Relative abundance and health of megabenthic invertebrate species on the southern California shelf in 1994

Janet K. Stull[1], M. James Allen, Shelly L. Moore, and Chi-Li Tang[1]

ABSTRACT

Megabenthic (trawl-caught) invertebrate populations have been monitored locally in southern California for more than 25 years, but the populations have not been described synoptically. This study describes the distribution, relative importance, and health of dominant invertebrate species in the first synoptic survey of the southern California mainland shelf. Invertebrates were collected by 7.6-m head rope semiballoon otter trawls from 114 stations at depths of 10-200 m from Point Conception, California, to the United States-Mexico international border in July-August 1994. Species were identified, counted, examined for anomalies, and weighed. In all, 204 megabenthic invertebrate species from 110 families were collected; mollusks were the most diverse phylum and malacostracan crustaceans the most diverse class. Overall, ridgeback rock shrimp (*Sicyonia ingentis*), California sand star (*Astropecten verrilli*), gray sand star (*Luidia foliolata*), white sea urchin (*Lytechinus pictus*), brokenspine brittlestar (*Ophiura luetkenii*), California sea cucumber (*Parastichopus californicus*), fragile sea urchin (*Allocentrotus fragilis*), and California heart urchin (*Spatangus californicus*) were among the top three species in areal coverage, total abundance, or total biomass. All are echinoderms except the ridgeback rock shrimp. A single anomaly was found among 66,333 invertebrates; burnspot disease occurred on a southern spinyhead (*Metacrangon spinosissima*), a deepwater shrimp from northern Santa Monica Bay. Relative to earlier non-synoptic studies, anomaly prevalence has decreased significantly since the early 1970s, when crabs and sea urchins from outfall areas exhibited exoskeletal lesions and spine loss. Regionwide, megabenthic invertebrate populations appear to be relatively healthy.

[1]*County Sanitation Districts of Los Angeles County, 1965 S. Workman Mill Road, Whittier, CA 90607*

INTRODUCTION

Southern California is one of the most rapidly changing coastal environments in the country. The human population in the coastal basin has increased from 11 million (SCCWRP 1973) to 17 million (CDF,DRU 1995) during the past 25 years, with urbanization of the coast increasing in proportion to this change. This explosive growth has resulted in the increased recreational, commercial, and industrial use of the southern California coastal ocean, although the impacts of these activities have at times decreased. Mass emissions of contaminants in stormwater have increased while mass emissions of contaminants in wastewater discharges have decreased by more than 80% (at the same time that volumes were increasing) (Raco-Rands 1999, Schiff *et al.* 2000). The ocean climate in the area of the Southern California Bight (SCB) has also changed dramatically during the past 25 years. The cool, productive waters of the 1960s and 1970s were replaced largely by the warmer waters of the 1980s and 1990s, due to El Niño events and general ocean warming (Smith 1995).

Megabenthic (trawl-caught) invertebrate populations have been monitored extensively on a local level but not regionwide. For more than 25 years, populations of these relatively sedentary invertebrates have been monitored regularly near ocean outfalls to assess effects from waste-water discharge (e.g., Carlisle 1969a,b; Mearns and Greene 1974; CSDLAC 1997; CLAEMD 1994; CSDMWWD 1995; CSDOC 1996; Stull 1995). While local areas have been well studied, spatial and temporal variability throughout the SCB has not been adequately addressed. Past regional assessments compiled trawl data for various times, places, and purposes (Allen and Voglin 1976, Thompson *et al.* 1993a) and collected data in reference surveys of limited scope (Word *et al.* 1977, Thompson *et al.* 1987a,b). Mearns and Greene (1974) describe a synoptic survey of Santa Monica Bay, Palos Verdes Peninsula, and San Pedro Bay in 1973; however, megabenthic invertebrate populations have not been examined synoptically along the mainland shelf of southern California coast at any time.

In 1994, we conducted the first regional synoptic trawl survey along the southern California mainland shelf (Allen *et al.* 1998). The objectives of this report are (1) to describe the distribution, relative importance (areal coverage, abundance, and biomass), and health of the dominant invertebrate species of the southern California mainland shelf, and of predetermined geographic, depth, and wastewater influence subpopulations; and (2) to integrate this information with existing information on the general distribution and ecology of the species, making historical comparisons where possible. This information can also provide a context for understanding local population patterns. Previous studies from this survey described variability in trawl catch parameters (Allen and Moore 1996), recurrent groups (Allen and Moore 1997), and assemblages (Allen *et al.* 1999). However, the distribution, relative importance, and health of the species' populations have not been reported.

METHODS

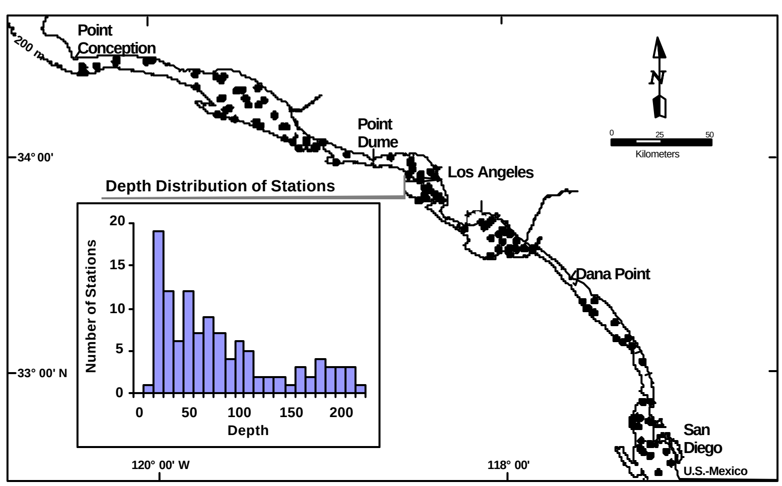
Trawl samples were collected at 114 randomly selected stations from Point Conception, California, to the United States-Mexico international border at depths of 9 to 215 m (Figure 1). Samples were collected from July 12 to August 22, 1994, with 7.6-m head-rope semiballoon otter trawls with 1.25-cm cod-end mesh. Trawls were towed for 10 min at 1 m/sec (2 kn) along isobaths. Invertebrates were identified to species, counted, measured, examined for anomalies, and weighed by species to the nearest 0.1 kg. Megabenthic invertebrates were considered to be those epibenthic species with a minimum dimension of 1 cm; infaunal, pelagic, and colonial species, and unattached fish parasites (e.g., leeches and cymothoid isopods) were noted but not processed. Each invertebrate was examined for external anomalies, including burnspot disease and external parasites.

Stations were selected using a stratified random design (Stevens 1997, Allen *et al.* 1998). Three subpopulation categories were defined: (1) Regions — northern (Point Conception to Point Dume), central (Point Dume to Dana Point), and southern (Dana Point to United States-Mexico international border); (2) Depth zones — inner shelf (10-25 m), middle shelf (26-100 m), and outer shelf (101-200 m); and (3) Type of Area - publicly owned treatment works (POTWs), which discharge treated wastewater, and non-POTW areas (see Figure 2 in Allen *et al.*, this report). The POTW areas were broad regions encompassing much or all of the area monitored around the outfalls of the four major POTWs: City of Los Angeles, Hyperion Treatment Plant outfall at 60 m in Santa Monica Bay; County Sanitation Districts of Los Angeles County, Joint Water Pollution Control Plant outfall at 60 m off Palos Verdes; County Sanitation Districts of Orange County outfall at 60 m in San Pedro Bay; and City of San Diego, Point Loma Wastewater Treatment Facility outfall at 100 m off Point Loma. The non-POTW area was the remaining area, even though additional sources discharge into shallow waters. Sample numbers from these strata were not equal, with the following numbers of samples by subpopulation: Region – northern (45), central (41), and southern (28); Depth zone – inner shelf (30), middle shelf (53), and outer shelf (31); and POTW (23) and non-POTW (30) (Allen *et al.* 1998). Further, the distribution of sampling effort by 10-m depth intervals was also uneven, with the highest numbers of samples collected at the 15-, 25-, and 45-m depth classes (Figure 1).

Data Analysis

Area-weighted means were calculated using a ratio estimator (Thompson 1992, Allen *et al.* 1998). Weighting factors for each station are given in Allen *et al.* (1998). The distribution by abundance and biomass of the top three dominant species for occurrence, abundance, and biomass were mapped. Percent of occurrence was defined as the percent of the total occurrence of a species that occurred within 10-m depth intervals.

FIGURE 1. Map of 114 invertebrate population stations sampled by trawl on the mainland shelf of southern California at depths of 10-200 m, July-August 1994, with inset of number of stations sampled per 10 m depth classes.



RESULTS

We collected 66,333 invertebrates weighing 891.3 kg. These comprised 204 species, representing 8 phyla, 20 classes, and 110 families (Table 1). There were 67 species of mollusks, 56 species of arthropods, at least 41 species of echinoderms, 24 species of cnidarians, 6 species of annelids, 5 species of chordates, 5 species of poriferans, and 3 species of brachiopods. Equitability curves for occurrence, abundance, and biomass indicate that more species occurred frequently than abundantly or with a high biomass (Figure 2). Echinoderms accounted for 78 and 83% of the abundance and biomass, respectively, and arthropods accounted for 18 and 9%, respectively.

Occurrence

Twelve species occurred individually in 20% or more of the area sampled (Table 2). California sand star (*Astropecten verrilli*), ridgeback rock shrimp (*Sicyonia ingentis*), gray sand star (*Luidia foliolata*), white sea urchin (*Lytechinus pictus*), California sea slug (*Pleurobranchaea californica*), and California sea cucumber (*Parastichopus californicus*) were the most widely distributed species, with California sand star and ridgeback rock shrimp found in over half the total area.

Geographically, California sand star was the most common (i.e., frequently occurring) species in the northern and central regions, whereas white sea urchin was the most common species in the southern region (Table 3). Bathymetrically, California sand star was the most common species in the inner and middle shelf zones, and fragile sea urchin (*Allocentrotus fragilis*) was the most common species in the outer shelf zone. California sand star and ridgeback rock shrimp were the most common species in the POTW areas; California sand star inhabited the most area in the non-POTW areas. No species occurred in more than half of the area in all subpopulations; however, California sand star inhabited more than 50% of the area in all subpopulations except the outer shelf zone. Fragile sea urchin, shortkeel bay shrimp (*Neocrangon zacae*), and northern heart urchin (*Brisaster latifrons*) were only common on the outer shelf, and Pacific spiny brittlestar (*Ophiothrix spiculata*) and yellow sea twig (*Thesea* sp. B; a sea pen) were only common in the POTW region.

Abundance

The 10 most abundant species together accounted for 95% of the survey catch (Table 4). White sea urchin accounted for 43% of the total invertebrate abundance; brokenspine brittlestar (*Ophiura luetkenii*) and ridgeback rock shrimp accounted for 19 and 15% of the total, respectively.

White sea urchin was the most abundant species in half of the subpopulations (central and southern regions, outer shelf and middle shelf POTW area); brokenspine brittlestar was most abundant in the northern region, the middle shelf zone, and the middle shelf non-POTW area; and California sand star was most abundant on the inner shelf (Table 5). The second most abundant species was also variable. Geographically, ridgeback rock shrimp was second in abundance in the northern and central regions. Bathymetrically, tuberculate pear crab (*Pyromaia tuberculata*) was second on the inner shelf, white sea urchin was second on the middle shelf, and fragile sea urchin was second on the outer shelf. Ridgeback rock shrimp was second in abundance in middle shelf POTW and non-POTW areas.

Biomass

Ten species together accounted for the top 95% of biomass in the survey (Table 6). Together, California sea cucumber, fragile sea urchin, and California heart urchin (*Spatangus californicus*) accounted for 70% of the total biomass.

Geographically, California sea cucumber was dominant in the central and southern regions, whereas California heart urchin was dominant in the northern region (Table 7). Shortspined sea star (*Pisaster brevispinus*) was dominant on the inner shelf, California sea cucumber on the middle shelf, and fragile sea urchin on the outer shelf. On the middle shelf, California sea cucumber was dominant in both POTW and non-POTW areas.

Species Distributions

Ridgeback Rock Shrimp *(Sicyonia ingentis)*

Ridgeback rock shrimp, a middle and outer shelf species, occurred in 61% of the area surveyed and accounted for 15% of the abundance and 9% of the biomass (Figure 3; Tables 2, 4, and 6). By depth, this species occurred in 50% or more of the stations at all depths between 41 and 160 m, occurring at 100% of the stations at almost half of the depths from 71-200 m (Figure 3). Abundance increased to the north (Table 5). This species ranked second in abundance in the northern and central regions, and at middle shelf POTW and non-POTW areas; and second in biomass in the middle shelf depth zone and the middle shelf non-POTW area (Tables 5 and 7). In the middle shelf non-POTW area, this species accounted for 27% of the abundance and 28% of the biomass. Over 1,100 ridgeback rock shrimp (7.2 kg) were taken in 71 m fine sediments south of Santa Barbara. This shrimp occurred in sediments with over 25% fines.

California Sand Star *(Astropecten verrilli)*

California sand star, an inner and middle shelf species, was the most widely distributed organism. This species occurred in 72% of the area, and accounted for 1% of the

TABLE 1. Taxonomic list of megabenthic invertebrate species collected in the regional survey of the mainland shelf of southern California at depths of 10-200 m, July-August 1994.

Taxon/Species	Author	Common Name
PORIFERA		
CALCAREA		
—SCYCETTIDA		
Amphoriscidae		
Leucilla nuttingi	(Urban 1902)	urn sponge
HEXACTINELLIDA		
Hexactinellida unid.		glass sponge
DEMOSPONGIAE		
—CHORISTIDA		
Pachastrellidae		
Poecillastra tenuilaminaris	(Sollas 1886)	“sponge”
—HADROMERIDA		
Spirastrellidae		
Spheciospongia confoederata	de Laubenfels 1930	gray moonsponge
—AXINELLIDA		
Raspailiidae		
Hemectyon hyle	de Laubenfels 1932	bushy sponge
—POECILOSCLERIDA		
Myxillidae		
Myxilla incrustans	(Esper 1805-1814)	scallop sponge
CNIDARIA		
HYDROZOA		
—ATHECATAE		
Tubulariidae		
Tubularia crocea	(L. Agassiz 1862)	pink-mouth hydroid
—THECATAE		
Aglaopheniidae		
Aglaophenia sp.		feather hydroid, unid.
—SIPHONOPHORA		
Rhodaliidae		
Dromalia alexandri	Bigelow 1911	sea strawberry
ANTHOZOA		
—ALCYONACEA		
Alcyonacea sp. A		“soft coral”
Gorgoniidae		
Adelogorgia phyllosclera	Bayer 1958	orange gorgonian
Eugorgia rubens	Verrill 1868	purple gorgonian
Heterogorgia tortuosa	Verrill 1868	“gorgonian”
Lophogorgia chilensis	(Verrill 1868)	pink sea whip
Muriceidae		
Thesea sp. B	Ljubenkov 1986*	yellow sea twig
—PENNATULACEA		
Renillidae		
Renilla kollikeri (=koellikeri)	Pfeffer 1886	purple sea pansy
Virgulariidae		
Acanthoptilum sp.		trailtip sea pen, unid.
Stylatula elongata	(Gabb 1862)	slender sea pen
Stylatula sp. A	Ljubenkov 1991*	“sea pen”
Virgularia agassizi (=*bromleyi*)	Studer 1849	“sea pen”
Virgularia californica (= *galapagensis*)	Pfeffer 1886	California sea pen
Pennatulidae		
Pennatula phosphorea	Linnaeus 1758	“sea pen”
Ptilosarcus gurneyi	(Gray 1860)	fleshy sea pen
—SCLERACTINIA		
Caryophylliidae		
Desmophyllum dianthus	(Esper 1794)	“cup coral”
Paracyathus stearnsii	Verrill 1869	brown cup coral
—ACTINIARIA		
Actiniidae		
Epiactis prolifera	Verrill 1869	brooding anemone
Hormathiidae		
Amphianthus sp. OC1		“anemone”
Metridiidae		
Metridium senile Cmplx		“clonal plumose anemone”

TABLE 1 (continued)

Taxon/Species	Author	Common Name
—CORALLIMORPHARIA		
Corallimorphidae		
Corynactis californica	Carlgren 1936	strawberry corallimorpharian
MOLLUSCA		
POLYPLACOPHORA		
—NEOLORICATA		
Ischnochitonidae		
Callistochiton palmulatus	Carpenter in Dall 1879	big-end chiton
Lepidozona mertensii	(Middendorff 1847)	Merten chiton
Lepidozona sinudentata	(Carpenter in Pilsbry 1892)	whitestripe chiton
Mopaliidae		
Placiphorella sp SD1		“veiled chiton”
GASTROPODA		
—VETIGAGASTROPODA		
Fissurellidae		
Puncturella multistriata	Dall 1914	many-rib puncturella
Turbinidae		
Lithopoma undosum	(Wood 1828)	wavy turban
Trochidae		
Calliostoma canaliculatum	(Lightfoot 1786)	channeled topsnail
Calliostoma tricolor	Gabb 1865	tricolor topsnail
Calliostoma turbinum	Dall 1895	spindle topsnail
Cidarina cidaris	(Carpenter 1864)	Adam spiny margarite
—NEOTAENIOGLOSSA		
Calyptraeidae		
Calyptraea fastigiata	Gould 1856	Pacific Chinese-hat
Ovulidae		
Neosiminia (=Delonolva) aequalis	(G. B. Sowerby I 1832)	Vidler simnia
Lamellariidae		
Lamellaria diegoensis	Dall in Orcutt 1885	San Diego lamellaria
Naticidae		
Calinaticina oldroydii	(Dall 1897)	delicate moonsnail
Neverita reclusiana	(Deshayes 1839)	southern moonsnail
Bursidae		
Crossata californica	(Hinds 1843)	California frogsnail
—NEOGASTROPODA		
Muricidae		
Boreotrophon bentleyi	(Dall 1908)	“trophon”
Pteropurpura festiva	(Hinds 1844)	festive murex
Pteropurpura macroptera	(DeShayes 1839)	frill-wing murex
Pteropurpura vokesae	Emerson 1964	wrinkle-wing murex
Coralliophilidae		
Babelomurex oldroydi	(I. S. Oldroyd 1929)	Olyroyd coralsnail
Columbellidae		
Amphissa undata	(Carpenter 1864)	Carpenter amphissa
Amphissa versicolor	Dall 1871	variagate amphissa
Buccinidae		
Kelletia kelletii (=*kelletti*)	(Forbes 1850)	Kellet whelk
Neptunea tabulata	(Baird 1863)	tabled whelk
Nassariidae		
Nassarius fossatus	(Gould 1849)	channeled nassa
Nassarius perpinguis	(Hinds 1844)	fat western nassa
Fasciolariidae		
Fusinus barbarensis	(Trask 1855)	Santa Barbara spindle
Mitridae		
Mitra idae	Melville 1893	half-pitted miter
Cancellariidae		
Cancellaria cooperi	Gabb 1865	Cooper nutmeg
Cancellaria crawfordiana	(Dall 1891)	Crawford nutmeg
Conidae		
Conus californicus	Hinds 1844	California cone
Terebridae		
Terebra pedroana	Dall 1908	San Pedro auger
Turridae		
Antiplanes catalinae (=perversus)	(Raymond 1904)	Catalina turrid
Crassispira semiinflata	(Grant & Gale 1931)	California drillia

TABLE 1 (continued)

Taxon/Species	Author	Common Name
Megasurcula carpenteriana	(Gabb 1865)	tower snail
Megasurcula stearnsiana	(Raymond 1904)	Stearns turrid
Ophiodermella cancellata	(Carpenter 1864)	cancellate snakeskin-snail
—CEPHALASPIDEA		
Philinidae		
Philine alba	Mattox 1958	white paperbubble
—NOTASPIDEA		
Pleurobranchaeidae		
Berthella californica	(Dall 1900)	California sidegill slug
Pleurobranchaea californica	MacFarland 1966	California sea slug
—NUDIBRANCHIA		
Cadlinidae		
Cadlina modesta	MacFarland 1966	modest cadlina
Discodorididae		
Diaulula sandiegensis	(J. G. Cooper 1863)	ringed doris
Platydorididae		
Platydoris macfarlandi	Hanna 1951	California flat doris
Onchidorididae		
Acanthodoris brunnea	MacFarland 1905	brown spiny doris
Acanthodoris rhodoceras	Cockerell in Cockerell & Elliot 1905	black-tipped spiny doris
Notodorididae		
Aegires albopunctatus	MacFarland 1905	salt-and-pepper doris
Polyceratidae		
Triopha maculata	MacFarland 1905	maculated triopha
Dendrodorididae		
Doriopsilla albopunctata	(J. G. Cooper 1863)	salted yellow doris
Tritoniidae		
Tritonia diomedea	Bergh 1894	rosy tritonia
Tritonia festiva	(Stearns 1873)	diamondback tritonia
Dendronotidae		
Dendronotus iris	J. G. Cooper 1863	giant frond-aeolis
Arminidae		
Armina californica	(J. G. Cooper 1863)	California armina
Flabellinidae		
Flabellina iodinea	J. G. Cooper 1863	purple aeolis
Flabellina pricei	(MacFarland 1966)	smooth-tooth aeolis
BIVALVIA		
—OSTREOIDA		
Pectinidae		
Chlamys hastata	(G. B. Sowerby II 1843)	spiny scallop
Delectopecten vancouverensis	(Whiteaves 1893)	Vancouver scallop
Euvola diegensis	(Dall 1898)	San Diego scallop
Leptopecten latiauratus	(Conrad 1837)	kelp scallop
Anomiidae		
Anomia peruviana	d'Orbigny 1846	Peruvian jingle
Pododesmus macroschisma	(Deshayes 1839)	Alaska falsejingle
CEPHALOPODA		
—SEPIOIDEA		
Sepiolidae		
Rossia pacifica	Berry 1911	eastern Pacific bobtail
—TEUTHOIDEA		
Loliginiidae		
Loligo opalescens	Berry 1911	California market squid
—OCTOPODA		
Octopodidae		
Octopus californicus	Berry 1911	orange bigeye octopus
Octopus rubescens	Berry 1953	red octopus
Octopus veligero	Berry 1953	short arm octopus
ANNELIDA		
POLYCHAETA		
—PHYLLODOCIDA		
Aphroditidae		
Aphrodita armifera	Moore 1910	copper sea mouse
Aphrodita castanea	Moore 1910	chestnut sea mouse

TABLE 1 (continued)

Taxon/Species	Author	Common Name
Aphrodita japonica	Marenzeller 1879	black sea mouse
—SABELLIDA		
Serpulidae		
Protula superba	Moore 1909	chalktube worm
HIRUDINEA		
Piscicolidae		
Astrobdella californiana	Burreson 1977	striped leech
ARTHROPODA		
CIRRIPEDIA		
—THORACICA		
Scalpellidae		
Hamatoscalpellum californicum	(Pilsbry 1907)	California blade barnacle
Balanidae		
Balanus nubilus	Darwin 1854	giant acorn barnacle
Balanus pacificus	Pilsbry 1916	Pacific acorn barnacle
MALACOSTRACA		
—STOMATOPODA		
Hemisquillidae		
Hemisquilla ensigera californiensis	Stephenson 1967	blueleg mantis shrimp
—ISOPODA		
Cymothoidae		
Elthusa (=Livoneca) californica	(Schiodte and Meinert 1883)	California fish louse
Elthusa (=Livoneca) vulgaris	(Stimpson 1857)	Pacific fish louse
—DECAPODA		
Penaeidae		
Farfantepenaeus (=Penaeus) californiensis	(Holmes 1900)	yellowleg shrimp
Sicyoniidae		
Sicyonia ingentis	(Burkenroad 1938)	ridgeback rock shrimp
Pandalidae		
Pandalus danae	Stimpson 1857	dock shrimp
Pandalus platyceros	Brandt 1851	spot shrimp
Hippolytidae		
Heptacarpus palpator	(Owen 1839)	intertidal coastal shrimp
Heptacarpus stimpsoni	Holthuis 1947	Stimpson coastal shrimp
Spirontocaris holmesi	Holthuis 1947	slender blade shrimp
Spirontocaris sica	Rathbun 1902	offshore blade shrimp
Crangonidae		
Crangon alaskensis	Lockington 1877	Alaska bay shrimp
Crangon alba	Holmes 1900	stout crangon
Crangon nigromaculata	Lockington 1877	blackspotted bay shrimp
Metacrangon spinosissima	(Rathbun 1902)	southern spinyhead
Neocrangon communis	(Rathbun 1899)	gray shrimp
Neocrangon resima	(Rathbun 1902)	flagnose bay shrimp
Neocrangon zacae	(Chace 1937)	shortkeel bay shrimp
Diogenidae		
Paguristes bakeri	Holmes 1900	digger hermit
Paguristes turgidus	(Stimpson 1857)	slenderclaw hermit
Paguristes ulreyi	Schmitt 1921	furry hermit
Paguridae		
Enallopaguropsis guatemoci	(Glassell 1937)	“hermit”
Orthopagurus minimus	(Holmes 1900)	tubicolous hermit
Parapagurodes laurentae	McLaughlin & Haig 1973	spinypalm hermit
Parapagurodes makarovi	McLaughlin & Haig 1973	smoothpalm hermit
Pagurus redondoensis	Wicksten 1982	bandclaw hermit
Pagurus spilocarpus	Haig 1977	spotwrist hermit
Phimochirus californiensis	(Benedict 1892)	Calirornia hermit
Lithodidae		
Lopholithodes foraminatus	(Stimpson 1859)	brown box crab
Paralithodes californiensis	(Benedict 1894)	California king crab
Paralithodes rathbuni	(Benedict 1894)	forknose king crab
Galatheidae		
Galathea californiensis	(Benedict 1902)	California squat lobster

TABLE 1 (continued)

Taxon/Species	Author	Common Name
Calappidae		
Platymera gaudichaudii	Milne Edwards 1837	armed box crab
Leucosiidae		
Randallia ornata	(Randall 1839)	globose sand crab
Majidae		
Chorilia longipes	Dana 1851	longhorn decorator crab
Erileptus spinosus	Rathbun 1893	shortneck pear crab
Loxorhynchus crispatus	Stimpson 1857	moss crab
Loxorhynchus grandis	Stimpson 1857	sheep crab
Podochela hemphillii	(Lockington 1877)	Hemphill kelp crab
Podochela lobifrons	Rathbun 1925	thinbeak neck crab
Pugettia dalli	Rathbun 1893	spined kelp crab
Pyromaia tuberculata	(Lockington 1877)	tuberculate pear crab
Scyra acutifrons	Dana 1851	sharpnose crab
Parthenopidae		
Heterocrypta occidentalis	(Dana 1854)	sandflat elbow crab
Cancridae		
Cancer amphioetus	Rathbun 1898	bigtooth rock crab
Cancer antennarius	Stimpson 1856	Pacific rock crab
Cancer anthonyi	Rathbun 1879	yellow rock crab
Cancer gracilis	Dana 1852	graceful rock crab
Cancer jordani	Rathbun 1900	hairy rock crab
Cancer productus	Randall 1839	red rock crab
Xanthidae		
Lophopanopeus bellus	(Stimpson 1860)	blackclaw crestleg crab
Pinnotheridae		
Pinnixa franciscana	Rathbun 1918	innkeeper pea crab
ECHINODERMATA		
CRINOIDEA		
—COMATULIDA		
Antedonidae		
Florometra serratissima	(A. H. Clark 1907)	feather star
ASTEROIDEA		
—PAXILLOSIDA		
Luidiidae		
Luidia armata	Ludwig 1905	mosaic sand star
Luidia asthenosoma	Fisher 1906	fringed sand star
Luidia foliolata	Grube 1866	gray sand star
Astropectinidae		
Astropecten armatus	Gray 1840	spiny sand star
Astropecten ornatissimus	Fisher 1906	orange sand star
Astropecten verrilli	de Loriol 1899	California sand star
—VALVATIDA		
Goniasteridae		
Mediaster aequalis	Stimpson 1857	red sea star
Asterinidae		
Asterina miniata	(Brandt 1835)	bat star
—SPINULOSIDA		
Echinasteridae		
Henricia leviuscula	(Stimpson 1857)	blood star
—FORCIPULATIDA		
Asteriidae		
Leptasterias hexactis	(Stimpson 1853)	knobless six-rayed sea star
Pisaster brevispinus	(Stimpson 1857)	shortspined sea star
Pycnopodia helianthoides	(Brandt 1835)	sunflower star
Rathbunaster californicus	Fisher 1906	sun star
Sclerasterias heteropaes	Fisher 1924	banded sea star
Stylasterias forreri	(de Loriol 1887)	fish-eating sea star
OPHIUROIDEA		
—PHRYNOPHIURIDA		
Gorgonocephalidae		

TABLE 1 (continued)

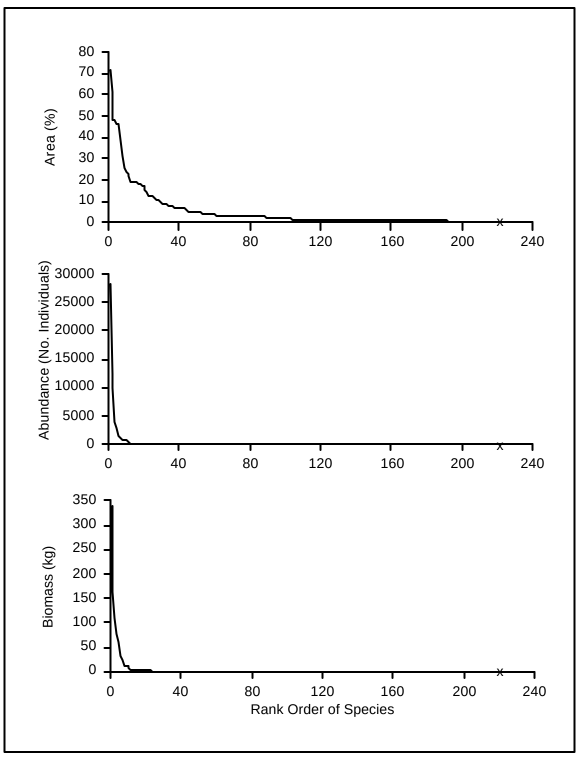
Taxon/Species	Author	Common Name
Gorgonocephalus eucnemis	(J. Müller & Troschel 1842)	basket star
—OPHIURIDA		
Ophiacanthidae		
Ophiacantha phragma	Ziesenhenne 1940	fragile spinyarm brittlestar
Ophiactidae		
Ophiopholis bakeri	McClendon 1909	roughspine brittlestar
Amphiuridae		
Amphichondrius granulosus	Nielsen 1932	roughdisk brittlestar
Amphiodia psara	H. L. Clark 1935	"brittlestar"
Amphiodia urtica	(Lyman 1860)	red brittlestar
Amphipholis squamata	(Delle Chiaje 1828)	holdfast brittlestar
Amphiura arcystata	H. L. Clark 1911	"brittlestar"
Dougaloplus amphacanthus	(McClendon 1909)	"brittlestar"
Ophiotricidae		
Ophiothrix spiculata	Le Conte 1851	Pacific spiny brittlestar
Ophiocomidae		
Ophiopteris papillosa	(Lyman 1875)	flatspine brittlestar
Ophionereidae		
Ophionereis eurybrachiplax	H. L. Clark 1911	"brittlestar"
Ophiuridae		
Ophiura luetkenii	(Lyman 1860)	brokenspine brittlestar
ECHINOIDEA		
—TEMNOPLEUROIDA		
Toxopneustidae		
Lytechinus pictus	(Verrill 1867)	white sea urchin
—ECHINOIDA		
Strongylocentrotidae		
Allocentrotus fragilis	(Jackson 1912)	fragile sea urchin
Strongylocentrotus purpuratus	(Stimpson 1857)	Pacific purple urchin
—CLYPEASTEROIDA		
Dendrasteridae		
Dendraster terminalis (=excentricus)	(Grant & Hertlein 1938)	"sand dollar"
—SPATANGOIDA		
Schizasteridae		
Brisaster latifrons	(A. Agassiz 1898)	northern heart urchin
Brissidae		
Brissopsis pacifica	(A. Agassiz 1898)	Pacific heart urchin
Spatangidae		
Spatangus californicus	H. L. Clark 1917	California heart urchin
Loveniidae		
Lovenia cordiformis	A. Agassiz 1872	sea porcupine
HOLOTHUROIDEA		
—DENDROCHIROTIDA		
Psolidae		
Psolus chitonoides	H. L. Clark 1901	slipper sea cucumber
Sclerodactylidae		
Pachythyone rubra	(H. L. Clark 1901)	redback sea cucumber
Cucumariidae		
Pseudocnus sp.		"sea cucumber"
—ASPIDOCHIROTIDA		
Stichopodidae		
Parastichopus californicus	(Stimpson 1857)	California sea cucumber
BRACHIOPODA		
ARTICULATA		
—TEREBRATULIDA		
Cancellothyrididae		
Terebratulina crossei	Davidson 1882	white lamp shell
Laqueidae		
Laqueus californianus	Koch 1847	California lamp shell
Terebratalia occidentalis	(Dall 1871)	ribbed lamp shell

TABLE 1 (continued)

Taxon/Species	Author	Common Name
CHORDATA		
ASCIDIACEA		
—PHLEBOBRANCHIATA		
Corellidae		
Corella willmeriana	Herdman 1898	icy tunicate
—STOLIDOBRANCHIATA		
Styelidae		
Polyandrocarpa sp.		“sea squirt”
Styela gibbsii	(Stimpson 1864)	wrinkled sea squirt
Pyuridae		
Boltenia villosa	(Stimpson 1864)	spiny-headed tunicate
Halocynthia igaboja	Oka 1906	spiny sea peach

Taxonomic order and scientific names from SCAMIT (1998).
* Unpublished provisional name (see SCAMIT 1998).
= Name has been changed since Allen *et al*. (1998).
Cmplx = ‘complex,’ possibly set of poorly discriminated species.

FIGURE 2. Equitability curves of invertebrate occurrence, abundance, and biomass by species on the mainland shelf of southern California at depths of 10-200 m, July-August 1994. x = 222nd species.



abundance and 3% of the biomass (Figure 4; Tables 2, 4 and 6). By depth, it occurred in at least 50% of the stations at all depths between 11 and 140 m and occurred at 100% of the stations at many of these depths and at 151-160 m (Figure 4). California sand star accounted for 48% of the abundance and 14% of the biomass in the inner shelf zone (Tables 5 and 7). The largest catch, 116 specimens weighing 0.2 kg, was taken off Ventura, and had more than twice the number of specimens at any other site.

Gray Sand Star *(Luidia foliolata)*

Gray sand star occurred in all depth zones, occupied 49% of the area, and accounted for 1% of the abundance and biomass (Figure 5; Tables 2, 4 and 6). By depth, it occurred in 50% or more of the stations at all depths between 71 and 190 m, except 131-140 m, occurring at 100% of the stations at half of the depths from 91-210 m (Figure 5). The largest catch was 26 specimens, weighing 1.7 kg from a 73 m coarse sediment area south of Point Conception.

White Sea Urchin (*Lytechinus pictus*)

White sea urchin, a middle and outer shelf species, occurred in 48% of the area and accounted for 43% of the abundance and 7% of the biomass (Figure 6; Tables 2, 4 and 6). By depth, this species occurred in 50% or more of the stations at all depths between 71 and 160 m, occurring at 100% of the stations at all depths from 91-160 m, except for 141-150 m (Figure 6). White sea urchin was the numerical dominant in the central and southern regions, the outer shelf depth zone, and the middle shelf POTW area (Table 5). Over 2,000 white sea urchins were taken at each of

TABLE 2. Megabenthic invertebrate species occurring in 20% or more of the mainland shelf of southern California at depths of 10-200 m, July-August 1994.

Scientific Name	Common Name	No. of Stations	Percent Stations	Percent Area*
Astropecten verrilli	California sand star	80	70	71.8
Sicyonia ingentis	ridgeback rock shrimp	67	59	61.4
Luidia foliolata	gray sand star	55	48	48.5
Lytechinus pictus	white sea urchin	55	48	47.9
Pleurobranchaea californica	California sea slug	44	39	46.0
Parastichopus californicus	California sea cucumber	53	46	45.9
Ophiura luetkenii	brokenspine brittlestar	44	39	38.9
Ophiothrix spiculata	Pacific spiny brittlestar	33	29	31.1
Loligo opalescens	California market squid	28	25	25.6
Acanthoptilum sp.	trailtip sea pen, unid.	25	22	24.0
Allocentrotus fragilis	fragile sea urchin	31	27	23.2
Stylatula elongata	slender sea pen	17	15	21.9

Total stations = 114.
Total area = 3,075 km^2.
*Based on area-weighted frequency of occurrences.

TABLE 3. Megabenthic invertebrate species comprising 50% or more of the area by subpopulation in the regional survey of the mainland shelf of southern California at depths of 10-200 m, July-August 1994.

	Percent Area							
	Region			Shelf Depth Zone			Middle Shelf Outfall Status	
Common Name	N	C	S	IS	MS	OS	POTW	NPOTW
California sand star	73	72	69	76	84	-	87	83
ridgeback rock shrimp	68	-	62	-	81	69	87	80
California sea slug	64	-	-	-	60	-	-	67
gray sand star	62	-	-	-	55	69	65	53
brokenspine brittlestar	53	-	-	-	-	-	61	-
California sea cucumber	50	-	-	-	60	55	78	57
white sea urchin	-	-	71	-	64	50	83	60
fragile sea urchin	-	-	-	-	-	86	-	-
shortkeel bay shrimp	-	-	-	-	-	57	-	-
northern heart urchin	-	-	-	-	-	55	-	-
Pacific spiny brittlestar	-	-	-	-	-	-	61	-
yellow sea twig	-	-	-	-	-	-	57	-

"-" = Species not occurring in at least 50% of the area or absent.
POTW = Publicly owned treatment work monitoring areas.
N = Northern; C = Central; S = Southern; IS = Inner shelf; MS = Middle shelf; OS = Outer shelf;
P = Middle-shelf POTW; NP = Middle-shelf non-POTW.
Total area (km^2) by subpopulation: N = 1,561; C = 820; S = 694; IS = 676; MS = 1,709; OS = 689; P = 290; NP = 1,419.

three 57-113 m sites in Santa Monica Bay and off the Orange County and San Diego coasts. Maximum biomasses, greater than 4.5 kg per haul, were taken from 57 to 113 m at sites off Santa Barbara, in Santa Monica Bay, and off San Diego.

Brokenspine Brittlestar (*Ophiura luetkenii*)

Brokenspine brittlestar, a middle shelf species, occurred in 39% of the area surveyed and accounted for 19% of the abundance and 1.4% of the biomass (Figure 7; Tables 2, 4 and 6). By depth, it occurred in 50% or more of the stations at all depths between 51 and 150 m, occurring at 100% of the stations at all depths from 111-150 m, except for 131-140 m (Figure 7). Although this species ranked second in overall abundance, over 300 specimens were taken at only one site. Off Santa Barbara, 11,575 brokenspine brittlestar were taken at a 38 m station with coarse sediments. Therefore, this species ranked first in abundance in the northern region, second in abundance in the middle depth zone, and third in biomass among middle shelf non-POTW areas (Tables 5 and 7).

California Sea Cucumber (*Parastichopus californicus*)

TABLE 4. Megabenthic invertebrate species comprising 95% or more of the total invertebrate abundance in the regional survey of the mainland shelf of southern California at depths of 10-200 m, July-August 1994.

Scientific Name	Common Name	No. Individuals Mean/Haul*	No. Individuals Total	Percent Total	Percent Cumulative
Lytechinus pictus	white sea urchin	201.4	28,378	42.8	42.8
Ophiura luetkenii	brokenspine brittlestar	184.8	12,385	18.7	61.5
Sicyonia ingentis	ridgeback rock shrimp	120.8	10,078	15.2	76.6
Allocentrotus fragilis	fragile sea urchin	27.0	3,825	5.8	82.4
Spatangus californicus	California heart urchin	21.7	2,825	4.3	86.7
Acanthoptilum sp.	trailtip sea pen, unid.	18.5	1,613	2.4	89.1
Brisaster latifrons	northern heart urchin	9.3	1,296	2.0	91.1
Neocrangon zacae	shortkeel bay shrimp	5.2	937	1.4	92.5
Astropecten verrilli	California sand star	8.2	918	1.4	93.9
Parastichopus californicus	California sea cucumber	5.6	742	1.1	95.0

Total abundance = 66,333 fish.
Total area = 3,075 km^2.
* Area-weighted mean.

TABLE 5. Megabenthic invertebrate species comprising 80% or more of the invertebrate abundance by sub-population on the mainland shelf of southern California at depths of 10-200 m, July-August 1994.

	Region						Shelf Depth Zone						Middle Shelf Outfall Status			
	North		Central		South		Inner		Middle		Outer		POTW		NPOTW	
Common Name	M	%	M	%	M	%	M	%	M	%	M	%	M	%	M	%
white sea urchin	101	**16**	213	**54**	414	**81**	1	**3**	209	**40**	380	**49**	477	**76**	163	**18**
brokenspine brittlestar	360	**37**	-	-	-	-	1	**5**	331	**30**	-	-	-	-	209	**47**
ridgeback rock shrimp	194	**20**	46	**14**	-	-	-	-	197	**21**	51	**7**	74	**11**	127	**27**
fragile sea urchin	-	-	32	**8**	-	-	-	-	-	-	120	**15**	-	-	-	-
California heart urchin	41	**9**	-	-	-	-	-	-	-	-	97	**11**	-	-	-	-
shortkeel bay shrimp	-	-	17	**5**	-	-	-	-	-	-	-	-	-	-	-	-
California sand star	-	-	-	-	-	-	12	**48**	-	-	-	-	-	-	-	-
tuberculate pear crab	-	-	-	-	-	-	2	**6**	-	-	-	-	-	-	-	-
blackspotted bay shrimp	-	-	-	-	-	-	1	**5**	-	-	-	-	-	-	-	-
fat western nassa	-	-	-	-	-	-	1	**5**	-	-	-	-	-	-	-	-
sandflat elbow crab	-	-	-	-	-	-	1	**4**	-	-	-	-	-	-	-	-
slenderclaw hermit	-	-	-	-	-	-	1	**4**	-	-	-	-	-	-	-	-
spiny sand star	-	-	-	-	-	-	1	**3**	-	-	-	-	-	-	-	-

M = area-weighted mean; units — number of individuals/haul.
"-" = Species absent or not included in the top 80%.
POTW = Publicly owned treatment work monitoring areas; NPOTW = non-POTW areas;
N = Northern; C = Central; S = Southern; IS = Inner shelf; MS = Middle shelf; OS = Outer shelf
Total catch abundance (no. of individuals) by subpopulation: N = 6,131; C = 7,064; S = 5,717; IS = 1,515; MS = 9,271; OS = 8,126; POTW = 4,887; NPOTW = 4,384.
Total area (km^2) by subpopulation: N = 1,561; C = 820; S = 694; IS = 676; MS = 1,709; OS = 689; POTW = 290; NPOTW = 1,419.

California sea cucumber, a middle and outer shelf species, was found in 46% of the area and accounted for 1% of the abundance and 39% of the biomass (Figure 8; Tables 2, 4 and 6). By depth, it occurred in 50% or more of the stations at all depths between 51 and 170 m, occurring at 100% of the stations at all depths from 91-170 m, except for 111-120 and 141-150 m (Figure 8). This species was not a numerical dominant in any of the subpopulations; however, it contributed the largest biomass taken in the survey, including the central and southern regions, at the middle shelf depth zone, and the middle shelf POTW and non-POTW areas (Tables 6 and 7). The maximum number of California sea cucumber taken (over 50 per haul) were taken from 50-66 m depth in Santa Monica Bay and near the La Jolla Canyon off San Diego. Maximum biomass measurements (greater than 25 kg per haul) were also taken in southern Santa Monica Bay and near La Jolla Canyon. California sea cucumber preferred sediments with greater than 25% fines in this survey.

Fragile Sea Urchin (*Allocentrotus fragilis*)

Fragile sea urchin, an outer shelf species, occurred in

TABLE 6. Megabenthic invertebrate species comprising 95% or more of the total invertebrate biomass in the regional survey of the mainland shelf of southern California at depths of 10-200 m, July-August 1994.

		Biomass (kg)		Percent	
Scientific Name	Common Name	Mean/Haul*	Total	Total	Cumulative
Parastichopus californicus	California sea cucumber	2.53	340.6	38.6	38.6
Allocentrotus fragilis	fragile sea urchin	1.18	164.5	18.7	57.3
Spatangus californicus	California heart urchin	0.83	108.2	12.3	69.6
Sicyonia ingentis	ridgeback rock shrimp	0.88	75.2	8.5	78.1
Lytechinus pictus	white sea urchin	0.42	59.0	6.7	84.8
Brisaster latifrons	northern heart urchin	0.24	32.9	3.7	88.5
Metridium senile Cmplx	clonal plumose anemone	0.14	23.7	2.7	91.2
Ophiura luetkenii	brokenspine brittlestar	0.19	12.7	1.4	92.7
Luidia foliolata	gray sand star	0.12	10.6	1.2	93.9
Pisaster brevispinus	shortspined sea star	0.08	10.5	1.2	95.1

Total biomass = 891.3 kg.
Total area = 3,075 km^2.
* Area-weighted mean.

TABLE 7. Megabenthic invertebrate species comprising 80% or more of the invertebrate biomass by subpopulation on the mainland shelf of southern California at depths of 10-200 m, July-August 1994.

	Region						Shelf Depth Zone						Middle Shelf Outfall Status			
	North		Central		South		Inner		Middle		Outer		POTW		NPOTW	
Common Name	M	%	M	%	M	%	M	%	M	%	M	%	M	%	M	%
California sea cucumber	1.63	**17**	3.64	**58**	3.25	**40**	-	-	3.48	**61**	2.66	**21**	6.80	**70**	1.93	**49**
fragile sea urchin	1.19	**21**	1.23	**15**	1.09	**20**	-	-	-	-	5.22	**34**	-	-	-	-
California heart urchin	1.59	**29**	-	-	-	-	-	-	-	-	3.71	**22**	-	-	-	-
ridgeback rock shrimp	1.41	**13**	-	-	-	-	-	-	1.38	**15**	-	-	-	-	0.93	**28**
white sea urchin	-	-	-	-	0.63	**15**	-	-	0.46	**9**	-	-	1.01	**11**	-	-
northern heart urchin	-	-	0.71	**7**	-	-	-	-	-	-	1.07	**7**	-	-	-	-
clonal plumose anemone	-	-	-	-	0.32	**8**	-	-	-	-	-	-	-	-	-	-
shortspined sea star	-	-	-	-	-	-	0.22	**62**	-	-	-	-	-	-	-	-
California sand star	-	-	-	-	-	-	0.05	**13**	-	-	-	-	-	-	-	-
mosaic sand star	-	-	-	-	-	-	0.03	**7**	-	-	-	-	-	-	-	-
brokenspine brittlestar	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.22	**7**

M = Area-weighted mean; units — kilograms/haul.
POTW = Publicly owned treatment work monitoring areas; NPOTW = non-POTW areas.
N = Northern; C = Central; S = Southern; IS = Inner shelf; MS = Middle shelf; OS = Outer shelf; POTW = Middle-shelf POTW; NPOTW = Middle-shelf non-POTW.
Total catch biomass (kg) by subpopulation: N = 170.5; C = 301.8; S = 149.5; IS = 137.0; MS = 277.1; OS = 207.7; POTW = 165.4; NPOTW = 111.7.
Total area (km^2) by subpopulation: N = 1,561; C = 820; S = 694; IS = 676; MS = 1,709; OS = 689; POTW = 290; NPOTW = 1,419.

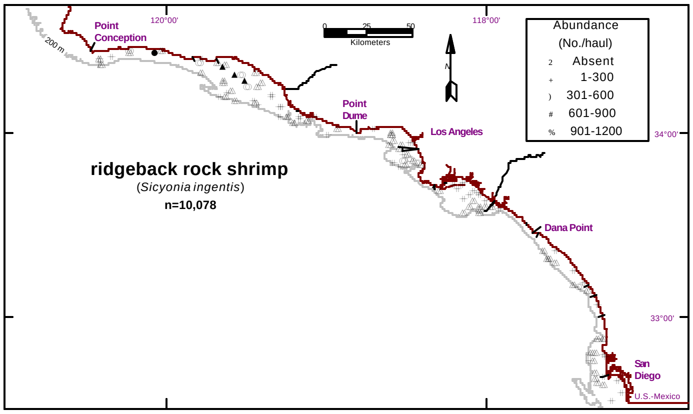
23% of the area, and accounted for 6% of the abundance and 19% of the survey biomass (Figure 9; Tables 2, 4, and 6). By depth, it occurred in 50% or more of the stations at all depths between 101 and 220 m, occurring at 100% of the stations at all depths from 151-220 m (Figure 9). This species was second most abundant in the outer shelf zone and third in the central region (Table 5). However, fragile sea urchin contributed the most biomass in the outer shelf depth zone (34%) and the second most biomass in all three geographic regions (northern, central, and southern) (Table 7). The largest numbers (over 450 per haul) were taken in fine sediments at 162-208 m, near the Orange County outfall, off Oceanside and in southern Santa Monica Bay. The largest biomass measurements (over 16 kg per haul) were taken near the Orange County outfall and in southern Santa Monica Bay.

California Heart Urchin *(Spatangus californicus)*

California heart urchin, an outer shelf species, was found in 9% of the area, and accounted for 4% of the abundance and 12% of the biomass (Figure 10; Tables 2, 4, and 6). By depth, it occurred in 50% or more of the stations at 111-120 m and all depths between 151 and 180 m, occurring in 100% of the stations at 111-120 m and 141-160 m (Figure 10). This species was most common in the

FIGURE 3. Distribution of ridgeback rock shrimp (*Sicyonia ingentis*) on the mainland shelf of southern California at depths of 10-200 m, July-August 1994: (a.) map of abundance with inset diagram of species; and (b.) map of biomass with inset graph of frequency of occurrence by depth. Numbers of samples by depth class are shown in Figure 1.

a.



b.

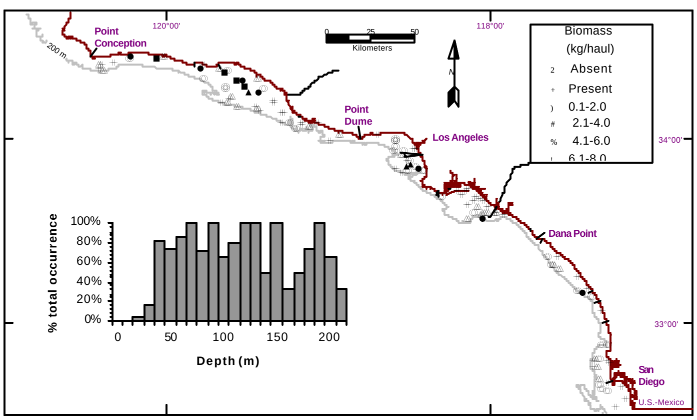
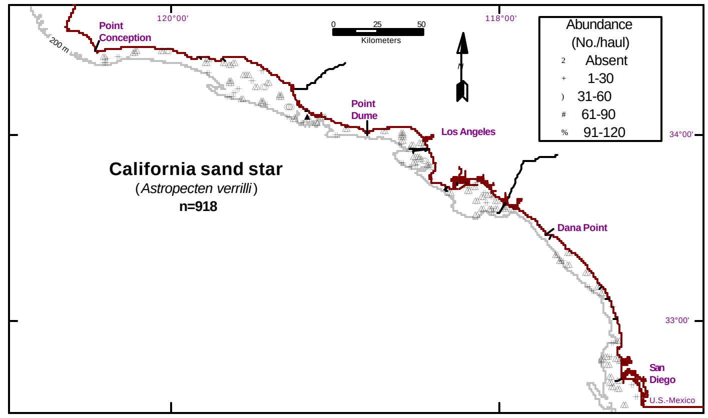
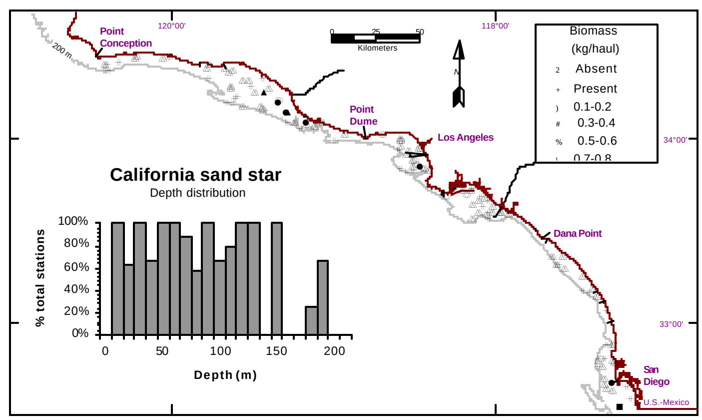


FIGURE 4. Distribution of California sand star (*Astropecten verrilli*) on the mainland shelf of southern California at depths of 10-200 m, July-August 1994: (a.) map of abundance with inset diagram of species; and (b.) map of biomass with inset graph of frequency of occurrence by depth. Numbers of samples by depth class are shown in Figure 1.

a.



b.



northern region (9% of abundance, 29% of biomass) and outer shelf zone (11% of abundance, 22% of biomass) (Tables 5 and 7). An exceptional catch of 2,077 individuals weighing 74 kg was taken off Santa Barbara.

Anomalies

A single invertebrate anomaly was observed. Burnspot disease occurred in one southern spinyhead (*Metacrangon spinosissima*); a shrimp from a depth of 215 m directly south of Malibu Point.

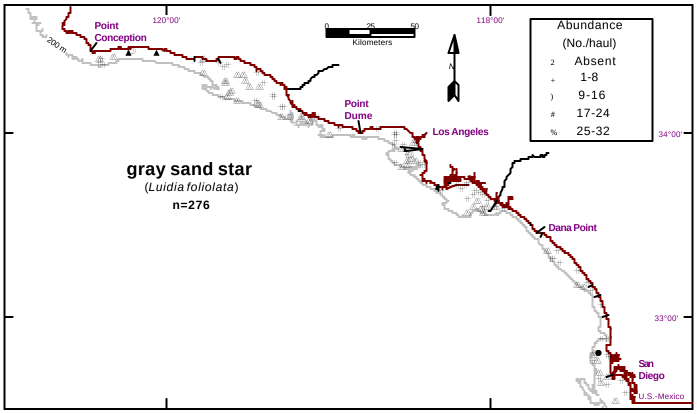
DISCUSSION

Although 204 species of invertebrates were collected in the survey, only eight species dominated either areal coverage, abundance, or biomass in this survey. These include ridgeback rock shrimp, California sand star, gray sand star, white sea urchin, brokenspine brittlestar, California sea cucumber, fragile sea urchin, and California heart urchin. All but the ridgeback rock shrimp (an arthropod) were echinoderms. Of these, the ridgeback rock shrimp and California sea cucumber are harvested commercially in trawl fisheries in southern California.

Ridgeback rock shrimp was the most important shrimp species in the survey, and is the species with the most information on its distribution and ecology. It is a benthic omnivore, feeding on detritus, diatoms, and infaunal polychaetes, gastropods, and crustaceans (Mearns 1982; P.L. Striplin, Striplin Environmental Associates, Seattle, WA, personal communication). Regionally, abundance appears to decrease from north to south. In the 1994 survey, the mean

FIGURE 5. Distribution of gray sand star (*Luidia foliolata*) on the mainland shelf of southern California at depths of 10-200 m, July-August 1994: (a.) map of abundance with inset diagram of species; and (b.) map of biomass with inset graph of frequency of occurrence by depth. Numbers of samples by depth class are shown in Figure 1.

a.



b.

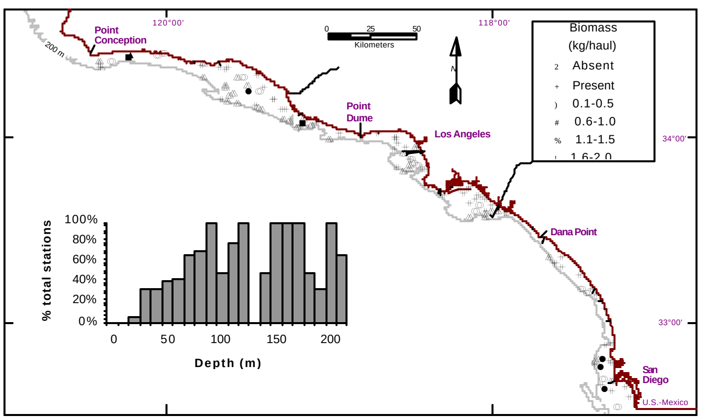
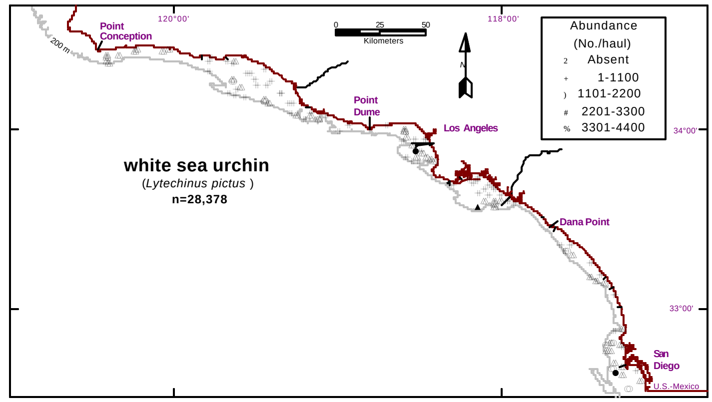
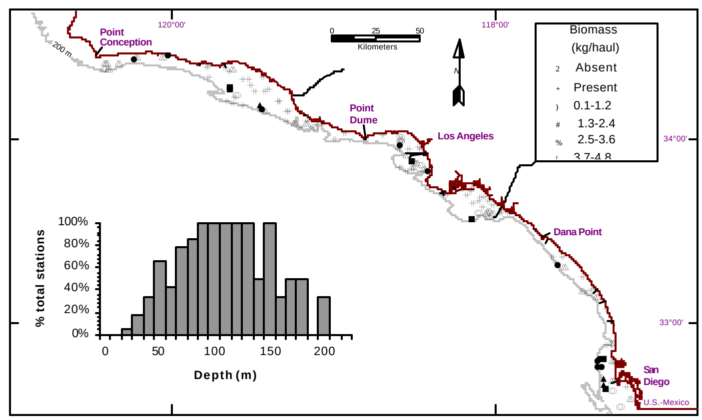


FIGURE 6. Distribution of white sea urchin (*Lytechinus pictus*) on the mainland shelf of southern California at depths of 10-200 m, July-August 1994: (a.) map of abundance with inset diagram of species; and (b.) map of biomass with inset graph of frequency of occurrence by depth. Numbers of samples by depth class are shown in Figure 1.

a.



b.



abundance of this species was five times higher in the northern region than in the central region (Table 5). This distribution of abundance is also reflected by the areas where the species is fished commercially (i.e., in the Santa Barbara Channel and off Santa Monica Bay) (Sunada and Richards 1992). Major population centers in southern California occur in the Ventura-Santa Barbara Channel area, Santa Monica Bay, and Oceanside. From 1971-1985, it was the second most abundant species in the northern and central region invertebrate assemblages, with abundance increasing with latitude (Thompson *et al.* 1993a). By depth, the species is common on the middle and outer shelf zones. Within its depth range of 5-307 m, Perez-Farfante (1985) indicated that it was most abundant at 55-82 m (within the middle shelf zone of the 1994 survey). In 1994, it was also most abundant in the middle shelf zone, with its mean abundance being 4 times higher in the middle shelf zone than on the outer shelf zone (Table 5). Thompson *et al.* (1993a) reported that ridgeback rock shrimp was the most common and abundant species in the outer shelf-upper slope assemblage, in 1971-1985, especially at approximately 150 m. It was also the second most abundant species in the middle shelf zone assemblage, and it was second in biomass on the middle shelf. It occurs on substrates of sand, shell, and green mud (Sunada and Richards 1992), preferring sediments with over 25% fines in 1994. Populations of this harvested species typically increase following El Niño events (Sunada and Richards 1992, Thompson *et al.* 1993a, Stull and Tang 1996). Because the 1994 survey followed soon after the 1992-1993 El Niño event (Hayward *et al.* 1995), catches may have been higher than normal.

The California sand star, the most widespread (72% of the area) invertebrate species overall in the survey, was the most frequent species in northern and central zones, with

FIGURE 7. Distribution of brokenspine brittlestar (*Ophiura luetkenii*) on the mainland shelf of southern California at depths of 10-200 m, July-August 1994: (a.) map of abundance with inset diagram of species; and (b.) map of biomass with inset graph of frequency of occurrence by depth. Numbers of samples by depth class are shown in Figure 1.

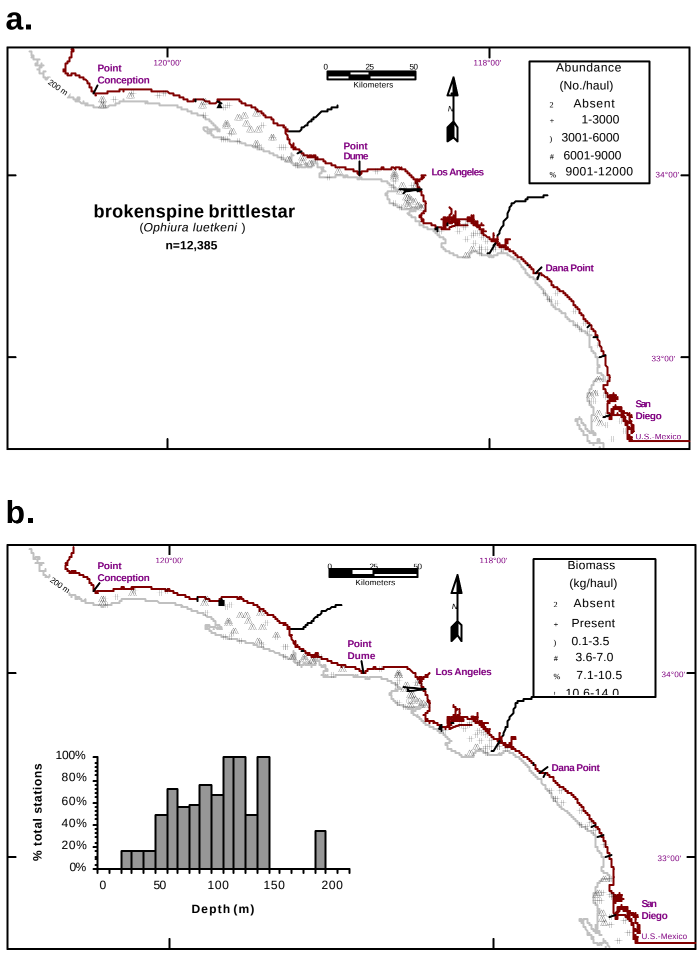
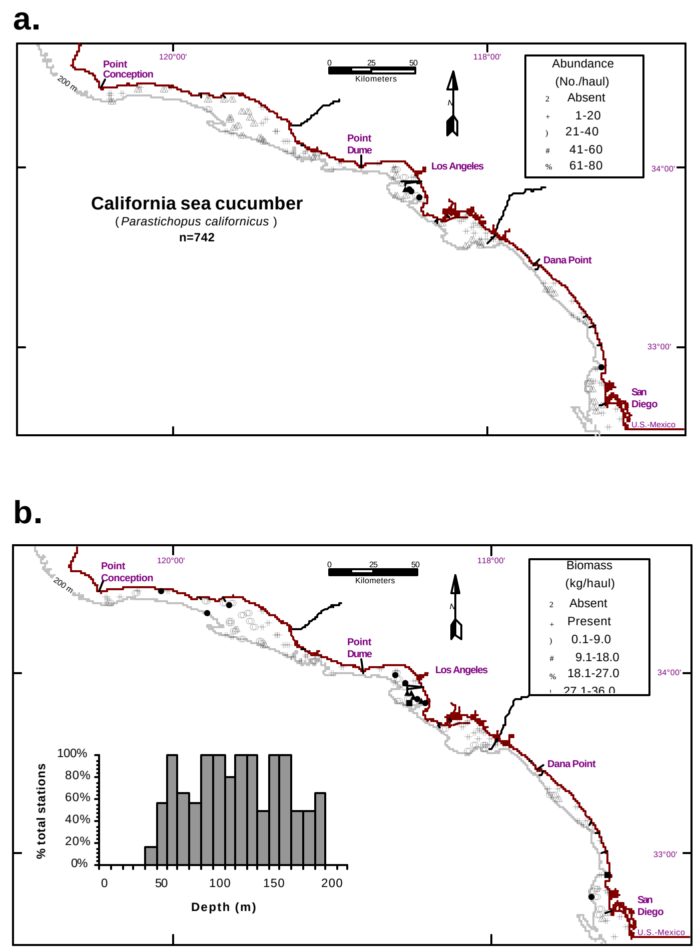


FIGURE 8. Distribution of California sea cucumber (*Parastichopus californicus*) on the mainland shelf of southern California at depths of 10-200 m, July-August 1994: (a.) map of abundance with inset diagram of species; and (b.) map of biomass with inset graph of frequency of occurrence by depth. Numbers of samples by depth class are shown in Figure 1.



abundance increasing toward the north; fewer specimens were taken south of Santa Monica Bay. Thompson *et al.* (1993a) reported that California sand star was the most commonly collected species in the normal SCB mainland shelf assemblage, occurring in 79% of 10-137 m sites, with greatest abundance at 90 m. In 1994, it was generally present in trawls from 10-150 m, and was most abundant in the inner and middle shelf zones. Its known depth range is 2-488 m (Maluf 1988). Peak numbers occurred at 25-50% fines in 1994. Thompson *et al.* (1993a) found numbers increased during El Niño events. California sand star feeds like similar species of its genus (*Astropecten*) on annelids, clams, scaphopods, small crustaceans, other sea stars, sea cucumbers, sea urchins, brittle stars, and fishes (Feder 1980). It feeds by forcing its arms into the soft substrate around a prey organism, and swallowing the prey whole, without everting the stomach (Lissner and Hart 1996a).

Gray sand star was the next most important sea star in the survey. It had a wider depth range from the inner shelf to over 200 m. Its known depth range is 0-476 m (Lissner and Hart 1996a). Numbers were highest on the middle shelf, but occurrence was higher on the outer slope. The species has been found on mud, sand, and shell substrates in a previous study (Lissner and Hart 1996a), and sediments with 25-75% fines in 1994. It is an active predator that burrows into the sediment to capture prey organisms, such as mollusks, crustaceans, heart urchins, and other echinoderms (Striplin 2987, Lissner and Hart 1996a).

The brokenspine brittlestar was the dominant brittlestar, and the second most abundant invertebrate in the survey. Although it occurs over a wide depth range (9-1,265 m; Hendler 1996), its highest mean abundance in this survey was on the middle shelf due to a single large catch of 11,575 specimens at 38 m off Santa Barbara. Ziesenhenne (1937) reported a catch from a single trawl as “bushelsful.” These

FIGURE 9. Distribution of fragile sea urchin (*Allocentrotus fragilis*) on the mainland shelf of southern California at depths of 10-200 m, July-August 1994: (a.) map of abundance with inset diagram of species; and (b.) map of biomass with inset graph of frequency of occurrence by depth. Numbers of samples by depth class are shown in Figure 1.

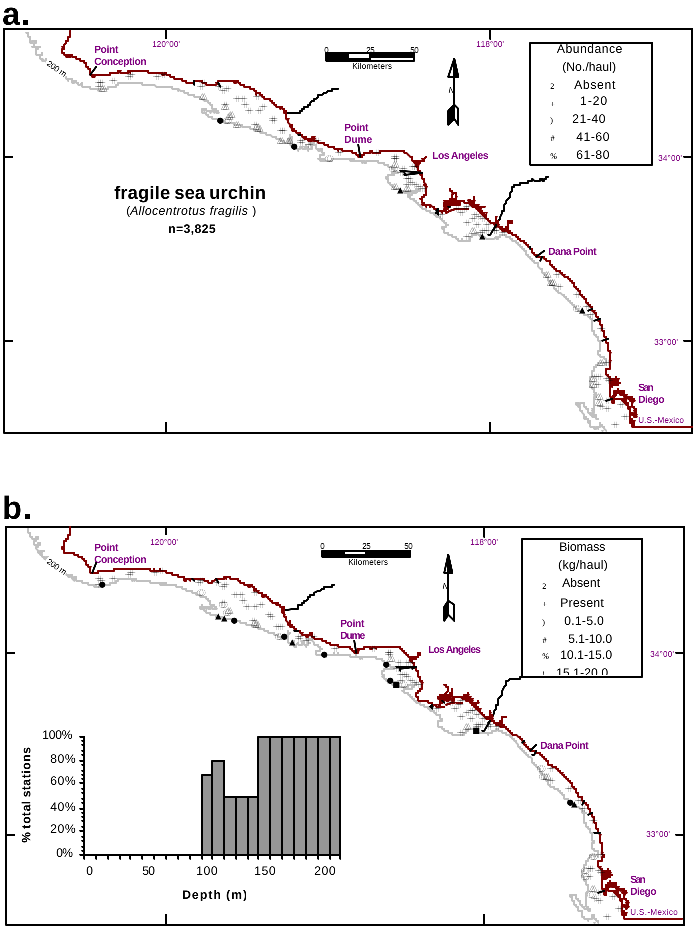
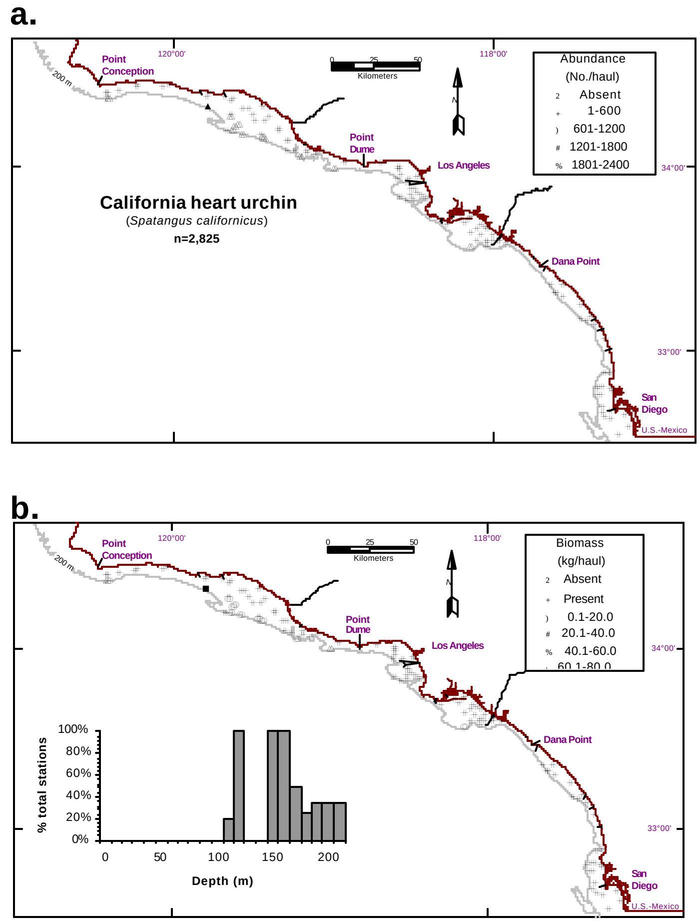


FIGURE 10. Distribution of California heart urchin (*Spatangus californicus*) on the mainland shelf of southern California at depths of 10-200 m, July-August 1994: (a.) map of abundance with inset diagram of species; and (b.) map of biomass with inset graph of frequency of occurrence by depth. Numbers of samples by depth class are shown in Figure 1.



aggregations may be reproductive aggregations. Hendler (1996) noted that its distribution was patchy, and this is confirmed in its occurrence in only 39% of the area sampled in 1994. It occurs in silt, mud, sand, shell, and gravel bottoms (Kyte 1969), and in 1994 in sediments with 25% fines. Brokenspine brittlestar is a sediment-surface deposit feeder, ingesting protozoans, small animals, and detritus (Kyte 1969).

The California sea cucumber was the most important holothurian in the survey, and ranked first among all invertebrates in biomass (Table 6). It is a sediment-surface deposit feeder that uses its tentacles to ingest mud, sand, and detritus (Kalvass 1992). Although adults are patchily distributed on sand and rocks from the intertidal zone (in northern California) to 216 m depth (Bergen 1996), little is known of its populations in California (Kalvass 1992). In 1994, it was common on the middle and outer shelf zones, and it contributed the most biomass on the middle shelf zone, and in central and southern regions. A small trawl fishery for this species is found mostly in the Santa Barbara Channel (Kalvass 1992) and, in the recent past, also on the San Pedro Shelf (G. Robertson, Orange County Sanitation District, Fountain Valley, CA, persersonal communication).

White sea urchin was overall the most abundant invertebrate in the 1994 survey (Table 4), with mean abundance increasing to the south, with depth, and near POTWs (Table 5). White sea urchin also dominated 1971-1985 SCB trawls, occurring in over 40% of the samples at 10-200 m (Thompson *et al.* 1993a). These investigators reported heterogeneous distributions in both space and time, including “herds” up to 50,000 in size, with several age classes and with orders of magnitude variation at different depths, in different years, and as a result of storms and El Niño events. The species lives on mud, sand, rocks, and shells at depths from intertidal to 300 m (Lissner and Hart 1996b). White sea urchins are sediment-surface omnivores, feeding on diatoms, juvenile algae, kelp (Durham *et al.* 1980, Lissner and Hart 1996b), and dead fish (observed in *situ* videos; by the second author (MJA).

The fragile sea urchin is an outer shelf species that was second in overall biomass for the survey (Table 6). This species occurs from 50 to 1,200 m (Maluf 1988), with a predominant range from 150 to 480 m; it is most abundant at 300 m (Thompson *et al.* 1987b). In 1994, the fragile sea urchin was the most frequently taken species on the outer shelf, and contributed the most biomass on the outer shelf. It occurs primarily on very fine to fine silty clay sediments (but also on hard substrate) (Maluf 1988), preferring sediments with over 25% fines in 1994. It is a predator and scavenger, feeding on algal debris and dead fish (Lissner and Hart 1996b).

The California heart urchin was the most important heart urchin in the 1994 survey. It was infrequent on the outer shelf (although second to the fragile sea urchin in biomass; Table 7), and contributed significant biomass to the northern zone. The one exceptionally large catch from 150 m off Santa Barbara (2,100 specimens, 74 kg), in sediments with 82% fines, likely represented part of a herd, as described for other SCB echinoids (Thompson *et al.* 1987a). It ranges in depth from 150 to 380 m, and is most abundant at 300 m (Thompson *et al.* 1987b). This species probably burrows beneath the sediments, feeding on subsurface organically enriched sediments as do other heart urchins (e.g., Durham *et al.* 1980).

Invertebrate catches are naturally highly variable. Apparent differences between middle shelf POTW and non-POTW populations (Tables 3, 5, and 7) may, in some cases, be more related to geography than to ocean outfalls. For example, there were no POTW areas in the northern region and three in the central region. The most notable differences between POTW and non-POTW populations of common species were the larger biomass and areal extent of California sea cucumbers, and the larger abundance, biomass, and area of white sea urchins in the POTW areas. These two species were also important contributors to non-POTW assemblages. Ridgeback rock shrimp abundance and biomass were higher in non-POTW areas; this is a more northerly species, which may account for the larger catches in non-POTW areas. On average, more brokenspine brittlestars were found in non-POTW areas; this was because of the single large sample off Santa Barbara. Two less abundant species, Pacific spiny brittlestar and yellow sea twig, were only common in outfall areas.

Species distributions further support the observation of Allen and Moore (1996) and Allen *et al.* (1998). Based upon the 1994 survey, Allen and Moore (1996) reported that outfall areas generally had higher catch parameter values than non-outfall areas, including significantly higher biomass and diversity. They speculated this result may be attributable to stimulation from wastewater discharge, but may also be related to a broader shelf in the vicinity of the outfalls in much of the survey area; only two stations were on the narrow Palos Verdes Shelf area. Similarly, Allen *et al.* (1998, 1999) found no pollution effects in the SCB study area; unique cluster groups were not formed near potential anthropogenic sources of contamination, including wastewater outfalls, river discharges, and oil platforms.

Historical Comparisons

While direct historical comparisons are limited because past studies were either not synoptic or were not of a similar regional scale, three studies (Carlisle 1969a,b; Mearns and Greene 1974; Thompson *et al.* 1993a) had sufficient scope or value for comparison. Carlisle (1969a,b) reported on 705 trawl samples collected at 39 sites, 20-200 m, in Santa Monica Bay, 1958-1963. Invertebrate species were listed with depth range encountered but only qualitative descriptions of abundance were given and no biomass or frequency of occurrence. Mearns and Greene (1974) described a small-scale synoptic study at similar depth zones (25, 60, and 140 m) in the central region (including Santa Monica Bay, Palos Verdes Shelf, and San Pedro Bay) in September 1973, but it only sampled 28 transect stations and these were near outfall areas. However, this study did provide information on abundance, biomass, and frequency of occurrence of invertebrate species. Thompson *et al.* (1993a) compiled data on megabenthic invertebrates from 1,203 otter trawl samples in the central regional and over a greater depth range (10-915 m) from 1971 to 1985. Station distributions differed from 1994, including many in POTW areas, and multiple years were analyzed, in which some species increased several orders of magnitude. This study was an assemblage analysis that identified dominant species in site and species clusters, but did not provide a listing of dominant species by the population attributes described for 1994 nor in the same subpopulation categories. It nevertheless provides the best large-scale information on megabenthic invertebrates for comparison with this survey. In addition to having different regional scopes and presenting information on different catch parameters, these reports included certain infauna, smaller organisms, colonial fauna, and others that were excluded from the 1994 survey. Nevertheless, it is apparent that some changes in the invertebrate populations have occurred since the 1950s.

Carlisle (1969a) noted that ridgeback rock shrimp was common, sometimes with high abundance, and that California sand star, white sea urchin, California sea cucumber, and fragile sea urchin were all common. In 1994, California sand star and ridgeback rock shrimp were the most common species in the central region, with the other species being relatively uncommon. Carlisle (1969a) lists a diverse molluscan fauna, many of which would now be categorized as benthic infauna.

Mearns and Greene (1974) found fewer echinoderms and more arthropods and mollusks than were found over a larger area in 1994. In both periods, California sand star and ridgeback rock shrimp were common and abundant and California sea cucumber was commonly taken. White sea urchin and fragile sea urchin were reported as "sometimes abundant" in 1973; both were widespread and common in 1994. Octopus (*Octopus* spp.), in all three depth zones, and armed box crab (*Platymera gaudichaudii*) on the outer shelf, were more frequent in 1973. Certain shrimp were absent or less abundant in 1994, including blackspotted bay shrimp (*Crangon nigromaculata*) on the inner shelf, Alaska bay shrimp on the middle shelf, and slender blade shrimp (*Spirontocaris holmesi*) and ocean shrimp (*Pandalus jordani*) on the outer shelf. The lean nassa (*Nassarius mendicus*; a gastropod) was sometimes abundant in 1973. In 1994, gray sand star, brokenspine brittlestar, and northern heart urchin were more frequent and abundant. The shifts in occurrence and abundance between 1973 and 1994 may be due, in part, to the differences in sampling locations (three outfall areas in 1973 and the mainland shelf of southern California in 1994) (Mearns and Greene 1974; Mearns *et al.* 1976) or in part to a warming of the oceanic environment since the 1980s (Smith 1995).

As with the 1994 study (Allen *et al.* 1998, 1999), Thompson *et al.* (1993a) showed that assemblage composition is primarily influenced by water depth and other related factors. Thompson *et al.* (1993a) reported changes coincident with contamination (e.g., a Palos Verdes Shelf pre-1980 assemblage), El Niño events (e.g., ridgeback rock shrimp and pelagic red crab *Pleuroncodes planipes* increases by two orders of magnitude), and strong storms in shallow water (e.g., reduced diversity at 18-37 m).

The most common and abundant species on the mainland shelf and upper slope in 1971-1985 were white sea urchin, ridgeback rock shrimp, California sand star, pelagic red crab, and fragile sea urchin. All but the pelagic red crab also dominated in 1994. Pelagic red crabs are transported from west of Baja California to the SCB during many El Niño events (Gomez-Gutierrez and Sanchez-Ortiz 1997). In 1994, fewer ridgeback rock shrimp and pelagic red crab and more white sea urchin were found on the outer shelf. On average, there were more brokenspine brittlestars on the middle shelf and California heart urchin on the outer shelf.

Invertebrate external anomalies have decreased markedly since the early 1970s. In 1994, a single case of burnspot disease was observed in the southern spinyhead shrimp, one of 66,333 invertebrates collected in the survey. In the early 1970s, exoskeletal lesions resembling burnspot disease (and of unknown etiology) were observed in armed box crabs and rock crabs (*Cancer* spp.) (SCCWRP 1973). For armed box crabs, 15 cases were identified among 180 specimens taken from Palos Verdes, 12 of 27 taken from Santa Monica Bay, and 1 of 3 taken from Newport Beach in Orange County. Also in the early 1970s, the following anomolies were identified on urchins: spine loss (from samples taken at White Point on the Palos Verdes Peninsula, fungal infections (from samples taken from White Point and Corona del Mar); and an epizootic growth on tissue lesions (from a sample taken from Point Loma).

LITERATURE CITED

Allen, M.J., D. Diener, J. Mubarak, S.B. Weisberg and S.L. Moore. 1999. Megabenthic invertebrate assemblages of the mainland shelf of southern California in 1994. pp. 113-124 *in:* S.B. Weisberg and D. Hallock (eds.), Southern California Coastal Water Research Project Annual Report 1997-1998. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J. and S.L. Moore. 1996. Spatial variability in southern California demersal fish and invertebrate catch parameters in 1994. pp. 114-127 *in*: M.J. Allen, C. Francisco, and D. Hallock (eds.), Southern California Coastal Water Research Project Annual Report 1994-1995. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J. and S.L. Moore. 1997. Recurrent groups of megabenthic invertebrates on the mainland shelf of southern California in 1994. pp. 129-135 *in:* S.B. Weisberg, C. Francisco, and D. Hallock (eds.), Southern California Coastal Water Research Project Annual Report 1996. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J., S.L. Moore, K.C. Schiff, S.B. Weisberg, D. Diener, J.K. Stull, A. Groce, J. Mubarak, C.L. Tang and R. Gartman. 1998. Southern California Bight 1994 Pilot Project: V. Demersal fishes and megabenthic invertebrates. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J. and R. Voglin. 1976. Regional and local variability of bottom fish and invertebrate populations. pp. 217-221 *in*: Southern California Coastal Water Research Project Annual Report 1975-1976. Southern California Coastal Water Research Project. El Segundo, CA.

Bergen, M. 1996. Class Holothuroidea. pp. 195-250 *in*: J.A. Blake, P.H. Scott and A. Lissner (eds.), Taxonomic Atlas of the Benthic Fauna of the Santa Maria Basin and the Western Santa Barbara Channel Volume 14, Miscellaneous taxa. Santa Barbara Museum of Natural History. Santa Barbara, CA.

California Department of Finance, Demographic Research Unit

(CDF,DRU). 1995. Population Estimates for California Cities and Counties, January 1, 1995 and 1994. Report 95 E-1 (Official State Estimates). California Department of Finance, Demographic Research Unit. Sacramento, CA.

Carlisle, J.G. 1969a. Invertebrates taken in a six year trawl study in Santa Monica Bay. *Veliger* 11:237-242.

Carlisle, J.G. 1969b. Results of a six-year trawl study in an area of heavy waste discharge: Santa Monica Bay, California. *California Fish and Game* 55:26-46.

City of Los Angeles, Environmental Monitoring Division (CLAEMD). 1994. Santa Monica Bay, Annual Assessment Report 1994. City of Los Angeles, Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division. Los Angeles, CA.

City of San Diego, Metropolitan Wastewater Department (CSDMWWD). 1995. Receiving Waters Monitoring Report 1995. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division. San Diego, CA.

County Sanitation Districts of Los Angeles County (CSDLAC). 1997. Annual Report 1996: Palos Verdes Ocean Monitoring. County Sanitation Districts of Los Angeles County. Whittier, CA.

County Sanitation Districts of Orange County (CSDOC). 1996. CSDOC Marine Monitoring Annual Report 1995; including a ten-year synthesis: 1985-1995. County Sanitation Districts of Orange County. Fountain Valley, CA.

Durham, J.W., C.D. Wagner and D.P. Abbott. 1980. Echinoidea: The sea urchins. pp. 160-176 *in*: R.H. Morris, D.P. Abbott, and E.C. Haderlie (eds.), Intertidal Invertebrates of California. Stanford University Press. Stanford, CA.

Feder, H.M. 1980. Asteroidea: The sea stars. pp. 117-135 *in*: R.H. Morris, D.P. Abbott, and E. C. Haderlie (eds.), Intertidal Invertebrates of California. Stanford University Press. Stanford, CA.

Gomez-Gutierrez, J. and C.A. Sanchez-Ortiz. 1997. Larval drift and population structure of the pelagic phase of *Pleuroncodes planipes* (Stimpson) (Crustacea: Galatheidae) off the southwest coast of Baja California, Mexico. *Bulletin of Marine Science* 61:305-325.

Hayward, T.L., D.R. Cayan, P.J.S. Franks, R.J. Lynn, A.W. Mantyla, J.A. McGowan, P.E. Smith, F.B. Schwing and E.L. Venrick. 1995. The state of the California Current in 1994-1995: A period of transition. *California Cooperative Oceanic Fisheries Investigations Reports* 36:19-39.

Hendler, G. 1996. Class Ophiuroidea. pp. 113-179 *in*: J.A. Blake, P.H. Scott, and A. Lissner (eds.), Taxonomic Atlas of the Benthic Fauna of the Santa Maria Basin and the Western Santa Barbara Channel. Volume 14, Miscellaneous taxa. Santa Barbara Museum of Natural History. Santa Barbara, CA.

Kalvass, P. 1992. Sea cucumbers. pp. 44-45 *in*: W.S. Leet, C.M. Dewees, and C.W. Haugen (eds.), California's Living Marine Resources and Their Utilization. Sea Grant Extension Publication, UCSGEP-92-12. California Sea Grant. University of California, Davis, CA.

Kyte, M.A. 1969. A synopsis and key to the Recent Ophiuroidea of Washington State and southern British Columbia. *Journal of the Fisheries Research Board of Canada* 26:1727-1741.

Lissner, A. and D. Hart. 1996a. Class Asteroidea. pp. 97-112 *in*: J.A. Blake, P.H. Scott, and A. Lissner (eds.), Taxonomic Atlas of the Benthic Fauna of the Santa Maria Basin and the Western Santa Barbara Channel, Volume 14, Miscellaneous taxa. Santa Barbara Museum of Natural History. Santa Barbara, CA.

Lissner, A. and D. Hart. 1996b. Class Echinoidea. pp. 181-194 *in*: J.A. Blake, P.H. Scott, and A. Lissner (eds.), Taxonomic Atlas of the Benthic Fauna of the Santa Maria Basin and the Western Santa Barbara Channel, Volume 14, Miscellaneous taxa. Santa Barbara Museum of Natural History. Santa Barbara, CA.

Maluf, L. 1988. Composition and Distribution of Central Eastern Pacific Echinoderms. Technical Report No. 2. Natural History Museum of Los Angeles County. Los Angeles, CA.

Mearns, A.J. 1982. Assigning trophic levels to marine animals. pp. 125-141 *in:* W. Bascom (ed.), Southern Coastal Water Research Project Biennial Report 1981-1982. Southern California Coastal Water Research Project. Long Beach, CA.

Mearns, A.J., M.J. Allen, L.S. Word, J.Q. Word, C.S. Greene, M.J. Sherwood and B. Myers. 1976. Quantitative Responses of Demersal Fish and Benthic Invertebrate Communities to Coastal Municipal Wastewater Discharges. Grant R801152. Prepared for United States Environmental Protection Agency, National Marine Water Quality Laboratory. Corvallis, OR.

Mearns, A.J. and C.S. Greene. 1974. A Comparative Trawl Survey of Three Areas of Heavy Waste Discharge. Technical Memorandum 215. Southern California Coastal Water Research Project. El Segundo, CA.

Perez-Farfante, I. 1985. The rock shrimp genus *Sicyonia* (Crustacea: Decapoda: Penaeoidea) in the eastern Pacific. *Fishery Bulletin* 83:1-79.

Raco-Rands, V. 1999. Characteristics of effluents from large municipal wastewater treatment facilities in 1996. pp 2-17 *in*: S.B. Weisberg and D. Hallock (eds.), Southern California Coastal Water Research Project Annual Report 1997-1998. Southern California Coastal Water Research Project. Westminster, CA.

Southern California Association of Marine Invertebrate Taxonomists (SCAMIT). 1998. A Taxonomic Listing of Soft Bottom Macro- and Megainvertebrates from Infaunal and Epibenthic Monitoring Programs in the Southern California Bight. Third Edition. Southern California Association of Marine Invertebrate Taxonomists. San Pedro, CA..

Schiff, K.C., M.J. Allen, E.Y. Zeng and S.M. Bay. 2000. Southern California. pp. 385-404 *in:* C.R.C. Sheppard (ed.), Seas at the Millennium: An Environmental Evaluation. Elsevier Science. New York, NY.

Southern California Coastal Water Research Project (SCCWRP). 1973. The ecology of the Southern California Bight: Implications for Water Quality Management. Technical Report 104. Southern California Coastal Water Research Project. El Segundo, CA.

Smith, P.E. 1995. A warm decade in the Southern California Bight. *California Cooperative Oceanic Fisheries Investigations Reports* 36:120-126.

Stevens, D.L., Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. *Environmetrics* 8:167-195.

Striplin, P.L. 1987. Resource utilization by Astropecten verrilli along gradients of organic enrichment. M.S. thesis. California State University, Long Beach, Long Beach, CA.

Stull, J. 1995. Two decades of marine biological monitoring, Palos Verdes, California, 1972 to 1992. *Bulletin of the Southern California Academy of Sciences* 94:21-45.

Stull, J.K. and C.-L. Tang. 1996. Demersal fish trawls off Palos Verdes, southern California, 1973-1993. *California Cooperative Oceanic Fisheries Investigations Reports* 37:211-240.

Sunada, J.S., and J.B. Richards. 1992. Ridgeback prawn. pp. 11-12 *in*: W.S. Leet, C.M. Dewees, and C.W. Haugen (eds.), California's Living Marine Resources and Their Utilization. Sea Grant Extension Publication. UCSGEP-92-12. California Sea Grant. University of California, Davis, CA.

Thompson, B.E., G.F. Jones, J.D. Laughlin and D.T. Tsukada. 1987a. Distribution, abundance, and size composition of echinoids from basin slopes off southern California. *Bulletin of the Southern California Academy of Sciences* 92:25-42.

Thompson, B.E., J.D. Laughlin and D.T. Tsukada. 1987b. 1985 Rference Site Survey. Technical Report 221. Southern California Coastal Water Research Project. Long Beach, CA.

Thompson, B., D. Tsukada and J. Laughlin. 1993a. Megabenthic assemblages of coastal shelves, slopes, and basins off southern California. *Bulletin of the Southern California Academy of Sciences* 92:25-42.

Thompson, B., D. Tsukada and D. O'Donohue. 1993b. 1990 reference site survey. Technical Report 269. Southern California Coastal Water Research Project. Westminster, CA.

Thompson, S.K. 1992. Sampling. John Wiley & Sons. New York, NY.

Word, J.Q., A.J. Mearns, and M.J. Allen. 1977. Better control stations: The 60-meter survey. pp. 89-97 *in*: Southern California Coastal Water Research Project Annual Report 1976-1977. Southern California Coastal Water Research Project. El Segundo, CA.

Ziesenhenne, F. 1937. The Templeton Crocker Expedition. X. Echinoderms from the west coast of lower California, the Gulf of California and Clarion Island. *Zoologica* 22:209-239.

ACKNOWLEDGEMENTS

This study was conducted as part of the Southern California Bight Pilot Project (SCBPP). The authors wish to thank the technical staffs of the following organizations, who jointly conducted field collection and data processing: City of Los Angeles Environmental Monitoring Division (CLAEMD), County Sanitation Districts of Los Angeles County (CSDLAC), Orange County Sanitation District (OCSD), City of San Diego Metropolitan Wastewater Department (CSDMWWD), Southern California Coastal Water Research Project, MEC Analytical Systems, Inc., and MBC Applied Environmental Sciences. We also thank the SCBPP Trawl Group members for their involvement in all steps of the analyses: Stephen B. Weisberg (SCCWRP); Douglas Diener and Jason Mubarak (MEC Analytical Systems, Inc.); Ami Groce and Robin Gartman (CSDMWWD); C. Irwin Haydock, George Robertson, Mike Mengel, and Jeff Armstrong (CSDOC); Greg Deets, Dr. Masahiro Dojiri, Tony Phillips, and Jim Roney (CLAEMD). We also thank the Southern California Association of Marine Invertebrate Taxonomists, and in particular Don Cadien (CSDLAC), Dave Montagne (CSDLAC), and Ron Velarde (CSDMWWD) for their advice on taxonomic nomenclature changes.