Exhibit D.1.b
Attachment 1
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FISHERY EFFECTS OF EXISTING WEST COAST MARINE RESERVES: THE SCIENTIFIC EVIDENCE

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Although fully-protected marine reserves are being touted as effective fishery management tools worldwide, it is important to consider in detail whether existing reserves along the West Coast of the United States provide fishery benefits, or more specifically, would provide benefits if scaled-up. It is clear from the outset that existing West Coast reserves are much too small and too few to benefit fisheries in ways that are directly detectable statistically. Indeed, there are only about 7 reserves in Washington (all in Puget Sound, accounting for only ca. 0.003% of state waters), only 1 in Oregon (Whale Cove, ca. 0.003% of state waters), and 11 scattered along the California coast (ca. 0.2% of state waters). Only half of these reserves are truly fully-protected. However, it is nonetheless possible to examine indicators of whether a scaled-up network of reserves would provide fishery benefits.

The predicted fishery benefits of fully-protected reserves are twofold: (1) the "**seeding effect**," whereby reserves function as a source of eggs and larvae that replenish fish and shellfish populations outside reserves via dispersal in ocean currents, and (2) the "**spillover effect**," whereby reserves function as a source of juvenile and adult emigrants that literally swim or crawl out of reserves into adjacent fished areas. The **seeding effect** occurs only if the *number* and especially the *size* of organisms inside reserves is substantially greater than outside, so that abundant eggs and larvae produced inside reserves can effectively seed a large area outside. The **spillover effect** occurs if (a) the *number* of mobile animals inside reserves becomes great enough that crowding occurs and a substantial number of animals consequently emigrates to adjacent fished areas or (b) the life history of mobile animals is such that they gradually move from habitat to habitat as they grow, so that the early stages of the life history can be protected within reserves, and the animals later move into fished areas. Thus, comparisons inside vs. outside reserves can provide an indication of whether seeding and spillover effects are probable, and examination of *movement* patterns can further suggest whether spillover is likely.

There have been scientifically rigorous comparisons inside vs. outside about a dozen existing reserves in Washington, Oregon, and California that were studied at least 10 years after the reserves were established (**Table 1**). Excluded from this compilation are analyses of (1) the Edmunds Marine Park in Washington, because seafloor habitats inside and outside the reserve are not strictly comparable, and (2) the Big Creek Reserve in California, because protected status was implemented only in 1994. In all studies, SCUBA divers compared areas inside and outside reserves by visually censusing plots or transects. Compared indicators included seafloor habitats, fish (mostly rockfish) and invertebrate (sea urchin and abalone) number and size, and sometimes calculated egg production. Egg production is well-documented in increase dramatically with body size in these fish and invertebrates, so areas with high abundance and large sizes of animals clearly produce numerous eggs that may contribute to the seeding effect.

Table 2 summarizes 9 independent scientific studies that compared unfished marine reserves with nearby fished areas of similar seafloor habitat. A total of 22 comparisons involving 17 fished species (1 species of sea urchin, 2 species of abalone, and 14 species of fish) were conducted among the 13 reserves listed in Table 1. Considering cases where statistical differences were detectable, in 15 of 17 comparisons (88%), animals were more abundant inside reserves than outside. In 12 of 15 comparisons (80%), animals were larger inside reserves than outside. In 15 of 17 comparisons (88%), animals were inferred to produce more eggs inside reserves than outside. The exceptions may be cases of smaller species that are out-competed or eaten by more abundant or larger fish inside reserves, although there are presently no definitive data.

Table 3 summarizes movement patterns of representative West Coast groundfish determined from tag-and-recapture studies. The general life history pattern is that lingcod and rockfishes, among other species, live in shallow water as young, then slowly migrate to deeper water as they grow, eventually living within relatively limited home ranges as adults. Movement distances suggest that these fish could spillover from marine reserves of substantial size. Exceptions include exclusively shallow species that inhabit coastal rocky reefs for their entire juvenile and adult life.

Overall, for a wide variety of fished species along the U.S. West Coast, available data indicate that the existing few and small marine reserves are effective in supporting substantially more abundant, larger, and more fecund animals (i.e., more eggs) than comparable fished areas outside. Moreover, many groundfish move sufficiently during their lifetimes to allow for spillover to occur from reserves of substantial size. These results are consistent with the prediction that a scaled-up network of numerous larger reserves would produce detectable fishery benefits via both the spillover and seeding effects.

TABLE 1. Existing U.S. West Coast marine reserves that have been the subject of inside vs. outside scientific comparisons. Comparisons made at two other reserves are not included: (1) Edmunds Marine Park in Washington (0.04 nmi^2, established in 1970) because seafloor inside and outside are not directly comparable; and (2) Big Creek in California (1.11 nmi^2, established in 1994) because protection is only recent.

Reserve	Area (nmi^2)	Year	Protection
WASHINGTON:			(reference 2)
Shady Cove	0.49	1990	herring and salmon fishing allowed
Shaw Island	0.37	1990	herring and salmon fishing allowed
Yellow Island	0.07	1990	herring and salmon fishing allowed
OREGON:			(reference 8)
Whale Cove	0.04	1967	seaweed collection allowed
NO. CALIFORNIA:			(reference 7)
Pt. Cabrillo/Caspar	0.13	1975/90	only sea urchins protected
Salt Point	1.60	1990	only sea urchins protected
Bodega Marine Lab	0.18	1965	only invertebrates protected
Hopkins Marine Lab	0.09	1984	fully protected
Pont Lobos	0.80	1973	fully protected
SO. CALIFORNIA:			(reference 7)
E. Anacapa Island	0.04	1978	fully protected
Laguna Beach	0.04	1973	fully protected
Catalina Marine Lab	0.05	1988	fully protected
La Jolla	0.54	1971	fully protected

TABLE 2. Comparisons of number, size, and calculated egg production of fished species inside vs. outside existing U.S. West Coast marine reserves listed in Table 1. "Yes" means that values were statistically greater inside, "No" means that values were statistically greater outside, "ns" means no statistically detectable difference, and "?" means not reported. ("Yes") and ("No") are conclusions regarding egg production based on relative number and size of fish (i.e., egg production not calculated directly, but if number and size of adult fish are greater inside the reserve, than egg production must be greater). "Ref" refers to the reference number(s) cited.

Species	Number	Size	Eggs	Comments	(Ref)
WASHINGTON:				[all WA data from 3 reserves]	
lingcod	ns	Yes	Yes		(2,10,11)
black rockfish	Yes	Yes	(Yes)	seen only in reserve	(2)
copper rockfish	Yes	Yes	Yes		(2,10,11)
quillback rockfish	No	No	(No)	competition or predation?	(2)
yellowtail rockfish	Yes	Yes	(Yes)	seen only in reserve	(2)
OREGON:					
red sea urchin	Yes	Yes	Yes		(8)
NO. CALIFORNIA:					
red sea urchin	Yes	?	?	Caspar, Salt Pt., Bodega	(13)
red abalone	Yes	?	?	Caspar, Salt Pt., Bodega	(13)
lingcod	ns	Yes	(Yes)	[fish data from Pt. Lobos]	(18)
cabezon	ns	No	(No)	competition or predation?	(18)
black rockfish	ns	Yes	(Yes)		(18)
black-&-yellow rockfish	No	No	?	conflicting egg data	(9,18)
copper rockfish	Yes	Yes	(Yes)	seen only in reserve	(18)
gopher rockfish	Yes	Yes	(Yes)		(18)
kelp rockfish	ns	Yes	Yes		(9,18)
olive rockfish	Yes	Yes	(Yes)		(18)
vermilion rockfish	Yes	Yes	(Yes)		(18)
SO. CALIFORNIA:					
red sea urchin	Yes	?	?	Anacapa	(1)
pink abalone	Yes	?	?	Anacapa	(1)
barred sand bass	Yes	?	Yes	Laguna (sand bottom)	(17)
kelp bass	Yes	?	Yes	pooled So. Cal. reserves	(17)
California sheephead	Yes	?	Yes	pooled So. Cal. reserves	(17)
Total Yes (greater inside):	15	12	15		
Total No (greater outside):	2	3	2		

TABLE 3. Movement patterns of commonly fished West Coast groundfish. The general pattern is that lingcod and rockfish, among other species, live in shallow water as young, then slowly migrate to deeper water as they grow, eventually living within relatively limited home ranges as adults. These data suggest that these fish move sufficiently for the spillover effect to occur from marine reserves of substantial size. Exceptions include exclusively shallow species (e.g., black-and-yellow and gopher rockfish) that inhabit coastal rocky reefs for their entire juvenile and adult life (reference 4). "Ref" refers to the reference number(s) cited.

Species	Location	Movement Distance	Ref
JUVENILE FISH:			
bocaccio rockfish	California	move up to 80 nmi over 2 yr	(3)
brown rockfish	California	move up to 27 nmi as they migrate from San Francisco Bay to the outer coast	(5)
yellowtail rockfish	Washington	move up to 195 nmi as they migrate from Puget Sound to the outer coast	(6)
ADULT FISH:			
lingcod	Alaska	mean movement of 7.2 nmi	(15)
lingcod	British Columbia	95% of males move up to 9 nmi/yr 95% of females move up to 18 nmi/yr	(14)
bocaccio rockfish	California	10 of 16 adults spent less than 10% of 4 mo within 3.5 nmi^2 area, one for 50% of the time, and 5 for the entire time	(16)
yellowtail rockfish	Oregon	adults move up to 0.7 nmi/mo	(12)

Literature Cited

(1) Davis, G. Unpublished data. U.S. National Park Service, Ventura, California.

(2) Eisenhardt, E. 2001. Master's thesis. School of Fisheries, University of Washington, Seattle, Washington.

(3) Hartman, A. R. 1987. Movement of scorpionfishes (Scorpaenidae: *Sebastes* and *Scorpaena*) in the southern California Bight. California Fish and Game 73:68-79.

(4) Larson, R. J. 1980. Territorial behavior of the black and yellow rockfish and gopher rockfish (Scorpaenidae, *Sebastes*). Marine Biology 58:111-122.

(5) Love, M. S., M. H. Carr, and L. J. Haldorson. 1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Environmental Biology of Fishes 30:225-243.

(6) Mathews, S. B., and M. W. Barker. 1983. Movements of rockfish (*Sebastes*) tagged in northern Puget Sound, Washington, U.S. Fishery Bulletin 82:916-922.

(7) McArdle, D. A. 1997. California marine protected areas. California Sea Grant Extension Program, La Jolla, California.

(8) Montaño, G. 2001. Master's thesis. Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.

(9) Paddack, M. J., and J. A. Estes. 2000. Kelp forest fish populations in marine reserves and adjacent exploited areas of central California. Ecological Applications 10:855-870.

(10) Palsson, W. A., and R. E. Pacunski. 1995. The response of rocky reef fishes to harvest refugia in Puget Sound. Puget Sound Research '95 Proceedings 1:224-234.

(11) Palsson, W. A. 1998. Monitoring the response of rockfishes to protected areas. NOAA Technical Memorandum NMFS SWFSC 255:64-73.

(12) Pearcy, W. G. 1992. Movements of acoustically-tagged yellowtail rockfish *Sebastes flavidus* on Heceta Bank, Oregon. Fishery Bulletin 90:726-735.

(13) Rogers-Bennett, L., and J. S. Pearse. 2001. Indirect benefits of marine protected areas for juvenile abalone. Conservation Biology 15:642-647.

(14) Smith, B. D., G. A. McFarlane, and A. J. Cass. 1990. Movements and mortality of tagged male and female lingcod in the Strait of Georgia, British Columbia. Transactions of the American Fisheries Society 119:813-824.

(15) Starr, R. M. Manuscript. Lingcod movements in Edgecumbe Reserve, Alaska.

(16) Starr, R. M., J. N. Heine, J. M. Felton, and G. M. Cailliet. 2002. Movements of bocaccio (*Sebastes paucispinis*) and greenspotted (*Sebastes chlorostictus*) rockfishes in Monterey submarine canyon: implications for the design of marine reserves. Fishery Bulletin 100:324-337.

(17) Tetreault, I. 2002. Doctoral dissertation. Department of Biology, U.C.L.A., Los Angeles, California.

(18) VenTresca, D. A., M. L. Gingras, M. Donnellan, J. Fisher, B. Brady, H. King, C. King, and D. Osorio. Manuscript. Density and length estimates of some kelp forest fishes within and adjacent to central California marine protected areas.