Information Concerning the Pink Shrimp Trawl Fishery off Northern California

Report to the
California Fish and Game Commission

California Department of Fish and Game
Marine Region
State Fisheries Evaluation Project
(12/24/2007)

State Fisheries Evaluation Project*

Adam Frimodig
Michelle Horeczko
Tom Mason
Brian Owens
Michael Prall
Stephen Wertz
* Terry Tillman provided economic summaries for this report

TABLE OF CONTENTS

INTRODUCTION

In 2004, the Legislature approved Senate Bill 1459, adding Fish and Game Code (FGC) §8841 to statute, granting the Fish and Game Commission (Commission) management authority over California's commercial bottom trawl fisheries and amending FGC §8842, which pertains specifically to management of the pink shrimp trawl fishery. The Bill establishes that state waters previously open to pink shrimp trawling will be closed commencing January 1, 2008. These fishing grounds are specifically defined as the area in state waters not less than two nautical miles (nm) from the mainland shore between False Cape (Humboldt County) and Point Reyes (Marin County), and are referred to as the pink shrimp trawl grounds (PSTG) in this report. The Commission may choose to reverse the pending January 1, 2008 closure and open the above indicated area if performance criteria listed in FGC §8842 for the fishery are deemed to have been met. The performance criteria are that the use of trawl gear: 1) minimizes bycatch; 2) will not damage seafloor habitat; 3) will not adversely affect ecosystem health; and 4) will not impede reasonable restoration of kelp, coral, or other biogenic habitats.

The purpose of this report is to provide the Commission with the best available information about the pink shrimp bottom trawl fishery operating within the PSTG. Information was obtained from monitoring data (logbook, market receipt, and dock-side market sample data) and relevant scientific literature and informational documents published by academic, government agency, and non-government organizations.

Pacific ocean shrimp (*Pandalus jordani*), commonly referred to as pink shrimp, is a commercially important species in California. They are sold as salad shrimp, or cocktail shrimp, after being machine peeled, cooked, and frozen (CDFG *in prep.*). Pink shrimp range from Unalaska in the Aleutian Islands to San Diego, California, but they are most abundant off the Oregon coast (Dahlstrom 1970, Hannah and Jones 2007). From 1981 through 2006, 18 percent of the total United States catch of pink shrimp was landed in California ports, while 57 percent was landed in Oregon ports and 25 percent was landed in Washington ports (PacFIN 2007). Off the coast of California, they are most abundant over green mud or muddy-sand bottoms referred to as pink shrimp "beds" in depths between 300 and 650 ft (Bergstrom 2000, PFMC 2002).

The pink shrimp trawl fishery began in California in 1952 off Morro Bay after commercial quantities were found in the early 1950s by California Department of Fish and Game (Department) research vessels (PFMC 1981). The pink shrimp fishery developed into a relatively productive fishery by the mid 1950s, primarily off the north coast, and expanded to include areas off Bodega Bay, Fort Bragg, as well as Oregon and Washington. In recent years, the California fishery has been mostly concentrated in federal waters off the north and north-central coast. Roughly 3 percent of the historic pink shrimp fishing grounds off California lie within the PSTG (Figure 1).

The PSTG encompass an area of 307 square miles (Figure 2), although only three beds, comprising 17 percent of these grounds have been fished from 1960 to the present (Figure 2). Two of these beds are located to the north of Fort Bragg and the third is adjacent to Bodega Harbor (Figure 2). In combination, these three beds span approximately 52 square miles of ocean bottom in state waters.

Figure 1. Historical pink shrimp bottom trawl effort (green) throughout California from 1960 to 2006, including the effort within the pink shrimp trawl grounds (tan), which run two nautical miles offshore from False Cape to Point Reyes. Data source: CDFG historical Annual Ocean Shrimp Reports (i.e. Administrative Reports) and pink shrimp logbooks.

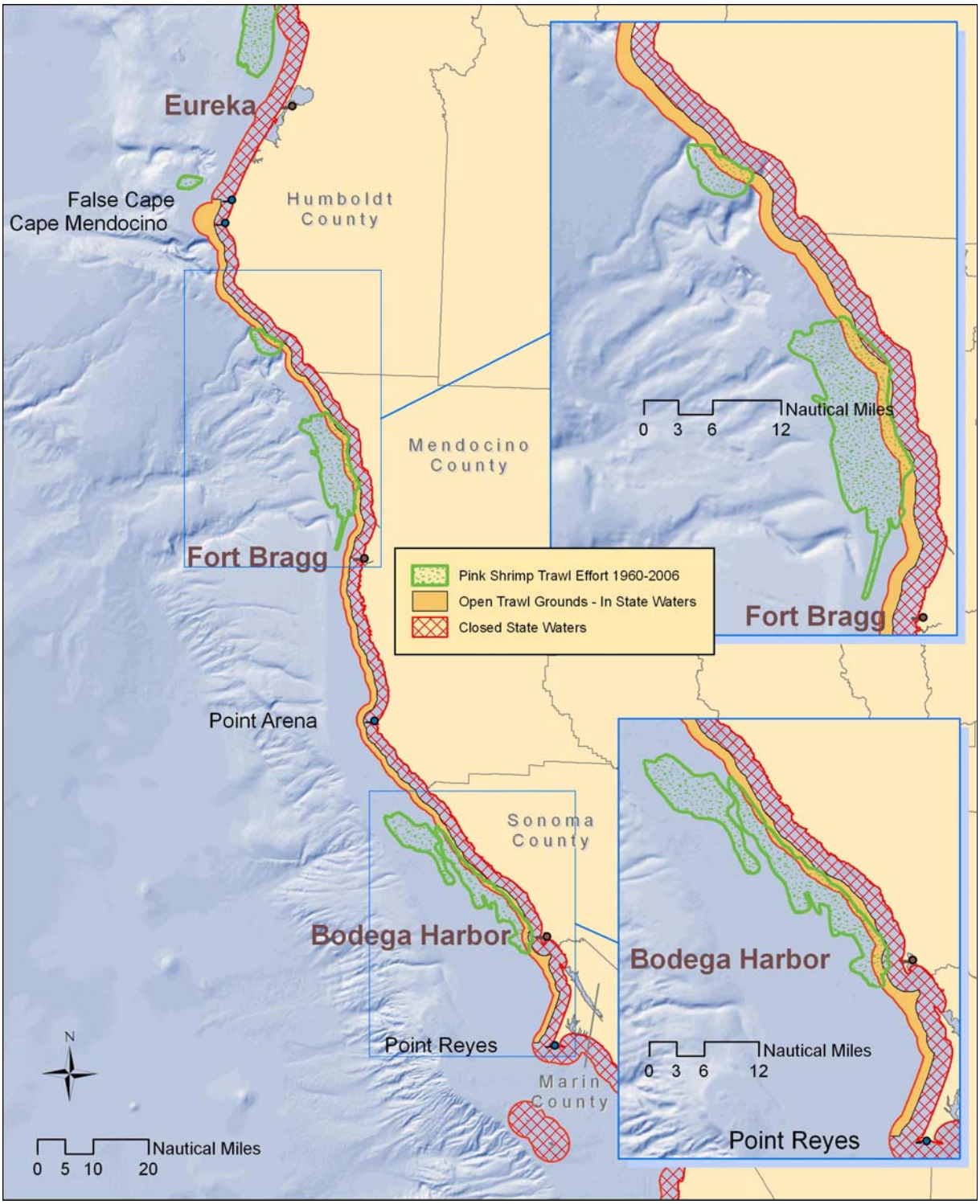

Figure 2. Historical pink shrimp trawl effort from 1960 to 2006 showing the main shrimp beds off the coast of northern California. Inset maps show the trawl effort from 1960 to 2006 in the three beds within the pink shrimp trawl grounds. Data source: CDFG historical Annual Ocean Shrimp Reports (i.e. Administrative Reports) and pink shrimp logbooks.

Pink Shrimp Regulations

Historically, the California pink shrimp trawl fishery was managed by three regulatory areas from 1952 until 2000 (CDFG *in prep.*). In 2001, the regulatory areas were eliminated and the fishery was divided into northern and southern management regions, requiring a separate permit to fish in each region (California Code of Regulations (CCR) Title 14 §120). The northern region extends from the California-Oregon border to Point Conception and it is a limited entry fishery. The southern region extends from Point Conception to the California-Mexico border and it is an open access fishery. A statewide requirement for bycatch reduction devices (BRDs) was implemented in 2002 to minimize bycatch of groundfish, especially depleted species such as canary rockfish. Three types of BRDs satisfy the requirement for this device in the California fishery: 1) the rigid-grate (similar in design to the Nordmøre grate); 2) soft-panel; and 3) fisheye excluder. Other current state regulations in effect presently include:

- Closed season from November 1 through March 31 to protect egg-bearing females
- Maximum count-per-pound of 160 to prevent overfishing juvenile shrimp
- Minimum mesh size of 1 3/8 inches to allow escapement of juvenile shrimp
- State and federal incidental catch limits to minimize mortality of non-target species

The pink shrimp fishery off the west coast of the United States is principally state-managed, although some federal regulations apply, such as daily and monthly trip limits for incidental catches of federally managed groundfish species, a vessel monitoring system beginning with the 2008 season, and area restrictions protecting groundfish Essential Fish Habitat (EFH) (Code of Federal Regulations Title 50; Figure 3).

In 2003, the federal groundfish fishing capacity reduction program, or vessel buyback program, implemented by the National Marine Fisheries Service (NMFS) had a significant effect on the amount of effort in the pink shrimp fishery coastwide. A total of 85 pink shrimp permits were relinquished from California, Oregon and Washington, 31 of which were linked to California vessels (Federal Register: Vol. 68, No. 213).

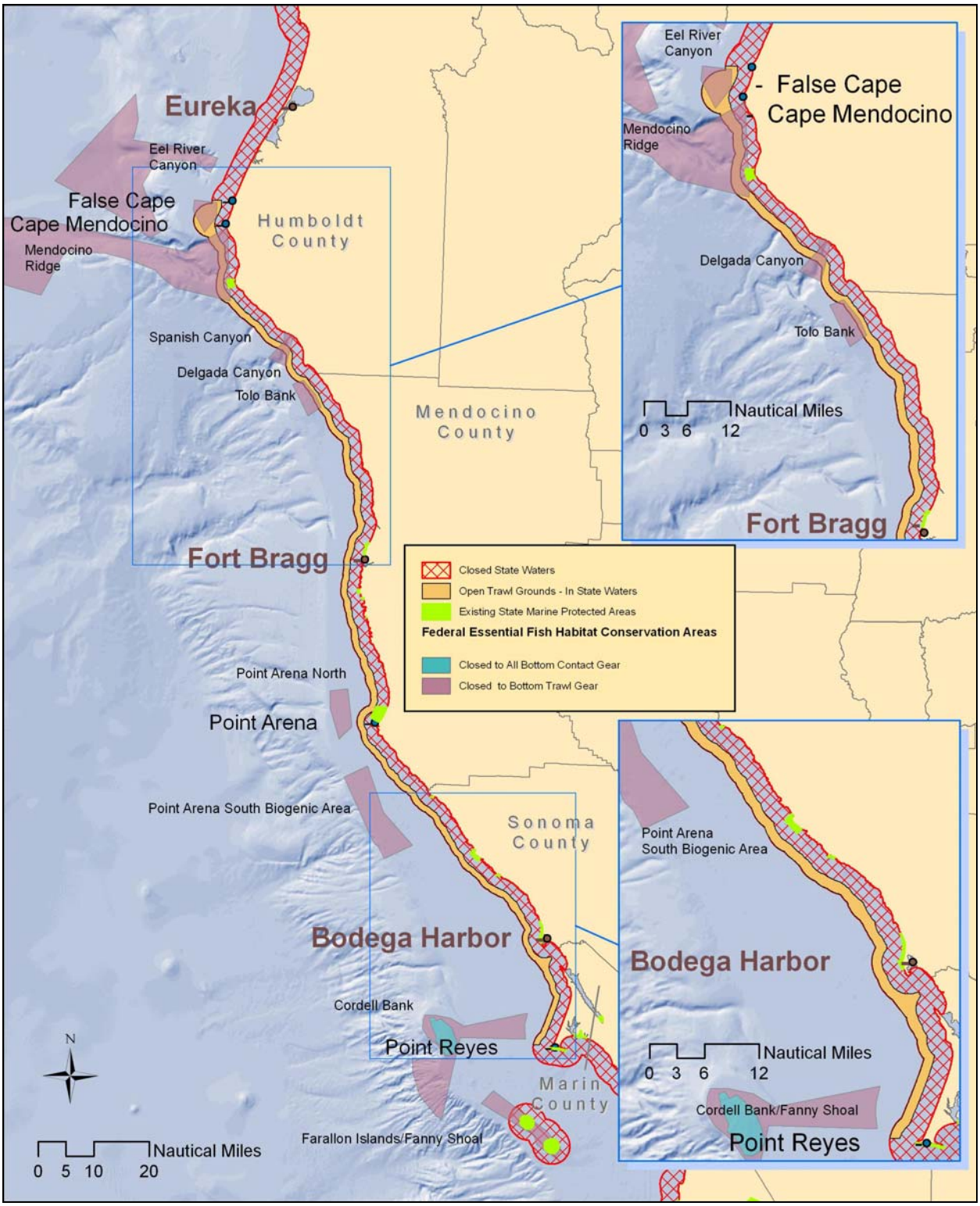

Figure 3. State marine protected areas, and federal essential fish habitat conservation areas closed to trawling near and inside the pink shrimp trawl grounds. Data source: Federal Register (Vol. 71, No. 123) and CDFG (2007).

Gear Description

Vessel registration information from 2001 to 2006 for the northern California pink shrimp fleet shows the average vessel length was 59 ft. In recent years, nearly all of pink shrimp fishermen off the coasts of Oregon, Washington, and the northern California region used a double-rigged vessel (Jones et al. 1996, Hannah and Jones 2003, Roberts 2005, CFIS 2007). A double-rigged vessel has two otter trawl nets, one on each side of the vessel (Figure 4). Following each tow, the nets are hauled out of the water with a boom, and the catch is dumped into sorting bins on the deck.

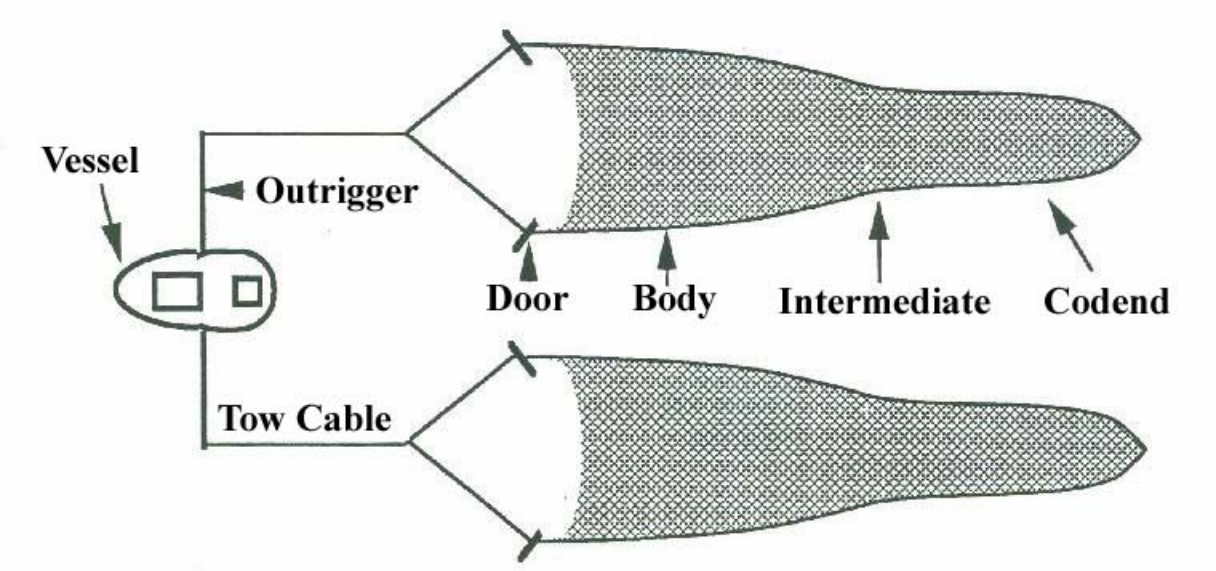

Figure 4. Diagram of a double-rigged pink shrimp vessel with gear in tow, pulling two otter trawl nets each with two otter boards. Credit: Jones et al. (1996).

The typical net configuration is a standard 4-seam design that has the ability to rise higher in the water column compared to the 2-seam configuration on the traditional Gulf of Mexico semiballoon trawl. The footrope configuration is semi-pelagic, elevating the net approximately one to three ft above the seafloor while the two pairs of trawl doors and the center of the nets are in contact with the seafloor (Robert W. Hannah, Oregon Department of Fish and Wildlife [ODFW], personal communication). During the 1990s, the pink shrimp fleet in Oregon switched from the traditional "tickler chain" style of footrope to a roller/ladder style of footrope (Hannah and Jones 2000) and the average footrope length was 25 ft (Jones et al. 1996). Vessels operating in the northern region of the California fishery tend to use this same gear configuration (Robert W. Hannah, ODFW, personal communication). This finding was confirmed by an informal phone survey conducted in 2007 by the Department with active pink shrimp fishermen in California, although a nominal number of vessels in the northern region were single-rigged (one otter trawl net) (Figure 5). Rigid-grate BRDs are well suited for the northern California fishery because the double-rigged otter trawl nets are not wrapped on a reel but piled on the vessel deck after the load has been released. Vessels operating in the southern region are primarily single-rigged (CFIS 2007), and operators have reported that soft-panel BRDs are preferred because rigid-grate BRDs get crushed when the codend is wrapped on the net reel.

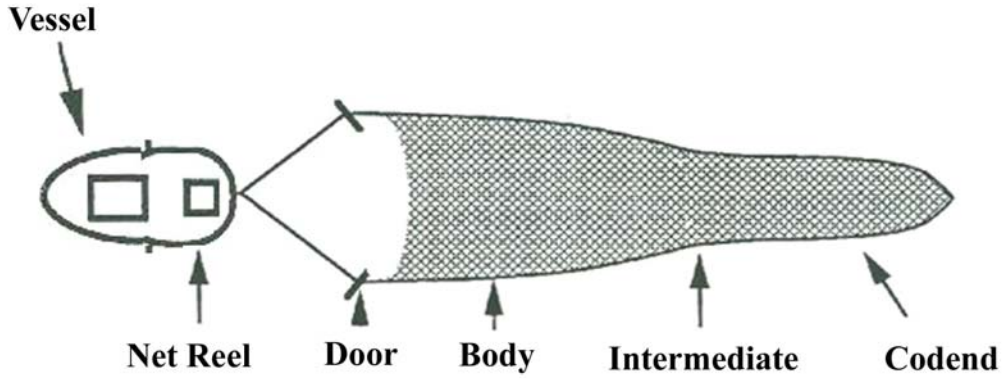

Figure 5. Diagram of a single-rigged pink shrimp vessel with gear in tow, pulling one otter trawl net with a pair of otter boards. Credit: modified from Jones et al. (1996).

Fishery Performance

The California pink shrimp fishery was consistently more productive in the late 1980s and early 1990s compared to any other period in the 55 years of the fishery (CDFG *in prep.*). Since the mid 1990s, annual pink shrimp landings ranged from a high of 14 million pounds in 1997 to a record low of 140,000 pounds in 2006 (Figure 6). The number of active vessels in the northern region has steadily decreased each year from 2002 through 2006 (Table 1), and annual landings statewide have been well below average since 2003 (Table 2). Similarly, annual landings in Oregon have also been below average since 2003 (ODFW 2006, 2007). A combination of factors may explain the decline in landings in recent years, such as a weak market attributed to competition from other warm and cold water shrimp fisheries, competition from aquaculture production of warm water species worldwide, the federal groundfish vessel buyback program in 2003, and environmental conditions negatively affecting recruitment (Roberts 2005, MSC 2007, NMFS 2007, CDFG *in prep.*).

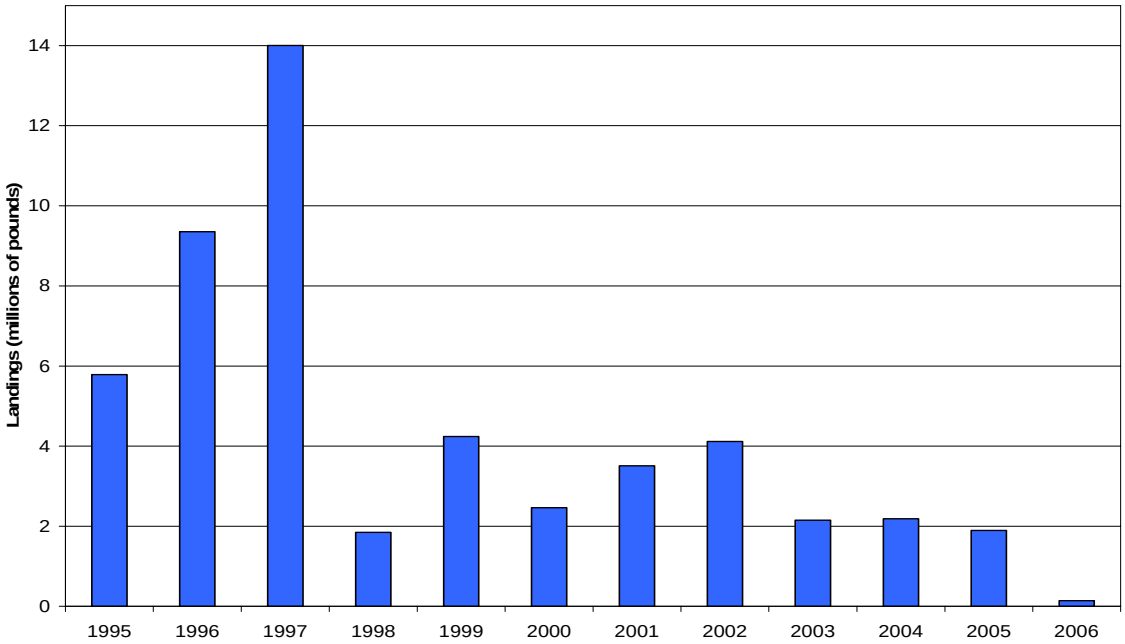

Figure 6. Annual commercial landings (pounds) of pink shrimp in California from 1995 to 2006. Data source: CFIS (2007).

At the height of annual ex-vessel revenue generated from the pink shrimp fishery in 1996, pink shrimp landings were valued at over $7 million (adjusted to 2006 dollars to account for inflation), with over 70 percent of the revenue going to Del Norte County (Table 3). More recently, pink shrimp landings in 2006 occurred only in Humboldt and San Luis Obispo Counties, generating a combined ex-vessel revenue of $66,000 (Table 3). This was due to the low landings statewide in 2006 compared to 1996; 140,000 pounds versus 8,954,000 pounds, respectively (Table 2). The 12 year trend shows a dramatic decline in landings revenue for counties and local economies. Nearly all of the pink shrimp revenue over the last 12 years occurred at ports in Del Norte (56 percent), Humboldt (24 percent), San Luis Obispo (14 percent), and Mendocino (4 percent) Counties (Table 3). Other counties with ports that contributed nominally to the total pink shrimp revenue include Los Angeles, Monterey, San Francisco, San Mateo, Santa Barbara, Santa Cruz, Sonoma, and Ventura.

Table 1. Number of permits sold and active permits for the southern and northern management regions of the California pink shrimp fishery. Data source: Number of permits sold data was obtained through the Department's License and Revenue Branch website (Licensing Statistics).

Year	Southern region[1]		Northern region[2]	
	Permits sold	Active vessels	Permits sold	Active vessels
2001	56	6	78	32
2002	57	7[†]	80	26[†]
2003	46	4	78	9
2004	38	0	47	7
2005	35	1[†]	43	12[†]
2006	21	1[†]	40	4[†]

[1] Refers to waters south of Point Conception.
[2] Refers to waters north of Point Conception.
[†] In 2002, 2005, and 2006, one vessel landed pink shrimp in both southern and northern waters.

Table 2. Annual pink shrimp landings (pounds) in the eight major port areas of California from north to south, 1995 to 2006. Data source: CFIS (2007).

Year	Eureka	Fort Bragg	Bodega Bay	San Francisco	Monterey	Morro Bay	Santa Barbara	Los Angeles	Total
1995	4,303,117	235,719	0	0	0	1,178,501	67,607	0	5,784,944
1996	7,851,280	760,168	7,699	95	10	704,819	27,015	0	9,351,086
1997	12,371,073	971,112	36,471	6,422	40	605,199	11,323	0	14,001,640
1998	1,393,292	36,439	9,748	10	37,782	364,577	1,408	0	1,843,256
1999	3,581,747	318,623	56,062	96	1,016	278,024	6,176	0	4,241,744
2000	2,083,382	3,638	0	0	65,788	303,273	3,013	0	2,459,095
2001	3,260,208	0	0	0	0	247,412	1,706	0	3,509,326
2002	3,296,103	17,228	57,386	0	0	743,999	1,497	0	4,116,213
2003	1,233,759	0	0	0	0	913,116	47	276	2,147,198
2004	1,605,874	0	0	0	0	581,646	0	0	2,187,520
2005	1,510,817	0	0	0	0	383,096	0	0	1,893,913
2006	74,947	0	0	0	0	64,954	0	0	139,901
Average	3,547,133	195,244	13,947	552	8,720	530,718	9,983	23	4,306,320

Table 3. Ex-vessel revenue (real value of landings adjusted for inflation to 2006 prices) of all pink shrimp landings reported from 1995 though 2006, by region and county.

Northern California	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Del Norte	$3,101,125	$5,111,922	$4,353,829	$737,537	$1,512,046	$751,029	$570,224	$379,561	$48,932	$65,361	$168,406	
Humboldt	$1,144,536	$963,766	$1,567,026	$129,357	$556,533	$162,437	$441,762	$688,041	$340,240	$644,830	$556,689	$27,323
Mendocino	$220,953	$534,638	$368,940	$31,274	$152,840	$1,684		$6,041				
Monterey				$31,496	$3,779	$47,583						
San Francisco		$51			$33							
San Luis Obispo	$1,071,311	$570,041	$361,093	$322,147	$244,257	$226,229	$99,851	$346,040	$334,077	$286,358	$236,184	$38,972
San Mateo			$2,948									
Santa Cruz			$10									
Sonoma		$6,190	$20,671	$8,853	$35,018			$21,305				
Subtotals	$5,537,924	$7,186,609	$6,674,518	$1,260,665	$2,504,505	$1,188,962	$1,111,837	$1,440,987	$723,250	$996,549	$961,279	$66,296
Southern California	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Los Angeles									$1,373			
Santa Barbara	$34	$228	$14,073	$2,440	$5,661	$5,400	$2,261	$1,017				
Ventura	$71,225	$8,376	$75		$341	$49		$181				
Subtotals	$71,259	$8,604	$14,148	$2,440	$6,002	$5,449	$2,261	$1,198	$1,373	$0	$0	$0
Totals	$5,609,183	$7,195,213	$6,688,665	$1,263,105	$2,510,507	$1,194,411	$1,114,098	$1,442,185	$724,623	$996,549	$961,279	$66,296

All values presented are in year 2006 dollars.

From 2001 through 2006, over 99 percent of the annual landings occurred in ports located in the northern region (Table 2). During this period, the average number of active vessels in the northern region was 16 compared to only three in the southern region (Table 1). There is a significant amount of latent effort in recent years for both regions because of the number of inactive permits in the fleet. An average of 61 permits were sold in the northern region from 2001 through 2006, of which 25 percent (15 permits) were active (Table 1). In 2006, a record low of only four of the 40 permitted vessels in the northern region actively participated in the fishery (Table 1). The percentage of active permits is considerably less in the southern region. From 2001 through 2006, an average of 42 permits were sold, but only 7 percent (three permits) were active (Table 1).

Historically, the majority of pink shrimp fishing off the west coast of the United States occurred in federal waters. However in some years, as much as 10 percent of the landings were taken from within state waters (PFMC 1981). From 2001 through 2006, the percentage of annual landings statewide taken within state waters ranged from a high of 21 percent in 2005 to a low of 3 percent in 2006. No individual vessel in the current fleet has relied on the PSTG for more than 45 percent of their recent annual catch. The ex-vessel revenue generated from state waters from 2001 through 2006 ranged from a high of $200,000 in 2005 to a low of $2,000 in 2006 (Figure 7).

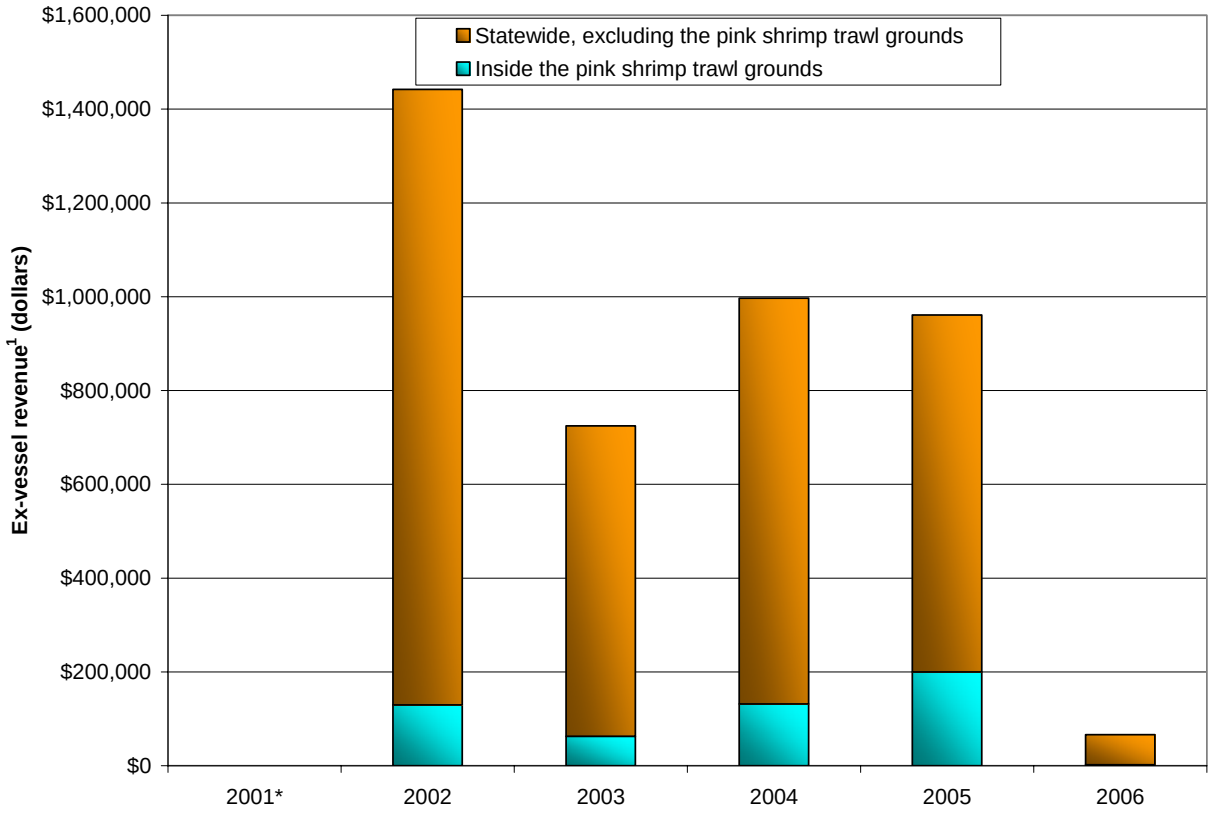

Figure 7. Ex-vessel revenue[1] from waters within the pink shrimp trawl grounds and federal waters adjacent to state waters from 2001 through 2006. Data source: CFIS (2007) and CDFG pink shrimp logbooks.

[1] Ex-vessel revenue adjusted for inflation to 2006 prices.
* Logbook data for 2001 is not available for northern California.

FISHERY PERFORMANCE CRITERIA

In accordance with FGC §8842, information about the pink shrimp bottom trawl fishery operating within the PSTG was obtained from monitoring data (logbook, market receipt, and dock-side market sample data) and relevant scientific literature and informational documents published by academic, government agency, and non-government organizations. Based on these sources and the criteria delineated in FGC §8842, the Department reports the following:

Bycatch

Direct bycatch studies in the PSTG have not been done. According to FGC §8842, the NMFS West Coast Groundfish Observer Program (WCGOP) is specified as a potential source of information concerning the future of trawling in the PSTG, but the raw data from NMFS for the pink shrimp fishery in California was not available to the Department for analysis. However, Hannah and Jones (2007) used bycatch data, such as WCGOP data and other sources[1] to: 1) determine the magnitude of bycatch reduction, and 2) summarize the fish bycatch species composition before and after BRDs in the Oregon pink shrimp trawl fishery. They found that pre-BRD bycatch percentages in the fishery ranged from 32 percent to 61 percent of total catch weight, and post-BRD bycatch percentages decreased to an average of eight percent (when either rigid-grate or soft-panel BRDs were used). These results may be a reasonable substitute for the northern California fishery because both fisheries use similar gear and the fishing occurs over a similar depth range and habitat type.

The amount and composition of bycatch has long been a concern in shrimp trawl fisheries around the world (Alverson et al. 1994). Nearly 85 percent of the total estimated bycatch from shrimp fisheries worldwide is discarded (Alverson et al. 1994). However, discard rates in the pink shrimp fishery off the west coast of the United States are nominal compared to other shrimp fisheries in the world (Table 4).

Bycatch in the pink shrimp fishery off the west coast of the United States is either: 1) discarded because it is an unwanted or unmarketable species, or because regulations prohibit retention; or 2) retained and sold because it is a non-targeted species with commercial value. The majority of bycatch in the pink shrimp fishery is composed of groundfish species (PFMC 2002). The amount of marketable incidental groundfish in California was reduced from 11.5 short tons (t) in 1998 to less than 0.3 t in 2002, and no marketable incidental groundfish was landed in subsequent years (CFIS 2007). Similarly, the catch of marketable incidental groundfish has also been eliminated in Oregon and Washington in recent years (Hannah and Jones 2007, WDFW 2007). This drop in marketable bycatch coincides with the requirement for BRDs starting in 2002 in California, and in 2003 in Oregon and Washington, thus removing the economic incentives to use less efficient BRDs (Hannah and Jones 2007).

[1] Data sources used in Hannah and Jones (2007) include WCGOP data from 2002 to 2005, gear comparison studies conducted by ODFW from 1981 to 2000, and a discard study conducted by E. Pikitch, University of Miami, from 1986 to 1987.

Table 4. Top weight-based discard to landed target catch ratios by geographic region. Data source: Alverson et al. (1994) and *Hannah and Jones (2007).

Shrimp trawl fishery	Pound discard per pound landed
Trinidad	32.4
Indonesia	26.5
Australia	24.5
Sri Lanka	24.3
U.S., Gulf of Mexico	22.7
Mexican	21.4
India, west coast	18.7
U.S., southeast coast	17.6
Persian Gulf	9.3
Brazil	9.0
India, east coast	8.4
Malaysia	6.6
Senegal	6.0
North Sea	3.2
Newfoundland	3.0
U.S., Oregon coast*	0.1

Hannah and Jones (2007) evaluated the effectiveness of different types and various bar spacing intervals of BRDs. They found that the use of rigid-grate BRDs resulted in a 66 to 88 percent reduction in total fish bycatch compared to pre-BRD levels. Rigid-grate BRDs are generally considered to be the most effective of the three BRD types (Hannah et al. 2003, ODFW 2006, Hannah and Jones 2007). Rigid-grate BRDs with bar spacing from 1 1/4 inches to 1 1/2 inches have been most commonly used in Oregon and California in recent years (Figure 8), although recent experimentation suggests that 3/4 inch bar spacing or less may further reduce bycatch rates with minimal shrimp loss (Hannah and Jones 2007, Robert W. Hannah, ODFW, personal communication).

There have been no significant interactions identified between the pink shrimp fishery and threatened or endangered marine species of birds, mammals, or fish (Roberts 2005, MSC 2007). The pink shrimp fishery is classified as a Marine Mammal Protection Act category III fishery with no observed or documented take of marine mammals (Federal Register: Vol. 72, No. 124). Other biologically sensitive species in waters near the PSTG include canary rockfish, bocaccio, widow rockfish, and yelloweye rockfish (NMFS 2005, MSC 2007). The bycatch of these rockfish species has been minimized due to BRDs (Hannah et al. 1996, ODFW 2006, Hannah and Jones 2007, MSC 2007).

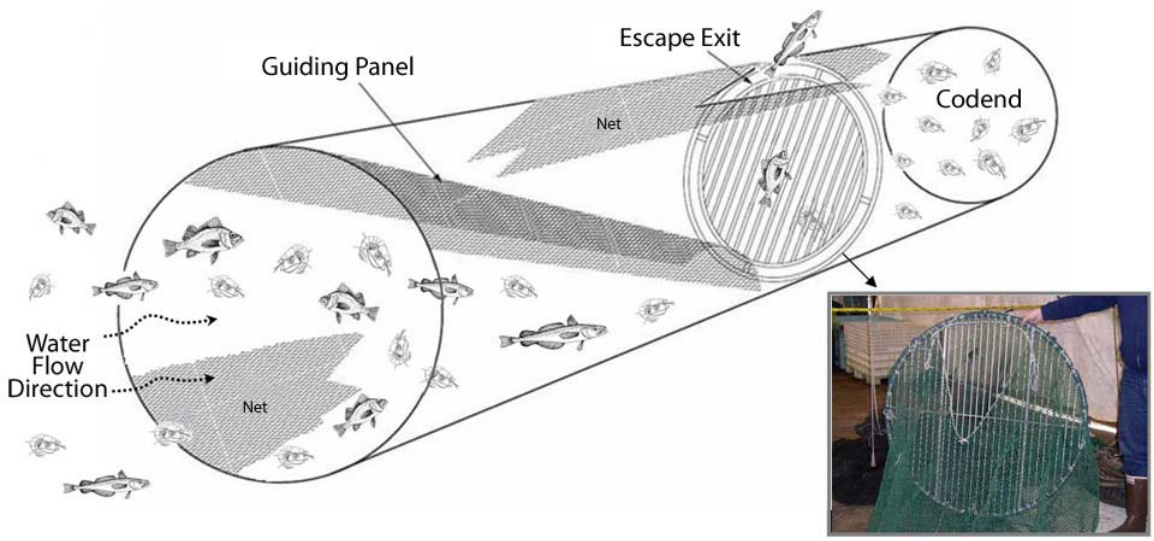

Figure 8. Diagram of a typical rigid-grate BRD used in the pink shrimp trawl fishery. The diagram depicts shrimp traveling through the BRD, and larger fish species deflected by the BRD and guided through the escape exit opening. The inset picture is an actual rigid-grate BRD with 1 1/2 inch bar spacing. Credit: Diagram and inset picture modified from Robert W. Hannah, ODFW.

Largely attributed to the use of BRDs, the pink shrimp fishery in Oregon was recently certified in accordance with the Marine Stewardship Council (MSC) Principles and Criteria for Sustainable Fishing, which is the world's first sustainable shrimp certification under the MSC certification program. MSC (2007) states:

> "The ocean [pink] shrimp fishery of the Pacific coast is one the cleanest shrimp fisheries in the world due to the implementation of mandatory fish excluder devices or bycatch reduction devices in Washington, Oregon, and California."

Both the Monterey Bay Aquarium (Roberts 2005) and Blue Ocean Institute (Blue Ocean Institute 2005) have recently indicated that pink shrimp harvested off coastal waters of California, Oregon, and Washington is a good choice for environmentally conscious consumers.

Seafloor Habitat

The effects of trawling on seafloor habitat can vary, depending on the size and type of trawl gear, level of fishing effort, and the type of habitat. The extent of these effects and rate of recovery also depend on habitat stability. Relatively stable habitats, such as hard bottom and dense mud, experience the greatest changes and have the slowest recovery rates compared to less consolidated coarse sediments in areas of high natural disturbance (NRC 2002).

Few studies on impacts of bottom trawl gear off the west coast of the United States have been undertaken, and currently no studies have been completed on the impacts of pink shrimp trawl gear to the seafloor habitat in the PSTG. Two studies on the effects of trawling on soft substrates have been completed in waters off the west coast of the United States; one off Point Sur, California (Engel and Kvitek 1998) and the other near Cape Blanco Oregon (Hixon and Tissot 2007). Both studies used observations from the two person Delta submersible to characterize and compare effects in trawled and untrawled areas. Hixon and Tissot (2007) studied areas of mud

bottom adjacent to Coquile Bank, which is fished by the Oregon pink shrimp and groundfish fleets. They found extensive trawl door tracks in the trawled area and lower densities of fish and macroinvertebrates. Species diversity was lower for fish in trawled areas, but higher for invertebrates. Engel and Kvitek (1998) studied two areas of sand mud habitat; one heavily trawled by the groundfish fleet primarily targeting flatfish species and one the other located inside of state waters where trawling effort was minimal. They used video from the Delta submersible, sediment grab samples, and experimental trawling to compare differences in habitat structure and the densities of invertebrates. Results from this study show higher invertebrate densities in the minimally trawled area, but some species of polychaete worms and brittle stars were found in higher numbers in the heavily trawled area. Habitat complexity was found to be lower in the heavily trawled area. Both of these studies concluded that trawling alters the soft bottom habitat resulting in physical and biological changes.

General gear impacts on estuarine, shelf, and slope habitats have been described and analyzed for the Pacific Fishery Management Council (PFMC) and NMFS in part by the Environmental Impact Statement (EIS) for designating Essential Fish Habitat for the Pacific coast groundfish fishery (NMFS 2005). The study consisted of a Geographic Information System-based analysis of habitat types, review of gear types on the west coast of the United States, and literature reviews on the impacts of fishing gear on bottom habitats. This information was used to categorize and rate impacts by gear type, habitat, substrate, and depth range. The EIS indicated that the habitat impacts by bottom trawl gear in areas where pink shrimp trawling occurs is rated between 0.5 and 1, which is the lowest sensitivity classification for impacts to seafloor habitat by bottom trawl gears. Additionally, the semi-pelagic trawl gear used in the northern California pink shrimp fishery is likely to have less impact on bottom habitats than other trawl gear, and is considered less damaging than gear used in other cold water shrimp fisheries (Roberts 2005). The rating scale is as follows:

Sensitivity level	Sensitivity description
0	No detectable adverse impacts on seabed; i.e. no significant differences between impact and control areas in any metrics
1	Minor impacts such as shallow furrows on bottom; small differences between impact and control sites, <25 percent in most measured metrics.
2	Substantial changes such as deep furrows on bottom; differences between impact and control sites 25 to 50 percent in most metrics measured.
3	Major changes in bottom structure such as re-arranged boulders; large losses of many organisms with differences between impact and control sites >50 percent in most measured metrics.

Data source: NMFS (2005).

Although soft bottom seafloor habitats on the continental shelf where pink shrimp fishing occurs are considered to have a low sensitivity to trawl gear, their recovery times from gear impacts may be longer compared to other substrate types. Several studies examining gear effects on soft bottom indicate that mud substrates are more stable and have longer recovery times than sand substrates (NRC 2002). A mean recovery time for trawl gear impacts in pink shrimp fishing grounds is estimated to be less than one

year in the absence of bottom trawl fishing (NMFS 2005). Due to the seasonality of the fishery, trawling is prohibited in the PSTG from November through March each year, allowing a minimum recovery period of five consecutive months with no fishing on seafloor habitats that may have been affected by pink shrimp trawl effort. The seafloor may have more time to recover from trawling impacts since shrimp beds within the PSTG may not be fished in all months of the season or in all years.

Ecosystem Health

An ecosystem is generally defined as a functional system consisting of living organisms in a given area, and all the non-living physical and chemical factors of the associated environment, linked together through nutrient cycling and energy flow. An ecological system is considered healthy if it is stable and sustainable; i.e., a system that maintains its organization and autonomy over time and is resilient to stress (Costanza and Mageau 1999).

Our ability to predict ecosystem dynamics is limited due to their complex nature. Properties characterizing an ecosystem can vary within large boundaries and time scales (NMFS 2005). According to Field et al. (2006), an ecosystem approach to fisheries management in the California Current must take into consideration the constantly changing climate-driven physical and biological interactions in the ecosystem, the trophic relationships between fished and unfished elements of the food web, the adaptation potential of life history diversity, and the role of humans as predators and competitors. Current state and federal pink shrimp management measures were not implemented to specifically address ecosystem management. The current management measures in place may collectively foster a sustainable fishery and indirectly promote a healthy ecosystem by reducing potential fishery impacts on the system. These measures include:

- Limited entry pink shrimp permitting system to control fishing capacity
- Reduction of fleet capacity due to vessel buyback programs
- Logbook program to monitor catch location, effort, and gear information
- Maximum count per pound of landed catch to avoid overfishing juvenile shrimp
- Closed fishing season to protect egg-bearing females
- Minimum mesh-size required to allow for escapement of juvenile shrimp
- Bycatch reduction device required on the net to minimize groundfish bycatch
- Area restrictions (Essential Fish Habitat)
- Federal at-sea observer coverage mandated by law
- State and federal incidental trip limits to minimize mortality of non-target species

Kelp and Coral Habitats

Biogenic habitat has been defined as any habitat created by plants or animals which provide space for attachment, hiding places from predators, and refuge from harsh environmental conditions (Tyrell 2005). In addition to coral and kelp species, the most common types of biogenic habitats off the north-central coast of California include species of seagrasses and other structure-forming invertebrates (NMFS 2005). Seagrasses are restricted to shallow depths in nearshore waters (Dennison and Alberte

1985, Moore and Short 2006), and are not directly influenced by trawling activity in the PSTG. However, a variety of kelp, coral, and other biogenic habitats do occur in waters within or adjacent to the PSTG.

Kelp

Bull kelp is the dominant canopy forming species in the kelp community occurring near the PSTG (North 1971). Bull kelp occurs in depths between 10 and 70 ft on bedrocks, boulders, and reefs (Vadas 1972). The inshore boundary of the PSTG occurs at a depth of at least 220 ft, and the nearest kelp forest is more than a mile from the PSTG according to aerial surveys conducted by the Department. The size and shape of the nearest kelp forest fluctuates on an annual basis (Table 5).

Since kelp does not recruit to soft sediments or occur in the PSTG there is no direct physical disturbance to kelp forests by pink shrimp trawl gear. Bottom trawl gear towed over the sea floor can create a sediment plume. These plumes are a potential indirect disturbance to kelp recruitment and growth because they can block sunlight which is necessary during the early life history of kelp (Vadas 1972). However, kelp recruitment and early development occurs throughout the winter and spring months (Foreman 1984), at a time when the pink shrimp fishery is closed (November through March). Furthermore, experiments conducted near the Eel River and the Russian River found sediment transport to be primarily offshore and either southward or northward depending on the time of year (Ogston and Sternberg 1999, Puig et al. 2002, Sherwood et al. 1994), which may limit the onshore transport of trawl plumes created by the pink shrimp fleet.

Table 5. Estimated annual bull kelp canopy (square miles) from False Cape to Point Reyes in waters adjacent to the pink shrimp trawl grounds. Data source: CDFG aerial flight surveys.

Year	Kelp growth (square miles)
1989	5.7
2002	2.0
2003	1.2
2004	2.0
2005	1.1

Coral Habitats

Structure-forming invertebrates, such as corals, can support complex ecological communities and increased biodiversity compared to areas without these species (Roberts and Hirshfield 2004). Bottom trawling may cause substantial damage to coral habitats (Auster and Langton 1999, Koslow et al. 2001, Fosså et al. 2002, Roberts et al. 2006). Observations of coral taxa from the WCGOP, research trawls and in-situ observations (SCUBA, ROV, submersibles) were summarized and compiled to assist in the creation of the federal groundfish EFH closure areas (NMFS 2005). In waters within and adjacent to the PSTG, these data indicate the presence of six major taxa of coral or coral-like species: hydrocorals (order Stylasterina), black corals (order Antipatharia),

stony corals (order Scleractinia), sea fans (order Gorgonacea), true soft corals (order Alcyonacea), and sea pens (order Pennatulacea) (Figure 9). These data are not a spatially comprehensive description of the occurrence of coral species, although it provides information about what taxa might be found within the PSTG. All of these taxa, except sea pens, require hard substrate for attachment and sea pens are the only taxa observed within the PSTG and within the pink shrimp beds (NMFS 2005).

High resolution bathymetry mapping and seafloor classification was completed in 2007 for the southern third of the PSTG from False Cape to Point Reyes (CDFG 2007). Another area mapped in high resolution is in the immediate vicinity of Cape Mendocino and False Cape. This data shows that significant rocky reef habitat does occur within the PSTG (Figure 10). Other areas are known but not mapped in high resolution. Comparison of these known areas of rocky substrate with trawl effort mapped from trawl logs shows that the pink shrimp fleet has avoided hard substrate within the PSTG (Figure 10). Additionally, two submarine canyons, Delgada Canyon and Spanish Canyon, extend toward shore into the PSTG (Figure 9). Sea fans (Order Gorgonacea) and soft corals (Order Alcyonacea) may occur on the hard substrate portion of these canyon slopes. A considerable pink shrimp bed is located on a plateau of soft seafloor between the canyons, but the pink shrimp trawling fleet has historically avoided the canyon slopes (Figure 10).

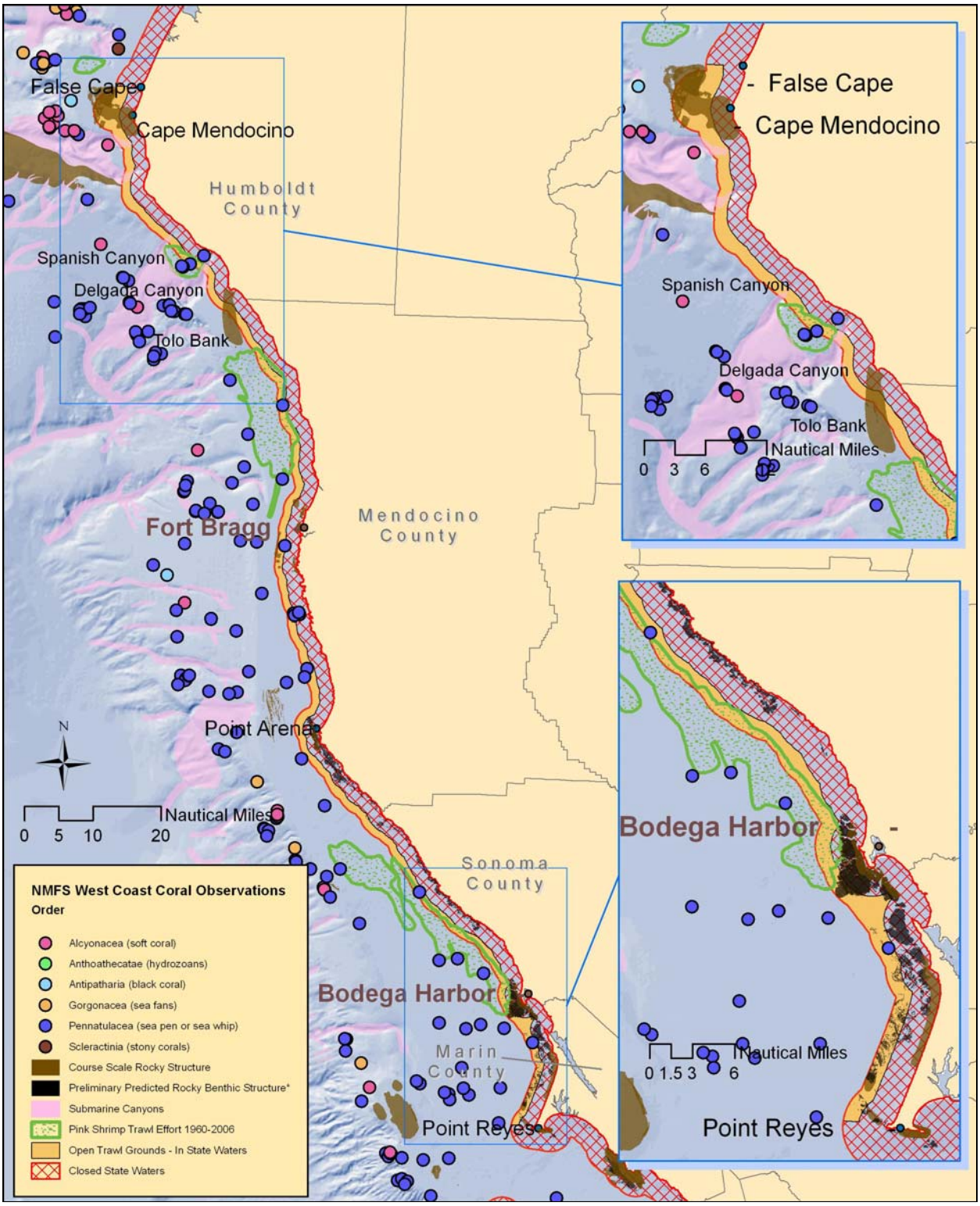

Figure 9. Locations of coral taxa observed from groundfish trawls, research trawls and in-situ observations off north and north-central California. Locations of coral indicate presence but are not a comprehensive map of occurrence*.

* Preliminary substrate classification of substrate from bathymetric surveys conducted by the Marine Life Protection Act Initiative (CSUMB/Fugro/USGS/MLML) and classified by CDFG Marine Region GIS Lab using methods created by Pat Lampietro at CSUMB.

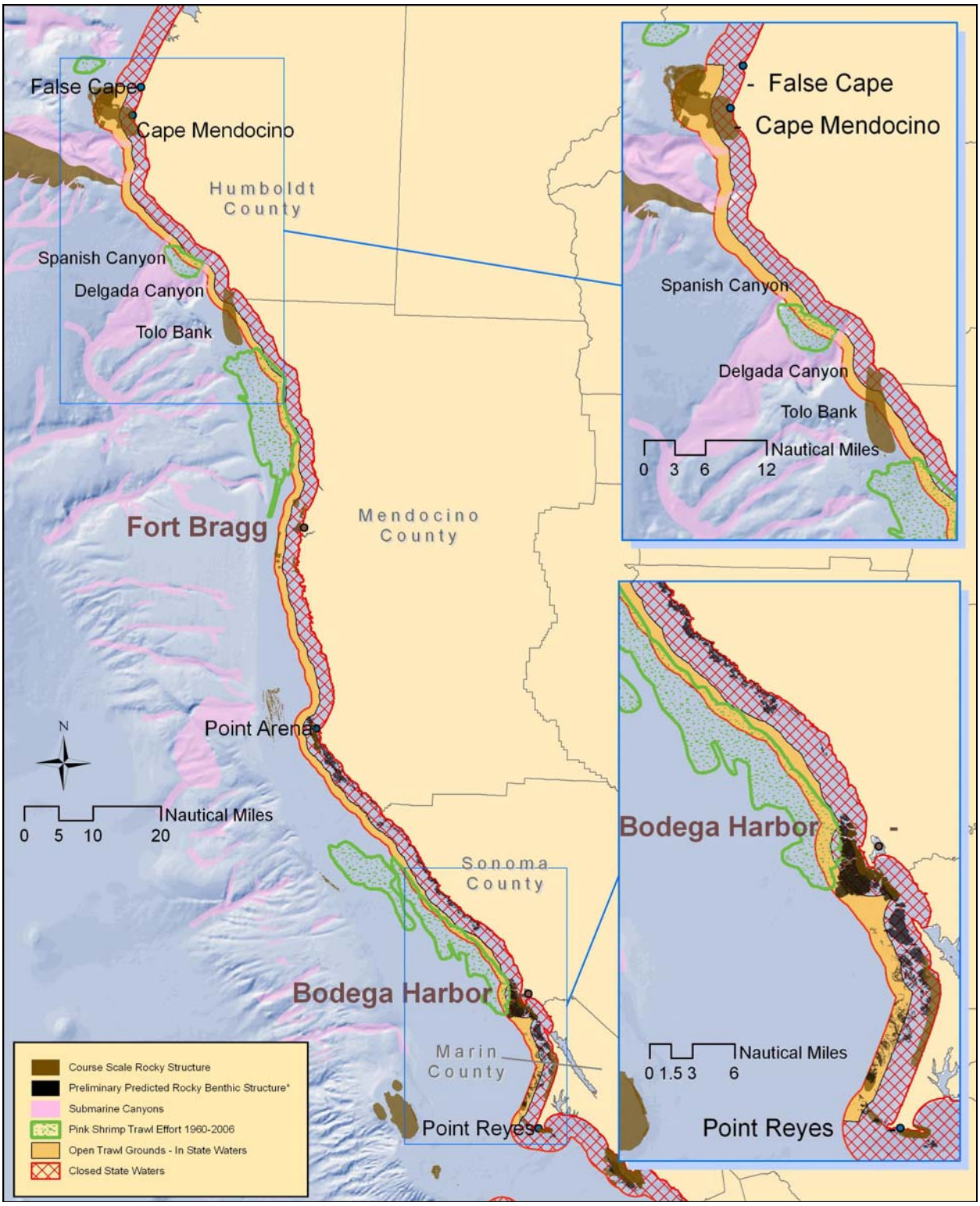

Figure 10. Areas of rocky substrate and submarine canyons off north and north-central California. Also shown is pink shrimp trawling effort inside and outside the pink shrimp trawl grounds from 1960 to 2006*.

* Preliminary substrate classification of substrate from bathymetric surveys conducted by the Marine Life Protection Act Initiative (CSUMB/Fugro/USGS/MLML) and classified by CDFG Marine Region GIS Lab using methods created by Pat Lampietro at CSUMB.

LITERATURE CITED

Alverson, D. L., M. H. Freeberg, S. A. Murawski, and J. G. Pope. 1994. A global assessment of fisheries bycatch and discards. Fisheries Technical Paper 339, FAO (United Nations Food and Agriculture Organization).

Auster, P. J., and R. W. Langton. 1999. The effects of fishing on fish habitat. American Fisheries Society Symposium 22:150-187.

Bergstrom, B. I. 2000. The biology of *Pandalus*. Pages 57-228 *in* A. J. Southward, P. A. Tyler, C. M. Young, and L. A. Fuiman (Eds.), Advances in Marine Biology. Academic Press, London.

Blue Ocean Institute. 2005. Guide to ocean friendly seafood species score card: Pink shrimp. Retrieved July 20, 2007, from http://www.blueoceaninstitute.org/seafood/species/139.html.

CDFG. 2007. Marine Life Protection Act Initiative (MLPAI) Internet Map Service. Retrieved September 3, 2007, from http://maps7.msi.ucsb.edu/mlpaims/viewer.htm.

CDFG. *in preparation*. Frimodig, A. J., Hannah R. W., and P. C. Collier. Pacific ocean shrimp. *in* Barsky, K. (Ed.), California's Living Marine Resources: A Status Report. California Department of Fish and Game.

CFIS. 2007. California Fisheries Information System. California Department of Fish and Game.

Costanza, R., and M. Mageau. 1999. What is ecosystem health? Aquatic Ecology 33:105-115.

Dahlstrom, W. A. 1970. Synopsis of biological data on the ocean shrimp *Pandalus jordani*, Rathbun, 1902. FAO Fish. Rept. 57(4): 1377-1416.

Dennison, W. C., and R. S. Alberte. 1985. Role of daily light period in the depth distribution of *Zostera marina* (eelgrass). Marine Ecology Progress Series 25:51-61.

Engel, J., and R. Kvitek. 1998. Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. Conservation Biology 12:1204-1214.

Federal Register. 2003. Vol. 68, No. 213.

Federal Register. 2006. Vol. 71, No. 123.

Federal Register. 2007. Vol. 72, No. 124.

Field, J. C., R. C. Francis, and K. Aydin. 2006. Top-down modeling and bottom-up dynamics: Linking a fisheries-based ecosystem model with climate hypotheses in the Northern California Current. Progress in Oceanography 68:238-270.

Foreman, R. E. 1984. Studies on *Nereocystis* Growth in British-Columbia, Canada. Hydrobiologia 116:325-332.

Fosså, J. H., P. B. Mortensen, and D. M. Furevik. 2002. The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts. Hydrobiologia 471:1-12.

Hannah, R. W., and S. A. Jones. 2000. By-catch reduction in an ocean shrimp trawl from a simple modification to the trawl footrope. Journal of Northwest Atlantic Fishery Science 27:227-233.

Hannah, R. W., and S. A. Jones. 2003. Measuring the height of the fishing line and its effect on shrimp catch and bycatch in an ocean shrimp (*Pandalus jordani*) trawl. Fisheries Research 60:427-438.

Hannah, R. W., and S. A. Jones. 2005. A survey evaluating shrimp abundance, sex composition, bycatch and trawl gear performance on the northern Oregon shrimp grounds – fall 2004. Oregon Department of Fish and Wildlife, Newport, Oregon. Information Report 2005-01.

Hannah, R. W., and S. A. Jones. 2007. Effectiveness of bycatch reduction devices (BRDs) in the ocean shrimp (*Pandalus jordani*) trawl fishery. Fisheries Research 85:217-225.

Hannah, R. W., S. A. Jones, and V. J. Hoover. 1996. Evaluation of fish excluder technology to reduce finfish bycatch in the ocean shrimp trawl fishery. Oregon Department of Fish and Wildlife, Newport, Oregon. Information Report 96-4.

Hannah, R. W., S. A. Jones, and K. M. Matteson. 2003. Observations of fish and shrimp behavior in ocean shrimp (*Pandalus jordani*) trawls. Oregon Department of Fish and Wildlife, Newport, Oregon. Information Report 2003-03.

Hixon, M. A., and B. N. Tissot. 2007. Comparison of trawled vs. untrawled mud seafloor assemblages of fishes and macroinvertebrates at Coquille Bank, Oregon. Journal of Experimental Marine Biology and Ecology 344:23-34.

Jones, S. A., R. W. Hannah, and J. T. Golden. 1996. A survey of trawl gear employed in the fishery for Ocean Shrimp *Pandalus jordani*. Oregon Department of Fish and Wildlife, Newport, Oregon. Information Report 96-6.

Koslow, J. A., K. Gowlett-Holmes, J. K. Lowry, T. O' Hara, G. C. B. Poore, and A. Williams. 2001. Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. Marine Ecology Progress Series 213:111-125.

Moore, K. A., and F. T. Short. 2006. *Zostera*: Biology, Ecology, and Management. Pages 361-386 *in* A. W. D. Larkum, R. J. Orth, and C. M. Duarte (Eds.), Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht, The Netherlands.

MSC. 2007. The Oregon pink (ocean) shrimp trawl fishery. Final Report Version 3. http://www.msc.org/assets/docs/Oregon_pink_shrimp/Final_Report_Oct_2007.pdf

NMFS. 2005. Final Environmental Impact Statement: Pacific coast groundfish fishery management plan, essential fish habitat designation and minimization of adverse impacts. National Marine Fisheries Service, Seattle, Washington.

NMFS. 2007. Fisheries of the United States 2006. Current Fishery Statistics No. 2006, Silver Spring, Maryland.

North, W. J. 1971. The biology of giant kelp beds (*Macrocystis*) in California. Nova Hedwegia Beiheft 32:1-98.

NRC. 2002. Effects of trawling and dredging on seafloor habitat. National Academy Press, Washington, D.C.

ODFW. 2006. Annual Pink Shrimp Review. Oregon Department of Fish and Wildlife, Newport, Oregon.

ODFW. 2007. Annual Pink Shrimp Review. Oregon Department of Fish and Wildlife, Newport, Oregon.

Ogston, A. S., and R. W. Sternberg. 1999. Sediment-transport events on the northern California continental shelf. Marine Geology 154:69-82.

PacFIN. 2007. Pacific Coast Fisheries Information Network. Pacific States Marine Fisheries Commission. http://www.psmfc.org/pacfin/.

PFMC. 1981. Discussion draft fishery management plan for the pink shrimp fishery off Washington, Oregon and California. Pacific Fishery Management Council, Portland, Oregon.

PFMC. 2002. Proposed groundfish acceptable biological catch and optimum yield specifications and management measures: 2003 Pacific coast groundfish fishery review of 2001 ocean salmon fisheries. Pacific Fishery Management Council, Portland, Oregon.

Puig, P., A. S. Ogston, B. L. Mullenbach, C. A. Nittrouer, and R. W. Sternber. 2002. Shelf-to-canyon sediment-transport processes on the Eel continental margin (northern California). Marine Geology 193:129-149.

Roberts, S. 2005. Seafood Watch Seafood Report: Wild-caught Coldwater Shrimp. Monterey Bay Aquarium.

Roberts, S., and M. Hirshfield. 2004. Deep-Sea Corals: Out of Sight but no Longer Out of Mind. Frontiers in Ecology and the Environment 2:123-130.

Roberts, J. M., A. J. Wheeler, and A. Freiwald. 2006. Reefs of the deep: the biology and geology of cold-water coral ecosystems. Science 312:543-547.

Sherwood, C. R., B. Butman, D. A. Cacchione, D. E. Drake, T. F. Gross, R. W. Sternberg, P. L. Wiberg, and A. J. Williams. 1994. Sediment-transport events on the northern California continental shelf during the 1990-1991 STRESS experiment. Continental Shelf Research 14:1063-1099.

Tyrell, M. C. 2005. Gulf of Maine Marine Habitat Primer. Gulf of Maine Council on the Marine Environment. www.gulfofmaine.org.

Vadas, R. L. 1972. Ecological implications of culture studies on *Nereocystis leutkeana*. Journal of Phycology 8:196-203.

WDFW. 2007. Washington state coastal pink shrimp fishery: Regulations and information. Retrieved August 2, 2007, from http://wdfw.wa.gov/fish/shelfish/shrimp/comm/index.html.