these conclusions affected NPS decision making?

What are the most important subjects for future research to better understand the ecological consequences of anthropogenic influences on the estero, so as to inform NPS decision making?
[§]The committee will prepare a second report, published separately, that will address in more general terms the elements of best management practices for application to shellfish mariculture to enhance the benefits and minimize any negative ecological effects (See Appendix B).

[1] The term estero is used instead of estuary because Drakes Estero has more in common with coastal lagoons (low freshwater input and high salinity) than in a typical estuary.

Oyster mariculture necessarily has ecological consequences in Drakes Estero as in other lagoons and estuaries, the magnitude and significance of which vary with the intensity of the culturing operations. These effects derive from two different sources: the presence of and biological activity of the oysters, and the activities of the culturists. Oysters provide many ecosystem services, so the return of oysters to Drakes Estero through commercial mariculture could enhance the ecosystem by restoring some historic baseline functions. The degree to which the presence and biogeochemical activities of the nonnative Pacific oysters in Drakes Estero reproduce the historic contributions of the original Olympia oysters to the ecological functioning of the estero depends on how closely historic oyster abundances, collective biomass, and thus filtering capacity plus hard-substrate habitat are matched by the cultured nonnative oysters. The hard substrate habitat provided by oysters, elevated wooden racks, and plastic mesh bags on the bottom does not replicate the exact nature of structural habitat once offered by beds of native oysters on the bottom. Insufficient information is available to know how many oysters and how much biomass existed under historical baseline conditions, but Olympia oysters form extensive reefs covering the lower intertidal zone and extending into the subtidal of some relatively pristine lagoons, bays, and estuaries of British Columbia, a possible analog of the ecosystem in Drakes Estero prior to overharvesting of the native oyster. The activities of the oyster culturists can disturb wildlife such as harbor seals, which are of particular concern because they use the estero for resting, mating, pupping, suckling, molting, foraging, and sheltering from oceanic predators.

NPS has recently released documents to inform the public about the impacts of oyster mariculture on the Drakes Estero ecosystem. Scientific conclusions presented in *Drakes Estero: A Sheltered Wilderness Estuary* change in successive versions from late 2006 through 2007, with some notable deletions of earlier material and a few additions. However, *Drakes Estero: A Sheltered Wilderness Estuary* never achieved a rigorous and balanced synthesis of the mariculture impacts. Overall, the report gave an interpretation of the science that exaggerated the negative and overlooked potentially beneficial effects of the oyster culture operation. Ultimately, the NPS "Acknowledgment of Corrections" (July 2007) and "Clarification of Law, Policy, and Science" (September 2007) retracted several misrepresentations of the Anima (1991) and (Elliot-Fisk, 2005) studies and presented descriptions of ecological impacts of the shellfish culture operations that closely approach the conclusions reached by this committee, with two major exceptions. First, NPS does not acknowledge the changing ecological baseline of Drakes Estero, in which native Olympia oysters probably played an important role in structuring the estuary's ecosystem for millennia until human exploitation eliminated them in the period from the mid 1800s to the early 1900s. Second, NPS selectively presents harbor seal survey data in Drakes Estero and over-interprets the disturbance data which are incomplete and non-representative of the full spectrum of disturbance activities in the estero.

The committee reached the following conclusions about how oyster and clam mariculture affects key aspects and ecological functions of Drakes Estero:

(1) **Ecological impacts of enhancing benthic/pelagic coupling**. Oysters have a prodigious filtering capacity that can provide resilience in the event of an algal bloom or increased sedimentation from stormwater runoff. As a by-product of this filtering activity, oysters deposit large quantities of pseudofeces and feces and thus transfer materials, including nutrients and organic carbon, from the water column to the sediments on the bottom. Oysters also release ammonium, thereby fertilizing and stimulating growth of phytoplankton,

seagrasses, and macro- and microalgae. Limited studies of Drakes Estero show the following: (1) relatively high flushing and exchange with the ocean in the areas where most of the oysters are grown, and thus low likelihood of development of sediment anoxia; (2) no empirical evidence of enhanced organic content or sediment hypoxia in eelgrass beds proximate to oyster culture racks; (3) only small increases in sand content of sediments under racks; (4) little change in benthic macro-invertebrate communities with proximity to racks—only enhanced amphipod abundances and an apparent negative effect on another crustacean, the tanaid (*Leptochelia dubia*), and; (5) relatively low dissolved nutrient concentrations. Based on studies of oysters in other estuaries, cultured oysters in Drakes Estero will contribute to water filtration, the transfer of nutrients and carbon to the sediments, and biogeochemical cycling, although the magnitude of these effects will depend on the stocking density and may be limited by the estero's high rate of flushing through tidal exchange.

(2) **Effects of the mariculture on eelgrass**. Limited observations of eelgrass in Drakes Estero demonstrate absence of eelgrass directly under oyster culture racks and from propeller scar damage attributable to boats operated by the oyster farm. Mariculture activities had an impact on about 8% of the eelgrass habitat in Drakes Estero in 2007: 1% of eelgrass acreage was displaced by oyster racks and 7% was partially scarred by boat transit through the eelgrass beds. Research elsewhere demonstrates that damaged eelgrass blades have rapid regeneration capacity and that eelgrass productivity can be locally enhanced by the cultured oysters through a reduction in turbidity and fertilization via nutrient regeneration. Eelgrass habitat within Drakes Estero has doubled from 1991 to 2007, a trend seen in some other west coast estuaries.

(3) **Effects of the mariculture on fishes**. Only one study of the effects of oyster mariculture on fishes has been conducted in Drakes Estero. No statistically significant differences in species richness, abundance, or community composition of fish were detected among samples taken in eelgrass adjacent to oyster culture racks, 75 m away, or in neighboring Estero de Limantour. The guild of fishes known to associate with hard substrates exhibited a trend of higher abundances adjacent to the racks, driven largely by one species (kelp surfperch, *Brachyistius frenatus*). This observation is consistent with other research showing that fishes are attracted to structured habitat for protection and/or feeding.

(4) **Effects of the mariculture on harbor seals**. Drakes Estero is a significant breeding location for harbor seals, and about 20% of the mainland California population come ashore, or "haul-out", on sandbanks within the estero during pupping season. Ongoing harbor seal surveys, conducted mainly by volunteers with NPS oversight, were not designed to test the influence of shellfish mariculture on the seal population, but have been used to track trends in the size of seal colonies at the main locations, or sites, in the Point Reyes region where seals come ashore. Within a site, there may be several distinct features, such as a sandbar or rock outcrop, which are monitored as haul-out subsites. Since the restriction of kayakers from the estero during the breeding season (March 1 to June 30), mariculture has become the main anthropogenic activity in the upper estero at that time of year. Statistical analyses of Drakes Estero harbor seal count data during the breeding season suggest a possible relationship between mean counts at two of three subsites where seals haul out on sand bars in the upper estero and the combined signals from the 1998 El Niño and oyster production level.

Although these results cannot be used to infer cause and effect for many reasons, as explained in the body of this report, they highlight the need for a more detailed assessment of the extent to which different disturbance sources may impact harbor seals both on land and in the water. In Europe buffers of up to 500–1,500 m have been established around seal haul-outs to protect them from disruption by human activities. No studies have determined whether short-term responses to disturbance have long-term population consequences for harbor seals, but if the disturbance affects behavior during the breeding season, a precautionary approach to management would seek to reduce these types of disturbance to avoid potentially significant population effects.

(5) **Past, present, and future effects of mariculture on nonnative species**. The oysters and clams cultured in Drakes Estero are nonnative species that have some risk of establishing self-sustaining populations. In the past, importations of nonnative oysters were associated with the introduction of a salt marsh snail, *Batillaria attramentaria*, and the oyster pathogenic parasite, *Haplosporidium nelsoni*. Currently, the oyster farm imports oyster larvae and spat that meet certification requirements as specific pathogen free, which greatly reduces the potential for new introductions but does not eliminate the possibility of transmission of all oyster pathogens such as oyster herpes viruses. The invasive clonal tunicate, *Didemnum vexillum*, is considered a pest because it fouls submerged surfaces, including eelgrass to a small degree, and has rapidly overgrown valuable shellfish beds in some other areas. This nonnative tunicate has become established in Drakes Estero, where it covers much of the subtidal hard surfaces provided by oyster shells, racks, and other structures. The cultured oysters together with wooden culture racks and plastic mesh bags increase the availability of hard surface for colonization by tunicates in Drakes Estero, which has few natural hard substrates such as rocky bottom, although shells of native Olympia oysters would have provided substrate had they not been over-harvested to virtual extinction. The high coverage of tunicates increases the potential for spread of this invasive species within Drakes Estero and Estero de Limantour and possibly beyond through transport of the short-lived larvae and body fragments capable of regeneration.

(6) **Effects of the mariculture on birds**. Drakes Estero is recognized as an ecologically significant overwintering site for shorebirds and waterfowl, especially for overwintering and migrating black brant. The oyster farm likely has some impacts on birds caused by culture bags lying on intertidal sand flats, which limit access to and availability of soft-sediment invertebrate prey. Other shorebirds may benefit from enhanced foraging on small crustaceans and other invertebrates growing on and around intertidal bags and other mariculture structures. Birds can be flushed by the activities of the culturists, particularly while driving boats to and from culture sites, with unknown population consequences.

(7) **Effects of the mariculture on economics, recreation, and aesthetics**. The effect of oyster farming in Drakes Estero on the aggregate economic values generated by PRNS is likely to be small relative to recreational value (on the order of $100 million per year) and value of ecological services (on the order of $20 million to $30 million per year). Recreation is probably not influenced by the mariculture operation except to the degree that the construction and improvement of the road into the land-based oyster farm facilities provides access for launching kayaks and canoes. Visits to DBOC could be considered a form of

recreation and the oyster farm represents part of the cultural history of the estero. Conversely, the low-tide appearance of culture racks holding oysters partially covered by the invasive, yellow tunicate and the sight of plastic mesh culture bags lying on some intertidal flats conflict with the aesthetics of the vistas expected in a National Park Wilderness Area.

After evaluating the limited scientific literature on Drakes Estero and the relevant research from other areas, the committee concludes that there is a lack of strong scientific evidence that shellfish farming has major adverse ecological effects on Drakes Estero at the current levels of production and under current operational practices, including compliance with restrictions to protect eelgrass, seals, waterbirds, and other natural resources. Adaptive management could help address effects, if any, that emerge with additional scientific research and monitoring to more fully understand the Drakes Estero ecosystem and the effects of shellfish farming.

Based on their own conclusions on how shellfish mariculture affects the Drakes Estero ecosystem, NPS made some documented decisions. NPS and DBOC reached agreement in April 2008 on the Special Use Permit giving the company the right to operate in Drakes Estero until 2012, when the current RUO expires, and specifying conditions of operations. According to the Department of the Interior, the Superintendent of Point Reyes National Seashore does not have the authority to extend the RUO because of the congressional mandate designating Drakes Estero as a Potential Wilderness. Under this interpretation of the Wilderness Act, NPS has the mandate to convert a Potential Wilderness to Wilderness status as soon as the non-conforming activity can be removed.

Because the likely beneficial functions of oysters in biogeochemical processes were not acknowledged, they did not appear to play a role in NPS decision making. Similarly, NPS did not mention that Olympia oysters were part of the historic ecological baseline condition of Drakes Estero and that, in the past, Olympia oysters could have played a significant role in the biogeochemical processes of the estero.

The ultimate decision to permit or prohibit shellfish farming in Drakes Estero necessarily requires value judgments and tradeoffs that can be informed, but not resolved, by science. This report provides information that may be used by policymakers to reach a decision on the DBOC request to extend the mariculture lease beyond 2012, but statements in the report should not be interpreted as recommendations in support of or in opposition to an extension of the lease. If the legal opinion of the Department of Interior Solicitor's Office stands, then NPS has no authority to offer a new RUO because the mariculture operation is judged as a non-conforming use in a Wilderness area, preventing conversion to full Wilderness status. If a decision were made to extend the lease of DBOC, science would be required to help establish and adjust permit conditions to enhance the benefits (derived largely from the presence and biological activities of oysters) and minimize the risks (derived largely from the activities of the culturists) of the mariculture operation.

The challenges faced by the Point Reyes National Seashore in managing their natural and cultural assets in Drakes Estero represent an example of the NPS dilemma nationwide. NPS receives inadequate financial support to conduct the research necessary to follow its dual mandate of promoting access and enjoyment by the public yet preserving natural processes and values of its public trust assets. Research conducted to meet NPS management needs in Drakes Estero would have broader applicability to local, state, and federal agencies and would contribute to basic scientific understanding. Science could also contribute to educational exhibits if an educational demonstration project were developed to illustrate the beneficial ecological roles of oysters, the challenges of nonnative species, best practices for mariculture, the history of shellfish harvesting reflected in Coast Miwok middens beside the estero, conservation issues, and the biology of oyster propagation. Another possible application for science in management could emerge from a partnership between NPS and DBOC or other entity to restore the native Olympia oyster to Drakes Estero.

Research needs for effective management of Drakes Estero include most importantly evaluation of how to manage and control potential human disturbances to harbor seals from mariculturists, kayaks, hikers, and other sources. Assessing impacts of disturbance on seals, shorebirds, and waterbirds at the population level would help determine the long-term population impacts. Further research is needed to understand why eelgrass is expanding in Drakes Estero and not in some other systems. Additional research could be directed at understanding the relative habitat value of eelgrass, mud flat, and mariculture structures for fish at a landscape scale in the estero and similar systems. Additional observational and experimental studies are needed for use in carrying capacity models to determine how many oysters can be cultured in Drakes Estero without depleting phytoplankton and organic matter also used by native species and to avoid sediment anoxia from excess production of feces and pseudofeces by oysters. Research on control of abundance and risk of spread of the invasive tunicate, *Didemnum vexillum*, is urgently needed, not just in Drakes Estero, but worldwide. And research into the most effective way to control diseases that may be spread with transport of shellfish is important to the public trust and the mariculture industry broadly.

INTRODUCTION TO DRAKES ESTERO

Drakes Estero is located approximately 25 miles northwest of San Francisco, California within the Point Reyes National Seashore, a unit of the National Park Service (NPS) that was established by Congress in 1962 (Point Reyes National Seashore Enabling Act, 16 U.S.C. § 459c–459c-7). In 1976, Drakes Estero was designated as "Potential Wilderness" by Congress (Point Reyes Wilderness Act, Public Law 95-544), one of eleven marine Wilderness areas in the United States (NPS, 2007c). There is also a designated Wilderness Area in Point Reyes National Seashore that includes Estero de Limantour and the mouth of Drakes Estero (Figure 1). Several agencies have jurisdiction over various aspects of the Point Reyes National Seashore and Drakes Estero, including NPS, the California Fish and Game Commission, the California Coastal Commission, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service (Figure 2). NPS holds primary management authority over the Point Reyes National Seashore, including its tidelands and submerged lands (DOI, 2008). The California Department of Fish and Game regulates use of state water bottoms, including two mariculture leases located in Drakes Estero and currently operated by the Drakes Bay Oyster Company (DBOC); however, the Point Reyes National Seashore is acknowledged to have primary management authority over the mariculture operation. The California Coastal Commission holds primary enforcement authority for coastal development, enforcement, and violations under the Coastal Act Sections (e.g., 30106, 30600, 30610, and 30810). Section 30810 delineates the Commission's permitting jurisdiction over sea bottoms and submerged areas and property (those below the mean high tide level). Marin County asked the California Coastal Commission in 2003 to assume primary enforcement authority for Coastal Act violations resulting from mariculture activities on the portion of the property above the mean high tide line. The coastal waters off the Point Reyes National Seashore, including Drakes Bay, are part of the Gulf of the Farallones National Marine Sanctuary, which encompasses 1,255 square miles of marine waters extending just north of San Francisco, west beyond the Farallon Islands and north to Bodega Head. The National Marine Fisheries Service's Office of Protected Resources is responsible for protecting marine mammals and endangered marine life by working to conserve, protect, and recover species under the Marine Mammal Protection Act and the Endangered Species Act. The U.S. Fish and Wildlife Service is the primary federal agency tasked with protecting and enhancing the populations of and habitats for all types of water birds and migratory birds that spend some portion of their lives in the United States.

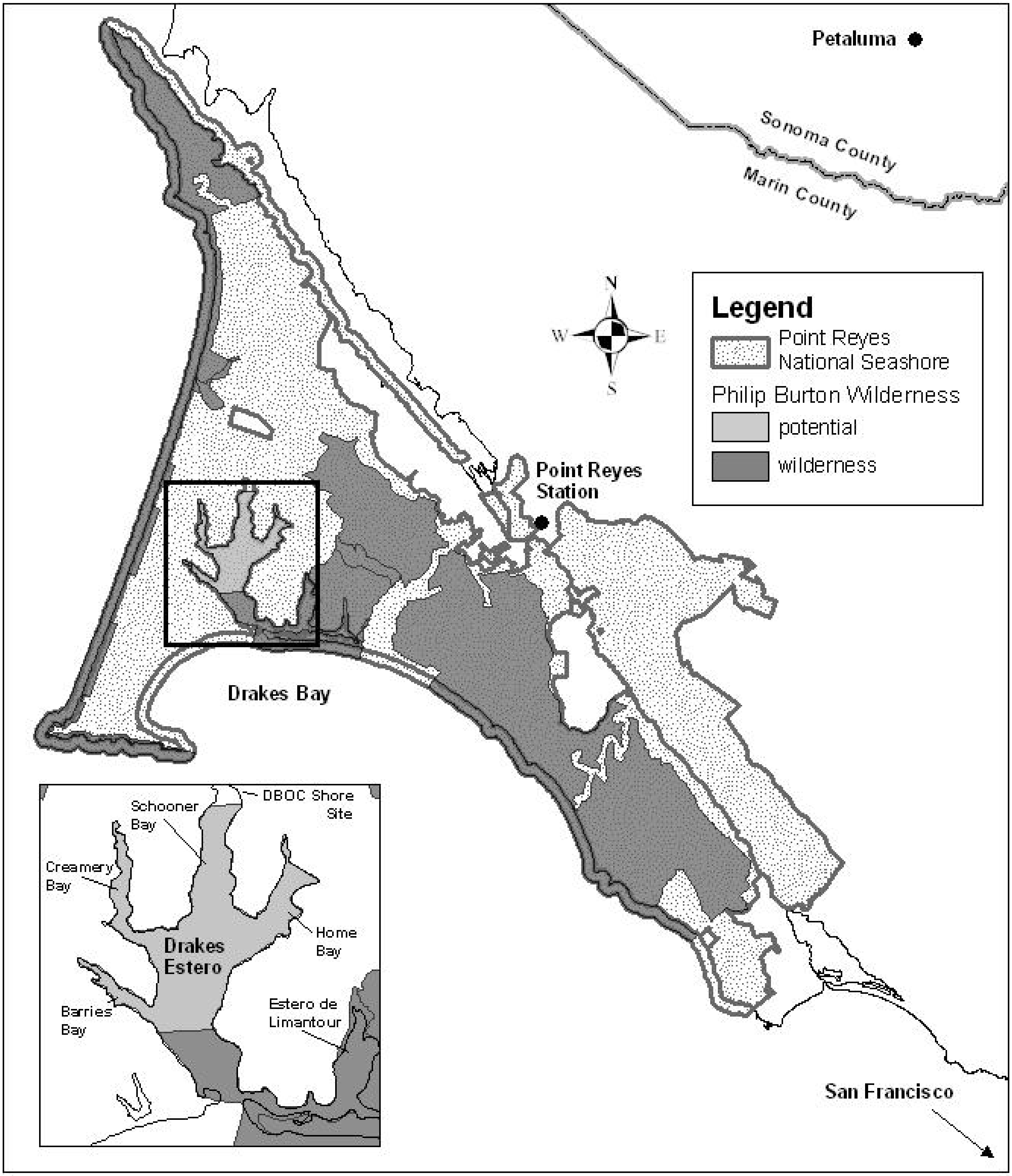

Figure 1. Drakes Estero is located within the Point Reyes National Seashore in Marin County, California. Inset provides larger view of Drakes Estero and shows the location of Drakes Bay Oyster Company. Map provided by courtesy of David Press, NPS.

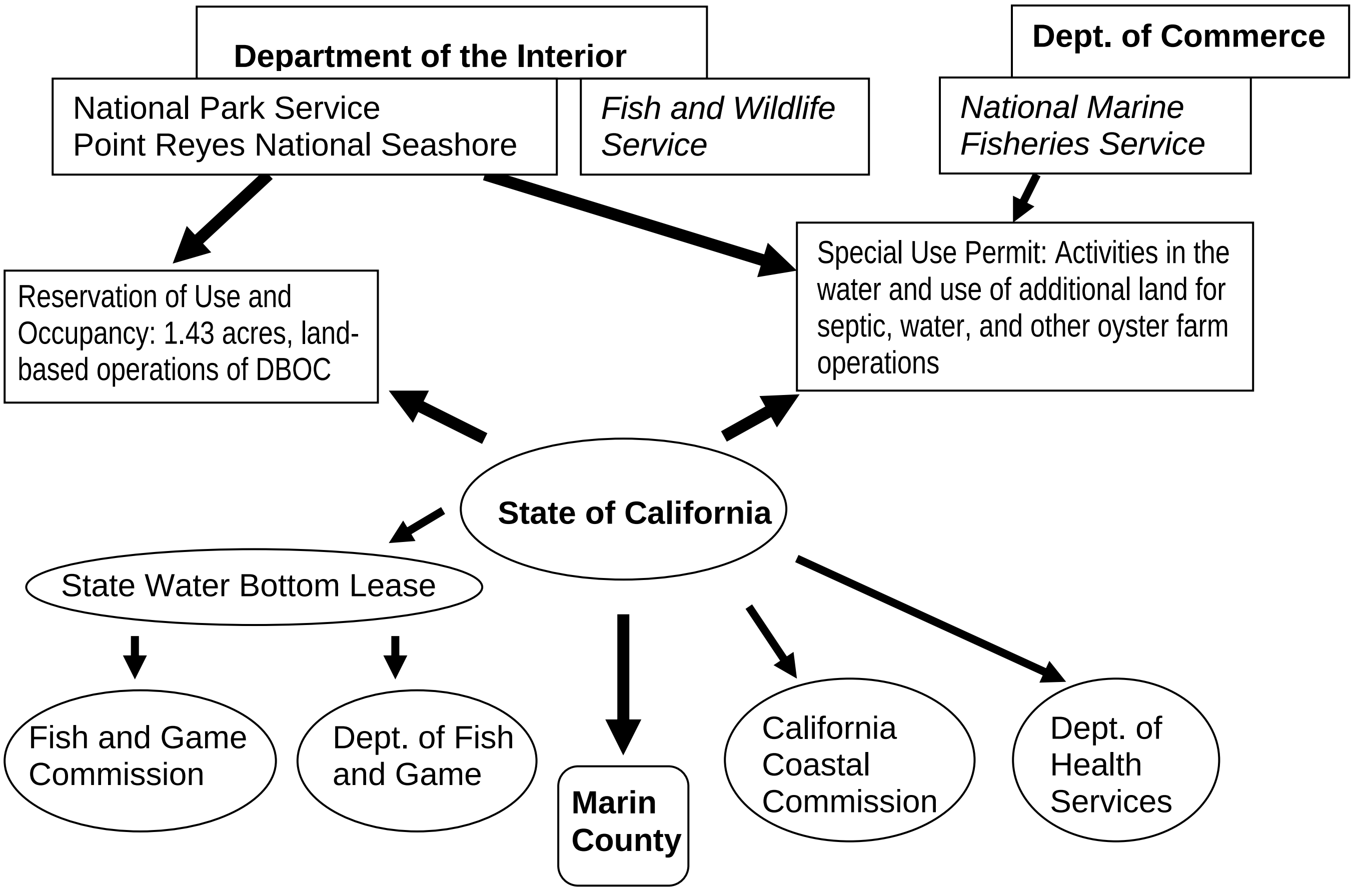

Figure 2. Jurisdictions that have a regulatory or advisory role in permitting for DBOC operations in Drakes Estero. Rectangles indicated federal agencies and authorities; ovals indicate state agencies and authorities, and rounded square indicates county authority. Responsibilities of the various entities are described in the text.

Both Drakes Estero and Estero de Limantour are under consideration for designation as state marine conservation areas under California's Marine Life Protection Act, in the Integrated Preferred Alternative from the Blue Ribbon Task Force for the North Central Coast. In its recommendations to the California Fish and Game Commission, the Task Force notes: "While the stakeholders generally preferred a state marine reserve designation for the entire estuary, accommodating the existing mariculture lease required an additional state marine conservation area designation in part of the area" (California Marine Life Protection Act Initiative Blue Ribbon Task Force, 2008).

Ocean waters bordering and flowing into Drakes Estero are characterized by local upwelling and are influenced by outflows from San Francisco Bay (John Largier, unpublished data), a highly modified ecosystem and urbanized area. Drakes Estero is a large, shallow coastal marine lagoon encompassing 2,270 acres or about 9 km^2 at high tide. Water depth is typically less than 2 m with the exception of the mouth and a channel with a depth of up to 7–8 m in the central lagoon (Dixon, 2007; NPS, 2007). The lagoonal system encompassing Drakes Estero has five branches off a main 1,300-acre lagoon; four of these branches plus the central lagoon are considered part of Drakes Estero including Home, Schooner, Creamery, and Barries Bays (Figure 1, inset). A fifth branch constitutes Estero de Limantour. A single passage to the sea remains open year-round and allows tidal exchange between Drakes Estero and Drakes Bay. Freshwater input consists of perennial and ephemeral streams that provide the majority of the freshwater during the rainy season, which typically runs from October through April; the watershed covers approximately 31 square miles (Anima, 1991; Balton, 2006). Drakes Estero is considered a low-inflow marine lagoon in which all but the innermost branch (Schooner Bay) is marine-driven and thus possesses salinities and temperatures reflecting nearby oceanic conditions. Two tidal cycles exchange a volume of water equal to that contained within the estero, although the estimated residence time of water in the innermost branch, Schooner Bay, is 20 days. Tidal excursion is the major driver of circulation in Drakes Estero (Largier et al., 1997; Balton, 2006; John Largier, unpublished data). Like other marine lagoons with little freshwater input, hypersaline conditions may develop during a dry summer season (Harbin-Ireland, 2004).

Drakes Estero is bordered by cattle grazing lands, all part of the Point Reyes National Seashore (Harbin-Ireland, 2004; Balton, 2006). In addition to cattle ranching, a single commercial oyster operation, DBOC, operates within the Point Reyes National Seashore. Oyster culture began in Drakes Estero in the early 1930s and has continued to the present under various owners. For most of that time, 1954 until 2005, the farm was operated by the Johnson Oyster Company (see Box 2 for details). DBOC took over the farm in 2005, which currently is composed of two leases administered by the California Department of Fish and Game. DBOC is the lease holder and operator of both leases in Drakes Estero. The on-land operations occur adjacent to Schooner Bay (Figure 1, inset) and house the shellfish hatchery, processing, and packing, and include boat docks and piers, two septic systems, a water well, worker housing, parking, interpretation for the visiting public, and retail sales.

DBOC holds a Reservation of Use and Occupancy (RUO) from the Point Reyes National Seashore for the use of 1.43 acres of land at the north end of Schooner Bay and operates in the estero waters under the conditions stipulated in an NPS Special Use Permit and the state lease from the California Fish and Game Commission (see Figure 2). The state lease is subject to the terms of the RUO and the conditions of the Special Use Permit: the present RUO expires in 2012.

Box 2
History of Oyster Mariculture in Drakes Estero

1932: Initial test plants of imported *Crassotrea gigas* seed in Drakes Estero.
1934: Earliest state water bottom leases in Drakes Estero that led in the next year to the establishment of the original DBOC.
1962: Point Reyes National Seashore established (Point Reyes National Seashore Enabling Act, 16 U.S.C. § 459c – 459c-7).
1965: California conveys the tidal and submerged lands within the boundaries of Point Reyes National Seashore to the United States and these areas, including Drakes Estero, become subject to the laws, regulations, and policies governing NPS property.
1972: Charles W. Johnson sells his property on Drakes Estero to NPS, subject to reservation of the right to use the property for 40 years "…for the purpose of processing and selling wholesale and retail oysters, seafood, and complimentary food items, the interpretations of oyster cultivation to the visiting public, and residential purposes reasonably incidental thereto..." (DOI, 2004; see Appendix A).

1976:	Point Reyes Wilderness Act of 1976 designates 25,370 acres as Wilderness and 8,003 acres as Potential Wilderness which includes Drakes Estero (P.L. 94-544, Oct. 18, 1976).
1992	Record of Agreement (ROA) restricts boat access to main and lateral channels during pupping season March 15–June 1 (ROA with NPS, the National Marine Fisheries Service, the California Department of Fish and Game, and the Johnson Oyster Company).
1997:	Marin County Stipulated Court Order (Marin County Superior Court #165361) that orders Johnson Oyster Company to be in compliance with the law (Coastal Act, building code, and health and safety code violations) and meet conditions as specified.
2003:	California Coastal Commission's Cease and Desist Order No. CCC-03-CD-12 concerns onshore development by Johnson Oyster Company without the required coastal development permit. This followed the Marin County request that the Commission assume primary enforcement authority with regards to Coastal Act violations on the property (California Coastal Commission, 2007).
2004:	California Fish and Game Commission issues a 25-year renewal of water bottom leases to Johnson Oyster Company contingent upon the term of the Reservation of Use and Occupancy agreement with NPS.
2005:	Tom Johnson (son of Charles W.) sells oyster farm with remainder of Reservation of Use and Occupancy to Kevin Lunny.
2008:	In April, DBOC and NPS reach agreement on the terms of a new Special Use Permit that authorizes operation of the oyster farm in Drakes Estero until November 2012.

DBOC practices two types of oyster mariculture. The first is Japanese rack culture that is used to grow oysters on shell cultch predominantly for the shucked product. The second is cultchless culture, in which individual oysters are grown in bags for the half shell market. These methods are described below with specific reference to their application in Drakes Estero.

DBOC imports Pacific oysters as eyed larvae from West coast hatcheries. The larvae are cultured in tanks where they set on bagged cultch, consisting of cleaned oyster shells from the shucking operation, or on ground oyster shell fragments (250–300 µm in size) for cultchless culture, depending on the desired end product. At DBOC, oysters can be set successfully from April to October. While in the tanks, the young oysters feed on algae from the estero's naturally productive water that is pumped into the shoreside facility.

For rack culture, the bags of cultch with oyster spat are suspended in the water column in the nursery area (area 6 in Drakes Estero, see Figure 3 map), a site with high productivity that supports rapid growth. After about two months, the bags of seeded cultch are brought back onshore and strung onto wires. At DBOC, the stringing can take place from April to December or January. Boats then transfer the loaded wires from the shoreside facility to racks, which are located near the main channels of Drakes Estero. Wires are hung over the racks, such that at the lowest point the cultch is 0.5 m off the bottom and at the top of the rack the cultch is 2 m above the bottom. The racks are submerged at high tide and become partially exposed during low tide (Figure 4). Once the oysters have matured to market size, the wires are brought onshore, and workers use a pneumatic hammer to remove and separate the oysters. Oysters are sorted and graded to determine whether they will be sold in the shell or shucked; both occur onsite. DBOC is the last on-site shucking and packing facility in California (Kevin Lunny, during October 30, 2008 site visit).

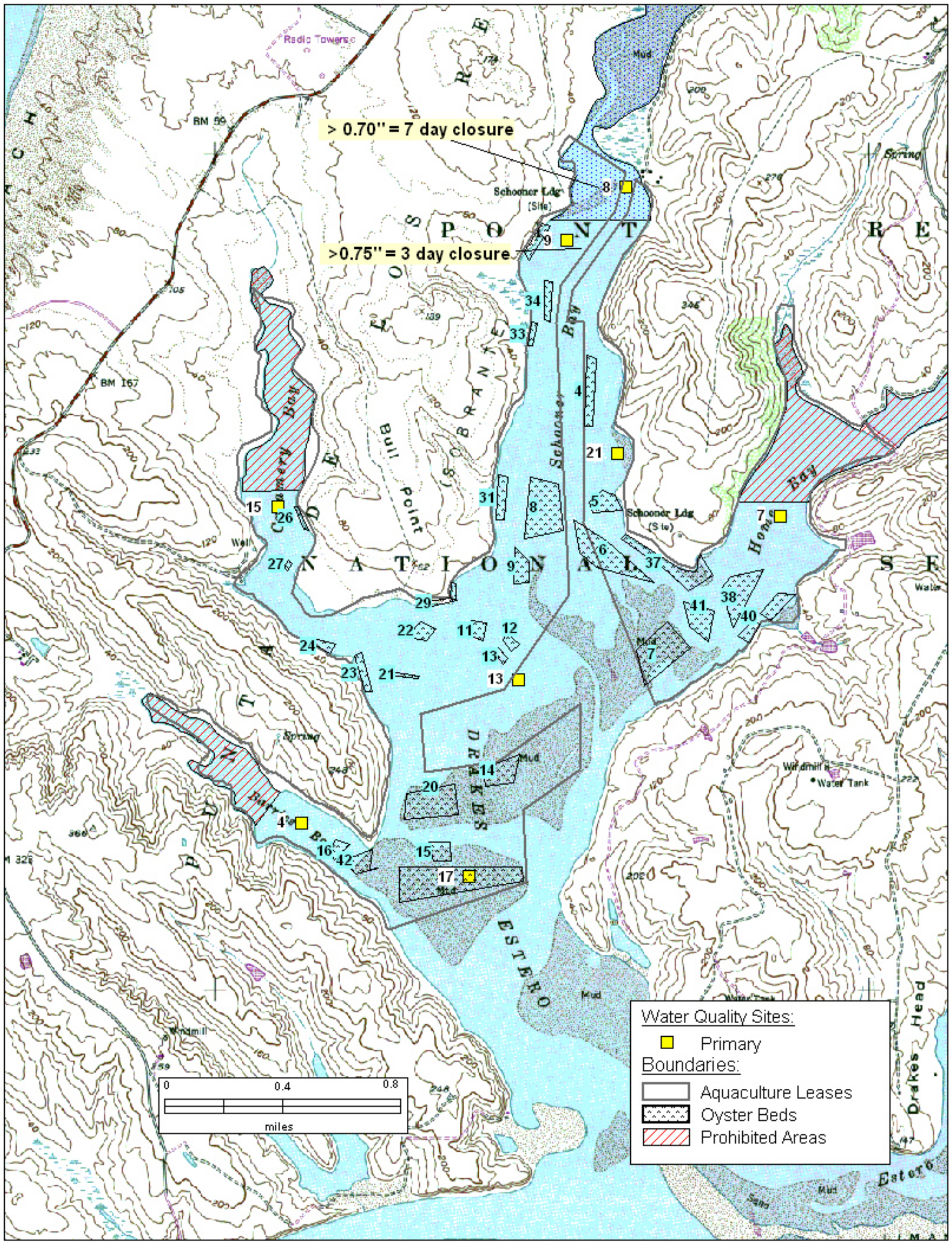

Figure 3. Map of Drakes Estero illustrating mariculture lease areas and oyster beds (sites used for growing oysters on racks or in bags). California Department of Health Services, 2007?.

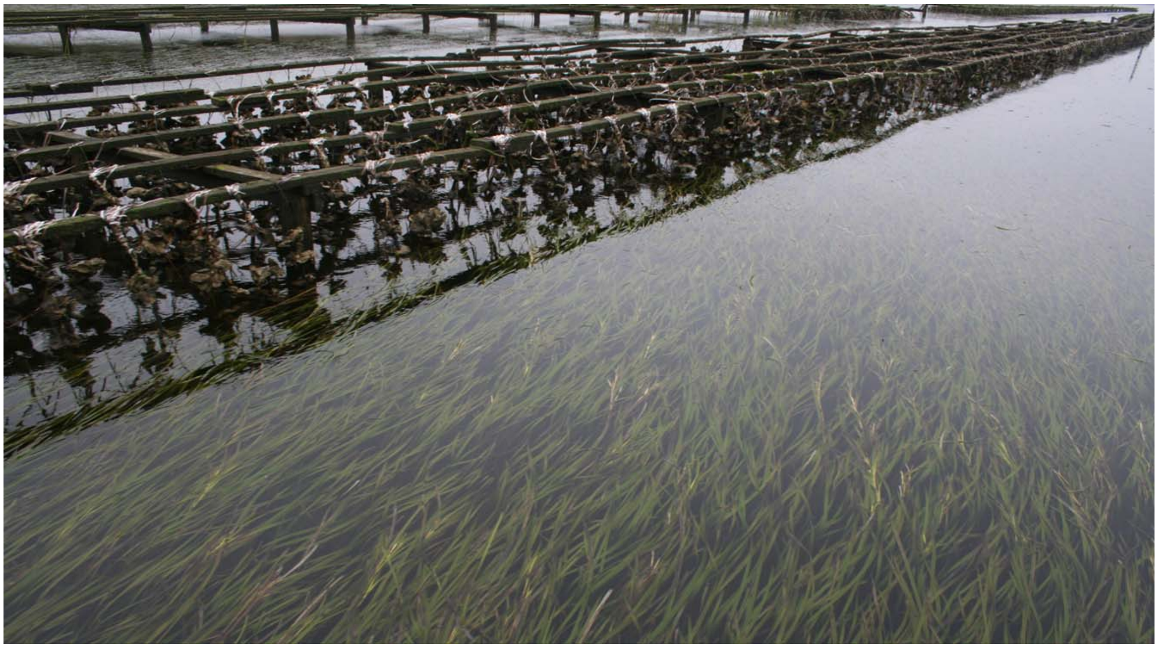

Figure 4. Oyster cultch strung on wire with spacers and hung over racks. Eelgrass, *Zostera marina*, appears in the foreground (photograph courtesy of T. Moore).

For cultchless culture, ground oyster shells are used to ensure settlement of a single larva per fragment. These seed oysters are put into a container with a mesh screen bottom and placed in another tank where an upwelling system pumps estero water through the screens to feed the young oysters. As the seed oysters grow, they are serially transferred into bags of increasing mesh size at lower densities for hanging bag culture in the estero. When the oysters reach a size of 3 mm, they are bagged and placed in the intertidal area where they float during high tide and sit on the substrate during low tide. When the oysters are approximately 2 inches long, about 120 oysters are bagged and tethered to groundlines staked on the sand bars in the estero. The bags are flipped once every 2–3 weeks both to reduce fouling and also to ensure more uniform shell growth (Figure 5). The oysters stay in these bags for 1–4 months for “beach hardening time” or “finishing time” to induce shell growth. This process is necessary in order to condition the oysters for transport of live animals to be sold to the half-shell market. The production of single oysters requires more effort and a longer culture period, but results in a higher value product.

Weekly oyster and water samples are provided to the Department of Health Services for monitoring of the presence and or levels of toxic phytoplankton. In Drakes Estero, biotoxins (e.g., saxitoxin, which is responsible for paralytic shellfish poisoning; domoic acid, which causes amnesic shellfish poisoning) are more of a problem towards the mouth of the bay and less of a problem in the upper reaches (Kevin Lunny, during October 30, 2008 site visit). During a biotoxin alert, it is possible that the water quality and/or harvested oysters will be sampled every day. However, after significant rainfall, automatic closures restrict harvesting to area 17, a 25 acre sand bar closer to the mouth of the estero approved for year-round harvest, the only fully approved shellfish growing area in California. Part of area 17 is inside the seal protection area, and therefore may not be used for oyster culture. Boat transit to area 17 is also directed away from the main channel to avoid disturbance of harbor seals. In periods of high rainfall, DBOC helps other growers keep their markets open by providing them with oysters from the approved area.

Figure 5. Oyster bags tethered to groundlines on a sand bar in Drakes Estero (photograph courtesy of T. Moore).

According to Kevin Lunny (October 30, 2008 site visit), DBOC harvests oysters daily throughout the year. Between harvest and setting, DBOC boats may make more than one trip to the racks or bags per day. The typical work day is 8:00 a.m. to 4:30 p.m., Monday through Saturday and occasionally on Sunday when it coincides with a holiday. With the hanging rack culture, DBOC can work at more stages of the tidal cycle than most other oyster operations.

In addition to oysters, DBOC also grows Manila clams. The technique is the same as for cultchless oyster culture, with the clams grown in mesh bags, but the clams require less tending than the oysters (Kevin Lunny, 3.4.09 communication).

The State of California has production minima that oyster growers must meet in order to maintain a lease for the state water bottom. Growers must plant a minimum of 10,000 oysters per acre and harvest a minimum of 2,000 oysters per acre per year; therefore DBOC is required to harvest 180,200 lbs shucked weight to meet this minimum based on lease acreage (Moore, 2008). According to the map produced by the California Department of Public Health, 147 acres of the total 1,059 acres available for oyster growing were under production in November, 2007—this represents a snapshot in time because areas used for growing oysters will shift at different times of year depending on the planting schedule (Kevin Lunny, 3.4.09 communication). The actual footprint of the racks and bags on bottom in Drakes Estero in 2008 was less than 30 acres (Moore, 2008).

Since 1960, the size of the oyster harvest has fluctuated from lows of 29,799 lb and 34,094 lb in 1960 and 2000, respectively, to a high of 769,590 lb in 1995 (Figure 6). Insufficient information is available to explain the steep decline in the oyster harvest from 1996 to 2000. A change in planting methods in the early 1990s may be responsible for the massive increase in the reported number of seed oysters planted as estimated by the owner of Johnson Oyster Company (Figure 6).

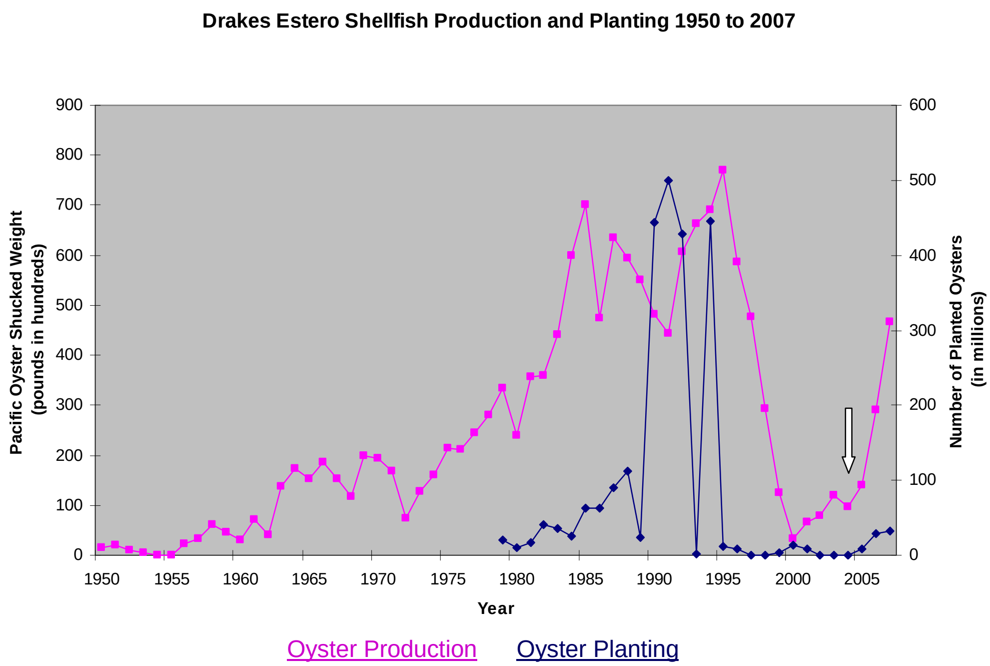

Figure 6. Drakes Estero Oyster Planting and Production 1950-2007. Shucked weight = 100 oysters/gal x 8.5 lbs/gal. Oyster shucked weight is calculated from Shellfish Harvest Tax Reports which are filed monthly for all state water bottom leases. Arrow indicates the year (2005) in which DBOC assumed operation of the oyster farm. Oyster production and planting values were obtained from Tom Moore, Marine Region Aquaculture Coordinator, California Department of Fish and Game).

The fate of DBOC after 2012 has become a matter of public controversy. Highly publicized disputes over the science addressing impacts of the oyster farm on Drakes Estero have erupted in the context of the continuing operation of a commercial shellfish farm within a designated Potential Wilderness area (Department of the Interior, 2004; see Appendix A) and an Office of the Inspector General investigative report (DOI, 2008) that was undertaken in response to complaints from the owners of DBOC with regard to the Point Reyes National Seashore actions. To resolve some of these issues, Senator Diane Feinstein and the NPS requested that the National Research Council (NRC) of The National Academies conduct an independent assessment of the scientific basis for NPS presentations and reports on the ecological effects of DBOC operations on the Drakes Estero ecosystem. In addition to the review of the science on Drakes Estero, the committee will produce a second report, published separately, that will address in more general terms the elements of best management practices that could be employed to enhance the benefits of shellfish mariculture and minimize any negative ecological effects (see Appendix B for the NRC statement of task).

The committee held its first meeting in Mill Valley, California and spent the first day receiving oral and written input directly from key participants in the controversy over the impacts of DBOC and the second day visiting Drakes Estero with guidance from NPS and DBOC principals (see Appendix C for meeting agenda). To fulfill part one of the statement of task, the committee organized a framework to answer the ecological questions using information from local empirical studies, studies in comparable ecosystems, and a conceptual understanding based on a synthesis of scientific studies and ecological theory. This report is organized according to this framework and includes an introduction to the Drakes Estero environment and the controversy, followed by sections that address questions about the accuracy of the science presented by NPS, the effects on NPS decision making, and suggestions for future research. The committee relied on the published scientific literature, presentations at the first committee meeting, and the many documents provided to the committee both on Drakes Estero and other sites worldwide in which studies have been conducted that could provide insight into impacts of shellfish culture on the Drakes Estero ecosystem.

Historical Baselines and Human Modifications

Although relatively unmodified by human interventions, especially as compared to highly developed portions of San Francisco Bay, Drakes Estero is not a pristine coastal lagoon. The current status of the estero's ecosystem reflects many influences of human populations both past and present. Modifications to the ecosystem include both local interventions and local manifestations of distant interventions operating on wider spatial scales.

Perhaps the ecologically most significant modifications of Drakes Estero follow from the local human over-exploitation and functional extinction of the native Olympia oyster population. The Olympia oyster, *Ostrea lurida*, was a former constituent of Drakes Estero of some appreciable but unquantifiable abundance, as evidenced by the mounds of its shells in the Coast Miwok midden near the on-land facilities of DBOC and other shell middens excavated around Drakes Estero (Stewart and Praetzellis, 2003). Kirby (2004) describes a pattern of regional over-exploitation of the native oyster during the 1800s across every estuary of the western states for which historical fisheries landings data are available. These oysters were harvested to supply the growing San Francisco market during the Gold Rush period (Conte and Dupuy, 1982). Baker (2005) provides a personal communication from C. Johnson that Olympia oysters are "common but not abundant" in Drakes Estero, but it is unclear what information this comment was based upon and when such observations were made. There are no recent observations of the Olympia oyster in Drakes Estero. This oyster has been functionally removed by unsustainable exploitation from most of its natural range in California, Oregon, and Washington (Kirby, 2004), but a recent 2008 photograph of natural Olympia oyster populations in Nootka Sound in British

Columbia (Figure 7) and descriptions of Olympia oyster populations at several sites throughout British Columbia (Gillespie, 2009) indicate conditions that may have prevailed in Drakes Estero before the mid-1800s. The natural Olympia oyster reefs form a nearly continuous band covering the low-intertidal surfaces of many tidal flats sheltered in lagoons, bays, and estuaries, where recent quantitative sampling of three such flats revealed densities of 109–360 per square meter (Gillespie, 2009). Before intense exploitation by fishermen, densities were described as far higher in locations in the Strait of Georgia, where populations now remain relatively low (Gillespie, 2009). The tidal flat in the Figure 7 photograph ends with a steep slope into the subtidal and the oysters do not extend below about mean low water, although the Olympia oyster typically extends into the subtidal where the slope is gradual (Couch and Hassler, 1989; Shaw, 1997; Gillespie, 2009).

Figure 7. Photograph of a natural Olympia oyster reef in Nootka Sound in British Columbia at low tide (taken in 2008 by Michael Beck, The Nature Conservancy).

Although no fisheries data are available for Drakes Estero per se, the lack of effective management of the native oyster fishery in the late 1800s to the early 1900s that led to overfishing and functional extinction of the native oyster throughout the western states (Kirby, 2004) for transport to San Francisco markets suggests that a similar pattern of over-exploitation occurred in the nearby Drakes Estero. Limited sampling of the bottom benthos in Drakes Estero (Harbin-Ireland, 2004 [in eelgrass beds]; Press, 2005 [on intertidal flats]) did not detect evidence of this native oyster, implying little or no recovery during the recent decades. The loss of oysters from estuaries and coastal lagoons has cascading consequences on the functioning, resilience, and value of ecosystem services of these environments worldwide (Jackson, J.B.C. et al., 2001;

Lotze et al., 2006). Oysters have been characterized as ecosystem engineers (term from Jones et al. [1994]; application to oysters in Lenihan and Peterson [1998]) and a foundation species (term from Dayton [1972]; application to oysters in Bruno and Bertness [2001]); these terms are used to imply the dramatic impacts that the presence and biological activities of oysters have on the composition and dynamics of an entire ecosystem. The Atlantic States Marine Fisheries Commission identifies oyster reef habitat as valuable, serving perhaps as essential fish habitat for some fish (Coen et al., 1999; Atlantic States Marine Fisheries Commission, 2007). Our report details the most important of these ecological consequences below.

Drakes Estero has also been modified by introductions of nonnative species. The most evident and aggressively invasive of these is the clonal tunicate, *Didemnum vexillum*, which forms yellow blankets over many subtidal hard substrates, especially shells of cultured oysters and oyster racks. Although the *Didemnum* introduction cannot be attributed to local human importation, other nonnative species were introduced by the shellfish mariculture operations, including the intentionally imported shellfish—the Pacific oyster (*Crassostrea gigas*), the Kumamoto oyster (*Crassostrea sicamea*), and the Manila clam (*Venerupis* [*Ruditapes*] *philippinarum*); and two hitchhikers—a nonnative marsh snail (*Batillaria attramentaria*) (Byers, 1999) and a protozoan parasite of oysters (Burreson et al., 2000).

Other local and regional interventions of humans have also modified the ecosystem of Drakes Estero from its baseline conditions. Cattle ranching takes place on all of the lands abutting the estero, probably modifying the composition and appearance of terrestrial vegetation in the Point Reyes National Seashore but with little apparent contribution to nutrient run-off in streams that feed into Drakes Estero, as noted in Anima (1991) that "it seems unlikely that surface nutrient inputs to Drakes Estero are of concern." Cattle typically destabilize stream banks, potentially enhancing erosion and sedimentation into Drakes Estero. Documented increases of sedimentation over the past 150 years in Drakes Estero (Anima, 1991) can be attributed to increased land use, such as "trail and road use, road building, increase in paved areas" as well as effects of cattle grazing (Anima, 1991). Kayakers and hikers make use of the lands surrounding Drakes Estero, and those who approach wildlife closely can cause seals and water birds to flush. Since 1900, California has lost over half of its coastal wetland habitat to development (Dahl, 1990, 2006) so these changes elsewhere in the state probably affect the numbers of shorebirds and wetland-dependent birds using Drakes Estero and elevate the value of Drakes Estero because of the comparatively high quality of its estuarine environment. Human activities and development have displaced harbor seals from traditional habitats in areas such as San Francisco Bay, highlighting the importance of Drakes Estero as a relatively unmodified habitat. Global climate change is modifying not only the distributions of individual species but also changing many communities as new mixes of species induce new dynamics in estuarine and lagoonal environments (Scavia et al., 2002; Parmesan and Yohe, 2003; Parmesan and Galbraith, 2004; Parmesan, 2006).

The initiation of commercial mariculture of *Crassostrea gigas* in the 1930s and its perpetuation through present represents another human intervention of significance to the ecosystem of Drakes Estero. The oyster re-introduction and enhancement through mariculture (albeit not the native oyster) represents a form of restoration of historic functionality of the estero, although there may be differences in the habitat functions of the native oyster beds compared to nonnative oysters grown in mariculture. Effects of nonnative oyster presence and its biogeochemical processing can be viewed as contributions towards restoring an historic baseline ecosystem in Drakes Estero (e.g., Jackson et al., 2001; Lotze et al., 2006). Past oyster culture came at a cost—modifying the ecosystem state by leaving a legacy of nonnative species. In addition, continued culture of nonnative oysters and clams poses some risk of their eventual naturalization in Drakes Estero and larval spread to other coastal lagoons, a risk that could be minimized but not entirely eliminated by culturing triploids (NRC, 2004). Given the proximity of the estero to a large urban area and the influence of the highly modified San Francisco Bay, and the other activities in the Point Reyes National Seashore (ranches and recreational use), the ecosystem of Drakes Estero will be affected by both legacy effects of earlier human interventions and also ongoing human activities, even if the oyster farm were closed and all the associated equipment removed. Nevertheless, removal of the Pacific oysters and nonnative clams under culture and all the structures used in the culture process would carry the consequences of removing the direct and indirect influences of the biogeochemical processes now provided by the filtration, excretion, and biodeposition of the shellfish and the influences of structural substrates of the oysters and the racks and bags that now hold them. In addition, the activities of the oyster culturists would also cease so impacts of those activities would disappear, some immediately and others gradually over time. The committee describes these effects, positive and negative, of oyster and shellfish feeding and biodeposition, of hard structures, and of activities of culturists in detail below.

Ecological and Environmental Responses

The committee organized its synthesis of the assessment of impacts of culturing nonnative oysters and clams in Drakes Estero by first preparing Table 1, which breaks down the question of mariculture impacts into seven largely separate ecosystem responses and one response for human use values. Columns separate the synthesis into a series of questions about each potential response. Answers to each question are presented in the report by treating each of the eight potential responses and addressing four questions: (1) reviewing relevant background science of Drakes Estero, (2) identifying the body of relevant studies on mariculture impacts in Drakes Estero, (3) specifying the impacts of mariculture that can be directly demonstrated by studies of Drakes Estero, and (4) specifying the impacts of the Drakes Estero mariculture that can be reasonably inferred from research conducted in other systems. The committee was asked to address two additional questions: (5) identify conclusions that can be drawn from the body of scientific studies, how they compare with what the NPS presented to the public, and how these conclusions affected NPS decision making; and (6) what research is recommended to resolve important remaining uncertainties—the answers to these questions were combined across all eight types of ecological/environmental/human use value responses and are presented after the discussion of the individual responses.

Potential ecological or environmental response or effect on human use value	Background of relevant science in Drakes Estero	Studies of relevant mariculture impacts in Drakes Estero	Impacts directly demonstrated by studies of Drakes Estero	Impacts reasonably inferred from research conducted in other systems
Benthic/pelagic coupling—nutrients and particulates	I. A	I. B	I. C	I. D
Eelgrass	II. A	II. B	II. C	II. D
Fish	III. A	III. B	III. C	III. D
Benthic invertebrates in soft sediments	IV. A	IV. B	IV. C	IV. D
Harbor seals	V. A	V. B	V. C	V. D
Nonnative species	VI. A	VI. B	VI. C	VI. D
Birds	VII. A	VII. B	VII. C	VII. D
Human-use values—economics, recreation, aesthetics	VIII. A	VIII. B	VIII. C	VIII. D

Table 1. Ecological, environmental, and human use values in response to mariculture operations. The column headings correspond to questions posed in the Statement of Task and the rows identify the various components of the Drakes Estero ecosystem that could be affected by mariculture. The Table provides a guide (Roman numerals) to the presentation of the committee's findings.

I. Benthic/Pelagic Coupling—Nutrients and Particulates

A. Background

Suspension feeders, such as oysters, mussels, and other bivalve mollusks, have been shown to influence the nutrient, organic, and materials coupling of benthic and pelagic systems in a broad range of habitats (Dame, 1996). Oysters feed by filtering particulates from the water column and when populations are abundant they can depress turbidity in their local vicinity and help graze down algal blooms in estuaries (Herman and Scholten, 1990; Haamer, 1996; Rice, 2000; Smaal et al., 2001; Landry, 2002; Newell, 2004). Epifaunal shellfish such as oysters have a very plastic response to increasing levels of phytoplankton and detritus in water, increasing their filtration rate and production of pseudofeces. This adaptability is not observed in infaunal shellfish (clams and cockles); they stop filtering when suspended particulate levels exceed their tolerance (Foster-Smith, 1975; Prins et al., 1991). Because oysters and other bivalves can filter so much material from the water, producing a large quantity of pseudofeces and feces, they function in the transfer of organic and inorganic particulates from the water column to the sediments—a process referred to as benthic-pelagic coupling (Dame, 1996; see review in Dame and Olenin, 2005).

The deposition of feces and pseudofeces can modify sediments in the vicinity of high abundances of bivalves, increasing concentrations of fine particles and organic content and altering sediment biogeochemistry (e.g., Newell et al., 2002). Under circumstances of limited physical flushing and transport of these biodeposits, high rates of transfer of organics from the water column to the bottom can result in sedimentary anoxia, diminishing the capacity of the sediments to sustain benthic invertebrates. On the other hand, low rates of organic enrichment from pseudofeces and feces may fertilize eelgrass and benthic macro- and microalgae, thereby increasing benthic primary production (Asmus and Asmus, 1991; Reusch et al., 1994; Peterson and Heck, 1999; Carroll et al., 2008).

B. What is the Body of Scientific Studies on the Impact of the Oyster Farm on Drakes Estero?

There are few and limited studies of sedimentation and nutrient inputs in Drakes Estero. Anima (1990, 1991) presents results from studies on sedimentation and pollution in Drakes Estero funded by NPS. In another study funded by NPS, researchers provided a preliminary inventory and assessment of the effects of the oyster farm on some of the biota in the estero, including analysis of sediment cores for benthic infauna, organic content, and particle size (Harbin-Ireland, 2004; summarized in Elliott-Fisk et al., 2005).

Anima (1990, 1991) conducted a survey of the sedimentation rate and composition of sediments in Drakes Estero in 1984–1986. Sedimentation appeared to increase over the past 150 years, potentially a response to changing land use as the population increased. In the report to NPS, Anima (1990) noted a few potential impacts associated with oysters or oyster farm activities on sedimentation in the estero. First, he observed that the Schooner Bay channel appears to be artificially maintained by boat traffic associated with oyster operations. Propeller action was inferred to maintain the navigation channel and prevent sedimentary in-filling from the adjacent, extensive eelgrass beds. In addition, Anima speculated on the role of oysters in deposition of fine sediments in the estero, based predominantly on studies of oyster biodeposition rates in other systems. Noting that the flushing rate in the upper reaches seems insufficient to transport fine sediments out of the estero, Anima (1990, 1991) concluded that "more research is needed to ascertain what amount of silt-sized material is being produced by oysters in the lagoon."

Anima (1990, 1991) also reported results from a study of nutrient inputs to the estero based on the monitoring of streams in areas with or without agricultural land use (cited as Hagar, 1990 [unpublished]). From short-term monitoring of nutrients (phosphorus and nitrogen) in the various streams, it appeared that the estero was unlikely to experience excess nutrient loading from the watershed (Anima, 1990, 1991). This report also asserted that there is low risk of eutrophication due to the high rate of tidal flushing relative to stream inputs.

In January and October 2003, Harbin-Ireland (2004) sampled sediments below oyster racks and 10 m away from the racks in eelgrass habitat and found that the sediments were slightly but significantly sandier immediately below the racks, appeared to be oxygenated to a depth of at least 10 cm in all locations, and did not exhibit a significant difference in the organic content among sampling locations. The report attributed the lack of a detectable difference in organic content beneath the racks to the already high inputs of detritus from eelgrass and concluded that the strong tidal flux appeared sufficient to prevent oxygen depletion in the sediments of eelgrass beds near oyster racks (Harbin-Ireland, 2004).

C. What Effects Can Be Directly Demonstrated by Research Conducted in Drakes Estero Itself?

The relatively small, low-flow watershed and high-energy hydrography of Drakes Estero, dominated by strong tidal flux (Anima, 1991; John Largier, unpublished data), appears to be sufficient to produce low risk of eutrophication in most of Drakes Estero. Even though these properties endow the estero with excellent water quality, filtration by the cultured oysters could provide additional benefits to eelgrass production by lowering turbidity and adding nutrients because these limit eelgrass distribution and production even in relatively oligotrophic estuaries (Carroll et al., 2008). In addition, the oysters in Drakes Estero could add ecosystem resilience in the event of a phytoplankton bloom or a high-turbidity event like sedimentation during run-off of stormwaters (Jackson et al., 2001). Also, the strong tidal currents and shallow water depths help maintain the oxygenation of sediments even under oyster racks where biodeposition (feces and pseudofeces) is expected to be highest. Thus, sedimentary anoxia induced by DBOC shellfish is unlikely.

D. What Effects Can Reasonably Be Inferred from Research Conducted in Similar Ecosystems?

Studies have shown that oyster reefs and oyster mariculture installations can contribute to the transfer of suspended material into the sediments (Mazouni et al., 1996; Nugues et al., 1996). These dense aggregations of oysters also release dissolved nutrients that can support new growth of algae or seagrasses (Asmus and Asmus, 1991; Reusch et al., 1994; reviewed in Dame and Olenin, 2005). To varying degrees, suspension feeders enhance benthic–pelagic coupling, nutrient remineralization, primary productivity, sediment transfer from water column to the bottom, and habitat complexity. Kaiser (2001) reviewed the effects of shellfish cultivation on estuarine ecosystems and identified a similar set of mechanistic influences, concluding that such processes have a generally positive influence on the overall water quality of a system. Oyster enhancement and oyster reef restoration is a major and expanding component of estuarine restoration throughout the United States (Coen and Luckenbach, 2000; Lotze et al., 2006), now widely promoted by several environmental organizations (M. Beck, The Nature Conservancy, Feb 2009).

Several reviews have highlighted the positive and negative feedback mechanisms observed in aquatic systems as a consequence of nutrient dynamics mediated by shellfish (Dame, 1996; Prins et al., 1998; Newell et al., 2005). Concentrated bivalve assemblages have been documented to play a role in regulating the abundance of phytoplankton in shallow seas (Newell et al., 2005; McKindsey et al., 2006). In summary, large populations of filter-feeding molluscs provide the system with a capacity to buffer episodic influxes of suspended materials such as turbidity after storms or excess phytoplankton blooms (De Angelis, 1986), thus enhancing and sustaining water clarity.

In their review, McKindsey et al. (2006) maintain that bivalve shellfish facilitate the cycling of nutrients both by direct excretion and through remineralization of organic biodeposits in the sediments. Nutrient regeneration in aquatic systems may be governed by flushing rates and water residence times as well as the abundance and location of bivalves in the systems (i.e., shallow versus deep water) (Dame, 1996; Newell et al., 2005). Subsequent primary production is therefore influenced by the degree of internal cycling of nutrients such as phosphorus, silicon, and nitrogen, as well as the degree of import and export from the systems, as determined by flushing rate (Dame and Prins, 1998). For example, some measurements of phosphorous budgets in and around shellfish assemblages have indicated a considerable removal of phosphorous from the system through biodeposition (reviewed in Dame, 1996; Newell et al., 2005). In relation to the cycling of silicon, Prins and Smaal (1994) concluded that the majority of silicon, a structural component of diatoms, was transferred to the sediment with little being released by bivalves.

Most nutrient studies have focused upon the fate of nitrogen because this nutrient is generally considered to be the most limiting for primary production in marine and estuarine systems. Benthic bivalves play an important role in nitrogen cycling in both subtidal and intertidal systems, usually through the release of ammonium (NH_4^+). Nixon et al. (1976) concluded that nitrogen flux across oyster reefs was highly variable and was heavily influenced by tidal flow. Dame (1986) reviewed a body of work relating to nutrient fluxes induced by *Crassostrea gigas* filtration and biodeposition in northern France and concluded that 15–40% of nitrogen input to the water column was recycled from oysters and that the measured values were always higher than the estimated values, probably enhanced by mineralization occurring in adjacent sediments containing oyster biodeposits. However, Dame and Libes (1993) contended that nitrogen is retained within the water column through direct recycling of nitrogen from shellfish (*Crassostrea virginica*) to phytoplankton. Recently, Newell et al. (2002) showed that oyster biodeposits can also serve as sites for the removal of nitrate from the ecosystem through the conversion of nitrate to nitrogen gas by anaerobic bacterially mediated processes (denitrification).

Although no specific study relating oysters to nutrient dynamics, sediment deposition, and water quality has been conducted in Drakes Estero, it is reasonable to assume that processes identified here apply under similar conditions (i.e., oyster production levels, and hydrological flushing and water residence times).

II. Eelgrass

A. Background

Seagrasses are important to estuarine and coastal lagoonal ecosystems because they provide food for some herbivores, notably black brant (*Branta bernicla nigrans*) on the Pacific coast of the United States and Canada, generate detritus to feed deposit-feeding invertebrates, and form structured habitat for fish and invertebrates in what would otherwise be a plain of soft sediments (Jackson, E.L. et al., 2001; Williams and Heck, Jr., 2001; Heck et al., 2003; Bostrom et al., 2006). Seagrasses are susceptible to multiple anthropogenic disturbances, which have been shown to be at least partly responsible for a general worldwide decline in their abundance (Orth et al., 2006). Although several species are found along the west coast of the United States, eelgrass (*Zostera marina*) is the dominant native species and apparently the only one found in Drakes Estero. The now common nonnative eelgrass, *Zostera japonica*, has not been documented in Drakes Estero, although *Ruppia maritime* may occur there (S. Williams, personal communication). *Zostera marina* typically occurs from about 1 m above to 1.5 m below Mean Low Water in estuaries along the west coast of the United States with its upper limit determined primarily by desiccation (Boese et al., 2005) and the lower limit determined by light. Consequently, its distribution varies by location and extends to almost 10 m depth where water clarity is high (Phillips, 1984; Thom et al., 2003). The *Z. marina* distribution, thus, overlaps directly with the depth range across which most oysters are cultured (Conte et al., 1994). The structured habitat formed by *Z. marina* in west coast estuaries has been shown to influence the abundance and diversity of everything from small epibenthic invertebrates to large fish and birds (Simenstad and Fresh, 1995; Moore et al., 2004; Dumbauld et al., 2005; Hosack et al., 2006; Ferraro and Cole, 2007). While seagrass abundance has declined worldwide (Orth et al., 2006), at least 24% of seagrass populations along the west coast have shown increasing trends in abundance (S. Williams, personal communication), including Drakes Estero, although, in some estuaries, this increase may be attributed to expansion of the introduced nonnative eelgrass *Z. japonica*.

B. What is the Body of Scientific Studies on the Impact of the Oyster Farm on Drakes Estero?

No study has comprehensively evaluated the impacts of shellfish mariculture on eelgrass in Drakes Estero. Eelgrass information is limited to some observations of eelgrass distribution relative to oyster mariculture racks in research examining potential impacts of the oyster mariculture on eelgrass invertebrate and fish communities (Harbin-Ireland, 2004; Wechsler, 2004), a visual analysis of the extent of tracks of boat propeller damage by NPS scientists and apparent eelgrass displacement by oyster racks (NPS Trip Report of March 13, 2007), and a monitoring of both eelgrass abundance and persistence over 18 months from April 1996 to October 1997, which included some structural parameters like densities of blades and turions at two sites in Drakes Estero and one in Estero de Limantour using six plots per site (Applied Marine Sciences, 2002).

C. What Effects Can Be Directly Demonstrated by Research Conducted in Drakes Estero Itself?

The limited scope and effort of the studies that infer impacts of shellfish mariculture on eelgrass of Drakes Estero prevent any definitive conclusions. The Applied Marine Sciences (2002) study did not control for tidal elevation in establishing its sites in Drakes Estero and Estero de Limantour. Reasonable inferences can be drawn, however, from the observations of propeller damage in the NPS GIS map of July 2007 (NPS, 2007) and from the Harbin-Ireland (2004) and Wechsler (2004) observations, consistent with research conducted elsewhere along the west coast as presented below.

D. What Effects Can Reasonably Be Inferred from Research Conducted in Similar Ecosystems?

Shellfish mariculture and eelgrass compete directly for space; however, they also interact indirectly via changes each makes to the immediate environment like altering water flow, sediment structure, light penetration, and nutrient supply. Other environmental changes arising from mariculture come from the addition of structures (e.g., bags, racks, and lines) and disturbances of transportation and culture operations. Whereas no directed research has been undertaken on these interactions in Drakes Estero, a fairly substantial amount of applicable information is available from elsewhere along the west coast of the United States (Rumrill and Poulton, 2004; Dumbauld et al., 2005). Oysters and other bivalve mollusks feed by extracting particulates from the water column, which can locally increase water clarity, thereby promoting spread of eelgrass, especially to depths where light would otherwise be limiting (Dennison et al., 1993; Peterson and Heck, 2001; Newell and Koch, 2004). Competition for space has been noted, particularly for on-bottom shellfish culture, with an apparent threshold loading function observed in Willapa Bay, Washington, above which eelgrass can "under-yield" or decline by more than the percent cover of oysters present; however, eelgrass can also over-yield or increase at lower levels of oyster cover (Dumbauld et al., 2005 [unpublished data]). Part of the under-yield response has been attributed to eelgrass blades rubbing across the sharp edges of growing oysters and being cut off (Schreffler and Griffen, 2000). Perhaps the most relevant to off-bottom rack-and-line culture—the dominant form of oyster culture in Drakes Estero—is work conducted by Everett et al. (1995) in Coos Bay, Oregon. This study demonstrated complete absence of eelgrass directly under oyster racks and lines, presumably due to shading and sediment erosion (10–15 cm at the base of the structure). The absence of eelgrass immediately beneath racks in Drakes Estero (as reported by Harbin-Ireland [2004] and Wechsler [2004]) can therefore be reasonably attributed to mariculture. Small reductions in eelgrass cover and density have been documented with other forms of off-bottom culture, such as long-lines and stakes, but losses tended to scale with density or spacing and were restricted primarily to the area beneath lines and stakes where there is shading or sedimentation (Everett et al., 1995; Rumrill and Poulton, 2004; Tallis et al., in press). Nonetheless, all culture methods were shown to result in decreased production of eelgrass in Willapa Bay (Tallis et al., in press).

Recovery of eelgrass from areas disturbed by mariculture can be fairly rapid, either by rhizome spread or from seed dispersal. Pregnall (1993) found that eelgrass density remained depressed five months after removal of oyster stake culture in Coos Bay, Oregon. Recovery was from vegetative propagation and related to the density of eelgrass plants present before oysters were added. Wisehart et al. (2007), who examined recovery over a longer period, found enhanced seedling survival following disturbance caused by on-bottom culture and dredge harvest versus long-line oyster culture in Willapa Bay, Washington. They speculated that dredging had removed more adult eelgrass plants as competitors and found that remaining plants in dredge areas also produced more seeds, suggesting that the mechanism for recovery is more complex and likely depends on surrounding eelgrass beds and other culture areas as well. Eelgrass may recruit to some areas where seeds are deposited or sediment has been stabilized by some mariculture practices.

In Drakes Estero, the mariculture footprint is roughly 8 acres for racks predominantly in areas of eelgrass and perhaps an additional 10 acres of bottom bag culture, most of which occurs on intertidal flats with no eelgrass (Brown and Becker, March 2007 NPS Trip Report: Figures 2 and 3). A secondary impact to eelgrass arises from damage by boat propellers; scars or disturbance tracks are visually documented in aerial photos of Drakes Estero (total area with scars loosely quantified to be about 50 acres; NPS GIS Map, July 27, 2007). The committee infers that these scars were caused by DBOC boats because the scars are located near the site of rack deployment and are aligned in the direction that leads from or to those racks. In addition, all other motorboats were excluded from Drakes Estero upon passage of the Point Reyes Wilderness Act of 1976. This photograph was thus taken in 2007 and is therefore indicative of current impacts of mariculture boating activities. In past years like 2000 when shellfish culturing activities were dramatically lower (Figure 6) as the Johnson Oyster Company became less active and before the sale to DBOC, eelgrass scarring by boats may have differed. Oyster production levels varied by more than an order of magnitude over the decades, shown in Figure 6, for a variety of reasons, and the past impacts of the oysters, clams, and mariculture activities doubtlessly varied as well. Recovery from scars has been shown to take up to four years in other areas for turtle grass, *Thalassia testudinum*, but this set of observations was made on a different species, only from small disturbance tracks, and in a very different system; recovery rate on a larger scale is unknown (Dawes et al., 1997). Based on existing data on growth and recovery of *Zostera marina* in Willapa Bay and elsewhere on the West coast, recovery from propeller scars should be rapid (weeks) for this species, unless the rhizomes were removed from the sediment (still less than 2 years based on above studies) or there was repeated scarring on a regularly travelled route. While bivalves have been shown in other systems to enhance eelgrass production via secondary mechanisms such as water clarification and fertilization of the sediments (Peterson and Heck, 2001; Newell and Koch 2004), the relatively small culture footprint in Drakes Estero suggests that these effects would be localized. Areal coverage of eelgrass in Drakes Estero has expanded from 368 acres in 1991 to about 740 acres in 2007 (Brown and Becker, 2007). At the 2007 level of mariculture activity in Drakes Estero, the estimates for potential eelgrass lost to rack culture (8 acres) and partially degraded by propeller scars (50 acres, likely an overestimate as a consequence of the spatial resolution of images used to estimate eelgrass loss from propeller tracks), represent less than 8% of the total eelgrass cover (NPS, 2007e; Brown and Becker, 2007) in the estuary. Changes in spatial scale of eelgrass cover at the estuarine landscape scale rarely have been assessed in areas with aquaculture, but a decline was attributed to storm events and not the presence of aquaculture in Bahia de San Quentin, despite a large increase in the number of oyster racks placed in that estuary between 1987 and 2000 (Ward et al., 2003).

III. Fish

A. Background

Fishes have been widely shown to associate with natural three-dimensional biogenic structures that emerge off the bottom like eelgrass and bivalve reefs (Heck et al., 2003; Peterson et al., 2003; Coen and Grizzle, 2007; Horinouchi, 2007), but less work has been conducted on the effects of shellfish mariculture on fish populations and communities. Studies of mostly off-bottom mariculture operations have shown higher abundances of some fishes and invertebrates in areas with mariculture structures than in nearby areas with eelgrass, unstructured open mudflat, and even nearby oyster reefs and rocky substrates, although eelgrass generally also harbors a few unique species (DeAlteris et al., 2004; Clynick et al., 2008; Erbland and Ozbay, 2008). Powers et al. (2007) demonstrated that densities of fish and nektonic invertebrates were as high over plastic bottom netting used to cover infaunal cultured clams and colonized by macroalgae and epifauna as in eelgrass beds in North Carolina, with much lower densities over unvegetated bottom. However, abundance estimates are not a definitive indication of how structured habitat benefits fishes because structures often attract fishes without necessarily enhancing their productivity (reproduction, growth, or survival). Nevertheless, a substantial body of experimental research has shown that structure provides nektonic organisms with protection against predation, thereby offering a survival advantage, especially to more vulnerable juvenile life stages.

B. What is the Body of Scientific Studies on the Impact of the Oyster Farm on Drakes Estero?

Only one study (Wechsler, 2004) has been conducted on the potential effects of oyster mariculture on fish communities in Drakes Estero, which was described as a preliminary study in the project report submitted to NPS (Elliott-Fisk et al., 2005). The lack of any additional fish research or population monitoring in this estero is notable. Wechsler sampled the eelgrass fish community using multiple techniques (trawls, traps, and experimental gill nets) in three settings: next to oyster racks in Drakes Estero, 75 m away from those racks, and in neighboring Estero de Limantour, which lacks mariculture operations. Because of difficulties collecting acceptable samples, only seven of the nine approximately monthly sampling dates were used in the analyses—from December 2002 to January 2004. No significant difference in fish abundance or species richness was detected among the three sampling sites; however, there is an indication that the composition of fish assemblages was modified near oyster racks by enhanced numbers of the guild characterized as structure-associated fishes. This pattern was driven by one species (kelp surfperch, *Brachyistius frenatus*) typically associated with hard substrate (Wechsler, 2004; Elliot-Fisk et al., 2005).

C. What Effects Can Be Directly Demonstrated by Research Conducted in Drakes Estero Itself?

The only study of fish in Drakes Estero (Wechsler, 2004) failed to detect impacts of oyster mariculture on fish abundances or community composition. This study appeared to have low statistical detection power.

D. What Effects Can Reasonably Be Inferred from Research Conducted in Similar Ecosystems?

Few reports address the effects of oyster mariculture on fish communities in circumstances that allow extrapolation to Drakes Estero, but there are numerous studies documenting enhanced densities of fish in structured habitats that include natural bivalve reefs (summarized in Peterson et al., 2003; Coen and Grizzle, 2007). Mariculture studies include one demonstrating that juvenile sole utilized oyster trestle culture areas for protection during the day and foraged over adjacent sand flats at night (Laffargue et al., 2006). A study in Narragansett Bay, Rhode Island found that scup (*Stenotomus chrysops*) grew slightly faster on adjacent rocky habitat than on oyster grow-out cages, although tagging suggested that they had greater fidelity to the cages (Tallman and Forrester, 2007).

Other studies of fish around mariculture operations from U.S. west coast estuaries provide useful insights into processes that may occur in Drakes Estero. In Humboldt Bay, California, oyster long-lines were found to harbor more fish than either eelgrass or open mudflats (Pinnix et al., 2005). In addition, Rumrill and Poulton (2004) observed substantial numbers of staghorn sculpin (*Leptocottus armatus*) and juvenile Dungeness crab (*Cancer magister*) within baited minnow-traps deployed beneath oyster long-lines in Humboldt Bay. In Willapa Bay, Washington, few statistically significant differences in density were found among the more than 20 species of fish and crabs collected at intertidal locations when oyster bottom culture, eelgrass, and open mudflat were comparatively sampled (Hosack et al., 2006). In both studies, some individual species like tube-snouts (*Aulorhynchus flavidus*) were more abundant in structured habitats. Larger mobile invertebrates have also been shown to display species-specific and even life stage-specific behavior around structure in response to the availability of prey and/or protection from larger predators. Juvenile Dungeness crabs (*C. magister*) rely on structured habitat for protection while older individuals utilize open mudflat to forage; however, red rock crabs (*Cancer productus*) prefer bottom oyster culture habitat (Holsman et al., 2006). These functional associations with habitat and links to population processes are little explored, especially on a larger spatial scale where it is known that patch size, connectivity, and proximity to other habitats are also important such that patchy habitats with more edges may actually enhance diversity and abundance (Bostrom et al., 2006; Selgrath et al., 2007). Based upon the (non-significant) trend of enhanced abundances of structure-associated fishes associated with oyster racks reported in Wechsler (2004) and Elliott-Fisk et al. (2005) and the often demonstrated affinity of many fishes to structural habitat, including oyster culture structures, it is reasonable to expect that some species of fishes are attracted to oyster racks in Drakes Estero. Additional research would be necessary to test this expectation and evaluate the significance of any such responses to the overall fish community of the estero.

IV. Benthic Invertebrates in Soft Sediments

A. Background

The benthic infaunal community would be expected to be modified by oyster mariculture through several processes: (1) provision of hard substrates in what is otherwise generally a flat plain of sediments, thereby occupying space and harboring predators of infaunal invertebrates; (2) deposition of oyster feces and pseudofeces, which under conditions of low flushing could induce sediment anoxia intolerable to most infaunal invertebrates; (3) modification of sediment organic content and thereby production of microbial foods for deposit feeders; (4) changes in sediment size, coarsening from erosion around bases of structures and fining where biodeposits settle, which can have large impacts on benthic invertebrate community composition; and (5) physical disturbance associated with culturists tending to and finally harvesting the shellfish. These separate processes are rarely distinguished experimentally; instead, comparisons are made between areas with and without all mariculture activity (Newell, 2004).

B. What is the Body of Scientific Studies on the Impact of the Oyster Farm on Drakes Estero?

Only one study has been conducted on the effects of oyster mariculture on the benthic invertebrate community in Drakes Estero (Harbin-Ireland, 2004; summarized in Elliott-Fisk et al., 2005). Comparisons were made between benthic macro-invertebrate assemblages directly under oyster culture racks and those at varying distances from the racks at two locations in Schooner Bay during January and October 2001. With the exception of enhanced abundance of amphipods and a decrease in abundance of a tanaid crustacean (*Leptochelia dubia*) under racks, few differences in community composition or diversity were found. No differences in sediment organic content were detected comparing the areas under and away from the racks, but there were small but significant changes in grain size, with proportionately more sand and less silt found under the racks.

C. What Effects Can Be Directly Demonstrated by Research Conducted in Drakes Estero Itself?

Few definitive conclusions can be drawn from the Harbin-Ireland (2004) research described above because of the limited nature of the study. Sampling was done during the winter and fall when invertebrate abundance is typically lower in temperate estuaries. Only eelgrass habitat was sampled and the test involved only oyster rack culture, whereas bottom bag culture on intertidal flats is now also an important part of the oyster operation. Nonetheless, some conclusions can be reached, which are supported by significant parallels to other work (see below) in several U.S. west coast estuaries and elsewhere. Specifically, the flushing by tidal currents in Drakes Estero is sufficient to induce erosion around the stakes holding the oyster racks in eelgrass beds, but the resulting change in size composition of sediments is minor. These tidal currents also are sufficient to disperse the organic rich oyster bio-deposits sufficiently widely to avoid inducing detectable organic enrichment of the sediments nearby and subsequent mass mortality of benthic macro-invertebrates from sediment anoxia. Any changes in the benthic infaunal communities of the eelgrass habitat induced by flow modifications and biodeposition are subtle.

D. What Effects Can Reasonably Be Inferred from Research Conducted in Similar Ecosystems?

Comparable studies of shellfish mariculture show that sediment enrichment from biodeposits varies depending on the culture practices, species cultured, biomass or stocking density, and the physical environment in which it is conducted (Callier et al., 2006; Nizzoli et al., 2006). When organic enrichment of sediments occurs, the typical response to the resulting decrease in sediment oxygenation involves a change from a diverse benthic community dominated by suspension feeders (mollusks, crustaceans, and some polychaetes) to a less diverse community dominated by smaller deposit feeders (usually polychaetes). Such responses are associated with low current flow, very dense shellfish culture, or both (Castel et al., 1989; Nugues et al., 1996; Mirto et al., 2000; Christensen et al., 2003; Forrest and Creese, 2006; Lu and Grant, 2008). Such modifications of the benthos are generally absent where stocking density is low or moderate or where currents are strong enough to disperse the biodeposits (Crawford et al., 2003; Mallet et al., 2006).

Tidal currents have previously been shown to enhance erosion around the base of mariculture structures (Pregnall, 1993; Everett et al., 1995), and this process probably explains the slightly coarser substrate found under oyster culture racks in Drakes Estero. Such an explanation is consistent with the conclusion that tidal flows are sufficient to disperse the biodeposits far enough to prevent detectable organic loading at the relatively low oyster stocking densities used in Drakes Estero. The absence of eelgrass underneath the racks also implies faster near-bottom flows than underneath the eelgrass canopy, which baffles flow velocity by friction. Slower flows underneath seagrass canopies induce deposition of fine particles and thus create finer sediment sizes (Madsen et al., 2001).

The observed enhancement of amphipods and reduction in tanaids underneath racks might represent a response to (1) sedimentary changes induced by local loss of eelgrass, allowing faster flows under racks; (2) some aspect of oysters and epibiota on racks that influences the soft-sediment benthos below; or (3) secondary effects of rack structure acting on predators of benthic macro-invertebrates. For example, racks might attract predatory fishes that feed on tanaids. This suggestion is supported by the recognition that small benthic crustaceans are often preferred prey by demersal fishes and by the trend of more structure-oriented predators like kelp surfperch near the racks (Wechsler, 2004). On the other hand, amphipods are also preferred prey for many demersal fishes. Some amphipods have been shown to associate with oysters and structures, or else with the macroalgae and fouling organisms found on them, both on the west coast

(*Eogammarus* and *Amphithoe*: Dumbauld et al., 2000; Dumbauld et al., 2001) and elsewhere (*Gammarus*: Rodney and Paynter, 2006). Scientific studies of both on-bottom culture (Trianni, 1995; Hosack et al., 2006; Ferraro and Cole, 2007) and off-bottom culture in other west coast estuaries (Pregnall, 1993; Rumrill and Poulton, 2004) generally indicate that the benthic community associated with oyster culture is more diverse than that of unstructured bottom, and either equal to or slightly less diverse than that of eelgrass habitat. Enhanced diversity in structured habitat has also been documented for epibenthic meiofauna, which represent important food items in fish diets (Castel et al., 1989; Simenstad and Fresh, 1995; Hosack et al., 2006) and may respond to oyster racks, but this has not been studied in the estero to date.

V. Harbor Seals

A. Background

Harbor seals are widely distributed along the coasts of the North Pacific and North Atlantic. They can be found on exposed coasts and island archipelagos, but frequently inhabit estuaries or coastal lagoons such as Drakes Estero (Bigg, 1981). Intertidal sand banks provide habitat for seals to give birth and suckle their pups or rest during the non-breeding season, and other estuarine areas provide foraging habitat (Wright et al., 2007) and areas where breeding adults engage in underwater display and aquatic mating (Van Parijs et al., 2000; Hayes et al., 2004).

B. What is the Body of Scientific Studies on the Impact of the Oyster Farm on Drakes Estero?

Harbor seal research and monitoring projects have been conducted within Drakes Estero over the last 30 years, but none of this research was designed specifically to assess the impacts of mariculture operations. With the exception of individual-based studies carried out in the 1980s (Allen, 1988), research has focused on monitoring changes in abundance at haul-out sites and recording disturbances to hauled-out seals. The nature and intensity of surveys have varied over this period, and sub-site specific data exist only from 1995, when NPS initiated a standardized monitoring program. This monitoring program relies heavily upon the efforts of trained volunteers, and has since been integrated into a wider pinniped monitoring program across the San Francisco Area Network of Parks (Adams et al., 2006). Trends in the abundance of harbor seals across the whole California coast are also monitored less frequently by state and federal agencies (Lowry and Carretta, 2003).

The data used to assess annual trends in abundance and distribution of harbor seals within Drakes Estero are from surveys made during the peak pupping season (March 15–June 1) and molting seasons (June 1–July 30) (Hester et al., 2004). During each two-hour survey, hauled-out seals were counted every 30 minutes. The timing of these surveys was determined primarily by the need to provide the most robust estimates of abundance trends. The time and source of all disturbances were also recorded throughout the observation period. Disturbances are listed as head alerts, flush (seals move toward but not into water), and flush to water (seals leave haul-out and enter water). Although a head alert indicates a potential for a more serious response, it is less likely to represent an action that depresses fitness or has a negative population-level consequence, and may be less informative as a response variable (Jansen et al. 2006). Assessment of population trends relies upon the assumption that observer bias and individual haul-out behavior and, thus detectability, have not changed over this period. Haul-out behavior could change as a function of prey availability or the level and types of disturbance.

Collectively, the data from these observer programs suggest that seals using the eight subsites within Drakes Estero are best considered a single unit, within which individual subsite choice may be influenced by factors such as disturbance (Allen, 1988). Mixing occurs between these seals and those at other local colonies, and there is more limited exchange among colonies outside the region. Consequently, any changes in abundance within the Drakes Estero/Limantour colony will result from a complex interaction between broader-scale drivers and local factors, such as disturbance. As examples, during the1998 El Niño, adult and pup counts were depressed throughout the entire Point Reyes region, and in 2003 a northern elephant seal (*Mirounga angustirostris*) disrupted the Double Point harbor seal colony in Point Reyes, killing about 40 seals and probably inducing emigration of others, judging from temporally corresponding increases in pup counts at Drakes Estero and Bolinas Lagoon (NPS, 2006a; Becker et al., 2009). Abundance trends within Drakes Estero should therefore be considered in relation to wider-scale population trends, but the time series of data is limited to the past 11 years (1997 through 2007), which is not sufficient to make a robust comparison with trends at other sites in the Point Reyes region with even fewer years of standardized count data.

There has been one statistical modeling study that tested for potential impacts of mariculture activity on harbor seals. Becker et al. (2009) examined how oyster mariculture activities are related to both interannual changes in counts of seals at haul-out subsites closest to mariculture operations and also records of disturbance to hauled-out seals by culturists, using annual oyster production levels as a proxy for mariculture activity. Becker et al. used data from 1997–2007 to assess whether counts of seals during the pupping season (April 15 to May 15) at different subsites within Drakes Estero varied in relation to oyster production levels in Drakes Estero, as well as to broader-scale effects such as density dependence (number of seals at haul-out sites) and the El Niño-Southern Oscillation (ENSO) events. In the statistical approach used by Becker et al., a statistically significant relationship was found between seal counts and years since the last ENSO event (positively related) and oyster harvest levels for two of the three subsites in Drakes Estero that are closest to the mariculture operations (negatively related). Neither ENSO alone nor oyster harvest alone significantly related to seal counts on these haul out subsites.

The statistical analyses serve as indicators of potential negative interactions between oyster harvest and seal attendance at these subsites but do not provide a causal link. Becker and colleagues did not have the official oyster harvest level for 2008 and hence did not include this 2008 datum in the statistical analyses. However, the relationship between the 2008 projected harvest and 2008 seal counts deviates from the pattern of the 11 previous years sufficiently as to call into question whether mariculture intensity would still be a statistically significant contributor to explaining patterns of seal use of upper-estero haul-outs had the analyses included the full 12 years of data (from 1997-2008). In the paper, Becker et al. (2009) acknowledge the marked deviation of the 2008 data from the previous 11 years. The authors attribute the departure from the previous pattern to new regulations issued by the California Coastal Commission which closed the lateral channel to the oyster farm's boats during the pupping season beginning in 2008 and further explain that this new restriction led to less disturbance of the seals and thus less displacement from their haul-out sites. However, this explanation is misleading because the previous owner of the oyster farm operated under a 1992 agreement to prohibit boat traffic in the main and lateral channels during the pupping season (DOI, 2008) and the current owners maintain that they have voluntarily complied with the 1992 agreement. More generally, the use of annual oyster harvest as a proxy for disturbance rate at the haul-out subsites relies on the assumption that mariculture methods and daily activities have not changed over the 11 years that were analyzed. Some potentially confounding factors include changes in the fraction of the harvest from oysters cultivated using the rack system (mostly more distant from the haul-out sites) and the fraction cultivated in bags placed on sand bars also used by seals as haul-out sites. Changes in boat traffic patterns as a result of agreements between the regulatory agencies and the owners of the oyster farm, and level of compliance, could also influence the rate of disturbance independently of the annual level of harvest.

Although the NPS seal monitoring program at Point Reyes provides robust data on seal abundance trends, the disturbance data serve mainly as an indicator of a new source of disturbance or a large change in a known source of disturbance. These data have more limited utility in estimating changes in the level of disturbance within the estero or in the relative importance of different disturbance sources for the following reasons. First, surveys consider disturbance only of groups of seals that are hauled out, rather than seals that are foraging or mating locally. Second, surveys are conducted towards the middle of the day to capture the peak counts, and about half of the surveys occur during the weekends. This captures sources of disturbance that occur during these times (such as hikers on weekends); whereas other disturbances may occur more frequently on other days or at other times of day. Finally, surveys will miss disturbance events occurring early in the ebb tide, before seals come ashore. These disturbances will not result in flushing but could depress the numbers of seals that haul out at that location at the low tide. The high level of overdispersion (variance greater than the mean and increasing with the mean) in Drakes Estero count data suggests that this may be a common occurrence.

Assessments of the relative importance of disturbance from the oyster farm and from other sources are further constrained for two other reasons. First, responses of seals to different types of disturbance may differ. For example, if seals are flushed into the water by a hiker on the beach, it is possible that any perceived risk is reduced or absent once the seals are in the water. In contrast, if seals are flushed into the water by a motor boat, underwater engine noise may result in a continued perception of risk and a stronger response by the seal. Second, the lack of definitive data on spatial and temporal variations in the precise location and behavior of the oyster farm boats prevents any scientific assessment of the authenticity of either the observations of disturbance during the seal surveys (see Box 3), or the counter-evidence provided by DBOC that the boats were absent at these times. For example, "it was not uncommon for DBOC employees to take boats out into the estero after hours to fish," according to Point Reyes National Seashore Chief Ranger Colin Smith as discussed in the Department of Interior Inspector General's report (DOI, 2008). If this statement is accurate, the work records of DBOC would not provide a complete accounting of motorboat activity that could cause seal disturbances.

Box 3
Harbor Seal Disturbance Data

There has been much discussion about the veracity of several observations of disturbance that appear in the NPS harbor seal database and have been referred to in various documents and public testimony prepared by NPS. It is beyond the scope of this study to try to determine the authenticity and reliability of these observations, and the committee does not have the investigative authority that would be required to assess any claims of falsification. The Office of the Inspector General for the Department of the Interior investigated charges about the deliberate misuse of scientific information by Point Reyes National Seashore and issued a report in 2008 (Department of the Interior, 2008). Nevertheless, in an effort to help clarify the issues raised in some of the documents provided by Dr. Corey Goodman and others, the committee provides here some general discussion on the nature of these types of observations and their significance for management.

The monitoring program at the Point Reyes National Seashore was developed with the following monitoring objectives:

> Determine long-term trends in annual population size and annual and seasonal distribution of pinniped populations at [the Point Reyes National Seashore] and Golden Gate National Recreational Area (GOGA).
>
> - Determine long-term trends in reproductive success of elephant seal and harbor seal populations through annual estimates of productivity at [the Point Reyes National Seashore] and GOGA.
>
> - Identify potential threats (i.e., presence of hikers, motor boats, or airplanes presence), and estimate degree of threat at harbor seal haul outs in order to identify management needs. (Adams et al., 2006)

Monitoring is conducted by trained volunteers and park staff who fill out standard survey forms. Each seal colony is surveyed at least twice per week during the breeding and molt seasons if possible. Seal counts are taken during low to medium tides (ideally 2+ feet MLW or less) between 10:00 and 16:00 because studies have shown that the maximum number of seals are hauled out during that part of the day in the San Francisco Bay region (Risebrough, 1978; Fancher, 1979; Allen, 1980; Stewart and Yochem, 1984 [as cited in Hester et al., 2004]; Allen et al., 1989; Grigg et al., 2002). In Drakes Estero, observers conduct the survey from a single location for monitoring the eight haul-out subsites. The surveys include both counts of seals (with adults and pups recorded separately in the pupping season) and notation of disturbance events. In the 2007 Harbor Seal Monitoring report (Truchinski et al., 2008), disturbance surveys are described as follows:

> Disturbance tallies were based on disturbance sources rather than the number of subsites or seals affected. Disturbance rates were calculated as the number of disturbance events that occurred during the time period from the first observation

> to the end of the final observation period. Because the disturbance data were not analyzed for effects on the seal count data in this report, all actual disturbance data were used for analysis regardless of the quality of the associated seal count data (Truchinski et al., 2008).

The important point for the current controversy is the last sentence which explains that the disturbance data are treated differently than the population count data. Specifically, the count data were screened to ensure that there was a high likelihood of obtaining reliable, maximum counts at a given site on a given day. Since disturbance events are not dependent on observing the maximum number of seals, the disturbance data are not screened to exclude less experienced observers or suboptimal viewing conditions. For example, disturbances are recorded throughout the survey and not just when the tide level is +2.0 feet (MLW) or lower. Seals will haul out at low to medium tides even when the sand bars are still submerged (see Figure 8). Typically, the highest number of seals will haul out when the sand bars are exposed. Limiting counts to these lower tide conditions provides a more consistent index of the abundance of seals in Drakes Estero for monitoring long term fluctuations in abundance. This filter was also important for Becker et al. (2009) in which only the qualifying count data were used in the statistical analysis. The differences in these two types of data (disturbances and counts) are reflected in the standard survey sheets. The seal counts survey form includes information on the low tide level while the disturbance survey form does not.

Figure 8. Harbor seals in Orkney rest on a submerged haul-out site in the early phase of the tidal cycle. Photograph provided by Paul Thompson.

Perhaps the most important confounding factor in any monitoring database, but especially one staffed by volunteers, is the potential for simple recording errors, such as date, time, or tide level. Such an error would generally have little or no effect on the overall trends identified in the database, but would make it difficult to reconstruct the exact events recorded during any individual survey. It is not possible for the committee to resolve the controversy over individual survey sheets, but the focus on these observations highlights how this type of monitoring program is best utilized to indicate potential disturbance problems (that might result in decreased use of a haul-out habitat) rather than to quantify them definitively. The latter would require a data collection system that could be independently verified, such as time and date stamped photographs. This verification is especially important in circumstances where there is an indication of a source of disturbance that could lead to a regulatory action, as was the case with disturbances attributed to DBOC.

In summary, research conducted in Drakes Estero confirms that this is an important year-round haul-out site and seasonal pupping area, supporting approximately 20% of the mainland California harbor seal population (Lowry and Caretta, 2003). The remote nature of the estero, combined with an absence of marine predators and other pinnipeds, make this an important habitat for harbor seals. This is reflected in the use of the estero by harbor seals for breeding—Drakes Estero, along with the Double Point colony, consistently accounts for a large fraction of the pups at Marin County haul-out sites (Truchinski et al., 2008). The observations of disturbance recorded in the NPS database cannot be reliably used to infer impacts of mariculture, relative importance of different sources of disturbance, or impacts on seal fitness. The disturbance observations that have been collected as part of the monitoring program serve to demonstrate that there are multiple sources of human and natural disturbances to seals hauled-out on sand bars in Drakes Estero, but they do not permit rigorous determination of which sources of disturbance, if any, have greater population-level consequences.

C. What Effects Can Be Directly Demonstrated by Research Conducted in Drakes Estero Itself?

None of the scientific research projects within Drakes Estero was designed specifically to assess whether the oyster farm operations were impacting the local harbor seal population, and this constrains attempts to draw definitive conclusions about potential impacts. Analyses of monitoring data found a correlation between seal counts and years since the last ENSO event and oyster harvest levels at two haul-out sites within the upper estero (Becker et al., 2009), but this cannot be used to infer cause and effect. Consequently, research that has been conducted within Drakes Estero cannot be used either to directly demonstrate any effects of the oyster farm on harbor seals or to demonstrate the absence of potential effects.

D. What Effects Can Reasonably Be Inferred from Research Conducted in Similar Ecosystems?

Research on interactions between marine mammals and mariculture in other areas has focused on finfish farming and the economic and ecological impacts that result from seal depredation (e.g., Nash et al., 2000). There has been no research conducted in similar ecosystems that has directly assessed the impact of shellfish mariculture on harbor seals or indeed any other seal populations. Nevertheless, potential conflicts between marine mammals and shellfish mariculture have been recognized, and Wursig and Gailey (2002) highlight the need to consider potential loss of feeding and breeding habitat from shellfish and finfish farms, particularly given predicted increases in these facilities in in-shore environments.

There has, however, been research on responses of harbor seals to disturbance from other sources that can inform assessments of disturbance from shellfish mariculture. These studies have focused on impacts upon groups of seals that are already ashore at haul-out sites, with disturbance sources that include people and dogs (Allen et al., 1984; Brasseur and Fedak, 2003), recreational boaters (Lewis and Mathews, 2000; Lelli and Harris, 2001; Johnson and Acevedo-Gutierrez, 2007), commercial shipping (Jansen et al., 2006), industrial activity (Seuront and Prinzivalli, 2005), and aircraft (Perry et al., 2002). Depending upon the intensity and proximity of the disturbance source, a harbor seal's response can vary from an increase in vigilance, through movement within the haul-out site towards the water, to flushing into the water (Allen et al., 1984). Once groups are flushed into the water, some seals may return to the same or nearby haul-out sites, but counts typically do not return to pre-disturbance levels within the same tidal cycle, particularly if disturbance occurs after low tide (Allen et al., 1984; Suryan and Harvey, 1999). Several studies have explored how the likelihood of a response by seals varies according to the proximity of the disturbance source. This depends at least partly upon the source of disturbance, for example where stationary boats elicit a stronger response than boats moving along a predictable route (Johnson and Acevedo-Gutierrez, 2007). The mean distance at which seals are flushed into the water by small boats and people ranges between 80 m and 530 m, with some disturbances recorded at distances of over 1,000 m (Appendix D). These empirical studies have been used to underpin zonation of marine protected areas, for example where a 1.5-km buffer exists around harbor seal haul-out sites in the Dutch Wadden Sea to exclude recreational disturbance (Brasseur and Fedak, 2003) and where a 500 m exclusion zone around breeding and molting haul-out sites has been included in the mariculture industry's best practice guidelines in Shetland, United Kingdom. The 100 yd (91 m) buffer between seal haul-out sites and mariculture activities, designated in the current Special Use Permit issued to DBOC, follows the guidelines of the National Marine Fisheries Service (http://www.nmfs.noaa.gov/pr/pdfs/education/viewing_northwest.pdf) for adherence to the Marine Mammal Protection Act. Nevertheless, there are few studies on the impact on seals as a function of distance of approach by various human activities. Allen et al. (1984), in a study of disturbance at Bolinas Lagoon, found that disturbances at a distance of 100 m or less were more likely to cause harbor seals to leave haul-out sites. Nonetheless, seals responded to boats (power and non-power) by leaving the haul-out in 20 out of 43 observations of boats at a distance greater than 100 m.

All of these studies assessed the likelihood of disturbing seals that are ashore on their haul-out sites. Because seals often remain in the vicinity of their intertidal haul-out sites at high tide (Allen, 1988), a full assessment of potential disturbance should also consider whether disturbance during other phases of the tidal cycle affects the seals' haul-out behavior. The only study to do this was an experimental study in the Dutch Wadden Sea, in which 13 harbor seals were satellite tagged to assess the impact of recreational boat traffic passing over their haul-out sites at high tide. During the experiment, tagged seals showed a 50% reduction in use of the area compared to use of the same area in years with less recreational boat traffic, and these disturbances also appeared to influence diving behavior (Brasseur and Fedak, 2003).

Some oyster rack and oyster bag areas within Drake Estero are located within 500 m of sand flats used by harbor seals as haul-out sites. Based upon the findings in the studies outlined above and the informal observations of biologists who study seals, visits to these areas by oyster farm workers can be expected to lead to the short-term disturbance of any seals using these haul-out areas at the time. Depending upon visibility and wind conditions, disturbance may also occur at greater distances. Furthermore, the work by Brasseur and Reijnders (2001) suggests that seals could be disturbed before they come ashore if boats pass through haul-out areas at high tide. It would be challenging to design a study that could demonstrate whether or not short-term responses to disturbance have long-term population consequences for harbor seals, and no studies of this kind have yet been conducted anywhere. This would require long-term study of known individuals, and high-quality data on those individuals' exposure both to disturbances and to other potential environmental stressors. In the absence of additional research, a precautionary approach to management would seek to reduce types of disturbance that affect behavior during the breeding season to avoid potential population effects that would only be evident with long term monitoring.

VI. Nonnative Species

A. Background

The introduction of nonnative species can result in dramatic environmental and economic impacts (Parker et al., 1999; Ruiz et al., 1999). The committee defines nonnative species as those "…that have been transported by human activities beyond their native ranges" (Wonham, 2003). Commonly employed synonyms are exotic or introduced; the definition explicitly excludes natural range extensions. The term invasive is sometimes used as a synonym for non-native, but it can also carry the implication that the species is especially aggressive in its ability to spread or proliferate in the new environment. In this report, we use invasive in this latter context. Some introductions may go unnoticed, while others may have either negative or positive environmental or economic impacts. Most shellfish mariculture in the United States is based on nonnative species (Goldburg et al., 2001), including the Pacific oyster (originally imported from Japan), which is grown in Drakes Estero and nearby Tomales Bay in California, as well as many other locations worldwide . When examining the potential introduction of nonnative species via mariculture practices, it is important to distinguish between ongoing and historical practices. Oysters are now supplied to DBOC as eyed larvae or spat on shell or cultchless (single) seed that have been certified free of known pathogens and hitchhiking species (Carolyn Friedman, personal observation; Kevin Lunny, personal communication). Clams are supplied as 3–15 mm juveniles and are also certified free of known pathogens and hitchhiking species. It is in this context that we examine the potential of ongoing culture of the nonnative Pacific oyster in Drakes Estero as a vector of exotic species.

Historical importation of the juvenile Pacific oysters on cultch (large shells) has resulted in the introduction of other species such as the Manila clam (*V. philippinarum*; Quayle, 1941), now another farmed bivalve, and several pests and parasites into various west coast estuaries (Chew, 1979). For example, the Japanese oyster drill, *Ocinebrellus inornatus*, was introduced to the United States in shipments of Pacific oysters. Nonnative species have been shown to bring a small proportion of parasites from their native environment to their transplanted location (Mitchell and Power, 2003; Torchin et al., 2003). When these parasites encounter new hosts that lack resistance, they may become pathogenic and cause epidemic disease. Many of the devastating, emerging infectious diseases are attributable to exotic pathogens (Harvell et al., 1999; Daszak et al., 2001).

The Pacific oyster has been cultured in Drakes Estero since the 1930s. The following issues require closer examination before the potential of these nonnative oysters to become naturalized in the estero can be identified:

- Do the Pacific oysters spawn naturally in Drakes Estero? The exclusive use of triploid stock could reduce but would not eliminate successful reproduction and the production of viable, dispersing larvae (NRC, 2004). In addition, unknown numbers of diploid Pacific oysters from previous bottom culture operations may exist loose on the estero's bottom, a legacy from past on-bottom culture practices.

- Is sufficient natural hard substrate available in the estero for oyster establishment in the absence of oyster racks and shells of the cultured oysters? There appears to be limited natural hard substrate within the estero, present mostly at Bull Point, but it is possible that there is enough to support a small population.

- Oyster larvae spend 10–30 days or more in the plankton, duration being largely dependent on ambient temperature conditions (Strathmann, 1987). Given the high flushing rate in the mariculture lease areas in Drakes Estero, it is uncertain whether larvae would be retained in the estero in sufficient numbers to sustain a viable adult population.

Whether the nonnative oysters would persist or go locally extinct in the absence of DBOC requires answers to these questions. Equally, if the cultured oysters spawn successfully, could they serve as a source population, supplying larvae that disperse to other suitable habitats both within and beyond the spatial limits of the estero? The failure of *C. gigas* to naturalize in Drakes Estero in the past might be considered an unreliable indicator of future naturalization potential given that *C. gigas* only recently has become established in the Wadden Sea, potentially in response to a warming climate, even though the species had been used in mariculture there since the 1960s (Diederich, et al., 2005). Notwithstanding the situation in the Wadden Sea, the combination of factors such as shellfish culture locations within the Estero, hydrography of the system (short residence time), and the lack of suitable natural habitat for settlement (as opposed to habitat associated with oyster culture) might mitigate against the successful establishment of the Pacific oysters in Drakes Estero.

The nonnative Manila clam, *V. philippinarum*, is also cultivated in Drakes Estero. DBOC currently raises about 1 million individuals (Point Reyes National Seashore, 2007) in bags on an acre of intertidal flat, at a density of about 250 individuals per m^2. The Manila clam, *V. philippinarum* was introduced in the mid-1930s and has become naturalized in some estuaries along the Pacific coast. Culture of clams in bags reduces some of the risk of naturalization compared to the method of culturing clams in beds because bags of clams can be readily recovered whereas some of the loose clams in beds could persist for years in a reproductively mature status. Even with bags, there is some risk of release because bags may break and clams may spawn within the bags. If the Manila clam successfully reproduces and establishes populations in Drakes Estero, it may compete with native infaunal suspension-feeding bivalves, but is less likely to compete with Macoma clams which are surface deposit feeders. Any culture bags used to contain *Manila clams* would provide additional solid surfaces for epibionts (species that attach to other living organisms).

Oyster mariculture provides solid surfaces in the form of the shells of oysters and the structures, such as wooden racks and plastic mesh bags, used in the culture operations. Hard surfaces are attractive to and necessary for the successful settlement of epibionts such as sponges, bryozoans, barnacles, and tunicates. A nonnative compound tunicate, *Didemnum vexillum*, (Lambert, 2009; Stefaniak et al., 2009) (also referred to in the literature as *Didemnum* species A or *Didemnum* sp.) has established a worldwide distribution. It is now a very evident epibiont covering a substantial fraction (up to about half, judging from the committee's observations made during its September 2008 visit) of subtidal surface space on shell surfaces of living Pacific oysters and on associated oyster-rearing gear in Drakes Estero and is also common in nearby Tomales and Bodega Bays. It is reported to have colonized the limited natural solid mud and sandstone substrates and rocks at Bull Point in Drakes Estero (Dixon, 2007; NPS, 2007c, 2007d). Finally, three more nonnative epibiotic species, the bryozoans *Schizoporella unicornis* and *Watersipora subtorquata* and the sponge *Halichondria bowerbanki*, have been recorded on oyster culturing gear in Drakes Estero (Elliott-Fisk et al., 2005).

B. What is the Body of Scientific Studies on the Impact of the Oyster Farm on Drakes Estero?

While numerous publications identify the extent to which nonnative species have invaded suitable marine habitats in California (Carlton, 1979, 1985; Carlton et al., 1990; Cohen and Carlton, 1998; Foss et al., 2007; http://www.dfg.ca.gov/ospr/about/science/misp.html), only one peer-reviewed publication (Byers, 1999) specifically addressed nonnatives in Drakes Estero. Byers examined the effect of the introduced mud snail, *Batillaria attramentaria*, on the native mud snail, *Cerithidea californica*, and found an interaction that could be detrimental to the native species. The nonnative mud snail is present in high intertidal salt pannes in Schooner Bay but "…remains very restricted" (Byers, 1999) in distribution for unknown reasons. In the study on infaunal invertebrates by Harbin-Ireland (2004), no nonnative invertebrate species were identified in unconsolidated sediment adjacent to the oyster racks in Drakes Estero. Unfortunately, one cannot conclude that nonnative infaunal invertebrates are absent from or even rare in Drakes Estero because of the limited spatial and temporal sampling and low degree of taxonomic resolution—of the taxa collected, fewer than 30% were identified to the species level.

Little research has been conducted within Drakes Estero on nonnative organisms, whether introduced as a result of importations of the Pacific oyster, or by some other mechanism. For example, although several studies surveyed California embayments for presence of the Japanese oyster drill, *Ocinebrellus inornatus*, the published literature does not include Drakes Estero among the sampling sites. Thus, there are no published reports indicating presence of the Japanese oyster drill in Drakes Estero (e.g., Carlton, 1992). The owners of DBOC, Kevin and

Nancy Lunny, also indicated that they and their workers have not seen oyster drills in the estero (Kevin and Nancy Lunny, committee tour of DBOC on 9.5.2008). Additionally, all importations to Drakes Estero of *C. gigas* on cultch were examined for the Japanese oyster drill by the California Department of Fish and Game at the point of delivery prior to issuance of a Planting Certificate. In the early 1990s, health examinations were conducted on seed and adult oysters (both with a sample size of 60) from Matsushima Bay, Japan, that were destined for importation into Drakes Estero. Following the observation of a haplosporidian parasite in the oysters, additional samples were collected from Japan and from several areas in Drakes Estero (e.g., Home Bay, Berries Bar). The latter samples were collected for several years (1990–1993) for histological examination and, later, molecular analyses (Friedman et al., 1991; Friedman, 1996; Burreson et al., 2000). In the early 2000s, a single sample of Pacific oyster seed from Drakes Estero was examined for the presence of an oyster herpes virus (see below). The oyster herpes virus has been observed in many coastal areas globally where Pacific oysters are cultured or native, including Tomales Bay and Drakes Estero, California, which are the only two known locations in the United States where this virus has been documented (Hine et al., 1992; Nicolas et al., 1992; Friedman et al., 2005; Kimberly Reece, unpublished data).

C. What Effects Can Be Directly Demonstrated by Research Conducted in Drakes Estero Itself?

As noted above, prior owners of the oyster farm (Johnson Oyster Company) imported seed on cultch directly from Japan for many years until the early 1990s. Microscopic and molecular examination of oysters revealed the presence of the pathogen, *Haplosporidium nelsoni*, which may have been introduced into Drakes Estero with Pacific oyster importations from Matsushima Bay, Japan (Friedman et al., 1991; Burreson et al., 2000). Haplosporidian infections were observed in adult and seed Pacific oysters destined for importation into Drakes Estero from Matsushima Bay, Japan, in 1989 and 1990 (Friedman et al., 1991). Although importations from Japan ceased, one to three percent of the Pacific oysters sampled from Drakes Estero between 1990 and 1993 had mild systemic or localized infections with haplosporidia, indicating that the parasite had become established in Drakes Estero (Friedman, 1996). No haplosporidia were observed in oysters from Tomales and Humboldt Bays in California. These protists appear to have been established at very low levels in domestic stocks of Pacific oysters reared in Drakes Estero, California, during the period of study in the early 1990s. A sampling of oysters from Drakes Estero in 2006 suggests that a low level (<1%) of *H. nelsoni* infection persists (J. Moore, CDFG, personal communication 4.6.09). There is currently a Memorandum of Understanding between DBOC and the California of Fish and Game that states that all oysters from Drakes Estero shall go to terminal markets and not be planted in any other waters of the state or be held in tanks that drain into waters of the state (T. Moore, CDFG, personal communication 4.7.09).

Currently, DBOC imports eyed larvae from two U.S. west coast hatcheries (Whiskey Creek Shellfish Hatchery in Tillamook, Oregon, and Coast Oyster Company in Quilcene, Washington) that participate in a High Health Program (see Appendix E). As directed by the California Department of Fish and Game, all importations require annual health examinations in which at least 60 individuals of both larvae and adults from each facility are examined (Jim Moore, personal communication).

D. What Effects Can Reasonably Be Inferred from Research Conducted in Similar Ecosystems?

Oyster parasites

Introductions are often the primary cause of diseases that drive formerly common species to low levels (Lafferty and Gerber, 2002). For example, the introduction of *Haplosporidium nelsoni*, which may have been introduced with importations of infected Pacific oysters from Matsushima Bay, Japan, where this disease agent is endemic, resulted in catastrophic losses of the native eastern oyster along the mid-Atlantic coast (Friedman et al., 1991; Burreson et al., 2000; Burreson and Ford, 2004). Unlike the eastern oyster, Pacific oysters, which appear to have co-evolved some level of resistance to *H. nelsoni*, do not experience epidemic losses when infected with this parasite.

DBOC currently imports High Health eyed larvae of the Pacific oyster (i.e., from one of two west coast hatcheries that are tested for diseases and pathogens annually; K. Lunny, personal communication) and sells their products directly to a terminal market. Thus, the potential introduction of disease is limited to those that infect larvae and those that go undetected in annual examinations. A disease agent, the ostreid herpes virus (OsHV), which causes catastrophic losses of both larval and seed oysters (Renault et al., 1995; Burge et al., 2006, 2007), has been observed in Tomales Bay (Burge et al., 2005; Friedman et al., 2005). The presence of OsHV nucleic acid has been detected in Drakes Estero oysters by polymerase chain reaction (PCR) analysis (Burge and Friedman, unpublished). This pathogen was lacking from all other U.S. regions examined, including juvenile oysters produced by the two hatcheries that provide larvae to DBOC (Friedman et al., 2005). Despite the PCR evidence of OsHV in Drakes Estero oysters, no associated oyster losses have been reported, whereas significant losses have occurred in nearby Tomales Bay (Burge et al., 2006, 2007). The origin of this virus is unknown, and there is no evidence of its introduction with regionally imported oysters (Friedman et al., 2005).

Nonnative Invertebrates affiliated with oysters

Understanding the threat posed by the invasive tunicate *D. vexillum* requires data on how it reproduces, its capacity to spread spatially and how it interacts with other benthic fauna and flora resident in Drakes Estero. Although it cannot grow on the sandy and muddy unconsolidated sediments that predominate in Drakes Estero, *D. vexillum* has recently been reported colonizing eelgrass blades at presently low levels in Tomales Bay (Susan Williams, personal communication; Benjamin Becker, personal communication). Its rapid growth and competitive over-topping abilities make it an ecological threat to many native and nonnative invertebrate taxa (Osman and Whitlatch, 2007; Mercer et al., 2009), as well as a nuisance potentially interfering with oyster cultivation and production activities. *D. vexillum* can reattach if fragmented (Bullard et al., 2007), thereby expanding asexually the presence and dispersal potential of the species. Commercial cleaning of fouled oysters and associated materials used to grow the shellfish, as now practiced by DBOC, could promote asexual spread of the species. Sexual reproduction in didemnid tunicates produces a dispersing larva spending "…a few minutes or several hours…" in the plankton (Strathmann, 1987), a short time that would severely limit larval dispersal. The biological requirements of *D. vexillum* suggest that it could neither flourish nor persist in the absence of the hard surfaces provided by oysters and oyster racks. Carman et al. (2009) found that shellfish and marine plants such as eelgrass were more likely to be colonized by tunicates when in close proximity to hard substrates, such as docks and shellfish aquaculture gear. The recent observations of eelgrass blades colonized by *D. vexillum* in Tomales Bay should drive further detailed research.

In summary, movement of oysters has resulted in the introduction of nonnative species including disease agents with varying impacts. Historical importations on cultch (wild-caught juvenile oysters on large oyster shells) from Japan are associated with the introduction of several nonnative species. Current practices of DBOC, in which they import larvae, minimize the risk for introduction of diseases and eliminate risk of external hitchhikers, like oyster drills, as long as the company continues to import larvae from local hatcheries that participate in a High Health Program. Both Whiskey Creek Shellfish Hatchery and Coast Oyster Company, current sources for DBOC, participate in a High Health Program (R. Elston, personal communication). Given the relatively high level of control, for larvae and young seed, coupled with annual health examinations, the risk of introducing unwanted exotic species is low, although the protections against nonnative introductions currently in place are not mandated.

VII. Birds

A. Background

The approximately 9.4 km^2 of water surface area in Drakes Estero and Estero de Limantour, some fraction of which is exposed at low tide, are ecologically significant for wintering shorebirds and waterfowl, with at least 73 species being recorded in a series of mid-winter counts (White, 1999). Dominant species are small ducks and shorebirds, with winter counts of five species, ruddy ducks, bufflehead, dunlin, western sandpiper, and least sandpiper exceeding 1,000 (Page and White, 1999). Drakes Estero is an important staging area for migrating black brant geese (*Branta bernicla nigrans*) (Shuford et al., 1989). This estero is also named a wetland of critical importance in the United States Shorebird Conservation Plan (Hickey et al., 2003).

B. What is the Body of Scientific Studies on the Impact of the Oyster Farm on Drakes Estero?

Despite the importance of Drakes Estero as habitat for shorebirds, not much is known about the influence of the oyster farm on these populations. Press (2005) reported that green algal mats on the intertidal flats of Drakes Estero affect foraging behavior and success of black-bellied plovers, marbled godwits, and western sandpipers. The black-bellied plovers were attracted to the algal mats and exhibited improved foraging success, probably taking advantage of the increased abundances of gammarid amphipod prey (Press, 2005). Likewise, marbled godwits had higher foraging rates in the green algal mats and showed a slight trend of increased use of algal mat areas. Only the western sandpiper avoided algal mats, but those feeding within them exhibited feeding rates similar to those on unvegetated sand flats (Press, 2005). Oyster culture bags placed on intertidal flats in Drakes Estero clearly prevent access by probing shorebirds to the sediments beneath them, thereby removing typical foraging habitat for many species. Bags also, however, act as substrate for attachment and growth of green algae. A testable hypothesis is that shorebirds that can pick surface prey may benefit from enhanced abundances of phytal prey like some amphipods on seasonal green algae associated with oyster bags, whereas pure probers like western sandpipers will not use these phytal invertebrates and suffer displacement by intertidal oyster bags. No test of this hypothesis exists.

C. What Effects Can Be Directly Demonstrated by Research Conducted in Drakes Estero Itself?

No studies address directly the effect of the oyster farm on bird behavior or abundance. Lengthy time series of wintering bird numbers do exist, courtesy of the Audubon Society's Christmas Bird Counts (Wimpfheimer, 2008). Summary numbers based on a 15-mile "count circle" include both Drakes Estero and Tomales Bay and thus represent a spatially broader perspective. The duration of the time span of these standardized bird counts, 1970–2007, is impressive. Population trends for two species and their potential roles in the ecosystem of Drakes Estero are discussed below.

D. What Effects Can Reasonably Be Inferred from Research Conducted in Similar Ecosystems?

Black brant breed in the high arctic and migrate along the Pacific coast. Estuaries provide staging (feeding) areas for flights of up to 5,000 km. Their primary source of energy is the eelgrass *Zostera marina* (Ganter, 2000), the dominant aquatic vegetation in many estuaries, including Drakes Estero. Small flocks of black brant are regular winter residents of Drakes Estero (White, 1999) and thousands may be seen during their migrations. Wimpfheimer (2008) reports an upward trend from 1970 to the present, with a low of 8 individuals and a maximum count of 2,550. The trophic relationship between brant and eelgrass deserves more attention. Brant foraging does disturb *Z. marina* meadows seasonally, and eelgrass provides a critical habitat for salmon smolts, other fishes, and numerous invertebrates. Brant foraging generates eelgrass detritus, and their feces probably represent a nutritional subsidy. The relative balance between these negative and positive influences remains generally unknown, although eelgrass in Drakes Estero has increased in areal coverage even as black brant abundances have increased.

Peregrine falcons (*Falco peregrinus*) feed predominately on other birds. Some falcons are resident in Drakes Estero; others migrate along the Pacific flyway (Anderson et al., 1988). Winter numbers in the count circle have increased dramatically since 1970 (Wimpfheimer, 2008) from an average of 2.4 birds in the 1970–1974 interval to 18.7 from 2005–2007. Peregrine attacks generally involve flushing their prey. Falcons represent a natural source of disturbance, and along with kayakers and motorboat traffic, all cause roosting or feeding waterbirds and shorebirds to take flight. Studies on "flush distances" in San Francisco Bay for eight species also found in the Drakes Estero suggest an average response distance of 51.5 m (Evans, unpublished). Stillman et al. (2007) have shown for a set of European waterbirds exposed to disturbances that over-winter mortality is increased, implying a connection between the energetic cost of risk avoidance and diminished demographic performance. Whether oyster culture is “a potentially very significant environmental impact” to waterbirds (Dixon, 2007) is undetermined and should be quantified and placed in the same context as other, more natural disturbances. Nevertheless, the activity of culturists, especially their boat traffic, is likely to cause many waterbirds and shorebirds to flush, but population consequences are not known.

Kelly et al. (1996) studied how oyster mariculture in nearby Tomales Bay affected use of tidal flats by wintering shorebirds by comparing 2-hectare low-intertidal plots, some with rows of plastic mesh bags (in a mix of two positions: on the ground and elevated on racks) and others without culture bags. Two of the most abundant shorebirds, dunlin and western sandpipers, demonstrated significant avoidance of mariculture plots. One shorebird, the willet, exhibited significant attraction to mariculture plots, and four others (black-bellied plover, marbled godwit, sanderling, and least sandpiper) did not vary in abundance as a function of the presence of culture bags. The dunlin and western sandpiper, which probe into the sediments for prey, foraged between rows of culture bags when on mariculture plots, while the least sandpiper, which uses a visual search for surface prey, was often found foraging on tops of culture bags. Willets foraged between rows of bags and on tops of bags: this species is known for its diverse feeding methods and diet. The presence and activity of mariculture workers on plots did not affect the distribution of shorebirds analyzed for many species and no movements in or out of culture plots were associated with culturist activity. These results from such a similar system, involving the same species of shorebirds that use Drakes Estero and the same plastic mesh culture bags, albeit not only placed on the ground but also on elevated racks, are probably directly transferrable to Drakes Estero. Consequently, only the obligate probers are likely to be negatively affected by mariculture on intertidal flats in Drakes Estero, while most species remain unaffected and some that forage visually on surface prey may benefit from invertebrates associated with culture bags and epibiotic growth on the bags and oysters. Feeding shorebirds do not seem prone to being flushed by normal activities of culturists, but insufficient information exists to know how closely culturists can approach the birds without causing retreat by walking or flying.

VIII. Human-Use Values—Economics, Recreation, and Aesthetics

A. Background

The environmental resources contained in parks, conservation land, and wilderness areas generate several recognized types of economic value[2], including those that derive from recreation, economic activity associated with use and maintenance, production of consumption goods, property value enhancement, ecosystem services, and non-use values (NRC, 1994,

[2] Economic values are defined here as anthropocentric; that is, they are determined by reference to values received or perceived by human beings. It is possible to take the position that environmental resources also give rise to non-anthropocentric values that emerge from the moral interests or rights of non-human species (Foster, 1977; NRC, 2004b). The committee constrains its discussion here to anthropocentric economic values.

2004b). Some of these values can, in principle, be derived from information about market transactions; for example, the change in property values due to nearby environmental amenities can be estimated from market data. Others, such as recreational and non-use values[3], require the careful application of “contingent valuation” survey techniques (Mitchell and Carson, 1989; Arrow et al., 1993) and travel cost analyses (Loomis and Walsh, 1997).

Recreational value is the non-market value realized by people who use the park or wilderness area for recreation. In most cases, access to recreational amenities of parks and wilderness areas is not purchased directly in a market where prices can be observed (Bateman and Langford, 1997; Schecter et al., 1998). As a result, recreational values are often estimated using techniques, such as the travel cost method or contingent valuation (Fredman and Emmelin, 2001; Hanley et al., 2003; Herath and Kennedy, 2004). The same techniques can be applied to valuing cultural heritage features within an area visited for recreation (Navrud and Ready, 2002; Sattout et al., 2007). Estimates of the recreational value generated per person-day in a wilderness area are typically on the order of $50 (Walsh et al., 1992; Loomis et al., 1998; Loomis, 2000).

Economic activity associated with use and maintenance of a park or wilderness area generates economic impacts in surrounding communities through public spending on park and wilderness management and maintenance (e.g., employee salaries) and through private spending by visitors in restaurants, hotels, and shops in the course of travel to the park or wilderness area. Property value enhancement refers to the increase in the market value of private property in the vicinity of park, wilderness, or conservation land. Consumption goods produced within the conservation area may be timber in a multi-use national forest or cattle and oysters in a setting such as the Point Reyes National Seashore.

Ecosystem services provided by aquatic and related terrestrial ecosystems generally include nutrient recycling, habitat for plants and animals, flood control, and water supply (NRC, 2004). The ecosystem service most closely associated with marine estuaries and seagrass beds is nutrient recycling; others include habitat and refuge, food production, and disturbance (i.e., storm or weather) regulation (Costanza et al., 1997). Although ecosystem services are usually not traded in markets, it is possible to estimate their economic value using shadow prices (Kaiser and Roumasset, 2002). The ecosystem *resources* embodied by Drakes Estero are fairly well understood and are described in the previous sections (I. through VII.) of this report. The ecosystem *services* provided by the specific resources in Drakes Estero have not been quantified in either ecological or economic terms.

Non-use values of wilderness were first formally articulated by Weisbrod (1964), who suggested that undeveloped forest areas might give rise to option value, and by Krutilla (1967), who added the categories of existence and bequest values. First efforts to estimate these values systematically for wilderness areas were carried out by Walsh et al. (1984) in a study of Colorado wilderness areas. Option value is the value attributable to the opportunity at some point in the future to make decisions about the disposition or conservation of an asset (Forsyth, 2000; Bulte et al., 2002; Bosetti et al., 2004; Buttle and Rondleau, 2004). Existence value refers to the non-use value derived by people from the knowledge that something exists, irrespective of whether they (or anyone else) ever make use of it or even see it (Hageman, 1985; McFadden, 1994; Blomquist and Whitehead, 1995; Loomis and White, 1996; Randall and Stoll, 1999). Bequest value is the satisfaction derived from preserving something for future generations (Greenley et al., 1981; Beaumont et al., 2007). All of these values may be lost, to some degree,

[3] Non-use values are also referred to as “passive-use values.”

when an area of wilderness is developed or a species is driven to extinction. Existence and bequest values are typically assessed using contingent valuation techniques (e.g., questionnaires, surveys, interviews) (Keith et al., 1996; McDaniels and Roessler, 1998).

Estimates of non-use values generated by designating a given area as wilderness (as opposed to leaving it open to development or multi-purpose access) are typically on the order of $10 to $100 per household per year or a present value on the order of $100 to $1,000 per acre of wilderness (Walsh et al., 1984; Pope and Jones, 1990; Gilbert et al., 1992).

B. What is the Body of Scientific Studies on the Impact of the Oyster Farm on Drakes Estero?

No social science research has been carried out to quantify or estimate the effects of oyster farming on the economic values generated by Drakes Estero or the Point Reyes National Seashore. Similarly, the recreation and non-use values generated by, and the importance of aesthetics to, the human uses of Drakes Estero remain unstudied.

Of the more than 2 million annual visitors reported by NPS to visit the Point Reyes National Seashore (Figure 9), it is not known how many spend time on or at the estero. The only vehicle access to the estero is a road to the oyster farm site on Schooner Bay, which is also the only kayak launching point. Alternatively, the estero may be reached via hiking trails from the Bull Point and Drakes Estero trailheads on Sir Francis Drake Boulevard and via hiking trails from the Muddy Hollow trailhead on Limantour Road.

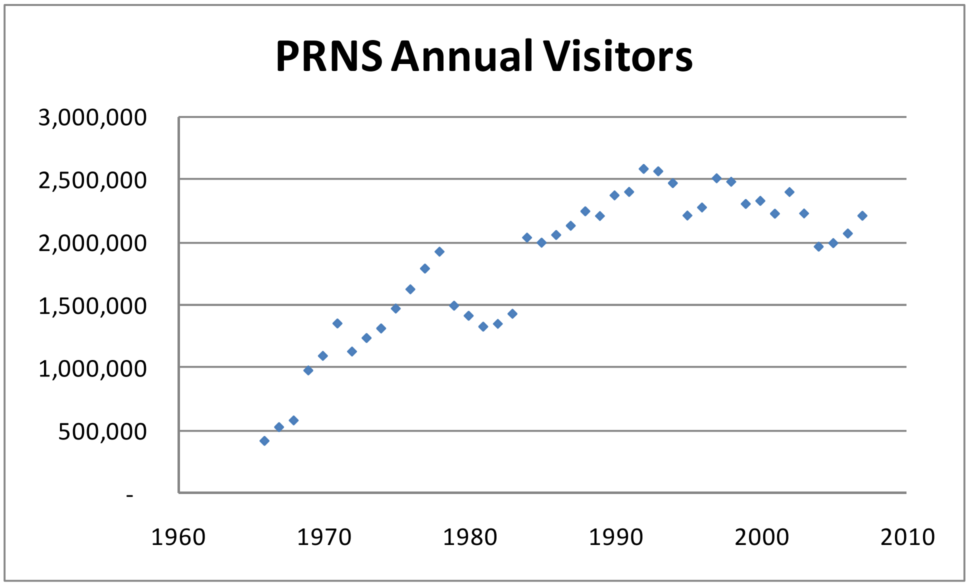

Figure 9. Trends in number of annual visitors to Point Reyes National Seashore (Source, National Park Service).

Baltan (2006) suggests that recreational use of Drakes Estero has increased since the early 1990s, particularly for kayaking and canoeing. Some 460 boaters participated in commercially organized kayak tours of Drakes Estero in 2005 (Baltan, 2006, citing personal communication with Kevin McKay, NPS); other boaters used the estero independently. Ten companies offered kayak tours of the estero under permits granted by NPS in 2005 (Baltan, 2006). These tours are not permitted during the harbor seal pupping season from March 1 to June 30. Unpublished data from the Point Reyes National Seashore visitor surveys carried out by students from Sonoma State University in 1997 and 1998 obtained from the Point Reyes National Seashore suggest that as many as 3% of the visitors surveyed planned to kayak during their visit to the Point Reyes National Seashore, but these surveys were not designed to capture a representative sample of all visitors to the Point Reyes National Seashore. Moreover, they do not provide information specifically about how many of these kayakers used Drakes Estero.

The oyster farming operation employs 30–40 people and produced 436,848 pounds of oyster meats in 2008 (Kevin Lunny, personal communication 5 March 2009 and California Department of Fish and Game) at an estimated value on the order of $2,000,000 based on NOAA's commercial landing statistics and the California Department of Fish and Game aquaculture survey database. Total May 2007 employment of agricultural workers in Marin, San Francisco, and San Mateo Counties was 1,510, with average annual earnings per worker of $26,000 (U.S. Bureau of Labor Statistics, 2009). This suggests that DBOC accounts for 2–3% of agricultural employment in the greater San Francisco-San Mateo-Redwood City metropolitan area and generates an annual payroll of about $1 million.

C. What Effects Can Be Directly Demonstrated by Research Conducted in Drakes Estero Itself?

No effects of the oyster farming operation can be directly demonstrated from social science research carried out on Drakes Estero because no such research has been done.

D. What Effects Can Reasonably Be Inferred from Research Conducted in Similar Ecosystems?

The oyster farming operation in Drakes Estero can be reasonably inferred on the basis of logical deduction to: (1) have a positive effect on total employment, tax revenue, and local food production in Marin County; (2) continue an historical use of the estero for shellfish mariculture, which likely enhances some visitors' experience in the estero and preserves a piece of local and regional culture and history; (3) introduce structures and activities into the estero that may affect negatively the wilderness experience and the aesthetic value of the estero for some visitors, and may detract from the existence value of the estero for those who value wilderness with minimal human structures and activities; (4) probably have no discernible effect on the aggregate recreational value (e.g., hiking, kayaking) of the estero; and (5) probably have a slight negative effect on non-use values associated with the estero.

At approximately 2–2.5 million visitors per year, the Point Reyes National Seashore may be estimated to generate on the order of $100 million per year in recreational value (see section VIII.A). Drakes Estero contributes an unknown fraction of this total. It is not known whether the presence of the oyster farming operation has a significant effect on the number of annual visitors to the Point Reyes National Seashore and Drakes Estero. It seems plausible that the net effect of the oyster farm on the Point Reyes National Seashore/Drakes Estero visitor counts is positive since some visitors are reported to come to Drakes Estero in part to purchase oysters from DBOC, and it seems unlikely that visitors are deterred from coming because of the oyster farm.

The level of economic activity in surrounding communities associated with the operation, maintenance, and use of the Point Reyes National Seashore and Drakes Estero has not been estimated. It is unlikely that the oyster farming operation has a significant effect on this, although there could be a modest positive effect if DBOC is contributing to higher numbers of visitors to the Point Reyes National Seashore (see above).

Property-value enhancement for private lands in the vicinity of the Point Reyes National Seashore from the existence of the national seashore has not been measured, but is likely to be positive. It is unlikely that this property-value enhancement is affected in any significant way by the presence of oyster farming operations in Drakes Estero.

DBOC produced about 467,000 and 437,000 pounds of oyster meats per year in 2007 and 2008 respectively. In the process, oyster culture in the estero generates an estimated $1 million in annual payroll and 2–3% of the roughly 1,500 agricultural jobs in the San Francisco-San Mateo-Redwood City metropolitan area.

In a synthesis of prior studies (i.e., Daily, 1997; Pimm, 1997), Costanza et al. (1997)[4] estimated the biogeochemical-ecosystem value of marine estuaries at $22,422 per hectare per year and of seagrass and algae beds at $19,004 per hectare per year (in 1994 dollars). These are equivalent to $12,695 per acre per year for estuaries and $10,759 per acre per year for seagrass and algae beds in 2007 dollars. Using the average of these values, and applying it to Drakes Estero (2,270 acres at high tide), suggests that the estero may generate ecosystem services on the order of $26.6 million per year. There is not sufficient quantitative information to assess the effect of oyster farming on ecosystem services provided by the estero, but the net effect could be positive due to the added filtering capacity and nutrient recycling provided by the oysters.

From the non-use values estimated for wilderness areas in other parts of the United States, it may be inferred that Drakes Estero and the Point Reyes National Seashore have significant existence, option, and bequest value as protected environmental resources. Most published estimates of non-use value of protected lands are attached to larger areas (millions of acres) than Drakes Estero or the Point Reyes National Seashore, and they deal with the value of preserving wilderness from development. These estimates do not provide much information that can be readily transferred to a 2,000-acre wilderness within a larger park, where the development in question (oyster culture) has a relatively small physical footprint. It is likely that the presence of oyster farming in Drakes Estero has a marginal negative effect on the non-use values of the estero.

SCIENTIFIC CONCLUSIONS THAT CAN BE DRAWN

The previous sections present the available information from the on-site investigations of potential impacts of DBOC operations on the Drakes Estero ecosystem. Those studies could be fairly characterized as preliminary results that would require additional focused research to allow

[4] These estimates are for marginal values of ecosystem services. There has been considerable criticism of the Costanza et al. (1997) approach to scaling from marginal values to global values. The committee is not engaged in scaling to global values here; it is looking closely at a particular estuary. In this situation, it is appropriate to apply the marginal value estimates.

definitive conclusions to be reached about the presence, absence, or magnitude of any ecological impacts. Although studies conducted in other systems may help support results from initial studies in Drakes Estero, the comparability is not always sufficient to reach confident conclusions on the most important issues of relevance to management decisions.

Nevertheless, some limited results have sufficient scientific support to reach the following conclusions:

(1) The presence and biological activities of cultured oysters in Drakes Estero results in locally enhanced filtration of the water column and deposition of feces and pseudofeces onto the bottom. One study was conducted in which sediment cores were taken in eelgrass as a function of distance away from oyster culture racks in Drakes Estero and also in nearby Estero de Limantour, which lacks oyster culture. No enhancement of sediment organics and no reduction in oxygen content of sediments were detectable near the culture racks or in Drakes Estero as compared to Estero de Limantour, indicating a lack of detectable negative impacts of oyster biodeposition, probably because of relatively low oyster stocking densities and high tidal flushing, which disperses the deposits. Limited water quality sampling did not demonstrate elevated levels of nutrients, pathogens (fecal coliform bacteria), or hypoxia. Ecologically, oyster culture in Drakes Estero replaces, to an unknown extent, the filtering capacity and biogeochemical processing that was lost in the mid-19th century and subsequent decades with the overharvest and functional elimination of the native Olympia oyster. Although mariculture of the Pacific oyster is not a direct replacement of the native populations of the Olympia oyster, it may be viewed as providing similar biogeochemical functions and ecological resilience. The structural habitat provided by cultured oysters and the racks holding them is elevated off the bottom such that habitat services associated with provision of hard substrates may differ from those provided by native oysters residing on the bottom. Intertidal oyster bags with oysters inside may come closer to matching the habitat provided by native oysters, although periodic flipping of the oyster bags likely disturbs (and is intended to inhibit) the epifaunal fouling community growing on the bags.

(2) The absence of eelgrass directly under oyster culture racks represents a small-scale and localized impact on the biogenic habitat. Numerous boat propeller scars in the eelgrass beds, partially affecting a total area of about 50 acres, are also evident and attributable to oyster culturists because they are the only ones allowed to use motorized vessels in the estero. Nevertheless, the total percentage of eelgrass area lost (1%) or partially degraded by propeller scars (7%) and thus attributable to oyster mariculture represents about 8% of all eelgrass habitat in Drakes Estero as of 2007. Eelgrass has approximately doubled in areal cover in Drakes Estero from 1991 to 2007, implying little systemic threat from the existing intensity of oyster culturing activities. Oysters have the potential to benefit eelgrass because their filtering activity improves local water clarity (and hence light penetration) and because they release biodeposits and ammonium (plant nutrients).

(3) Definitive conclusions about potential impacts of DBOC activities on fish cannot be reached. The only study done of fishes of Drakes Estero was unable to detect significant differences in fish abundance, species diversity, or community composition between

eelgrass fishes of Drakes Estero at varying distances from culture racks or between Drakes Estero and the Estero de Limantour, which has no oyster culture operation. There is some indication that the guild of fishes typically associated with hard substrates may be locally enhanced around culture racks, driven largely by response of one species, the kelp surfperch.

(4) The only study of how the benthic invertebrates of Drakes Estero may be affected by the mariculture operation found no significant differences in invertebrate abundance or composition of eelgrass infauna as a function of distance from mariculture racks or between Drakes Estero and Estero de Limantour. Nevertheless, amphipods tended to be enhanced in the sediments under racks, while a tanaid was depressed. A statistically significant increase in sandiness of sediments was detected under racks, but the magnitude of the change was small.

(5) Drakes Estero represents an important site for harbor seals, supporting about 20% of the mainland California population. The design of the program to monitor harbor seal abundances and disturbance events at sub-sites within the estero does not permit explicit tests of the impacts of mariculture. Seal disturbance data have been collected during surveys designed primarily to monitor seal abundance trends, and observations of disturbance are not sufficiently representative to infer the proportionate contribution of mariculture-related disturbance relative to other sources of disturbance to hauled-out seals. In particular, critical information is lacking on potential disturbances from mariculture activities at higher tidal levels, which could inhibit hauling out and other important activities. There is a lack of information on how various sources of disturbance affect seals on an individual basis. Nonetheless, precautionary measures to reduce the likelihood of disturbance of seals are consistent with current management practices in the U.S. and in other countries.

(6) Oyster culturing increases the existing amount of hard substrate in Drakes Estero, thereby sustaining high cover (up to about half of subtidal hard surface) of an introduced tunicate, *Didemnum vexillum,* and smaller populations of at least three other nonnative epifaunal invertebrates. The oyster that is cultured, *Crassostrea gigas*, is itself a nonnative species. Some culturing of the nonnative Manila clam, *V. philippinarum,* also occurs in the estero. There is risk that ongoing culture of *C. gigas* and *V. philippinarum* at Drakes Estero could lead to establishment of self-sustaining naturalized populations. Past importation of nonnative oysters at Drakes Estero is associated with the unintentional introduction of a nonnative haplosporidian oyster disease and a salt marsh snail, *Batillaria attramentaria*, whose introduction has had locally limited detrimental effects on the native marsh snail. However, the current mariculture practice of importing only larvae or seed from hatcheries practicing High Health Programs of inspections carries low risk of future new introductions of exotic species into Drakes Estero. Sustaining high cover of *Didemnum vexillum* elevates risk of its spread to other habitats, especially to eelgrass, and locations within Drakes Estero and Estero de Limantour.

(7) No study has been conducted to test the impacts of mariculture on birds of Drakes Estero. Drakes Estero represents an important site for overwintering and seasonally

migrating shorebirds- and waterfowl, with special significance as a feeding and staging site for migrating black brant geese. Boat travel by the mariculturists is likely to disturb and flush seaducks, shorebirds, and other waterbirds. Furthermore, the presence of lines of oyster bags on the intertidal flats is likely to diminish the feeding area for some probing shorebirds, while enhancing food supplies for other shorebirds willing to consume epibiotic amphipods and other invertebrates associated with algal growth on mariculture bags.

(8) The effect of oyster farming in Drakes Estero on the aggregate economic values generated by PRNS is likely to be small relative to recreational value (on the order of $100 million per year) and value of ecological services (on the order of $20 million to $30 million per year).

ACCURACY OF THE SCIENTIFIC CONCLUSIONS RELEASED BY NPS TO THE PUBLIC

The Point Reyes National Seashore produced one major document on the science of Drakes Estero, including conclusions about the impacts of DBOC, for public release in four successive versions, all entitled *Drakes Estero: A Sheltered Wilderness Estuary* (2006; 2007a; 2007b; 2007c). According to the Department of Interior Inspector General's report (DOI, 2008), *Drakes Estero: A Sheltered Wilderness Estuary* was prepared in part to respond to an article in the Point Reyes Light and other inquiries regarding the effects of the oyster farm on Drakes Estero and the termination of the current lease (RUO) in 2012. This document was released first as a Park News "information piece" (pdf and printed copies) in October 2006 (Box 4) and subsequent versions were posted on the Point Reyes National Seashore website. The committee received four discrete public versions of *Drakes Estero: A Sheltered Wilderness Estuary*. The last version released to the public was available on the Point Reyes National Seashore internet site on May 11, 2007, and was removed from the site on July 23, 2007. In addition, the Point Reyes National Seashore released one related document on July 25, 2007 (Acknowledgement of Corrections [NPS, 2007e]) and another (Clarification of Law, Policy, and Science on Drakes Estero [NPS, 2007d]) on September 18, 2007, to the Marin County Board of Supervisors that also reviewed the science on effects of DBOC on the ecosystem of Drakes Estero, which contained further modifications of NPS scientific conclusions. Whether NPS made appropriate use of available scientific information on potential impacts of the oyster culture operation on the ecosystem of Drakes Estero has been the subject of controversy, only partially addressed in the Inspector General's report (DOI, 2008). Here, the committee compares its conclusions on potential impacts (the available science) to what NPS reported in their multiple versions of *Drakes Estero: A Sheltered Wilderness Estuary* and the "Corrections" and "Clarification" documents.

Box 4
Timeline for Events Related to *Drakes Estero: A Sheltered Wilderness Estuary*
(Dates taken primarily from DOI, 2008)

May 18, 2006	Point Reyes Light article claiming DBOC has little impact on estero based on the Elliot-Fisk et al. (2005) report
October 28, 2006	Superintendent Neubacher gave copies of *Drakes Estero: A Sheltered Wilderness Estuary* (version I; NPS, 2006b) to Gordon Bennett, Sierra Club. Copies were also available to the public at this time.
February 9, 2007	*Drakes Estero: A Sheltered Wilderness Estuary* (version II; NPS, 2007a) first posting on NPS website
May 8, 2007	*Drakes Estero: A Sheltered Wilderness Estuary* (version III; NPS, 2007b) (date downloaded – date of posting unknown)
May 8, 2007	Marin County Board of Supervisors Meeting
May 11, 2007	*Drakes Estero: A Sheltered Wilderness Estuary* (version IV; NPS, 2007c)
May 15, 2007	Letter to NPS from California Department of Fish and Game documenting NPS authority over Drakes Estero (including leased bottom)
July 23, 2007	*Drakes Estero: A Sheltered Wilderness Estuary* removed from NPS website
July 25, 2007	NPS posts “Acknowledgement of Corrections” (NPS, 2007e)
September 18, 2007	NPS issues “Clarification Statement” (NPS, 2007d)
November 2007	California Coastal Commission Consent Order signed by Kevin Lunny, DBOC
April 22, 2008	NPS Special Use Permit signed by Kevin Lunny, DBOC

While NPS in all versions of *Drakes Estero: A Sheltered Wilderness Estuary* accurately depicted the ecological significance and conservation value of Drakes Estero, in several instances the agency selectively presented, over-interpreted, or misrepresented the available scientific information on potential impacts of the oyster mariculture operation. Consequently, *Drakes Estero: A Sheltered Wilderness Estuary* did not present a rigorous and balanced synthesis of the mariculture impacts. Overall, the report gave an interpretation of the science that exaggerated the negative and overlooked potentially beneficial effects of the oyster culture operation. NPS has issued two documents correcting and clarifying *Drakes Estero: A Sheltered Wilderness Estuary*—“Acknowledgment of Corrections to Previous Versions of the Park News Document *Drakes Estero: A Sheltered Wilderness Estuary*” posted on July 25, 2007 (NPS, 2007e), and the September 18, 2007 document, “National Park Service Clarification of Law, Policy, and Science on Drakes Estero” (NPS, 2007d). The Clarification document represents the most accurate NPS release of science relating to mariculture impacts; although, this document does not fully reflect the conclusions of this committee. It appears that hasty responses to local stakeholder concerns by NPS led to the publication of inaccuracies and a subsequent series of retractions and clarifications during this process from 2007–2008, which cast doubt on the agency’s credibility and motivation. A lack of coordination among the multiple agencies regulating the mariculture operation also gave mixed messages to stakeholders, fueling the controversy. For example, the extension in 2004 of the DBOC shellfish leases until 2029 by the California Fish and Game Commission sent a message that could be construed as conflicting with the Department of Interior Office of the Solicitor's interpretation of the congressional mandate for designating wilderness in the Point Reyes National Seashore, which would prohibit the extension of the lease beyond 2012. The California Fish and Game Commission did, however, stipulate termination of the leases if the RUO was not extended. The committee describes below the major scientific conclusions presented by NPS and how these conclusions change among the various NPS public releases.

- Version I (released in October 2006) of *Drakes Estero: A Sheltered Wilderness Estuary* reports that Anima (1990) "documented substantial sediment inputs of the pseudo-feces from the oysters." All four of the public versions of *Drakes Estero: A Sheltered Wilderness Estuary* make similar statements, with the last (version IV downloaded on May 11, 2007) stating that Anima (1990) "identified pseudo feces of oysters as the primary source of sediment fill." In fact, Anima (1990, 1991) does not report any direct observations of oyster pseudofeces or feces in the sediments. The Acknowledgment of Corrections (July 2007) and Clarification (September 2007) documents admit the error in the characterization of Anima's studies in *Drakes Estero: A Sheltered Wilderness Estuary* and retracts those claims. In the Clarification document, NPS uses scientific literature on effects of oyster biodeposition into sediments and quotes from independent scientific experts to reach reasonably substantiated conclusions about sedimentation effects that match those reached by this committee. Specifically, NPS concludes that any biodeposits from feeding oysters must necessarily fall to the estuarine bottom and to some undocumented extent become incorporated into the bottom sediments with a potential for inducing sedimentary anoxia under conditions of high shellfish stocking densities. The Clarification notes that the sediment cores taken under the racks in a subsequent study (Harbin-Ireland, 2004; Elliott-Fiske et al., 2005) did not show evidence of hypoxia, but NPS also suggests that these results from 2003 may not be representative of current conditions given the steady and substantial increase in oyster culturing activities from 2000 to 2007 (see Figure 6).

- All versions of *Drakes Estero: A Sheltered Wilderness Estuary* cite Anima (1990) in support of the conclusion that "pseudofeces of oysters are the primary source of sediment fill." In fact, Anima (1990, 1991) does not make any observations on rate of sedimentation from oyster pseudofeces or compare those rates to other sources of sedimentation. Erosion of sediments from grazed pastures and deposition of eelgrass detritus represent potentially important additional sources of sedimentation. The Clarification document correctly states that Anima did not make any measurements of sedimentation rate from oyster biodeposits and further qualifies Anima's (1990, 1991) statement as expert opinion that fine sediments deposited by oysters beneath the racks were likely resistant to erosion because tidal action would be limited in the upper reaches of the estero. In contradiction to Anima's opinion, Harbin-Ireland (2004) demonstrated that sediments underneath oyster culture racks are slightly coarser not finer than those at distance from the racks. This potentially conflicting observation is not presented by NPS in discussing the sedimentation issue in the Clarification document.

- Each version of *Drakes Estero: A Sheltered Wilderness Estuary* cites Harbin-Ireland (2004) and Elliott-Fisk et al. (2005) in support of the claim that "eelgrass growth is severely restricted under active oyster racks." While observations on eelgrass in Drakes Estero do imply some localized reduction in areal cover underneath oyster culture racks, affecting about eight acres in total (1% of eelgrass habitat in 2007), this statement does not place the relatively small effect of the oyster racks on eelgrass coverage in the appropriate context. NPS's Clarification document provides a more balanced assessment, explicitly characterizing the observed pattern of eelgrass distribution around culture racks and placing it into the context of an approximate doubling of eelgrass coverage in Drake Estero from 1991 to 2007. Another inconsistency between all four versions of *Drakes Estero: A Sheltered Wilderness Estuary* and the actual data relates to results of a study by Applied Marine Sciences (AMS, 2002). NPS wrote: "Eelgrass, for example, in Estero de Limantour where there is no oyster farming, had higher indicators of standing stock, as measured by the numbers of turions and blades, compared to Drakes Estero (AMS 2002)". Actually, AMS (2002) reports just the opposite—that both sites in Drakes Estero exhibited higher counts of eelgrass blades and turions than the one site sampled four times over 18 months in Estero de Limantour. Furthermore, AMS notes that this contrast is unreliable because elevation differences confound the site comparison. NPS also fails to include the demonstration by AMS (2002) that eelgrass disappeared over those 18 months from 5 of 6 plots in Estero de Limantour while persisting at all 6 plots at both sites in Drakes Estero. Later versions of *Drakes Estero: A Sheltered Wilderness Estuary* and the Clarification document appropriately include the observation that approximately 50 acres of eelgrass habitat show propeller scars leading to and from oyster culture racks that can be reasonably attributed to boats associated with oyster operations. A more complete overview of how eelgrass and oyster culturing may functionally interact would also mention the potential for oyster filtration to depress turbidity and thereby locally enhance light penetration and extension of eelgrass habitat into deeper water and would note the potential for oyster biodeposits and ammonium excretion to fertilize eelgrass. Each of these effects has been demonstrated experimentally for modest densities (16 per square meter) of hard clams (*Mercenaria mercenaria*) in a relatively oligotrophic Long Island estuary: the authors argued that positive effects of modest numbers of suspension-feeding bivalves are more likely to benefit eelgrass in relatively oligotrophic water bodies where massive additions of filtering capacity are not required to achieve meaningful enhancement of light reaching the bottom (Carroll et al., 2008). These potential positive contributions of oysters to seagrasses are not mentioned in any of the NPS public releases of information on effects of oyster mariculture in Drakes Estero.

- Based on research of Wechsler (2004), also summarized in Elliott-Fisk et al. (2005), the first version (October 2006) of *Drakes Estero: A Sheltered Wilderness Estuary* maintained that "Schooner Bay…supported an entirely different fish community than that in the Estero de Limantour." In fact, the only quantitative study of the fishes in Drakes Estero (Wechsler, 2004), based on limited sampling, failed to demonstrate substantial or statistically significant differences in the fish community composition between these two arms of the estero. There is some suggestion that the guild of fishes associated with hard substrates, a pattern driven by kelp surfperch, has enhanced abundances in close proximity to the oyster racks, but the spatial scope of any such signal is limited and not statistically significant (Wechsler, 2004). The later versions III and IV (May 8 and May 11, 2007, respectively) of *Drakes Estero: A Sheltered Wilderness Estuary* removed the reference to changes in the fish community associated with the oyster racks. The Clarification document provides a rigorous overview of Wechsler's (2004) fish sampling data, admitting that there is inadequate evidence to reach conclusions about whether oyster culturing in Drakes Estero has any impact, positive or negative, on fishes. This NPS release also correctly identifies the suggestion of elevated abundance or attraction of fish species associated with hard substrates, while noting the lack of any statistical significance of this pattern despite a logical mechanistic basis that could explain it.

- Version I of the *Drakes Estero: A Sheltered Wilderness Estuary* (October 2006) asserted that the "marine invertebrate fouling community could be properly characterized as 'introduced' or 'invasive' due to lack of hard substrata in Drakes Estero," citing Elliott-Fisk et al. (2005) as the source. The dominant occupier of space on the culture racks and oysters hung over them appears to be the nonnative tunicate, *Didemnum vexillum*, and three other nonnative fouling species are documented in Elliott-Fisk et al. (2005). Nevertheless, the assertion that hard substrates are absent in Drakes Estero is false (Bull Point contains some natural rocks), and insufficient sampling data exist to characterize the entire fouling community as nonnative. Furthermore, none of the versions of *Drakes Estero: A Sheltered Wilderness Estuary* acknowledges that hard substrate in the form of the native Olympia oyster shells likely existed in abundance within Drakes Estero in the past. Fouling organisms introduced into the estero would have found suitable hard substrate for attachment had the historical abundance of the Olympia oyster been sustained, assuming that its distribution extended into the subtidal zone as it does in British Columbia and elsewhere on the Pacific coast. The Clarification document provides a more accurate overview of the risks of enhancing populations of the nonnative tunicate, *D. vexillum*, by the provision of hard substrates in the form of oyster racks and oysters. Specifically, NPS identifies the concern that abundant populations of such an invasive species might change the biological environment in ways that lead to promoting successful invasion of other nonnatives—a process known as invasional meltdown (Grosholz, 2005). In addition, the Clarification document correctly identifies the risk that high populations of *D. vexillum* pose to enhancing the potential dispersal to other sites. Consequently, the Clarification document provides a rigorous summary of the issues relating to *D. vexillum* and other invertebrates occupying hard substrates, including oyster culture racks and the oyster shells. The only substantive difference between what NPS reported in the Clarification document and the findings of the committee is the failure of NPS to acknowledge the likely historical presence of common hard substrates in the form of shells of the native Olympia oyster.

- The first version also maintained that the "…oyster operation is a source for many invasive species…" Credible arguments support the inference that successful introductions of nonnative species into Drakes Estero are the consequence of historic oyster farming practices in Drakes Estero. Specifically, the introduced salt marsh snail, *Batillaria attramentaria*, has been associated with oyster farming (Byers, 1999) and introduction of a nonnative haplosporidian oyster parasite into Drakes Estero is also associated with importation of Pacific oysters (Burreson et al., 2000). The Pacific oyster now cultured in Drakes Estero, *Crassostrea gigas,* is itself a nonnative species and has potential to escape culture and establish a self-replicating population as does the nonnative Manila clam (*V. philippinarum*). However, historic oyster mariculture practices that involved transport of nonnative oysters in juvenile or partially grown forms on cultch (large shell) have ended. This practice has been replaced by the transport of eyed larvae for remote setting in the nurseries of DBOC in a fashion similar to current practice at other mariculture operations. Consequently, the oyster operation is not now likely to be a source for further introductions of nonnative species. The only types of species that now could conceivably be introduced along with importation of oyster larvae are microbes, including notably oyster herpes viruses. None of the NPS review documents describe this change in mariculture methods and the great reduction in risk of new introductions that is achieved by transferring larvae from hatcheries inspected by High Health criteria (see Appendix E) instead of juvenile oysters on cultch.

- Versions III and IV of *Drakes Estero: A Sheltered Wilderness Estuary* state that oyster culture operations have resulted in an 80% decline in harbor seals "at one area" in Drakes Estero. This description is misleading because it implies that there has been a decline in the seal population at Drakes Estero whereas what has been observed is a reduction in the use of some of the haul-out subsites during the breeding season. In addition, the 80% value represents a selective presentation of subsite use that does not place this information into context with the spatially replicated and longer-term count data throughout the Drakes Estero colony and the Point Reyes region. The paper by Becker et al. (2009) improves on this simplistic description by analyzing the use of three haul-out subsites over a decade and relating it to local mariculture activities and changes in oceanic conditions from the 1998 ENSO climatic event. The conclusions reached by the authors of the paper are generally consistent with the results of the analysis, but the limitations of the analysis and hence tenuous nature of the conclusions may not be obvious to the non-expert. First, it is important to recognize that the analysis showing a relationship between mariculture activities and a decline in the mean seal attendance at two of three haul-out subsites in Drakes Estero does not demonstrate cause and effect. Second, the use of oyster production level as a proxy for mariculture activities that displace or disturb seals may be confounded by changes in culture methods or management practices. Third, demonstrating changes in mean attendance at seal haul-out subsites is not equivalent to demonstrating a decline in the seal population at Drakes Estero. The entire estero should be considered as one unit for population analyses for comparison to trends at other nearby locations occupied by harbor seals. For these reasons, the Becker et al. (2009) paper has limited value for understanding the long-term trends in seal counts in Drakes Estero. The NPS 2007 Pacific Harbor Seal monitoring annual report recognizes the need to look at these longer-term trends: "Inclusion of all survey years (2000-2007) in the average calculation accounts for the inherent inter-annual variability in the harbor seal population and reproductive output. Declines below one standard deviation from the mean, especially over the course of a few years, may merit further analysis of the data for statistical significance, additional research, or management actions." (Truchinski, et al. 2008). The 2007 annual report shows that although the adult counts for 2007 are within one standard deviation of the 2000-2007 average, pup counts in Marin County colonies as a whole have declined to below one standard deviation for 2006 and 2007, which is a cause of concern that merits more detailed analysis. With regard to disturbance, we note that the 100 yd (91 m) buffer between mariculture activities and seal haul-out locations, while consistent with the National Marine Fisheries Service guidelines under the Marine Mammal Protection Act and Allen et al.'s (1984) observations of threshold disturbance distances for hauled-out seals in Bolinas Lagoon, is not as large as the 500–1,500 m buffers employed at two European locations to protect seals from human disturbance. Interpretation of the disturbance data is limited by the lack of critical information on how individual fitness and population consequences may vary with disturbance type. Hence, the disturbance monitoring conducted by NPS is inadequate for rigorous inferences on the impacts of mariculture on harbor seals.

- Version IV (May 11, 2007) of *Drakes Estero: A Sheltered Wilderness Estuary* highlights a quote from Dr. Janet Thompson of the U.S. Geological Survey, who inferred "a shift in the carbon from the pelagic food web to the benthic food web." Elsewhere, this document reports that "…in Drakes Estero, ecological function has been degraded and altered over the past several decades due to activities associated with oyster farming and ranching." Our review of available scientific information fails to demonstrate any empirical evidence of food web shifts in response to oyster farming in Drakes Estero. The scientific literature on the effects of culturing oysters and other suspension-feeding bivalves does not support a broad characterization of degradation of function, especially in physically well flushed estuaries and where stocking densities are relatively low, as in Drakes Estero. Furthermore, while some shift from pelagic to benthic food webs is a reasonable inference, there is no acknowledgement of the historical baselines of the natural ecosystem before humans caused the functional elimination of the native Olympia oyster in Drakes Estero during the mid 1800s to early 1900s (Barrett, 1963; Baker, 1995; Kirby, 2004). The presence of shells of living, albeit cultured, oysters re-introduces biogenic hard substrates for fouling organisms, although differing in location by including elevated rack and surface plastic mesh culture structures, and the maintenance of feeding cultured oysters represents re-introduction of ecological filtering and biodeposition functions that prevailed before the native oysters were overharvested. Characterizing these changes as a degradation of ecological function ignores the perspective of history by selecting as a baseline for contrast only the recent anthropogenically modified status of the estero, and ignoring the historical baseline conditions that prevailed before the 1850s (Jackson, J.B.C. et al., 2001; Lotze et al., 2006). Likewise, the historic presence and ecological roles of Olympia oysters in the estero, prior to commercial overharvest that was completed by the early 1900s, is not mentioned in the Clarification document, which reports instead: "The presence of a reported nine million oysters and one million clams within an area that would not have these resources naturally is itself enough to demonstrate an alteration of natural conditions." (NPS, 2007d).

The literature on estuarine ecosystems and restoration identifies oysters as a major contributor to maintaining or restoring water quality and as important biogenic habitat for demersal fishes and mobile crustaceans (Lenihan and Peterson, 1998; Newell, 2004; Hosack et al., 2006; Coen et al., 2007; Grabowski and Peterson, 2007). Although there is a dearth of research on the extent to which the cultured Pacific oyster restores the ecological contribution of the native Olympia oyster in Drakes Estero, none of the NPS documents released to the public acknowledges that oysters were part of the historical baseline ecosystem before substantial human intervention and that oysters typically have largely beneficial biogeochemical functions in estuarine and lagoonal ecosystems.

HOW SCIENTIFIC CONCLUSIONS AFFECTED NPS DECISION MAKING

To address how conclusions based on science affected NPS decision making required the committee to identify decisions made by NPS and infer the role that science may have played in those decisions. The committee identifies the following three explicit decisions:

- the decision to include a new restriction on boat use in the 2008 Special Use Permit for the commercial shellfish mariculture operation in Drakes Estero;
- the decision to release *Drakes Estero: A Sheltered Wilderness Estuary* in its four versions (2006; 2007a; 2007b; 2007c) and subsequent Acknowledgment of Corrections (NPS, 2007e) and Clarification (NPS, 2007d) documents; and
- the decision to discourage DBOC from seeking a new RUO to continue operations beyond 2012 when the current RUO expires.

Decision to Sign the April 2008 Special Use Permit through 2012

A Special Use Permit for commercial operations of DBOC within a national park was signed in April 2008. NPS included in the permit a new restriction on boat use by DBOC that directed boat passage away from a more direct deep channel (the "lateral channel") throughout the year, not just during the harbor seal pupping season. This restriction closes the channel running close to one of the haul-out sites and redirects oyster boat traffic to a more circuitous route over shallower eelgrass beds. This new provision may have been motivated by concluding that motorboats pose a high risk of disturbance to the harbor seal, a species protected under the Marine Mammal Protection Act, and that risk is more serious than the increased damage to eelgrass beds from propeller scars. This decision is consistent with the recommended Resource Protection Measures enumerated in the California Coastal Commission's Consent Order (CCC-07-CD-11, Nov. 29, 2007). By comparison to the year-round closure of the lateral channel to oyster boats, kayak use in Drakes Estero is restricted from March 1 through June 30, "to protect harbor seals from disturbance during the most crucial part of the pupping season," (available at www.nps.gov/pore/planyourvisit/kayak.htm).

Decision to Write and Release *Drakes Estero: A Sheltered Wilderness Estuary* plus the Acknowledgment of Corrections and Clarification Documents

NPS reported scientific observations and conclusions in all four versions of *Drakes Estero: A Sheltered Wilderness Estuary* that were released to the public. In that sense, this decision involved science. The degree to which the science motivated the decision to release this report is unclear. The scientific conclusions presented in the report included several that did not match what can be rigorously concluded from the limited scientific studies that have been conducted in Drakes Estero or analogous systems (see above). The scientific information on impacts of oyster culturing at Drakes Estero is limited and provides an insufficient basis on which to address some of the most important concerns about impacts. Based on this committee's conclusions, the most important concerns relate mostly to activities of the culturists rather than to presence of and activities of the oysters themselves, which is not reflected in the *Drakes Estero: A Sheltered Wilderness Estuary*. Potential negative effects of activities of the culturists on the harbor seal population represent the most serious concern, which cannot be fully evaluated because these effects have not been directly investigated. The reinterpretations of available science, prompted by stakeholder criticism and aided by solicited and unsolicited expert assessments, and corrections of misstatements of existing information in NPS documents appeared to play roles in motivating NPS to prepare and release the Acknowledgment of Corrections and Clarification documents.

Decision to Discourage DBOC from Seeking a New RUO

The crux of the controversy over Drakes Estero is the pending expiration of the RUO in 2012. The actions taken by Point Reyes National Seashore, including the addition of specific language in the Special Use Permit on termination of the lease, the preparation and release of "Drakes Estero: A Sheltered Wilderness Estuary," and the denial of a permit for research on whether it would be possible to grow native oysters in the estero, indicate that the NPS decided to discourage DBOC from seeking an extension of the RUO (DOI, 2008). NPS's actions are consistent with the Department of Interior's interpretation of the Wilderness Act and the Point Reyes Wilderness Act of 1976 (Appendix A). The July 2008 Inspector General's Report of Investigation (DOI, 2008) spoke unambiguously to this issue, noting that the Department of Interior's Office of the Solicitor advised Point Reyes National Seashore that the Superintendent does not have the authority to extend the RUO because of the congressional mandate designating Drakes Estero as Potential Wilderness (DOI, 2004; see Appendix A). The Solicitor stated that under the Wilderness Act, NPS is mandated to convert Potential Wilderness to Wilderness status as soon as the non-conforming activity can be removed. Consequently, our committee concludes that this decision on extension of the RUO hinges on the legal interpretation of the legislative mandate rather than a scientific analysis of the impacts of DBOC on the Drakes Estero ecosystem. As such, more scientific study of DBOC operations and Drakes Estero would not necessarily affect National Park Service decisions about the future of oyster farming in the estero.

In the past, NPS had incorporated oyster farming into the General Management Plan (National Park Service, 1980; cited in Wechsler, 2004) under the Point Reyes National Seashore objective to preserve aspects of cultural significance. If DBOC is successful in having the RUO extended beyond 2012, a collaborative interpretative center could be established between DBOC and NPS, as had been proposed by the previous owner (Tom Moore, personal communication). Results of scientific research on the role of cultured oysters in the Drakes Estero ecosystem would then be valuable contributions to the center. Collaboration on an interpretive center would be consistent with the purposes of the original RUO "for the purpose of processing and selling wholesale and retail oysters, seafood, and complimentary food items, the interpretation of oyster cultivation to the visiting public, and residential purposes reasonably incidental thereto…" (DOI, 2004; see Appendix A). Under this scenario, science would be needed to set and adaptively modify permit conditions under the new RUO and to develop exhibits for the interpretative center on the ecological role of oysters as an ecosystem engineer or foundation species in estuarine ecosystems, the history of overexploitation, the challenges of nonnative species, conservation problems, the issue of how changing ecological baselines influences wildlife preservation and habitat restoration, the relationships between mankind and oysters, and the challenges of environmental and cultural sustainability. Activities of oyster culturists necessarily have some impact on the ecosystem of Drakes Estero, subject to regulation by multiple management authorities to minimize serious impacts, while perpetuating a cultural history of oyster farming that goes back to the 1930s (Anima, 1990, 1991). Cattle ranching and dairy farming persist within the Point Reyes National Seashore as part of the cultural history of the lands, continuing the historical uses of the land that date back to the time of European colonization of this region of California. Oyster farming as currently practiced has a similar, although shorter, cultural history and heritage with modest impacts (positive and negative) on the ecosystem. The ecological impacts of the oysters themselves replace in part an ecological function that was lost when the native oyster became functionally extinct during the mid 1800s to early 1900s as a consequence of unregulated human exploitation (Kirby, 2004). In addition, efforts to restore a self-sustaining population of native oysters in Drakes Estero could be promoted and supported. Science would play an important role in that restoration planning and implementation. Drakes Estero has been recognized as one of the few locations on the U.S. west coast still environmentally suitable for re-establishment of the native Olympia oyster (Shaw, 1997).

Research Needs

Although Drakes Estero represents an ideal setting for addressing many scientific questions of basic and applied value, the committee restricts its suggestions for key research problems to those issues that could improve management of valuable natural resources within Drakes Estero. Results of research conducted to address these questions would have importance that stretches far beyond their application to management of Drakes Estero because the questions include important aspects of fundamental science. Research to answer such questions is critically needed in the Point Reyes National Seashore as in all National Parks. The lack of sufficient resources in NPS to support the research required to harmonize the facilitation of public use and enjoyment of the parks with the preservation of environmental and cultural assets is a national problem. The availability of sufficient resources to assess environmental impacts of management alternatives and to fund rigorous scientific review of NPS documents prior to release could have provided sufficient information to avoid over-interpretations and misstatements of science, such as those that appeared in the NPS depictions of oyster farm impacts in the Drakes Estero case.

The following research topics are not prioritized, but they address important unanswered questions about the various potential impacts of shellfish mariculture examined by the committee:

- **Carrying capacity for suspension-feeding bivalves.** An interdisciplinary oceanographic field and modeling study, coupled with empirical field monitoring validation on a recurring basis to account for climatic and other environmental change, is needed to determine how the physical flushing conditions in the estero determine the maximal carrying capacity for oyster biomass so as to avoid over-exploitation of phytoplankton resources shared with other suspension feeders and avoid organic deposition of biodeposits high enough to induce sedimentary anoxia.

- **Eelgrass, benthic invertebrates, and fishes.** A more detailed sampling or preferably experimental study is required to test how shellfish mariculture influences benthic invertebrates (including the native oyster), eelgrass, and fishes in Drakes Estero. Population-level research on how eelgrass responds to mariculture and why it is expanding in this estuary and not in many other systems would be useful. Also, more work is needed to understand how eelgrass, open sediment, native shellfish beds, and mariculture operations function as habitats for fish and benthic invertebrates at a landscape scale in the estero and other similar systems.

- **Control of *Didemnum vexillum*.** Further understanding of how to control abundances and reduce the risk of spread of the invasive *Didemnum vexillum* is urgently needed, not just in Drakes Estero but also worldwide. For Drakes Estero, methods need to be developed for how to dispose of *Didemnum* after scraping it off racks and oyster shells to prevent it from spreading by fragmentation. The current practice of disposing of scraped-off fragments into the estero increases the risk of spread, perhaps even to eelgrass given recent reports of the colonization of eelgrass blades elsewhere.

- **Disease and parasite research for bivalve mariculture.** Further research into controlling diseases potentially spread with transport of shellfish larvae, such as oyster herpes viruses, is important to the mariculture industry broadly and to protecting wild stocks of shellfish in recipient water basins.

- **Oceanographic processes leading to poor shellfish larval survival.** Major West Coast shellfish hatcheries are currently suffering catastrophic failures in rearing shellfish larvae that appear to be similar to failures in the survival of native bivalve larvae. Larval survival appears to be affected by major changes over the past 2–3 years in coastal ocean upwelling, which involves lowering the pH (Feeley et al., 2008), or changing the abundance of pathogenic microorganisms. This problem is urgent and will require interdisciplinary studies of natural- and human-induced processes because of its unusual nature and its threat to both wild and cultured shellfish populations over wide areas of the west coast.

- **Pinniped monitoring program.** The coordinated pinniped monitoring program across the San Francisco parks network now provides an important resource providing as yet untapped potential for assessing trends in the abundance of harbor seals in Drakes Estero in relation to wider regional trends. However, harbor seal haul-out surveys such as this have limited power to detect trends in abundance. The committee, therefore, recommends that NPS continue this program to provide an adequate time series to assess both colony-specific and regional trends.

- **Targeted spatially explicit study of activities of mariculturists and their boats in Drakes Estero.** Efforts to explain the changes in abundance and behavior of wildlife populations in relation to natural events and anthropogenic activities also require more robust data on patterns of change. Future assessments of the potential impact of mariculture disturbance in this area would greatly benefit from more detailed data on spatial and temporal changes in the distribution activities by the oyster farm boats and culturists working around oyster bags and racks. This information could be used to construct a more ecologically realistic footprint of the mariculture activity, including potential interactions at sea and on land. GPS loggers or transmitting systems would allow these data to be collected remotely and the resulting footprint modeled using standard techniques. Results could be used in adaptive management to minimize any demonstrated impacts of mariculture activities.

- **Individual seal and bird behavior and fitness studies.** If needed to manage future shellfish mariculture operations in Drakes Estero or in other systems, any assessments of direct impacts to harbor seals and birds would require a more detailed individual-based study using animal tracking devices that will allow an assessment of responses to known disturbances of different origin. However, the conservation benefits of such a study must be carefully balanced against any potential adverse effects resulting from more intrusive research techniques.

- **Alternative oyster culture techniques.** In the event of an extension of the RUO for DBOC, research would be needed on oyster culture techniques that form an economically viable alternative to placing culture bags near seal haul-out areas. The goal would be to find methods less disruptive to seals and birds. In addition, research on the viability of establishing a self-sustaining population of Olympia oysters would contribute to the potential restoration of the historic baseline ecosystem in Drakes Estero prior to over-exploitation of native oysters.

- **Socioeconomic impacts of oyster mariculture on visitors to the Point Reyes National Seashore.** It would be worthwhile to the development of NPS policy to assess the effects of oyster farming on the recreational, cultural, and aesthetic experiences of visitors to the Point Reyes National Seashore and to the economic value realized by these visitors. A study of this nature could also assess, for example, the potential educational value of constructing an interpretive center around the oyster culturing operations.

The Role of Science in Decision Making

Two lines of argument against continued shellfish mariculture in Drakes Estero have been raised: (1) shellfish mariculture is incompatible with Wilderness status as defined in the U.S. Wilderness Act (P.L. 88-577, Sep. 3, 1964; see Appendix A) and (2) shellfish mariculture should not take place in Drakes Estero because of the risk of adverse ecological effects. Science has more to say about the latter than the former.

In 2004, prior to the sale of the Johnson Oyster Company to the current owners, the Department of Interior's Office of the Solicitor reviewed the "potential wilderness" status of Drakes Estero and concluded that "the Park Service is mandated by the Wilderness Act, the Point Reyes Wilderness Act and its management policies, to convert Potential Wilderness, i.e. the Johnson Oyster Company tract and adjoining Estero, to Wilderness status as soon as the non-conforming use can be eliminated." (DOI, 2004; see Appendix A) This congressional mandate provides a legal basis for not extending the RUO to DBOC beyond 2012, as cited in the report of the Department of Interior's Office of Inspector General in finding that the Superintendent of Point Reyes National Seashore does not have the authority to extend the RUO beyond 2012 (DOI, 2008).

With regard to addressing the risk of ecological effects, NPS's Management Policies prioritize the protection of natural resources, including circumstances where the available scientific information contains substantial uncertainty: "In cases of uncertainty as to the impacts of activities on park natural resources, the protection of natural resources will predominate" (NPS, 2006c). This policy could be applied to permitting decisions before 2012 as well as providing an environmental rationale for not extending the 40-year term of the RUO that was granted upon the Johnson's sale of the property to NPS in 1972.

After evaluating the limited scientific literature on Drakes Estero and the relevant research from other areas, the committee concludes that there is a lack of strong scientific evidence that shellfish farming has major adverse ecological effects on Drakes Estero at the current levels of production and under current operational practices, including compliance with restrictions to protect eelgrass, seals, waterbirds, and other natural resources. Adaptive management could help address effects, if any, that emerge with additional scientific research and monitoring to more fully understand the Drakes Estero ecosystem and the effects of shellfish farming. Importantly from a management perspective, lack of evidence of major adverse effects is not the same as proof of no adverse effects nor is it a guarantee that such effects will not manifest in the future. A more definitive understanding of the adverse or beneficial effects cannot be readily or inexpensively obtained; the complexity of marine ecosystems and responses to ongoing environmental change (both natural and anthropogenic) requires substantial time and effort to understand. This situation is not unique to Drakes Estero—uncertainty about effects of human activities on ecosystems is a common feature of most decisions about actions that affect natural resources.

The ultimate decision to permit or prohibit a particular activity, such as shellfish farming, in a particular location, such as Drakes Estero, necessarily requires value judgments and tradeoffs that can be informed, but not resolved, by science. Science describes the effects (differences in outcomes) that can be expected with and without shellfish farming in Drakes Estero, the level of uncertainty given current knowledge about these effects, and approaches to assess and balance potential risks and benefits. Because stakeholders may reasonably assign different levels of priority or importance to these effects and outcomes, there is no scientific answer to the question of whether to extend the RUO for shellfish farming. Like other zoning and land use questions, this issue will be resolved by policymakers charged with weighing the conflicting views and priorities of society as part of the decision-making process.

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Appendixes

Appendix A
Wilderness Status

The National Park Service position that it cannot authorize continued operations beyond the expiration of the Reservation of Use and Occupancy in 2012 is primarily based upon the1976 Point Reyes National Seashore legislation. National Park Service Reservations of Use and Occupancy (RUOs) are created as part of the real property transaction when the United States purchases the underlying land, and the National Park Service does not renew or extend expired RUOs. After the expiration of a National Park Service RUO, continued use and occupancy of the land is possible if a new authorizing instrument can be issued under applicable laws. The National Park Service and the Department of the Interior Solicitor's Office read the 1976 legislation designating Drakes Estero as Potential Wilderness and strengthening the enabling act for Point Reyes National Seashore [P.L. 94-544 (Oct. 18, 1976) and P.L. 94-567 (Oct. 20, 1976), 16 U.S.C. § 1132 note] as eliminating the discretion of the NPS to authorize continued operations through a new authorizing instrument beyond the expiration of the RUO in 2012. In addition to the 1976 legislation, other legal requirements that the NPS has identified that would impact authorization of operations beyond 2012 include the National Environmental Policy Act, the National Park Service Organic Act, the Marine Mammal Protection Act, the Endangered Species Act, and the National Park Service regulations as set forth in Title 36 of the Code of Federal Regulations.

In this legal context, the decision on a renewal of the Reservation of Use and Occupancy for Drakes Bay Oyster Company to continue to operate in Point Reyes National Seashore is subject to the U.S. Wilderness Act (P.L. 88-577, Sep. 3, 1964), which defines Wilderness as follows:

> A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain. An area of wilderness is further defined to mean in this Act an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value.
> (16 U.S.C. 1131-1136, section 2©)

Regarding prohibited and permitted uses of Wilderness areas, the Wilderness Act states:

> Except as specifically provided for in this Act, and subject to existing private rights, there shall be no commercial enterprise and no permanent road within any wilderness area designated by this Act and, except as necessary to meet minimum requirements for the administration of the area for the purpose of

> this Act (including measures required in emergencies involving the health and safety of persons within the area), there shall be no temporary road, no use of motor vehicles, motorized equipment or motorboats, no landing of aircraft, no other form of mechanical transport, and no structure or installation within any such area.
> (16 U.S.C. 1131-1136, section 4©)

The Wilderness Act goes on to make special provisions regarding use: "the use of aircraft or motorboats, where these uses have already become established, may be permitted to continue subject to such restrictions as the Secretary of Agriculture deems desirable" (16 U.S.C. 1131-1136, section 4(d)(1)) and "[c]ommercial services may be performed within the wilderness areas designated by this Act to the extent necessary for activities which are proper for realizing the recreational or other wilderness purposes of the areas" (16 U.S.C. 1131-1136, section 4(d)(6)).

The Wilderness Act was amended as follows in the Point Reyes Wilderness Act of 1976 (PL 94-544, Oct. 18, 1976):

> SEC. 3. The area designated by this Act as wilderness shall be administered by the Secretary of the Interior in accordance with the applicable provisions of the Wilderness Act governing areas designated by that Act as wilderness areas, except that any reference in such provisions to the effective date of this Act, and, where appropriate, any reference to the Secretary of Agriculture, shall be deemed to be a reference to the Secretary of the Interior.
> SEC.4 (a) Amend the Act of September 13,1962 (76 Stat. 538), as amended (16 U.S.C. 459c-6a), as follows: In section 6(a) insert immediately after the words "shall be administered by the Secretary," the words "without impairment of its natural values, in a manner which provides for such recreational, educational, historic preservation, interpretation, and scientific research opportunities as are consistent with, based upon, and supportive of the maximum protection, restoration, and preservation of the natural environment within the area."
> (PL 94-544, Oct. 18, 1976)

At the request of the superintendent of the Point Reyes National Seashore and the regional administrator of NPS, the Office of the Solicitor, San Francisco Field Office, in the Department of the Interior prepared a memorandum on the status of Johnson Oyster Company (now DBOC) under the terms of sale of the property to NPS and the subsequent Potential Wilderness designation of Drakes Estero under the Point Reyes Wilderness Act of 1976 (PL 94-544, Oct. 18, 1976). The memorandum is reproduced in its entirety below.

United States Department of the Interior

OFFICE OF THE SOLICITOR
San Francisco Field Office
1111 Jackson Street, Suite 735
Oakland, California 94607

IN REPLY REFER TO:

February 26, 2004

To: Superintendent
Point Reyes National Seashore

From: Field Solicitor
San Francisco Field Office

Re: Point Reyes Wilderness Act

As requested, this memorandum opinion reviews the Point Reyes wilderness situation as it related to the Johnson Oyster Company 40-year Reservation of Use and Occupancy which expires in 2011, or might be terminated sooner for cause or other processes. The Wilderness Act of 1964, and the Point Reyes Wilderness Act of 1976, provide the guidance for implementation of wilderness within the Seashore and are the basis for NPS's obligations to manage the subject land and waters toward conversion of the potential wilderness areas to wilderness status.

In conjunction with the Seashore authorization Act of 1962, the State of California, by 1965 legislation (copy attached), conveyed to the United States all of the right, title and interest of the State in lands one-quarter mile seaward of the mean high tide. More precisely the State granted "all the tide and submerged lands or other lands beneath navigable waters situated within the boundaries of the Point Reyes National Seashore . . . " to the United States. Excepted from this grant and reserved to the State were the "right to fish upon, and all oil, gas and other hydrocarbons in the lands … together with the right to explore or prospect . . . " within the tidal and submerged lands. However, these reserved rights were not to be "exercised in such manner as to cause … unnecessary pollution of the coastal waters", and no "well or drilling operations of any kind shall be conducted upon the surface of such lands."

On October 18, 1976, the Point Reyes Wilderness Act designated 25,370 acres as wilderness, and 8003 acres as potential wilderness. Public Law 94-544, Oct. 18, 1976. The area designated as potential wilderness (2811 acres) for area 2 of three areas included the waters of the Drakes Estero and the adjoining inter-tidal land and upon which Johnson Oyster Farm operates a commercial oyster business.[1] (map attached)

This Congressional designation of the wilderness and potential wilderness (see the House and Senate discussions of the legislation in the Congressional Record -copy attached) was made notwithstanding a September 8, 1976 letter written by John Kyl, Assistant Secretary of the Interior, to James A. Haley, Chairman of the Committee on Interior and Insular Affairs wherein he stated the Department's position on the Point Reyes Wilderness Act. While DOI was largely supportive of the Act, Mr. Kyl's letter said that the Department did not recommend the inclusion of the tidelands extending one-quarter mile offshore within the boundaries of Point Reyes, as granted by the State of California as potential wilderness. According to the Kyl's letter, the State's retention of mineral and fishing rights rendered this area "inconsistent with wilderness." This letter is the only record in the legislative history that raises this point in the area's wilderness and potential wilderness designation. After review of the 1965 State Act, the Wilderness Act, Point Reyes Wilderness Act, case law and present day NPS Directors'orders and Management Policies, it is the view of this office that the remarks in the Kyl letter are not only inaccurate but overridden by the Congressional action, as explained below.

The 1965 State Act is very limited in its two reservations of rights, i.e., public right to fish and severely restricted mineral exploration access, i.e., no surface disturbance of any kind. Both reservations would not conflict with the Secretary converting the potential water area and shore land wilderness acres into designated wilderness. Further, notwithstanding the Departments' letter, the Congress ultimately designated 25,370 wilderness and 8000 potential wilderness acres which exceeded the acreage recommended by the Administration. This reflects that Congress did not heed Mr. Kyl's recommendation and conclusions and enacted its preferred wilderness act.

Addressing the potential wilderness lands and water, the House Report 94-1680, accompanying the eventually enacted Bill (HR 8002) states that it was its intent that there be "efforts to steadily continue to remove all obstacles to the eventual conversion of these lands and waters to wilderness status." (copy attached) The designations are implemented by the Park Service's 2001 Management Policies on wilderness which state that "[T]n the process of determining suitability, lands will not be excluded solely because of existing rights or privileges (e.g., mineral exploration and development, *commercial*

1. It is noted that the State continues to issue to Johnson Oyster Company commercial allotments in Drakes Estero which seem to be in conflict with the 1965 State legislative grant and 1976 Congressional mandate to convert the bays of the Estero into wilderness status. On the other hand, the continued public fishing in the Estero is consistent with the State legislative grant and the conversion to wilderness status.

Further, since the United States owns the tide and submerged lands in Drakes Estero, it clearly follows that permission of NPS is appropriate for commercial activities taking place on those granted lands.

operations…")[2] Further, the Park Service's Management Policies clearly state that the Park Service must make decisions regarding the management of potential wilderness even though some activities may temporarily detract from its wilderness character. The Park Service is to manage potential wilderness as wilderness to the extent that existing non-conforming conditions allow. The Park Service is also required to actively seek to remove from potential wilderness the temporary, non-conforming conditions that preclude wilderness designation. 6.3.1. Wilderness Resource Management, General Policy. (selected excerpts attached)

Hence, the Park Service is mandated by the Wilderness Act, the Point Reyes Wilderness Act and its Management Policies to convert potential wilderness, i.e., the Johnson Oyster Company tract and the adjoining Estero, to wilderness status as soon as the non conforming use can be eliminated. [3]

Ralph G. Mihan

2. See the District Court ruling that past commercial activities, in this case timber harvesting, do not preclude an area's wilderness designation. Minnesota Public Interest Research Group v. Butz, 401 F. Supp. 1276, 1329 (1975)

3. The status of the Johnson Oyster Company will be addressed in a separate document.

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DEC-20-2007 16:33 POINT REYES NATL SEASHORE 415 663 8132 P.02

United States Department of the Interior

OFFICE OF THE SOLICITOR
San Francisco Field Office
1111 Jackson Street, Suite 735
Oakland, California 94607

IN REPLY REFER TO

RECEIVED Point Reyes National Seashore MAR 3 '04

MEMORANDUM

To: Superintendent
Point Reyes National Seashore — February 27, 2004

From: Field Solicitor
San Francisco Field Office

Re: Johnson Oyster Company Property Status

As requested, this office has reviewed the case file pertaining to the long standing non compliance by the Johnson Oyster Company (JOC) with the terms and conditions of its Reservation of Use and Occupancy. ("Reservation")

The Johnson Oyster Company is operating on National Park Service fee land in Point Reyes National Seashore under a 1972 Reservation in which Tom Johnson, as a condition of his sale to the Park Service, reserved the right to operate an oyster farm for 40 years until 2012[1]. For the last many years, the JOC has operated in violation of the agreed upon conditions contained in the Reservation. Some of this property and the adjoining Drakes Estero where the oysters are farmed are currently within designated "potential wilderness" Area 2 and will become "wilderness" upon cessation of JOC's operations. As soon as the property and waters are vacated, NPS would proceed with its conversion to wilderness preservation, as required by the Wilderness Act (16 U.S.C. 1131-1136), and more specifically the Point Reyes Wilderness Act of 1976. (PL 94-544, Oct.18, 1976)

"Potential wilderness" is an area which contains "lands that are surrounded by or adjacent to lands with the wilderness designation but that do not themselves qualify for immediate designation due to temporary, non-conforming, or incompatible conditions." National Park Service Management Policies 2001, Section 6.2.2.1. This designation imposes land management obligations on NPS in that the NPS's 2001 Management Policies direct that the Park seek to remove the non-conforming conditions that preclude wilderness designation.

The October 12, 1972, Charles W. Johnson (Tom Johnson's father) sold his five acres of property for $79,200.00 to the National Park Service. The Reservation

[1] In addition, the National Park Service has issued various special use permits to Mr. Johnson over the years.

1

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retained for the "Vendor, its successors and assigns, a terminable right to use and occupy the ... property ... together with the improvements situated thereon, for a period of 40 years for the purpose of processing and selling wholesale and retail oysters, seafood and complimentary food items, the interpretation of oyster cultivation to the visiting public, and residential purposes reasonably incidental thereto...."

The right to engage in these activities, however, was made contingent upon the satisfaction of various conditions including maintaining the property in a "safe, sanitary, and sightly condition, open to reasonable inspection by the National Park Service, and meeting all Federal, State, and County health, sanitation, and safety standards applicable to operation of and residence within areas engaged in the processing and retail sale of oysters." In addition, the JOC was made responsible for utility services, including sanitation, not committing waste, and complying with all National Park Service rules and regulations. It also precluded constructing any temporary or permanent structures without the approval of the Park Service.

On December 5, 1995, the Superintendent, wrote JOC a letter describing a variety of violations of the conditions of the Reservation, i.e., operating a septic system, water system and buildings in violation of Marin County health and safety codes (Condition 1 of the Reservation); maintaining numerous buildings and trailers that were not authorized by NPS or permitted by Marin County (Condition 5); and erecting structures that were not authorized by NPS or permitted by Marin County (Condition 7).[2] Six months later, on April 10, 1996, the Superintendent sent JOC another letter explaining his noncompliance with the mobile home conditions imposed on JOC in the Reservation.[3]

To date JOC continues to violate the terms of the Reservation. In his most recent communication with Mr. Johnson on September 17, 2003, the Superintendent wrote a letter detailing JOC's continuous violations of the Reservation. The letter notes that required permits have not been obtained, a sewage system was not installed, and design and environmental compliance reviews have expired. The letter also describes other violations found during a recent inspection including water draining into the Estero from JOC's shucking room; the presence of overflowing oil and gas drums; inadequately contained above-ground fuel storage tanks; the careless presence of fuel containers, engines, refrigerators, and other items; operation of essentially a junkyard; and other health and safety violations.

Because JOC operates with major violations of the terms of the Reservation, well documented noncompliance JOC is clearly in breach of contract, which relieves the National Park Service of its obligation to permit JOC to remain on the property until

[2] The letter also described a variety of violations of the conditions of JOC's special use permits for the use of a water-well drilled on Seashore land, and also for parking facilities.
[3] Despite Mr. Johnson's continuous violation of both the terms of his agreements with the National Park Service and Marin County's regulations, the County sought to find a friendly solution that would avoid forcing Mr. Johnson off the property on which he operated JOC. Thus, on January 9, 1997, Marin County and Mr. Johnson entered into a Stipulated Agreement Between the Parties and Order ("Stipulated Agreement") detailing Mr. Johnson's maintenance obligations and specifying the consequences of noncompliance. Marin County Superior Court #165361.

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2012.[4] Given the requirements of the Reservation and JOC's failure to satisfy them, the Park Service clearly has the authority to terminate the Reservation and to direct JOC to vacate the property on which it operates.

Removal of JOC from the Point Reyes National Seashore property and its oyster farming from the Estero, would allow the Service to begin the conversion of the area to wilderness status, which directive Congress charged the Park Service to accomplish.

Ralph G. Mihan

[4] In contrast to the Reservation , the Marin County Court approved Stipulated Agreement does specify consequences for failure to comply with its conditions. These consequences are cessation and removal of the offending activity.

Appendix B
Full Statement of Task

Statement of Task

An ad hoc committee will be formed to produce two reports on shellfish mariculture in coastal areas. In the first report, the committee will assess the scientific basis for the National Park Service (NPS) presentations and the report (including revisions), "Drake's Estero: A Sheltered Wilderness Estuary," on the ecological effects of the Drake's Bay Oyster Company operations on Drake's Estero, Pt. Reyes National Seashore in California. In carrying out its task, the committee will address the following questions:

- What is the body of scientific studies on the impact of the oyster farm on Drake's Estero, and what have they shown?
- What effects can be directly demonstrated by research conducted in Drake's Estero itself?
- What effects can reasonably be inferred from research conducted in similar ecosystems?
- What conclusions can be drawn from the body of scientific studies, and how do they compare with what the NPS presented to the public? Have these conclusions affected NPS decision making?
- What are the most important subjects for future research to better understand the ecological consequences of anthropogenic influences on the Estero, so as to inform NPS decision making?

For the second report, the committee will develop recommendations for best practices for shellfish mariculture to maintain ecosystem integrity. To this end, the committee will address the following questions:

- What are the ecological effects of mariculture, and how do they vary in magnitude by duration, operation size, harvest intensity, species cultivated, habitat type, and geographic location (e.g., effects on carrying capacity, water clarity, physical disturbance, species shifts, diseases, benthic deposition)?
- What are the uncertainties surrounding these ecological effects?
- How do the ecological effects of mariculture compare with the harvest of wild populations?
- Does shellfish mariculture reduce the harvest pressure on wild populations?
- What are the risks for the spread of nonnative species, and how could these risks be reduced?

- What socioeconomic factors influence the size and location of shellfish mariculture activities (e.g., “not in my backyard” [NIMBY] issues, economic parameters [permitting/leases for seabed, price stability, labor, transportation], local traditions)?

- What are the most important subjects for future research to better understand and manage the ecosystem responses to mariculture operations?

The report will identify best management practices that could be employed to enhance the benefits of shellfish mariculture and minimize any negative ecological effects.

Appendix C
Agenda: Meeting of the Committee on Best Practices for Shellfish Mariculture and the Effects of Commercial Activities in Drakes Estero, Pt. Reyes National Seashore, California

Acqua Hotel
Mill Valley, CA
September 4-5, 2008

Thursday, September 4

10:00 AM	Welcome and introductions—Pete Peterson, chair, and Susan Roberts and Jodi Bostrom, study directors
10:15 AM	Request for NRC study—Jon Jarvis, National Park Service
10:30 AM	Models for harbor seal counts in Drakes Estero—Ben Becker, National Park Service
11:00 AM	Request for NRC study: issues of concern—Corey Goodman, Marshall, CA
11:45 AM	Discussion
12:00 PM	WORKING LUNCH – Discussion of morning presentations
1:00 PM	Potential Effects of Oyster Mariculture on the Natural Resources of Drakes Estero—John Dixon, California Coastal Commission
1:30 PM	Drakes Estero Mariculture, Past and Present, a California Department of Fish and Game Perspective—Tom Moore, California Department of Fish and Game
2:00 PM	Marine Mammal Population Monitoring—Grey Pendleton, Alaska Department of Fish and Game (joining by teleconference)
2:30 PM	The Oceanography of Drakes Estero – Residence Times, Flushing and Fluxes – Towards an Estimate of Carrying Capacity—John Largier, Bodega Bay Marine Laboratory
3:00 PM	BREAK
3:30 PM	Connections among Shellfish Mariculture, Seagrass, and Invasive Species—Susan Williams, Bodega Bay Marine Laboratory

4:00 PM Experimental Determination of the Ecological Impacts of Commercial Oyster Mariculture on Eelgrass and Invertebrate Communities in Humboldt Bay, CA—Steve Rumrill, South Slough National Estuarine Research Reserve

4:30 PM Responses to presentations from Ben Becker and Corey Goodman

5:00 PM Discussion and public comments

6:00 PM Meeting adjourns for the day

Friday, September 5

Field trip to Pt. Reyes

8:30 AM Drakes Bay Oyster Company, Pt. Reyes National Seashore
Boat tour of Drakes Estero and walking tour of Drakes Bay Oyster Company

12:30 PM Adjourn open session

Appendix D
Tabulated Summary of Reported Values of Harbor Seal Flushing Distances

Disturbance Source	Mean (m)	SD	Range (m)	Habitat Type	Reference
Powerboat	No Data	No Data	<100–300	Small Estuary	Allen et al., 1984
Powerboat	144	No Data	28-260	Island Archipelago	Suryan and Harvey, 1999
Powerboat	80	No Data	No Data	Glacial Fjord	Mathews, 1996
Powerboat	105	105	No Data	Glacial Fjord	Lewis and Mathews, 2000
Stationary Powerboat	191	125	27–371	Island Archipelago	Johnson and Acevedo-Gutierez, 2007
Motor yacht	533	No Data	100–1150	Large Estuary	Brasseur and Reijnders, 1994*
Rubber Dinghy	350	No Data	70–650	Large Estuary	Brasseur and Reijnders, 1994*
Cruise Ship	200	No Data	<100–850	Glacial Fjord	Nansen et al., 2006*
Cruise Ship	123	No Data	No Data	Glacial Fjord	Mathews, 1996
People	No Data	No Data	<100–200	Small Estuary	Allen et al 1984
People	200	No Data	10–400	Large Estuary	Brasseur and Reijnders, 1994*
People	142	135	No Data	Glacial Fjord	Lewis and Mathews, 2000

*values estimated from figures

Appendix E
Shellfish High Health Program Guideline: A Voluntary Program for Producers of Live Shellfish

Reprinted with permission from Ralph Elston, Ph.D., of the Pacific Shellfish Institute

January 2004
Pacific Coast Shellfish Growers Association
120 State Avenue, N. E. #142
Olympia, Washington 98501-8212
Prepared by
Ralph Elston, PhD
Pacific Shellfish Institute
Olympia, Washington
Under grant NA86FD0262,

from National Marine Fisheries Service
U.S. Department of Commerce
Saltonstall-Kennedy Program.

1.0 Purpose of the Shellfish High Health Program Guidelines

1.1 *These Shellfish High Health program guidelines are provided for producers of live shellfish larvae, seed, brood stocks or other products that are exported and placed in receiving waters.* Implementation of a Shellfish High Health program by an individual producer is voluntary. The purpose of implementing such a program for individual producer/exporters is to facilitate the process of obtaining import permits for live shellfish products from governments of importing countries or states and to reduce the risk of spreading infectious shellfish diseases.

1.2 We expect that the Pacific Coast Shellfish Growers Association (P.C.S.G.A.) Shellfish High Health Program guidelines to be endorsed by the Animal and Plant Health Inspection Service (A.P.H.I.S.) of the United States Department of Agriculture (U.S.D.A.). The U.S.D.A. is the federal agency responsible for negotiating the terms of bilateral trade agreements with trading partners of the United States in regard to live animal products. Under such agreements, the U.S.D.A. is recognized by foreign governments as the competent authority to provide assurance of health certification for U.S. export products. Such certification ensures that producers will have access to markets in countries or trading blocks that have established trade agreements with the United States. In addition, such certification should facilitate interstate transfer of live shellfish stocks to be placed in receiving waters.

1.3 The High Health Program is based upon regular surveillance of shellfish health, ongoing health documentation and the use of procedures that promote shellfish health. The framework High Health Program is designed to accomplish are the following:

> **1.3.1** Prevent the dissemination of certifiable infectious shellfish diseases with exported shellfish products.
>
> **1.3.2** Ensure free flow of healthy brood stocks, larvae and seed between health certified production facilities and participating countries by meeting or exceeding shellfish health regulatory requirements for the exportation of live shellfish from producer locations to other states or countries.
>
> **1.3.3** Increase and maximize production efficiency by proactive health management.

1.4 The High Health Program guidelines will be reviewed periodically by the Pacific Coast Shellfish Growers Association to ensure that the guidelines meet the Association's goals for high health shellfish.

2.0 Components and Implementation of a Shellfish High Health Program

2.1 ***Participating producers***. The Pacific Coast Shellfish Growers Association will maintain a list of voluntary participants in its Shellfish High Health program. It will be the responsibility of the individual producers to establish their own Shellfish High Health Program using these guidelines and to establish approval of their program and stocks by the U.S.D.A.

2.2 ***Health certifications, records and documentation***. Participating shellfish producers will maintain an ongoing historical record of the health of its shellfish, based on regular health examinations. These records will establish a documented disease free history which is the basis of qualifying as an exporter to many countries and states.

2.3 ***Examination for certifiable shellfish diseases***. Certifiable or reportable shellfish diseases are specified by state governments in the United States. In addition, recommendations may be provided by federal agencies and made by international advisory bodies such as the Organization Internationale Epizooties (OIE). The required frequency of shellfish health examinations is specified in some states in which members of the P.C.S.G.A. operate. In addition the sampling sensitivity (number of shellfish to need to be sampled and frequency of sampling to establish a disease free certification) may be similarly specified. The ability to export live shellfish to specific foreign countries may be dependent on meeting shellfish health certification requirements negotiated with that country or trading block by the competent authority (A.P.H.I.S. of the U.S.D.A.) of the United States.

2.4 *Brood Stock Management*. A key objective of the Shellfish High Health program is the protection of brood stock holding areas to maintain their health status and to prevent the introduction of exotic infectious diseases to these areas. A brood stock health management program must have the following components.

> **2.4.1** Dedicated areas. Dedicated areas will be used for brood stock maintenance. Each cultured species of shellfish must be held in a defined and localized area clearly demarcated for brood stock and not used for other purposes. Dedicated areas will be selected to minimize any potential means of accidental introduction of infectious shellfish diseases.
>
> **2.4.2** Limited entry. Entry of any new cultured animal stocks to brood stock holding areas is very limited and managed very conservatively. Any proposed shellfish introductions to the brood stock holding area or to a location close enough to the brood stock holding area to present a risk of disease transfer into the holding area must have a disease free health history and undergo a certification evaluation, consistent with applicable regulatory requirements and company policy.
>
> **2.4.3** Ongoing health surveillance. A program of ongoing health characterization and evaluation is conducted for each brood stock holding area consisting of regular health certification of brood stock in these areas.
>
> **2.4.4** Health records. An historical log of health certification and surveillance records is maintained for each brood stock holding area.

3.0 Hatchery and Nursery Operations Protocols

Hatchery and nursery production facilities producing exported shellfish must be managed to exclude certifiable infectious diseases. A program of health management to accomplish this goal will include the following components.

3.1 *Disease free water sources*. Hatchery and nursery facilities and brood stock holding areas must be operated in or use waters free of certifiable shellfish diseases. Sea water disinfection systems may be used to accomplish the goal of a disease free water source.

3.2 *Integrity of brood stocks in the hatchery*. Brood stocks must be managed in the hatchery so they do not contact brood or offspring from any uncertified areas or from areas certified to a lower standard. Similar isolation requirements apply to larvae and seed offspring.

3.3 *Operations protocols*. Facilities, at their option, may use health related protocols for the following operations, if needed to maintain freedom from certifiable diseases, or otherwise enhance the health of shellfish stocks.

> **3.3.1** Management of primary and expanded algal stocks

3.3.2 Spawning management of brood stock
3.3.4 Larval rearing management
3.3.5 Setting management
3.3.6 Water quality maintenance
3.3.7 Disinfection and sanitation procedures
3.3.8 Infectious disease vector control
3.3.9 Carcass disposal
3.3.10 Employee training
3.3.11 Visitor access

3.4 ***Hatchery records related to health management***. Records are maintained that document any control point or operation required to exclude infectious diseases from hatchery stocks.

4.0 Response Plan for Infectious Disease Outbreaks

The Shellfish High Health program is designed to exclude the introduction of certifiable infectious diseases to areas where shellfish for export are reared. Since infectious diseases can be introduced by natural means or other means outside of the control of a producer, the following response plan is in place in case of a significant infectious disease outbreak. This plan will be put in place if a certifiable disease is found or a new and significant infectious disease occurs with mortality not attributable to non-infectious causes exceeding a rate set by the pertinent regulatory authority. The response plan will consist of the following actions:

4.1 Confirmation of the infectious disease diagnosis.

4.2 Required notification of the responsible regulatory authorities of the disease outbreak.

4.3 Establishment of a disease containment area including containment and/or disinfection procedures to prevent the movement of infected shell stock, equipment and contaminated materials out of the disease affected area.

4.4 Disinfection of contaminated culture water from any affected hatchery or nursery facilities.

4.5 Adequate disposal of dead shell to prevent dissemination of infectious disease organisms with such stock.

4.6 Destruction of infected stocks, if required to contain the disease, or if required by the regulatory authority.

4.7 Determination of the source of the infectious disease agent, in collaboration with appropriate regulatory agencies, and implementation of a plan to eliminate any continuing source of the disease agent introduction, if needed.

4.8 Establishment of a monitoring and continuing response plan for the infectious disease and determination of needed continuing action, in conjunction with the appropriate regulatory agency.

Appendix F
Committee and Staff Biographies

COMMITTEE

Charles (Pete) Peterson *(Chair)* is an Alumni Distinguished Professor in the Institute of Marine Sciences at the University of North Carolina at Chapel Hill. Dr. Peterson earned a Ph.D. in biology from the University of California, Santa Barbara, in 1972. His research can be characterized as interdisciplinary marine conservation ecology. His specializations involve marine benthic ecology, including the importance and nature of predation and intra- and inter-specific competition in benthic communities and the role of resource limitation in suspension-feeding bivalve populations. He also conducts research in paleoecology, invertebrate fisheries management, estuarine habitat evaluation, and barrier island ecology. Dr. Peterson has served on numerous NRC committees.

Barry Costa-Pierce is the director of the Rhode Island Sea Grant College Program and a joint professor of fisheries, aquaculture and oceanography at the University of Rhode Island. Dr. Costa-Pierce earned a Ph.D. in oceanography from the University of Hawaii. His research focuses on capture-based aquaculture systems; on the environmental impacts and systems ecology of aquaculture ecosystems; and on the development of scientifically credible sustainability indices for mariculture projects worldwide. Dr. Costa-Pierce is on the Board of Directors of the World Aquaculture Society and is also one of the four international editors of *Aquaculture*.

Brett Dumbauld is an ecologist at the Agricultural Research Service of the U.S. Department of Agriculture. Dr. Dumbauld earned a Ph.D. in fisheries from the University of Washington. His research focuses on solving the problem shellfish growers have with burrowing shrimp and investigating the role of shellfish aquaculture in the estuarine environment. He is a member of the National Shellfisheries Association, the Coastal and Estuarine Research Federation, the Pacific Estuarine Research Society, and the Society for Conservation Biology.

Carolyn Friedman is an associate professor in the School of Aquatic and Fishery Sciences at the University of Washington. Dr. Friedman earned a Ph.D. in comparative pathology from the University of California, Davis. Her research focuses on the examination of infectious and non-infectious diseases of wild and cultured marine invertebrates and on the conservation of marine invertebrates, particularly abalone. More specifically, she investigates the mass mortality of the Pacific oyster (*Crassostrea gigas*) on the west coast of the United States and the herpes-like viral infection of Pacific oysters.

Eileen Hofmann is a professor of oceanography in the Center for Coastal Physical Oceanography at Old Dominion University. Dr. Hofmann earned a Ph.D. in marine science and engineering from North Carolina State University. Her research focuses on the analysis and modeling of biological and physical interactions in marine ecosystems and descriptive physical oceanography. She served on the Ocean Studies Board and on numerous NRC committees, including the Committee on Strategic Advice on the U.S. Climate Change Science Program.

Hauke Kite-Powell is a research specialist at the Marine Policy Center of the Woods Hole Oceanographic Institution. Dr. Kite-Powell earned his Ph.D. in ocean systems management from the Massachusetts Institute of Technology. His research focuses on public and private sector management issues for marine resources and the economic activities that depend on them. His current research projects include the policy issues surrounding use of ocean space for non-traditional activities, such as aquaculture and wind power; the potential of shellfish aquaculture to contribute to nutrient level management in coastal water bodies; the economics and management of marine aquaculture operations; and the environmental and ecological implications of long-term growth in marine aquaculture industries. Dr. Kite-Powell served on the NRC Committee on Assessment of Technical Issues in the Automated Nautical Chart System.

Donal Manahan is a professor of biological sciences at the University of Southern California. Dr. Manahan earned a Ph.D. in marine biology from the University of Wales, Bangor. His research focuses on animal environmental physiology; biological adaptations to temperature and food; marine biology of temperate, polar, tropical, and deep-sea species; Antarctic marine biology; hydrothermal vent biology; developmental biology; evolutionary biology; marine invertebrate life history; larval ecology; and aquaculture. Dr. Manahan has served on NRC committees and as the Chair of the Polar Research Board.

Francis O'Beirn is the benthos ecology team leader at the Marine Institute in Galway, Ireland. Dr. O'Beirn earned a Ph.D. in Zoology from the University of Georgia. His research interests focus on benthic ecology and monitoring, bivalve biology, as well as finfish and shellfish mariculture. He sits on a number of advisory committees responsible for licensing of marine activities in Ireland. He is currently the Chair of the International Council for Exploration of the Seas' (ICES) Working Group on Environmental Interactions of Mariculture and is the Irish delegate to the ICES mariculture committee. Dr. O'Beirn also has experience with shellfish mariculture and habitat restoration in the Chesapeake Bay area and the southeastern United States.

Robert Paine is a professor emeritus in the Department of Biology at the University of Washington. Dr. Paine earned a Ph.D. from the University of Michigan in 1961. His research focuses on experimental ecology of organisms on rocky shores, interrelationships between species in an ecosystem, and the organization and structure of marine communities. He has examined the roles of predation and disturbance in promoting coexistence and biodiversity. Dr. Paine is a member of the National Academy of Sciences and was a member of the Ocean Studies Board. He has served on numerous NRC committees, including the Committee on Ecosystem Effects of Fishing.

Paul Thompson has a Personal Chair in Zoology in the University of Aberdeen's School of Biological Sciences, and is Director of the Lighthouse Field Station, Cromarty, Scotland, which he set up in 1989. Dr. Thompson earned a Ph.D. in marine mammal ecology from the University of Aberdeen. He has been researching marine mammal behavior and ecology, including harbor and gray seals, for 20 years. His current research aims to assess how natural and anthropogenic environmental variations influence the behavior, physiology, and dynamics of marine mammal and seabird populations. Topics of particular interest have included interactions between wildlife populations and fisheries, the impact of disturbance and contaminants on marine mammal biology, seal foraging and breeding strategies, and the effects of changing prey stocks and climate change on the population dynamics of marine top predators. Dr. Thompson is a member of the International Union for the Conservation of Nature's Seal Specialist Group, the Scottish Association of Marine Sciences, among others.

Robert Whitlatch is a professor of Marine Sciences at the University of Connecticut. He earned a B.S. in Zoology, an M.S. in Marine Sciences, and a Ph.D. in Evolutionary Biology from the University of Utah, the University of the Pacific, and the University of Chicago, respectively. Dr. Whitlatch is a benthic ecologist interested in animal–sediment relationships, trophic dynamics of deposit-feeding invertebrates, life history analysis, shellfish ecology, the ecology of invasive species, and community ecology. He has worked extensively on both oyster reef biology and on the ecology of nonnative species in coastal New England. Dr. Whitlatch served on the NRC's Committee on Nonnative Oysters in the Chesapeake Bay.

STAFF

Susan Roberts became the director of the Ocean Studies Board in April 2004. Dr. Roberts received her Ph.D. in marine biology from the Scripps Institution of Oceanography. She worked as a postdoctoral researcher at the University of California, Berkeley and as a senior staff fellow at the National Institutes of Health. Dr. Roberts' past research experience has included fish muscle physiology and biochemistry, marine bacterial symbioses, and developmental cell biology. She has directed a number of studies for the Ocean Studies Board including *Nonnative Oysters in the Chesapeake Bay* (2004); *Decline of the Steller Sea Lion in Alaskan Waters: Untangling Food Webs and Fishing Nets* (2003); *Effects of Trawling & Dredging on Seafloor Habitat* (2002); *Marine Protected Areas: Tools for Sustaining Ocean Ecosystems* (2001); *Under the Weather: Climate, Ecosystems, and Infectious Disease* (2001); *Bridging Boundaries Through Regional Marine Research* (2000); and *From Monsoons to Microbes: Understanding the Ocean's Role in Human Health* (1999). Dr. Roberts specializes in the science and management of living marine resources.

Jodi Bostrom is an associate program officer with the Ocean Studies Board. She earned an M.S. in environmental science from American University in 2006 and a B.S. in zoology from the University of Wisconsin-Madison in 1998. Since starting with the Ocean Studies Board in May 1999, Ms. Bostrom has worked on several studies pertaining to coastal restoration, fisheries, marine mammals, nutrient over-enrichment, ocean exploration, capacity building, and marine debris.

Heather Chiarello is a senior program assistant with the Ocean Studies Board. She graduated Magna Cum Laude from Central Michigan University in 2007 with a B.S. in political science with a concentration in public administration. Ms. Chiarello joined the National Academies in July 2008.