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MARINE ADVISER

AN EVALUATION OF THE MARINE FAUNA AND FL
IN THE VICINITY OF DIABLO COVE, CALIFORN

By

Wheeler J. North

FISHING ACTIVITY IN THE DIABLO COVE ARE.

By

Frances N. Clark

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IN THE VICINITY OF DIABLO COVE, CALIFORNIA

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December 1966

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OBJECTIVES

During preliminary planning of the survey there was little information available concerning the biota of the coastline between Morro Bay and Point San Luis. The first objective, accordingly, was to gather sufficient general information from *in situ* inspections so that an adequate survey could be designed. Immediately before the first visit, a report by Earl E. Ebert[1], Department of Fish and Game, State of California, became available and supplied a substantial part of the general information needed. On the basis of this knowledge plus information gathered during our survey, it is believed that an adequate study was conducted and the first objective satisfactorily achieved. Other objectives were:

2. Describe the physical environment in terms useful for ecological assessments.
3. Identify the principal animal and plant species.
4. On the basis of items 2 and 3, develop a general ecological description of the study area.
5. Without excessive speculation, furnish reasonable predictions of effects that a warm discharge may have on the biota.
6. Suggest precautions that might aid in conserving the biota.

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1. Ebert, E. E., 1966, An evaluation of marine resources, Pt. Buchon to Pt. San Luis, San Luis Obispo County, with particular reference to abalone and the Diablo Canyon area May 2-4, 1966, Department of Fish and Game, State of California.

Concerning items 2 and 3, one can measure parameters and collect specimens virtually ad infinitum and continue to develop useful information. Nonetheless a point of diminishing returns is reached and it is believed that this position has been attained when information from the present survey is combined with results from prior studies. The current state of knowledge is sufficient to permit significant progress in achieving objectives 4, 5, and 6.

An additional objective should be mentioned but was not undertaken because of time limitations. Seasonal changes in the biota and the physical environment should be determined. Appropriate times for such work would be mid-to-late spring near the end of the stormy season, and again in mid-August to early September, when sea surface temperatures are likely to be maximal.

No emphasis was placed on commercially important species such as fish and abalone in the present study. These have already been given considerable attention in the reports by Ebert and by Frances Clark. Likewise the general character of the present study developed information that applies both to commercially important as well as to other species. If seasonal studies are undertaken, however, somewhat more emphasis should be given to the commercial species.

THE PHYSICAL ENVIRONMENT

Diablo Cove is a major indentation in an exposed and extremely rugged rocky coast. The highly irregular terrestrial topography is also representative of the sea floor. Smooth areas are limited and dimensions of the irregularities range from ridges measuring fractions of an inch to pinnacles standing 10 to 40 feet high. Sand and small cobbles fill some of the depressions, but the sediment cover on the bottom is not extensive.

Underwater visibility was good at the time of our visits, contrasting to the rather fair conditions found by Ebert's group in late spring. Bottom light intensities were low, but measurements were made on an overcast day (Table 1). On a clear day intensities would probably have been 50 to 100 times greater and submarine illumination values would be classed as excellent. Dense algal growths extended to depths of 50 to 60 feet, indicating that the light climate of the region was indeed good. The algal cover might extend even deeper if grazing urchins were removed.

Temperature was uniform from the surface to the deepest point reached (80 feet). Values of about 14° C were obtained, which is approximately normal for the area at the time of the study. The fauna and flora were a mixture of warm-water and cold-water forms. The warm-water species, however, were organisms that survive cold temperatures without apparent ill effects, but there were many cold-water species that do poorly in warmer temperatures. It was assumed, therefore, that water temperatures are characteristically cold in the region and that the presence of warm-water species was due to

Table 1

Bottom and Topside Light Intensities

Light intensities are given in ergs/cm^2/sec at Diablo Cove on November 5, 1966. Measurements were made while swimming along Transects D and F (Figure 1). Cloud cover changed substantially during the period so that surface illumination varied. The sky was overcast throughout and intensities about 50 to 100 times greater would be expected on a clear day.

	Depth			Intensity, ergs/cm^2/sec			
Time	feet	red*	orange*	yellow*	green*	blue*	violet*
0950	0	9,400	5,700	10,000	15,000	8,800	8,900
1000	70	66	130	350	720	370	150
	60	170	370	960	1,800	940	430
1025	50	370	460	2,100	2,300	2,000	2,300
1115	10	5,000	5,500	13,000	17,000	11,000	11,000
	20	2,500	3,100	6,200	9,300	4,900	3,000
	30	1,800	2,400	5,500	9,300	4,900	3,000
1200	40	870	1,500	4,100	6,500	2,600	1,400
1230	0	48,000	23,000	45,000	66,000	25,000	30,000

*Characteristics of the color filters and a description of the light meter are given in Anderson and North, Annual Report, Kelp Habitat Improvement Project, 1965-66, Calif. Inst. Tech., pages 31 to 44.

the proximity of their centers of distribution, south and east of Point Conception.

Many species characteristic of cold water were found in the intertidal zone. A substantial number were attached forms such as plants, requiring months or longer to develop. Their presence at this level suggests that fairly cold water exists throughout the water column even in summer. Thermoclines are probably reduced or absent throughout the year.

Wave exposure is greatest from the southwest. Some protection to swells from the west and northwest is offered by Diablo Rock and a shallow sill (Figure 1). Virtually complete protection is provided by the mainland in all other directions. In spite of the protection, longer or foliose algae are restricted primarily to deeper levels, suggesting that wave action is severe.

Although the surrounding headlands and offshore islands offer considerable lee from swells, Diablo Cove is very elongate across the entrance and is not sufficiently indented to form a baylike environment. All organisms found were typical of exposed rocky coasts. Water circulation and mixing are probably very well developed in all parts of the Cove.

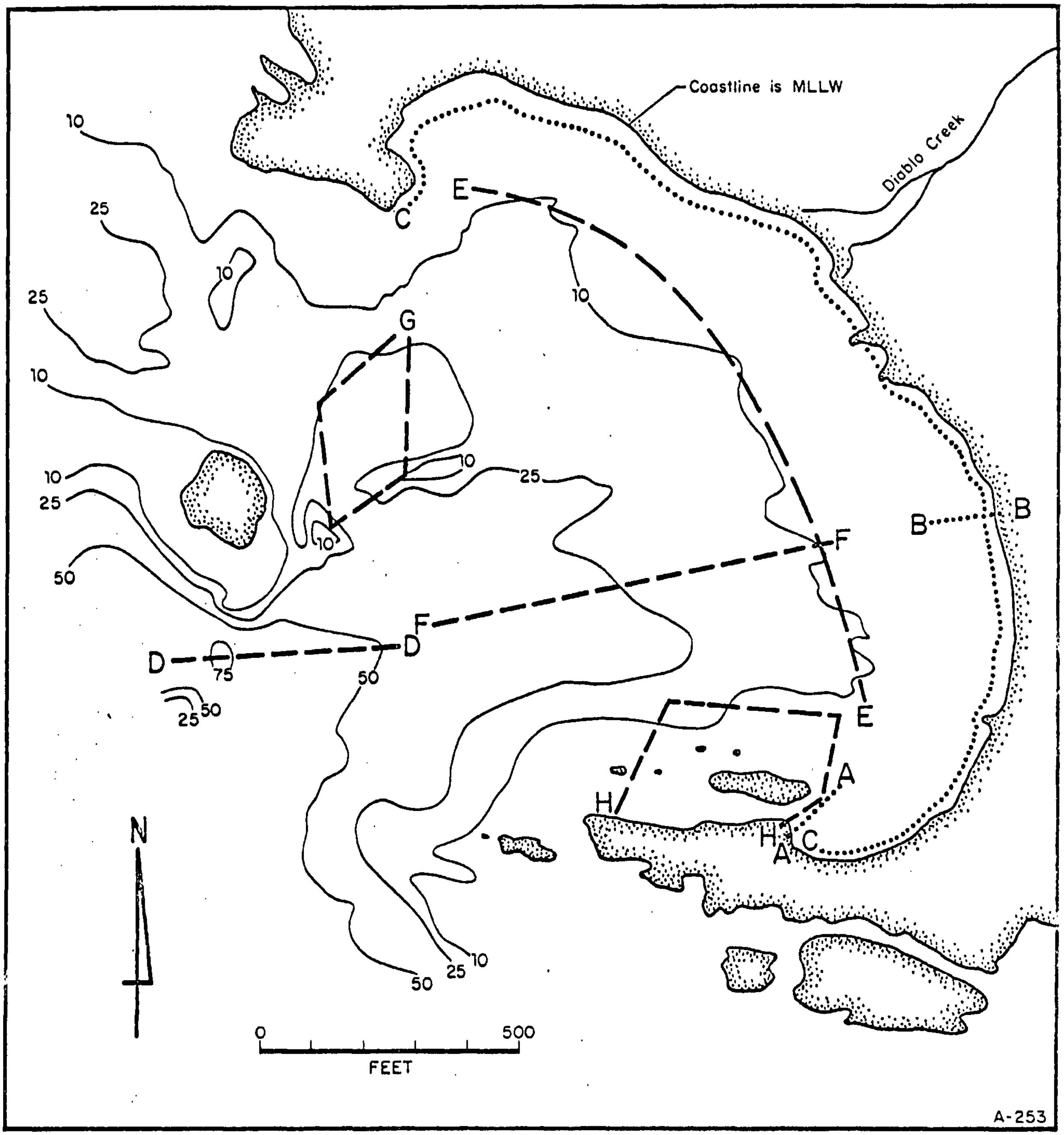

Figure 1. Diablo Cove, showing position of transects studied in November, 1966. Alphabetical designation of subtidal transects indicates order in which they were surveyed. Depths are in feet.

PLANT AND ANIMAL SPECIES

All species observed along three intertidal and five subtidal transects (Figure 1) were identified to the lowest taxon possible without seeking assistance from specialists. Intertidally, 44 plant species and 64 animal species were recorded (Tables 2 and 3). Subtidally, 52 plant forms and 134 animal types were identified (Tables 4 and 5). As indicated above, the biota was a mixture of northern and southern forms and those species that are common in warm water in southern California have been designated by an asterisk in the tables. Many forms could be identified only to families or genera. Such categories were counted as a single species in arriving at the totals cited above. Actually these groups may contain two or more species, hence the totals are minimal values. Undoubtedly species were overlooked or not recognized while running the transects. Crevice environments in particular were incompletely surveyed, simply due to lack of time. New species may appear in other seasons. Ebert's report lists 22 species not observed in the present survey. Probably the list of plant species is fairly complete (Ebert recorded only one alga not listed by us) but the total complement of animals in Diablo Cove may easily be double the number in our list. It is believed that additional transects in other parts of the Cove would probably not yield large numbers of additional species since recovery of unobserved species decreased markedly in the later transects. As mentioned, more intensive studies of complex habitats (crevice environments, algal mats, sediment samples, etc.) would probably be more fruitful.

Table 2

Species list of seaweeds observed intertidally at Diablo Cove, November 12, 1966.

Phylum or Major Group	Scientific Name	Common Name	Approx Level or Range, feet
Chlorophyta			
	Cladophora trichotoma*	sea grass	+4 to +1
	Codium Setchelli		+1 to -1
	Enteromorpha sp.*	green weed	+3 to 0
	Spongomorpha coalita	filamentous green	+1 to 0
Phaeophyta			
	Colpomenia sinuosa*	spongy kelp	+2 to 0
	Dictyoneurum californicum	blade kelp	0 to subtidal
	Egregia Menziesii*	feather boa kelp	0 to subtidal
	Fucus furcatus	rockweed	+3 to +1
	Hesperophycus Harveyanus*	rockweed	+3 to +2
	Laminaria Andersonii	palm kelp	0 to subtidal
	Nereocystis leutkeana	bull kelp	-1 to subtidal
	Pelvetia fastigata*	rockweed	+ 3 to +2
	Ralfsia pacifica*	encrusting brown	+3 to subtidal
Rhodophyta			
	Agardhiella Coulteri*	filamentous red	0
	Bossiella orbigniana*	coralline red	0 to -1
	Botryoglossum farlowianum	fleshy red	0 to subtidal
	Calliarthron Setchelliae*	coralline red	0 to subtidal
	Callophyllis crenulata	fleshy red	0 to subtidal
	Corallina gracilis*	coralline red	+2 to 0
	Corallina chilensis*	coralline red	+1 to subtidal
	Cryptosiphonia Woodii	fleshy red	+1 to 0
	Endocladia muricata*	busy red	+2 to +1
	Farlowia sp.	fleshy red	0
	Gastroclonium Coulteri	fleshy red	+2 to subtidal
	Gelidium cartilagineum*	fleshy red	+1 to subtidal
	Gigartina Binghamiae*	foliose red	0 to subtidal
	Gigartina canaliculata*	fleshy red	+1 to subtidal
	Gigartina cristata	fleshy red	+2 to 0
	Gigartina leptorhyncus*	fleshy red	+1 to -1

*Occurs in warm water

Table 2 (Continued)

Phylum or Major Group	Scientific Name	Common Name	Approx Level or Range, feet
Rhodophyta (Continued)			
	Gigartina papillata	fleshy red	+3 to 0
	Gigartina volans*	foliose red	0 to subtidal
	Gracilariopsis Sjoestedtii*	fleshy red	0
	Grateloupia schizophylla	foliose red	+2 to -1
	Gymnogongrus linearis	fleshy red	0 to subtidal
	Halosaccion glandiforme	tubular red	+1 to -1
	Hymenena flabelligera	foliose red	0
	Iridophycus flaccidum	foliose red	+2 to subtidal
	Iridophycus heterocarpum	foliose red	+2 to subtidal
	Laurencia spectabilis	fleshy red	+1 to subtidal
	Lithothamnium sp. *	encrusting coralline	+1 to subtidal
	Plocamium pacificum*	fleshy red	+1 to subtidal
	Polysiphonia californica	filamentous red	0 to subtidal
	Porphyra perforata	foliose red	+4 to +1
	Prionitis linearis*	stringy red	+1 to subtidal
	Rhodoglossum affine*	bushy red	+2 to 0
	Rhodomela floccosa	fleshy red	0
	Smithora niaidum*	epiphytic red	0 to subtidal
Spermatophyta			
	Phyllospadix Scouleri*	surf grass	+2 to subtidal

*Occurs in warm water

Table 3

Species list of animals observed intertidally at Diablo Cove, November 12, 1966.

Phylum or Major Group	Scientific Name	Common Name	Approx Level or Range, feet
Protozoa			
	*Gromia oviformis**	foraminiferan	+1 to subtidal
Porifera			
	Cliona sp.	sponge	0
	Haliclona spp.	sponge	0 to subtidal
Coelenterata			
	*Anthopleura elegantissima**	anemone	+2 to -1
	*Anthopleura xanthogrammica**	anemone	0 to subtidal
	*Sagartia elegans**	anemone	0 to subtidal
Platyhelminthes			
	*Leptoplana chloranota**	flatworm	+1 to -1
Bryozoa			
	Hippothoa hyalina	moss animal	0 to subtidal
	Lyrula hippocrepis	moss animal	-1
	*Membranipora membranacea**	moss animal	on drift kelp
	Membranipora villosa	moss animal	0
	Microporella sp. or spp.	moss animal	+1 to subtidal
	Rhyncozoon rostratum	moss animal	0 to subtidal
Annelida			
Polycheta			
	*Dexiospira spirillum**	spiral worm	0 to subtidal
	Eupomatus	tube worm	0
	Nereidae*	worm	+1 to subtidal
	Sabellariidae*	tube worm	0 to subtidal
	Spionidae	worm	+1 to subtidal
	Terebellidae*	worm	0 to subtidal
Mollusca			
Amphineura			
	*Mopalia muscosa**	hairy chiton	+1 to -1
	Unident. chiton		

*Occurs in warm water

Table 3 (Continued)

Phylum or Major Group	Scientific Name	Common Name	Approx Level or Range, feet
Mollusca			
Gastropoda			
	Acanthina spirata	unicorn snail	+2 to 0
	Aclis sp.	snail	+1
	Acmaea pelta*	limpet	+6 to 0
	Acmaea persona*	limpet	+2
	Acmaea scabra*	limpet	+3 to +2
	Haliotis cracherodii*	black abalone	+3 to subtidal
	Haliotis rufescens	red abalone	0 to subtidal
	Lacuna porrecta	chink snail	+1 to -1
	Littorina planaxis*	periwinkle	+7 to +4
	Littorina scutulata*	periwinkle	+2 to +1
	Lottia gigantea*	giant limpet	+6 to +2
	Mitrella aurantiaca	dove snail	+2 to 0
	Spiroglyphis lituellus	tube snail	0
	Tegula brunnea	brown top snail	+1 to subtidal
	Tegula funebralis*	black top snail	+3 to 0
Pelecypoda			
	Chama pellucida*	rock clam	+1 to subtida
Arthropoda			
Crustacea			
	Balanus glandula*	barnacle	+3 to +1
	Cancer sp.	rock crab	0
	Chthamalus fissus*	barnacle	+3 to +2
	Cirolana harfordi*	pillbug	+1 to subtidal
	Hemigrapsus oregonensis*	crab	0
	Idothea sp.	isopod	0
	Lygia occidentalis*	isopod	+6 to +3
	Mimulus foliatus*	decorater crab	+1 to -1
	Pachycheles pubescens*	rock crab	0
	Pachycheles rudis*	rock crab	0
	Pagurus granosimanus*	hermit crab	+1 to subtidal
	Pagurus hirsutiusculus*	hermit crab	+1 to subtidal
	Petrolisthes eriomerus*	porcelain crab	+1 to subtidal
	Pugettia richii	kelp crab	+1
	Pugettia productus*	kelp crab	+2 to subtidal
	Tetraclita squamosa*	barnacle	+1 to -1
	Pachygrapsus crassipes*	shore crab	+3 to 0

*Occurs in warm water

Table 3 (Continued)

Phylum or Major Group	Scientific Name	Common Name	Approx Level or Range, feet
Echinodermata			
Asteroidea			
	Linckia sp.	sea star	+1
	Pateria miniata*	bat star	+1 to subtidal
	Pisaster ochraceous*	ochre star	+1 to subtidal
	Pycnopodia helianthoides	sun star	0 to subtidal
Echinoidea			
	Strongylocentrotus purpuratus*	purple urchin	+2 to subtidal
Chordata			
Urochordata			
	Cystodites sp.	sea squirt	+1 to subtidal
	Pycnoclavella stanleyi	sea squirt	0
Pisces			
	Xererpes fucorum	rockweed blenny	+1 to -1
Aves			
	Larus sp. *	sea gull	
Mammalia			
	Zalophus*	sea lion	

*Occurs in warm water

Table 4

Species list of plants observed subtidally at Diablo Cove, November 5 and 6, 1966

Phylum or Major Group	Scientific Name	Common Name	Approx Depth or Depth Range feet
Chlorophyta			
	Bryopsis corticulans		30
	Cladophora*	sea grass	10
	Ulva lobata	sea lettuce	5 - 20
Phaeophyta			
	Cystoseira osmundacea*	kelp	30 - 40
	Dictyoneurum californica	kelp	20 - 40
	Dictyota binghamiae*		10
	Desmarestia herbacea		10 - 30
	D. munda		10 - 30
	Ectocarpus*	filamentous brown	30
	Egregia Menziesii	feather boa kelp	10
	Laminaria Andersonii	palm kelp	20 - 60
	Nereocystis leutkeana	bull kelp	10 - 50
	Pterygophora californica	palm kelp	20 - 70
Rhodophyta		red algae	
	Acrosorium uncinatum*		0 - 50
	Aeodes gardneri		40
	Amplisiphonia		
	Botryoglossum farlowianum		10 - 40
	Bossiella corymbifera		20
	Bossiella gardneri		20
	Calliarthron cheilisporoides		10 - 70
	Calliarthron regenerans		20
	Callophyllis firma		10 - 20
	Callophyllis flabellulata		30 - 60
	Callophyllis violacea		30
	Cryptosiphonia Woodii		30
	Endocladia muricala*		10
	Fryeella gardneri		60
	Gastroclonium coulteri		10
	Gelidium robustum*		10 - 30

*Occurs in warm water

Table 4 (Continued)

Phylum or Major Group	Scientific Name	Common Name	Approx Depth or Depth Range feet
Rhodophyta (Continued)			
	Gigartina canaliculata*		10 - 40
	Gigartina corymbifera*		10 - 30
	Gigartina binghamiae*		10 - 50
	Gigartina Leptorhynchus*		10
	Gigartina papillata		5
	Grateloupia schizophylla		5
	Gymnogongrus platyphyllus		10
	Hildenbrandia prototypus		
	Iridophycus flaccidum		10
	Iridophycus heterocarpum		5
	Laurencia spectabilis		20
	Lithothamniom*		80
	Opuntiella californica		30 - 60
	Peyssonnelia pacifica		10 - 70
	Polyneura latissima		30 - 60
	Prionitis lanceolata		10
	Prionitis linearis*		10 - 20
	Pterosiphonia gracilis		20
	Ptilota densa		30
	Rhodoglossum affine*		5
	Weeksia reticulata		30 - 60
Chrysophyta			
	Licmorpha sp. *	diatom	30
Spermatophyta			
	Phyllospadix scouleri*	surf grass	10 - 20

*Occurs in warm water

Table 5

Species list of animals observed subtidally at Diablo Cove, November 5 and 6, 1966.

Phylum or Major Group	Scientific Name	Common Name	Approx Depth or Depth Range feet
Protozoa			
	Gromia oviformis*	Foraminiferan	Intertidal to 20
Porifera			
	Acarnus erichthacus	sponge	
	Hymenamphiastra	sponge	30
	Leuconia heathii	sponge	20 - 40
	Leucosolenia eleanor	sponge	20 - 40
	Rhabdodermella nuttingi	sponge	20 - 40
	Spheciospongia confederata*	liver sponge	15
	Tethya aurantia	puffball sponge	70
	Tetilla arb	sponge	20 - 40
Coelenterata			
Hydrozoa			
	Abietinaria	ostrich plume	10 - 50
	Aglaophenia*	ostrich plume	20 - 30
	Allopora	blue coral	60 - 80
	Campanularia	hydroid	10 - 30
	Halecium	hydroid	
	Obelia*	hydroid	
	Plumularia	hydroid	
	Sertularella*	hydroid	
	Sertularia*	hydroid	
Scyphozoa			
	Haliclystus		20
Anthozoa			
	Anthopleura xanthogrammica*	anemone	
	A. elegantissima*	anemone	
	A. artemesia	anemone	
	Balanophyllia elegans	cup coral	50 - 70
	Corynactis	pink anemone	40 - 70
	Sagartia elegans*	anemone	20 - 40
	Telia	anemone	30 - 70

*Occurs in warm water

Table 5 (Continued)

Phylum or Major Group	Scientific Name	Common Name	Approx Depth or Depth Range feet
Bryozoa		moss animal	
	Cauloramphus		
	Costazia*		
	Crisia		
	Diaporoecia*		20 - 30
	Diasporella		
	Flustrella		
	Haloporella		
	Hippothoa		
	Lagenipora		
	Lyrula		
	Membranipora fusca		
	Membranipora membranacea*		encr. on kelp
	Microporella		20
	Mucronella		
	Parasmittina		
	Pherusella		
	Phidolopora*		30 - 50
	Rhyncozoon		
	Scrupocellaria		
	Thalamoporella		50
	Tricellaria		
	Tubulipora		
Nemertea	(unidentified)	ribbon worm	20
Sipunculoidea	(unidentified)	peanut worm	20
Annelida			
Polycheta			
	Chaetopterus*	fan worm	30 - 70
	Dexiospira*	spiral worm	10 - 50
	Eudistyla*	feather duster	20 - 70
	Nereidea	worm	10 - 30
	Polynoidae	scale worm	20 - 40
	Salmacina tribranchiata	tube worm	30
	Serpula*	tube worm	40

*Occurs in warm water

Table 5 (Continued)

Phylum or Major Group	Scientific Name	Common Name	Approx Dep or Depth Range feet
Mollusca			
Amphineura			
	Cryptochiton	gumboot	20 - 40
	Chiton, unident.		30
	Ischnochiton mertensii		20
	Ischnochiton radians		20
Gastropoda			
	Acmaea incessa*	limpet	5 - 20
	Acmaea mitra	limpet	10 - 50
	Acmaea paleacea*	limpet	20
	Acmaea persona*	limpet	3 - 15
	Aletes squamigerous*	tube mollusk	40
	Astraea inequalis	top snail	20 - 60
	Calliostoma annulata	ringed top snail	10 - 70
	Calliostoma costatum	ribbed top snail	20 - 40
	Crepidula*	slipper shell	
	Fissurella*	keyhole limpet	10
	Haliotis chracherodii*	black abalone	2 - 10
	Haliotis rufescens	red abalone	10 - 60
	Hopkinsia rosacea*	pink nudibranch	10
	Jaton*	snail	
	Margarites	snail	
	Mitra ida	snail	70 - 40
	Mitrella aurantiaca	dove shell	
	Nassarius*	whelk	40
	Norrisia*	smooth turban	20
	Pteropurpura*	3-wing murex	
	Tegula brunnea	brown top snail	
	Tegula funebralis*	black top snail	5
	Tegula montereyi	Monterey top snail	20 - 50
	Tegula pulligo	dusky top snail	
Pelecypoda			
	Hinnites*	rock scallop	40 - 70
	Mytilus californianus*	mussel	2
	Saxicava (Hiatella) sp.	clam	20 - 40

*Occurs in warm water

Table 5 (Continued)

Phylum or Major Group	Scientific Name	Common Name	Approx Depth or Depth Range feet
Arthropoda			
Crustacea			
	Balanus crenatus	white barnacle	5 - 50
	Balanus nubilis	giant barnacle	40
	Balanus tintinnabulum*	pink barnacle	70
	Cancer sp.	crab	20
	Caprella sp.	amphipod	10 - 50
	Cirolana sp.	pillbug	
	Crago	shrimp	30
	Gammaridea	amphipod	
	Idothea resecata	kelp isopod	on kelp blade
	Loxorhyncus	spider crab	20 - 40
	Mimulus	decorater crab	
	Pagurus sp.	hermit crab	
	Petrolisthes	porcelain crab	20
	Pugettia producta*	kelp crab	20
Pycnogonida			
	Tanystalum occidentalis	sea spider	20
Echinodermata			
Asteroidea			
	Astrometis sertulifera*	spiny star	30 - 40
	Henricia levisculis	spindle star	20 - 30
	Pateria miniata	bat star	20 - 70
	Pisaster giganteus*	giant star	50
	Pisaster ochraceous*	ochre star	5
	Pycnopodia helianthoides	sun star	30 - 40
Echinoidea			
	Strongylocentrotus franciscanus	giant urchin	15 - 80
	Strongylocentrotus purpuratus*	purple urchin	20 - 40
Ophiuroidea			
	Ophioncus granulosus	brittle star	30
	Ophiothrix spiculata	brittle star	20 - 60
Holothuroidea			
	Stichopus	sea cucumber	60

*Occurs in warm water

Table 5 (Continued)

Phylum or Major Group	Scientific Name	Common Name	Approx Dep[th] or Depth Range feet
Chordata			
Urochordata			
	Ascidia ceratodes	sea squirt	20 - 40
	Boltenia villosa		20 - 40
	Botryllus sp.		
	Metandrocarpa sp.		50
	Sigillinaria sp.		20 - 40
Pisces			
	Anisotremus davidsoni*	Sargo	20 - 30
	Clinocottus analis	wooly sculpin	40
	Embiotoca jacksoni*	black perch	20 - 70
	Girella nigricans*	opaleye	10 - 30
	Heterostichus*	kelpfish	30 - 60
	Leiocottus hirundo*	lavender sculpin	20
	Lepidogobius lepidus	pale goby	20 - 40
	Ophiodon elongatus	ling cod	40 - 70
	Oxyjulis californica*	senorita	40
	Paralabrax clathratus*	kelp bass	10 - 70
	Scorpaena guttata	sculpin	30
	Scorpaenicthys marmoratus	cabezone	30
	Sebastodes mystinus	blue rockfish	10 - 70
	Sebastodes sp. (various)	rockfishes	10 - 50
Mammalia			
	Zalophus*	sea lion	0 - 40

*Occurs in warm water

Such intensive studies were not attempted for several reasons. One important purpose of recording organism varieties, namely to gain a concept of species diversity, was adequately fulfilled. It was clearly established that the biota comprises an extremely diversified assemblage of plants and animals. Another objective fulfilled by species lists is to establish beforehand conditions to assist in evaluating subsequent changes. If any serious changes occur in Diablo Cove, certainly a great many of the species we have recorded will be affected and it is believed that our lists provide a reasonably adequate basis for future assessments. Finally, species lists are a *sine qua non* for determining ecological relationships such as food chains, energy flows, community structure, succession patterns, etc. Unfortunately recording species for these purposes is a task almost without end since one can never be certain that some crucial but obscure organism has not been overlooked. For present requirements only rather general concepts of the ecology are needed and the usual approach to such an understanding involves consideration primarily of the large, obvious, dominant organisms. Almost certainly these are represented quite completely in our lists.

Our survey concentrated almost exclusively on Diablo Cove. Additional information on adjacent regions would be desirable. It was felt, however, that top priority should be assigned to the Cove and further work could be done in other locations after a sufficient understanding had been achieved for this, the most critical region. The reports by Ebert and by Clark treat adjacent areas to some extent so they are not completely unknown, and this confirmed our decision to concentrate our limited resources in studies of the Cove.

Quantitative measurements were made only along Transects A and B (Figures 2 and 3, Tables 6 and 7). These were undertaken more for the purpose of scrutinizing two randomly selected areas, rather than for developing meaningful absolute values for population concentrations, percent plant coverage, etc. It should be emphasized that the biota is so luxuriant and diversified that a large and sophisticated effort will be necessary to produce quantitative data sufficiently reliable to be of use. At the present time it would be difficult to judge how much work would be necessary, and it is not at all certain that the effort would be justified in terms of being able to evaluate changes with significantly increased precision. These difficult questions should be resolved somewhat by information on seasonal changes.

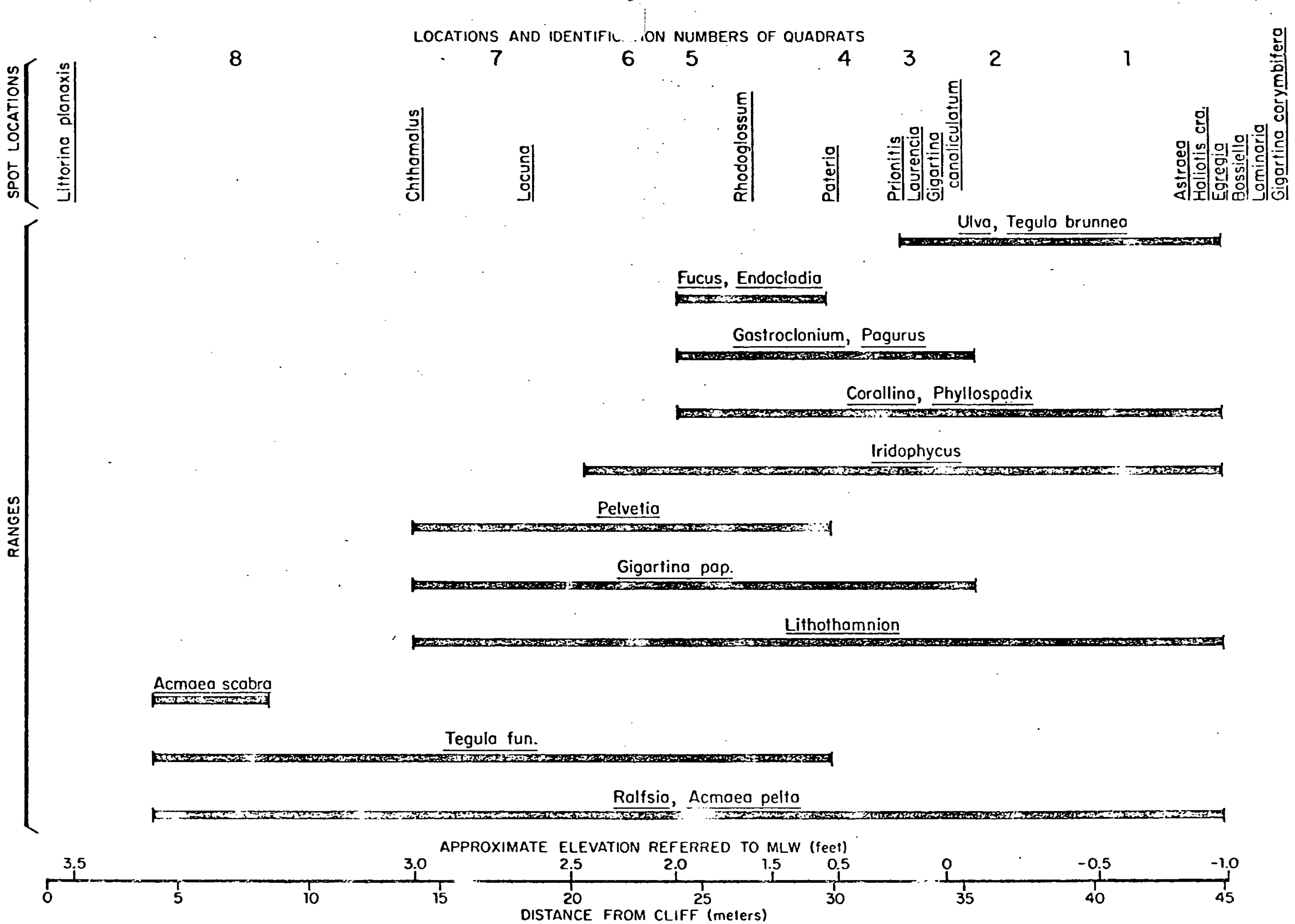

Figure 2. Ranges and/or locations of dominant organisms, Transect A, south side of Diablo Cove, 12 November 1966.

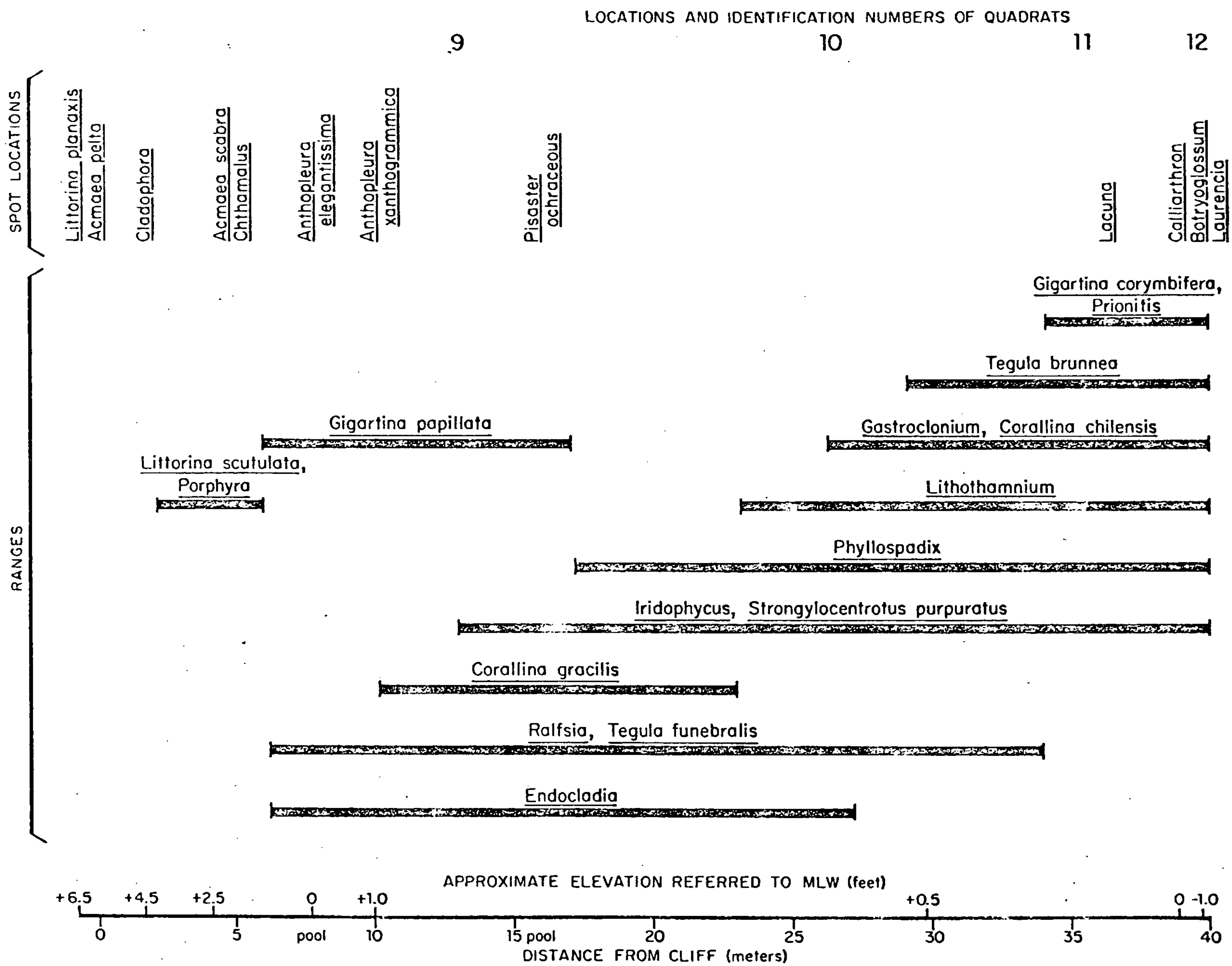

Figure 3. Ranges and/or locations of dominant organisms, Transect B, central Diablo Cove, approximate likely future location of discharge, 12 November 1966.

Table 6

Quadrat contents along Transect A, Diablo Cove, November 12, 1966. Quadrat was a brass square, 25 cm on a side. Locations of quadrats shown on chart of the Transect. Positions obtained by blind casts.

Quadrat Number	Organisms per Quadrat or percent Cover: Animals	Plants
1	5 *Acmaea pelta* 7 *Tegula brunnea*	12 *Gigartina corymbifera* (Juv.) 25% *Lithothamnium* 5% *Ralfsia*
2	3 *Acmaea pelta* 1 Chiton, unident. 6 *Pagurus* sp. 8 *Tegula brunnea*	8 *Gigartina papillata* 15% *Gigartina canaliculatum* 2% *Corallina* 6 *Iridophycus* 1 *Laurencia* 2 *Ulva*
3	3 *Acmaea pelta* 2% Bryozoa, unident.	30% *Gigartina papillata* 3 *Iridophycus* (ca. 30% coverage) 2% *Lithothamnium* 5% *Ralfsia* 2% *Ulva*
4	5 *Tegula brunnea* 15 *Tegula funebralis*	5% *Endocladia* 2 *Gastroclonium* 10% *Gigartina papillata* 5% *Lithothamnium* 1% *Ralfsia* 5% *Rhodoglossum* 5% *Ulva*
5	1 *Pagurus* sp. 140 *Tegula funebralis*	10% *Corallina* 1 *Gastroclonium* 20% *Gigartina papillata* 4 *Iridophycus* 5% *Lithothamnium* 2% *Ralfsia*
6	5 *Acmaea pelta* 1 Blenny, unident. many *Lacuna* (hidden in algae) 1 Unident. polychaete 50 *Tegula funebralis*	20% *Gigartina papillata* 5% *Ralfsia*
7	3 *Acmaea pelta* 7 *Tegula funebralis*	3% *Lithothamnium*
8		5% *Ralfsia*

Table 7

Quadrat contents along Transect B, Diablo Cove, November 12, 1966. Quadrat was a brass square, 100 cm on a side, divided into smaller squares 50 cm on a side. Animals were enumerated within a 1/4 m^2 area and plants were enumerated within a 1 m^2 area. Locations of quadrats shown on chart of the Transect. Quadrat positions were the result of blind casts.

Quadrat Number	Organisms per Quadrat or Percent Cover: Animals (per 1/4 m^2)	Plants (per m^2)
9	37 Tegula funebralis	25% Endocladia
	2 Strongylocentrotus purpuratus	30% Gigartina papillata
		5% Iridophycus
		40% Ralfsia
10		10% Corallina chilensis
		5% Endocladia
		50% Gastroclonium
		30% Iridophycus
		5% Ralfsia
11	1 Cancer sp.	90% Gastroclonium
	1 Fissurella	12 Iridophycus
	1 Henricia	1% Lithothamnium
	2 Mitrella	1% Laurencia
	1 Pugettia	1% Phyllospadix
	1 Tegula brunnea	5% Prionitis
12	9 Tegula brunnea	1 Botryoglossum
		15% Corallina chilensis
		5% Gastroclonium
		5% Gigartina canaliculatum
		1 Gigartina corymbifera
		15 Iridophycus (ca.20% covera
		1% Laurencia
		50% Phyllospadix
		5% Prionitis

THE ECOLOGY OF DIABLO COVE

General

As noted above, both the fauna and flora show considerable diversity. The diversity may arise in part from an ecotonal effect since Diablo Cove is near the well-known faunal and floral region of change at Point Conception (an ecotone is the region where two different habitats or environments overlap and species characteristic of each mingle with each other). Doubtless the diversity has also been abetted by the absence of human influence. Large numbers of legal sized black abalone in the intertidal region establish the pristine character.

One unusual feature that appeared to influence the distribution of the biota in a minor way was the discharge of fresh water from Diablo Creek in the center part of the Cove. Intertidally this results in the virtual disappearance of marine animals, and seaweeds are reduced to about four species (*Grateloupia*, *Prionitis*, *Cladophora*, and *Gigartina*).

The northwestern headland may cause some upwelling, although distributions are not influenced sufficiently to establish any clear relationship. Some of the deeper plants such as Nereocystis and Laminaria appear intertidally here, but protection from wave action might also be a factor. Underwater visibility was considerably better in the northern part of the Cove than in the southern, suggesting an influence by upwelling.

Surface drift was concentrated primarily in the southern and southeasterly portion of the Cove. Presumably this results more from the action of prevailing winds than from currents. A small accumulation of driftwood was also noted along the northern shore but virtually nothing was cast up over the large central region.

Nutritional Relationships

The economy of the Cove apparently depends heavily on productivity by attached algae. Herbivores noted were primarily grazing forms. While filter feeding animals were usually present in most areas, concentrations were typically sparse except in minor habitats such as the upper portions of large pinnacles. Environments where productivity is largely by phytoplankton (bays, polluted waters, etc.) usually display massive development of encrusting filter feeding organisms on virtually all solid surfaces. While the various genera and species of fouling animals were adequately represented (Porifera, Coelenterata, Bryozoa, Urochordata, Tables 3 and 5), abundances were exceptionally low, even for an exposed rocky coastal environment. Phytoplankton concentrations are typically higher in spring than in fall and perhaps greater numbers of fouling organisms would be observed in late spring. Certainly the "seeds" for fouling are present, only the "stimulus" for massive development seems to be lacking.

The importance of attached algae in the economy of the Cove was the primary reason we devoted considerable attention to characterizing the species of these plants. As noted above, our lists of algal species are believed to be fairly complete and contain perhaps 90 percent of the seaweeds present. Probably all the species contributing significantly to plant productiviare represented in the lists (Tables 2 and 4). Principal groups poorly represented are epiphytic and endophytic forms that may have important physiological effects on their hosts, but are very minor in their contribution to total plant productivity.

The intertidal plant communities were so complex that it would be extremely difficult to identify the relative contributions to plant productivity by the principal species without a long and careful study. Fortunately, the intertidal area is small compared to the total area of the cove, so it is safe to assume that the major portion of productivity occurs subtidally. Although 52 plant species were recorded subtidally, only 12 appeared sufficiently abundant to be considered significant to subtidal productivity (Desmarestia herbacea, Dictyoneurum, Egregia, Laminaria, Nereocystis, and Pterygophera among the brown algae; Botryoglossum, Calliarthron, Gigartina binghamiae, Iridopycus flaccidum, and Prionitis lanceolata among the red algae; Phyllospadix, a flowering plant). Approximate distributions of these major species were recorded while swimming the transects (Figure 4). In areas not covered by transects it was assumed that distributions and species were similar to comparable depths observed along the transects. Underwater visibility was sufficiently clear so that plant distributions could be determined from our skiff down to depths of about 15 feet and spotchecks were made throughout the shallow portions of the Cove to verify the data presented in Figure 4. Distributions of the bull kelp, Nereocystis, could be determined from the surface since this plant forms a canopy in the upper layers.

Of particular interest was a broad belt of barren territory found

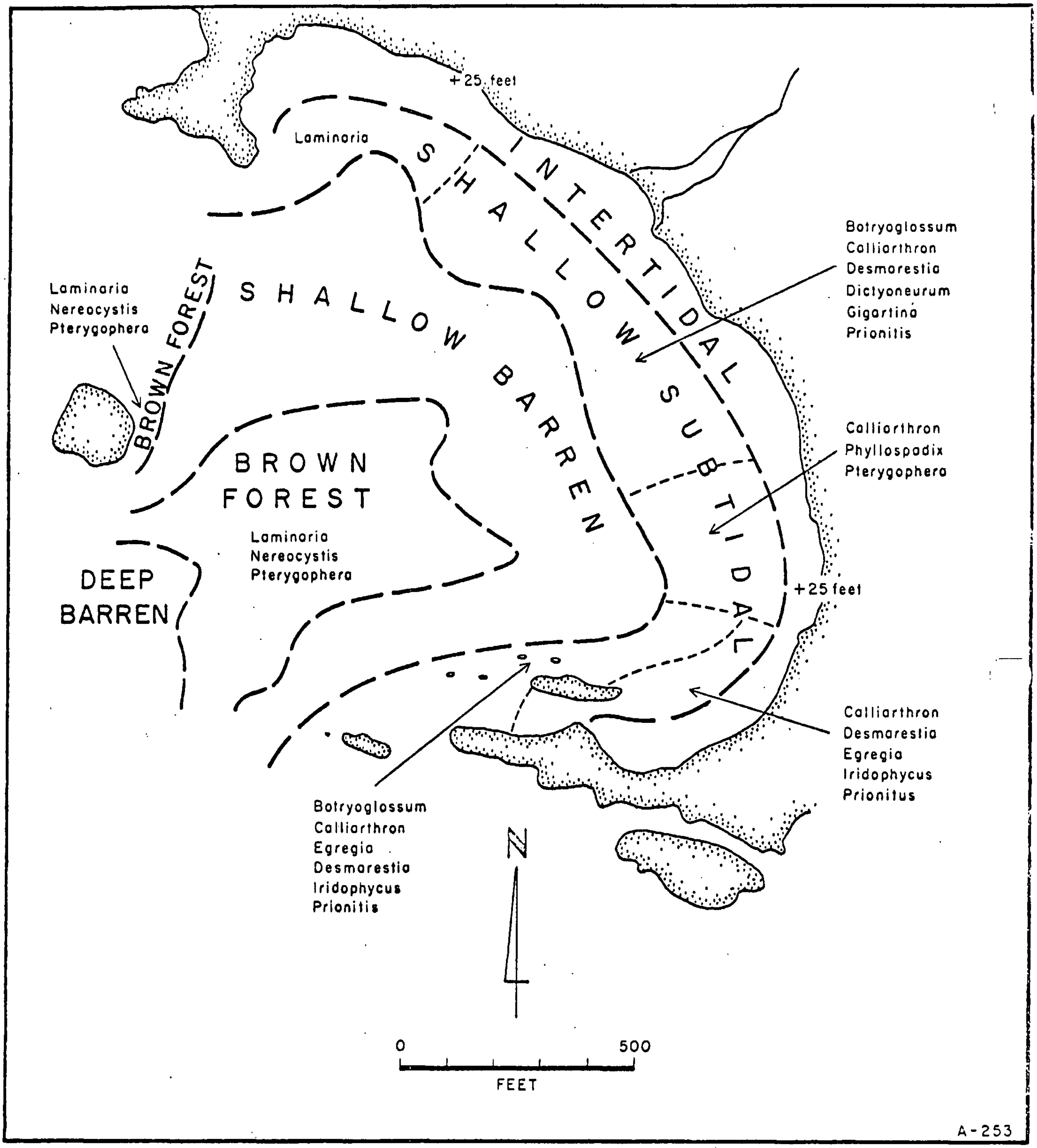

Figure 4. Zones and principal plant species observed within Diablo Cove, Nov. 1966

throughout the Cove approximately between the depth contours of 10 feet and 25 feet, and at depths greater than 50 to 60 feet. This territory invariably displayed dense concentrations of urchins (primarily the giant urchin, *Strongylocentrotus franciscanus*, estimated to range from 5 to 50 per square meter). Urchins graze plants and the dense populations of these animals undoubtedly accounted for the barren condition of the bottom. Other herbivorous animals, including abalone, were scarce or absent in the urchin dominated territory. Both Ebert and Frances Clark mention that Diablo Cove is considered only as fair territory by abalone fishermen and the reason for the lack of excellence is probably the extensive area dominated by urchins.

Zonation

Zonation was well developed at all levels, both intertidally and subtidally. Existence of clearly defined zones was demonstrated by Transects A and B which showed similar associations appearing at approximately the same levels (Figures 2 and 3) even though the transect areas were separated by several hundred feet and represented quite different exposures to the sea. For present purposes, however, there is no great need to characterize the many small zones that undoubtedly exist in Diablo Cove. We prefer to describe five major zonal subdivisions that are important in the general ecology of the cove. These zones must be defined before discussing possible effects that a warm water discharge may produce. Proceeding from deep to shallow, we have named the major zones as follows: Deep Barren, Brown Forest, Shallow Barren, Shallow Subtidal, and Intertidal (Figure 4).

Deep Barren Zone

This zone was found beyond the lower limit of the *Laminaria-Nereocystis-Pterygophera* complex (the "Brown Forest" zone). The Deep Barren Zone occurred at depths greater than 60 feet in the southwest entrance to Diablo Cove. Plant cover was limited to encrusting forms such as *Lithothamnium*, except for the peaks of very large pinnacles. A sparse scattering of the giant urchin (est. density 1/2 to 2 per m^2) probably removed all other plants as they appeared. The Deep Barren zone was only a minor area compared to the other zones of Diablo Cove. Several interesting species were unique to this zone (*Allopora*, *Balanophyllia*).

Brown Forest Zone

This zone displayed lower limits at about 50 to 60 feet and upper limits at about 25 feet. It was characterized primarily by dense growths of the two brown algal palm kelps, *Pterygophera* and *Laminaria* (Figure 5). Some patches of the bull kelp provided a midwater biotope that attracted benthic fishes (Figure 6). Many herbivorous animals achieved substantial concentrations in this zone. Ebert reported high abalone counts in the deeper portions of this zone in his Diablo Cove transect (Ebert's Station 1). Abalone numbers here were exceeded by only two other stations of the 18 sites studied by Ebert. We observed highest red abalone densities in this zone, and it was the only area where juvenile red abalone were found by us.

Shallow Barren Zone

As mentioned above, the Shallow Barren Zone was dominated by dense

Figure 5. Silhouette angle showing the Brown Forest Zone as viewed from underneath. Stalks and blades of the palm kelps form a dense thicket throughout this zone.

Figure 6. View towards the surface showing a bull kelp plant extending up through the water column, attracting benthic fishes (blue rockfish) upwards.

concentrations of giant urchins. The zone lay approximately between the 10- and the 25-foot depth contours. Urchin concentrations were highest at the borders of the zone (Figure 7); apparently the animals were attracted by the plant food occurring above and below the zone. Some abalones occurred in the open at these borders, mingling with the urchins (Figure 8), but within the seaweed forests the abalones remained hidden in crevices and under rocks. In southern California we have found that abalones tend to occur in the open in daytime only when there is intense competition for food, as in migrating "urchin fronts". The abalones appear to be forced into daytime foraging in order to keep pace with the urchins.

Shallow Subtidal Zone

The lower limits of the Shallow Subtidal zone occurred between 10 and 15 feet while the upper border was arbitrarily considered to be the Intertidal zone. There was, however, no sharply defined upper border and in places the fauna and flora of the Intertidal extended into the Subtidal while in other spots the reverse was true. Likewise the two zones had many species in common. Nonetheless, the upper portions of the Intertidal were clearly different from the main part of the Shallow Subtidal zone. The Shallow Subtidal was considerably more complex than the Brown Forest zone and was subdivided somewhat arbitrarily into smaller regions according to the principal plant cover (Figure 4). Some of these principal plants occurred in mingled associations (Figure 9) and some occurred in almost pure stands of a given species (Figure 10).

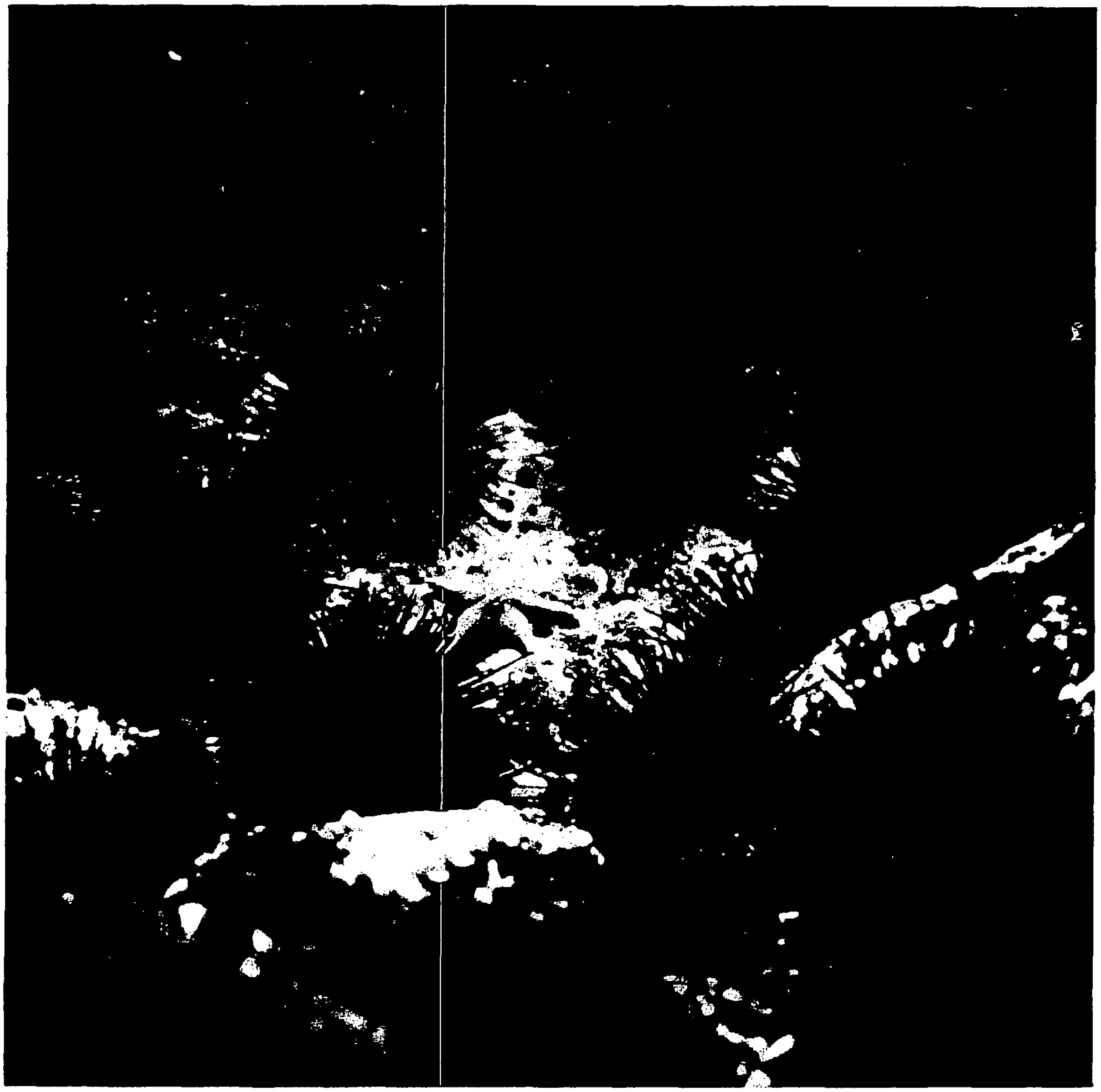

Figure 7. View along the boundary between the Shallow Subtidal Zone (background and lower left corner) and the Shallow Barren Zone (center and lower right). Note dense swarm of urchins, characteristic of the Shallow Barren Zone.

Figure 8. Vertical surface of boulder at boundary between the Shallow Subtidal Zone and the Shallow Barren Zone. Note red abalone exposed at top center. Abalone usually inhabit crevices during the day unless there is intense competition for food. Competitors in this case were giant urchins at bottom center. Stalk and holdfast of a palm kelp are in center, near abalone.

Figure 9. A thicket of feather boa kelp (Egregia) in the Shallow Subtidal Zone. The straplike blades are covered with clusters of an epiphytic green alga, sea lettuce (Ulva).

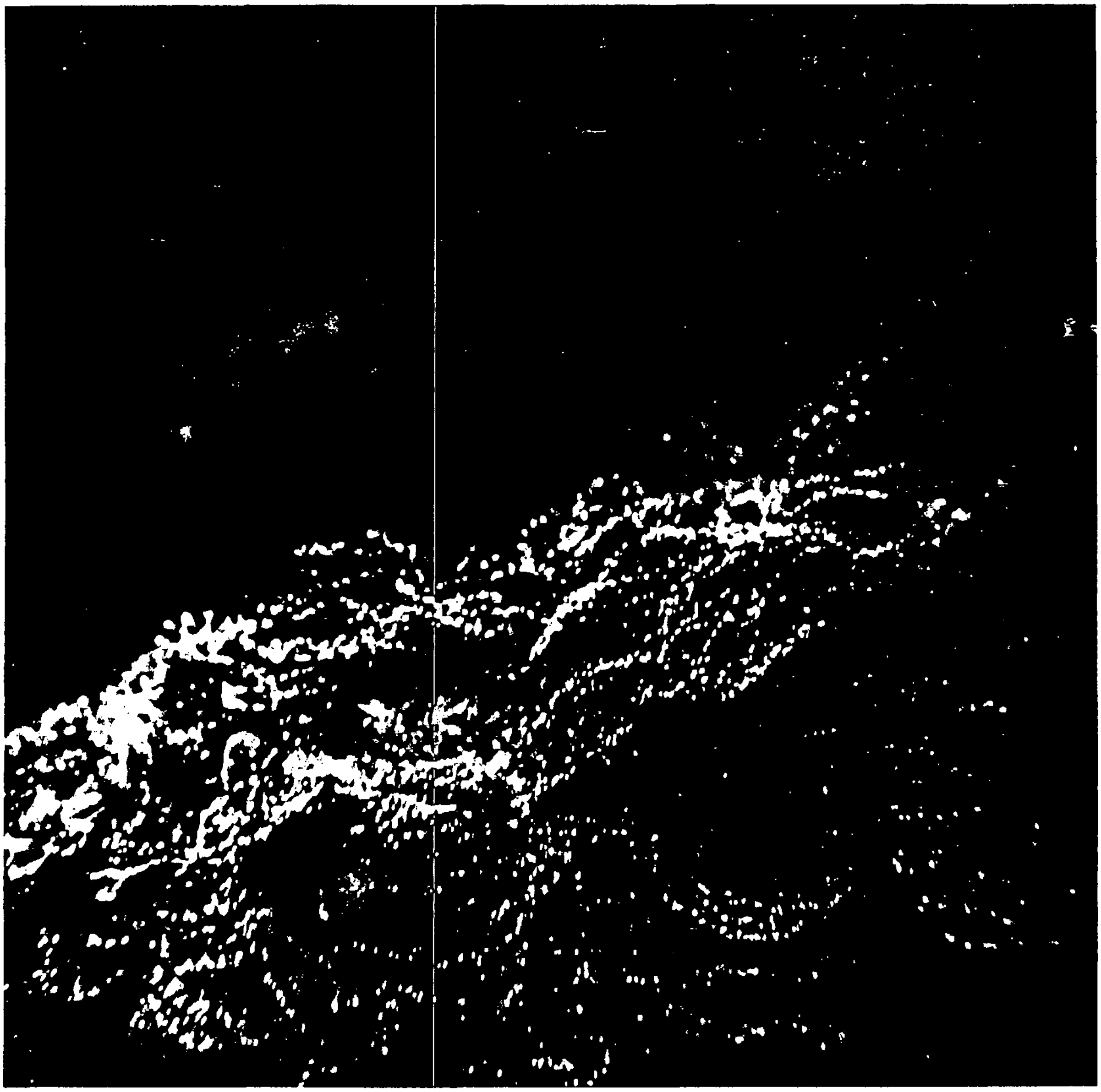

Figure 10. A patch of red coralline algae (Calliarthron) within the Shallow Subtidal Zone. Dense, luxurious foliage is typical of the Zone. Note grazing top snails (Astraea) slightly below and to the left of center.

The dense plant growths clearly offered abundant food and shelter for animals and the highly irregular bottom provided a maximal surface for attachment. Large boulder piles occurred near the southern border of the Cove in this zone and some provided deep crevice environments for abalones, urchins, etc. Some crevices were so large that they would be better described as small caves (Figure 11).

Intertidal Zone

As mentioned above, the Intertidal Zone graded uniformly into the Shallow Subtidal. Principal differences between the two were the species that appeared (and disappeared) in the upper regions of the Intertidal, and the thickness of the plant cover. Although most of the intertidal was completely covered by vegetation, the thickness of the cover was usually considerably less than found in the Shallow Subtidal. Probably this was the result of pruning action by surf. In consequence, there was undoubtedly significantly less seaweed standing crop in the Intertidal Zone and plant productivity per unit area of bottom may be substantially higher in the Shallow Subtidal. Nonetheless the Intertidal was clearly a luxuriant and productive zone.

Figure 11. Large cavelike crevice environment common among boulder piles in shallow water at the southern margin of Diablo Cove.

POSSIBLE EFFECTS OF A WARM WATER DISCHARGE

When considering biological changes that may occur in a situation such as Diablo Cove, it is important to realize that the end result could be a richer, more dense association of organisms than now present. Changes in species composition do not imply that a barren area will develop or that standing crops will decrease significantly. While the writer has not had the opportunity of inspecting sites where warm water discharges have altered natural communities in a restricted area, it is clear from discussions with individuals who have studied such areas that they often support luxurious and highly varied associations of plants and animals. The nearness of Diablo Cove to Point Conception will probably make colonization by warm water organisms an easy matter, and a rich fauna and flora could very well comprise the ultimate community at Diablo Cove.

Species Changes

Many marine organisms can tolerate wide temperature fluctuations, and many survive continuous exposure to temperatures well above average values in their natural environment. As a crude means of assessing possible survival of Diablo Cove species after a warm discharge is initiated, we have identified those species known to inhabit warm waters in southern California (Tables 2, 3, 4, and 5). Such species included 25 intertidal plants (52 percent of the total), and 37 intertidal animals (58 percent), 16 subtidal plants (31 percent), and 47 subtidal animals (35 percent). While survival will certainly be influenced by the degree of temperature elevation and perhaps to a lesser extent by the rapidity of fluctuations, it is evident that there is a substantial component of species that can be labeled "potential survivors". It seems reasonable to predict that species sensitive to warm water will disappear and be replaced by species now present that can tolerate the change. With the passage of time other warm water species, currently absent, may appear as larvae or eggs are brought into the area by ocean currents. In general terms, there will be an initial decrease in species diversity and standing crop, followed by a recovery of standing crop and probably a slower recovery of species diversity.

Ecological Imbalances

One problem remains to be considered, and this is whether appreciable ecological imbalances may arise during the initial period, while the biota is adjusting to the presence of warm water. Assuming there is a substantial loss of standing crop of living material, will the losses be equivalent among the various trophic levels (plant producers, herbivores, lower carnivores, higher carnivores, decomposers, etc.) or will losses be concentrated within one level, causing disruption of the entire system? If an imbalance develops, deterioration could be much more serious and extend beyond areas exposed to contact with warm water. Insufficient data exists to predict the possibilities of imbalance with any precision, but the potential for such an upset is believed to be present.

It seems likely that the large plant productivity occurring in the Intertidal and Shallow Subtidal Zones is not entirely consumed in situ. There is undoubtedly considerable transport of drift weeds from these zones to adjacent areas. As mentioned above, little drift was noted on the beach and probably the major portion of weeds torn loose moves seaward and is captured by the dense urchin populations lying just below the Shallow Intertidal Zone. During the diving operations, several urchins in the Shallow Barren Zone were broken open and appeared to be in a healthy nutritional state (starved urchins resorb yellow gonadal material and are easily identified as being in poor condition). The scarcity of algae in the Shallow Barren Zone suggests that the chief source of food for the healthy urchins is drift material.

Of the twelve plant species considered to be dominant producers in Diablo Cove (Figure 4), four are believed to be tolerant to warm water (Table 4). Of these four, Egregia and Prionitis are low on the scale of important plant producers in the Cove and Calliarthron, while quite abundant, is not nutritious since it is largely composed of inorganic skeletal material. Phyllospadix would be a truly major surviving species.

It is well established that urchin populations display massive migrations in search of food. If the large populations present in Diablo Cove are suddenly deprived of significant amounts of drift from higher levels, they can be expected to encroach on the Brown Forest Zone and to some extent into the Shallow Subtidal Zone (wave surge may limit migrations into shallow water to some extent). If this occurs, the effects on resident abalone may be far more severe than warm water damage. Severe competition for food would develop. The main portion of the temperature sensitive red abalone population lies at depths below 25 feet, and it seems unlikely that warm water would pose a serious threat to these animals. Urchins are apparently more mobile than abalone and are better able to catch drift. Many instances have been noted where urchins have survived while abalones disappeared, presumably dying of starvation.

The repercussions of an ecological imbalance might not extend beyond Diablo Cove, but it would be speculative to draw conclusions on this question at the present time. More information would be needed on plant and urchin distributions in adjacent areas before attempting further predictions.

CONSERVATION MEASURES

Species Changes

It appears that some change of species is unavoidable. It should be noted, however, that thus far we have found no rare or new species in the shallow water regions of Diablo Cove. Biological effects would be reduced by engineering works that minimize changes in water temperature in the shallow water and intertidal regions.

Ecological Imbalance

It is believed that the likelihood of creating an ecological imbalance can be substantially reduced by a modest expenditure of effort and funds. As noted above, the principal cause for concern lies in the presence of a large population of giant urchins in the Shallow Barren Zone of Diablo Cove. Urchins are not utilized to any extent commercially, and they can be eliminated by techniques developed by the Kelp Habitat Improvement Project at the California Institute of Technology. It is believed that the populations in the Shallow Barren Zone of Diablo Cove could easily be reduced to insignificant concentrations.

If urchin populations were destroyed, vegetation would develop almost immediately in the barren areas. An excellent cover would require six months to one year for growth. If control of the urchin populations is undertaken, quicklime treatments should be conducted as far in advance of initial power plant operations as possible, to allow adequate development of vegetation and stabilization to occur.

Defining Kelp Areas

Assessing the biological effects of power plant operations will be facilitated on defining the major kelp areas in the vicinity of Diablo Cove. The principal species of bed-forming kelp observed was the bull kelp, Nereocystis. This plant elaborates large amounts of tissue at the sea surface by means of a flotation device, so the distribution of the species can be determined without having to dive. Aerial photography has proved very useful in charting kelp beds in southern California and would be the logical method for mapping beds near Diablo Cove. Nereocystis is a cold water alga and would be expected to suffer deterioration if exposed for long to warm temperatures. It should prove very useful to indicate any adverse effects of power plant operation at or near Diablo Cove.

Adequate definition of kelp areas will require several series of aerial photographs. Beds vary in extent with season and from one year to the next. The task of establishing the location and extent of beds and the variations in size is in progress. The author had an opportunity recently to fly near Diablo Cove and was able to shoot oblique photographs of the coast, from which a rough map of the major kelp areas was sketched (Figure 12). This map should not be considered at all adequate for defining kelp areas because it is almost certainly quite inaccurate due to the obliquity and distance away of the photos (Figures 13 to 19). It does, however, provide a concept of the complex distribution patterns of kelp beds and establishes a base for additional work.

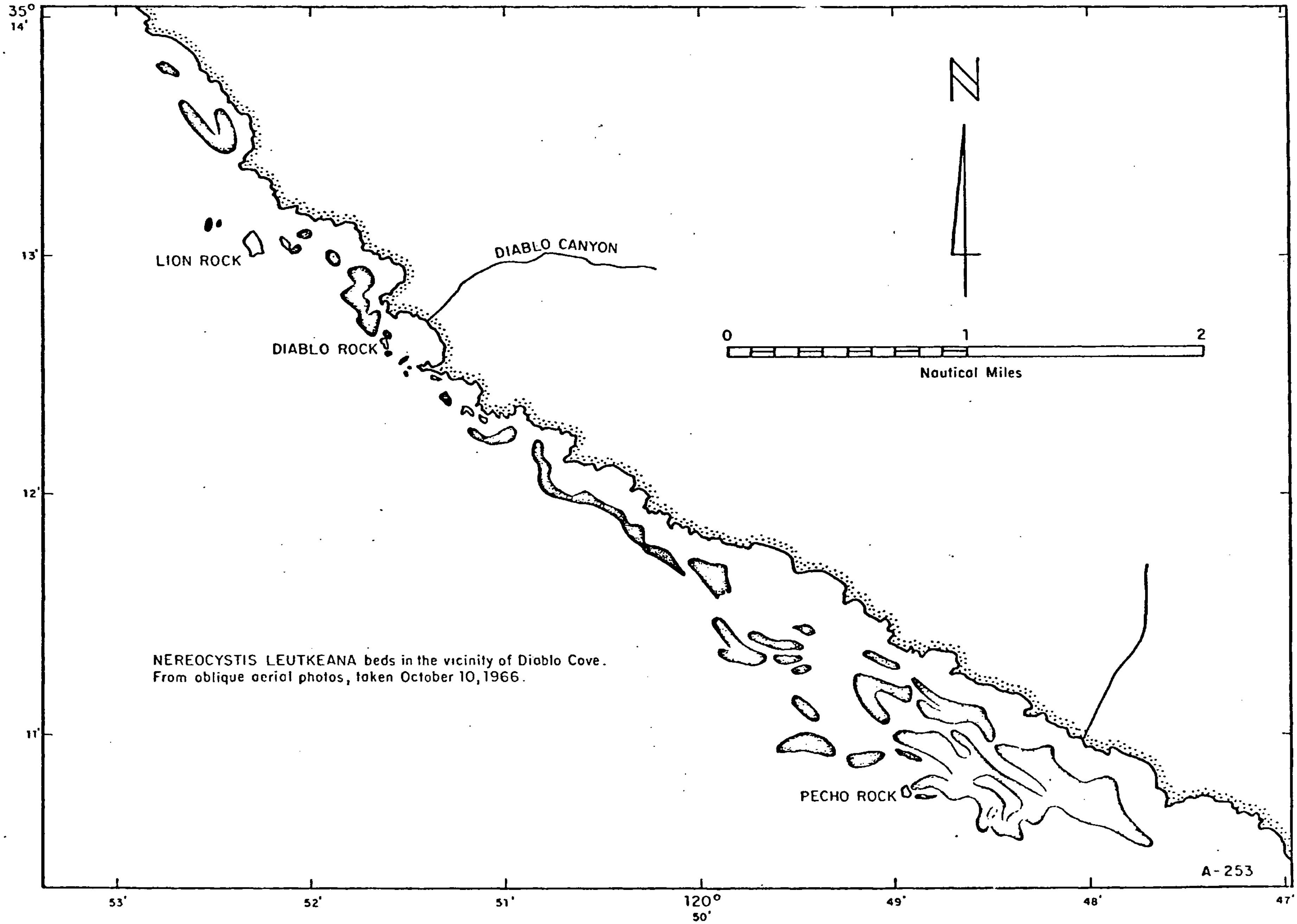

Figure 12. Chart of kelp beds in the vicinity of Diablo Cove.

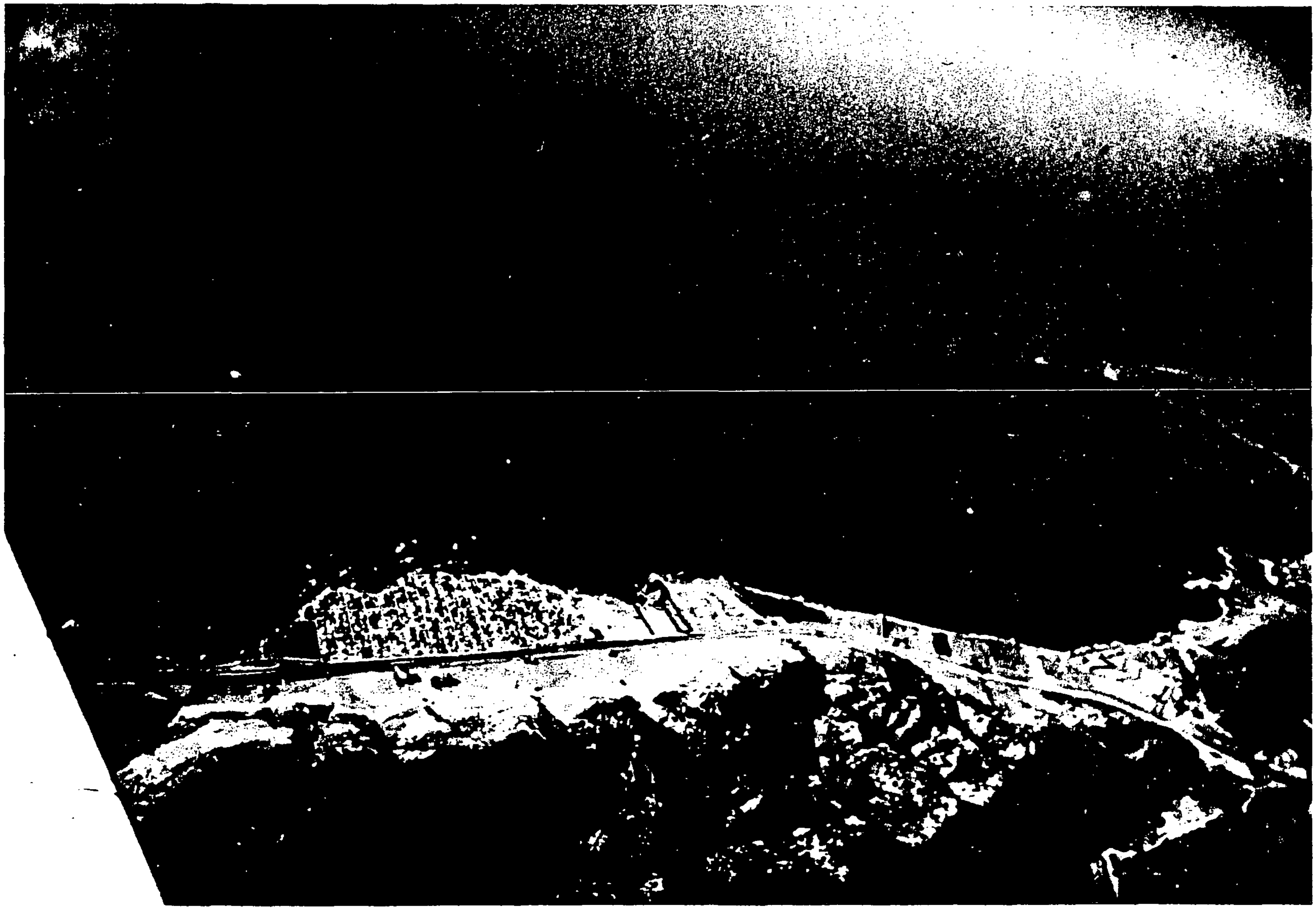

Figure 13. Black and white enlargement of a kodachrome slide, showing kelp beds in San Luis Obispo Bay and off Shell Beach, October 10, 1966.

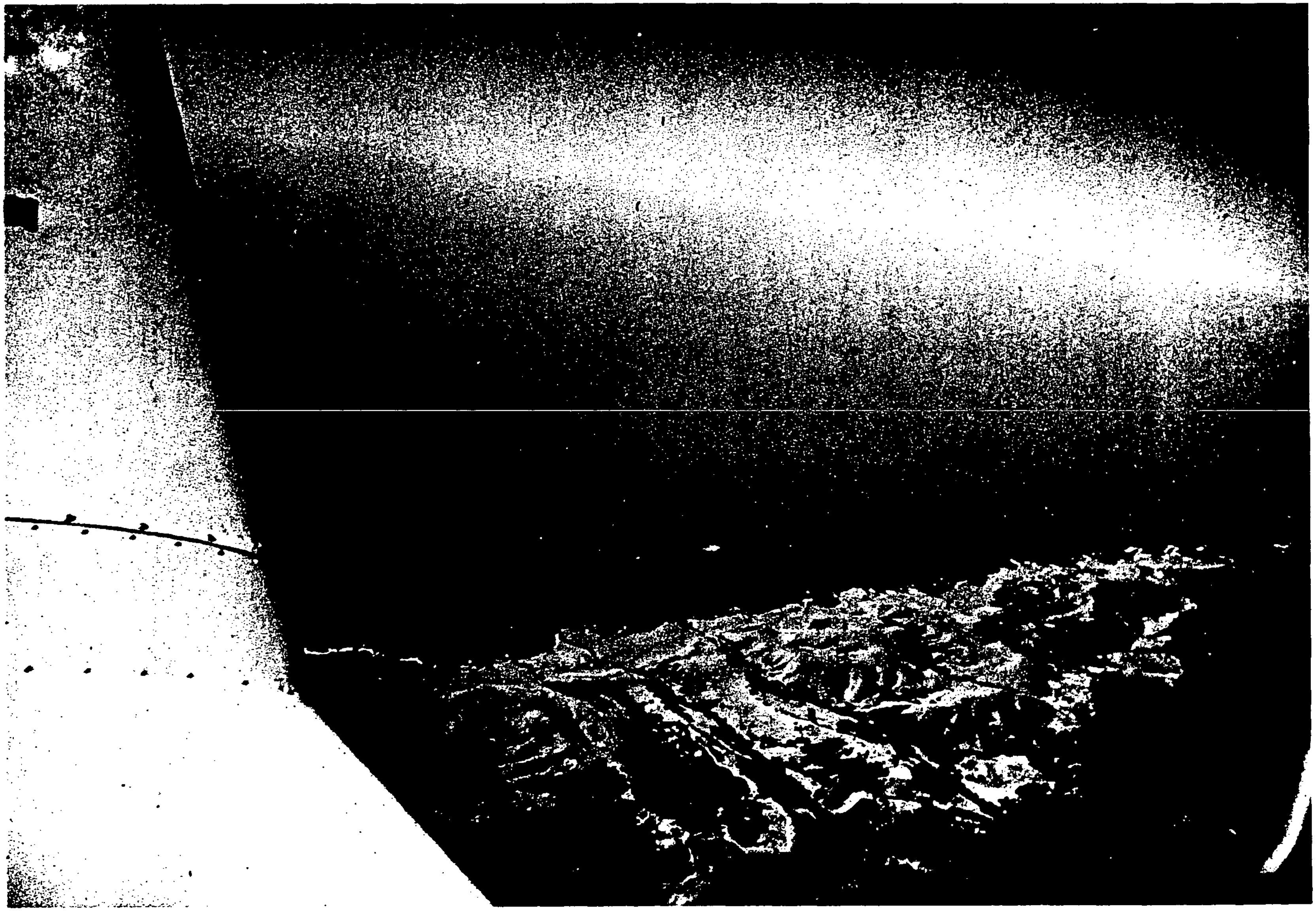

Figure 14. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) just north of Point San Luis, October 10, 1966.

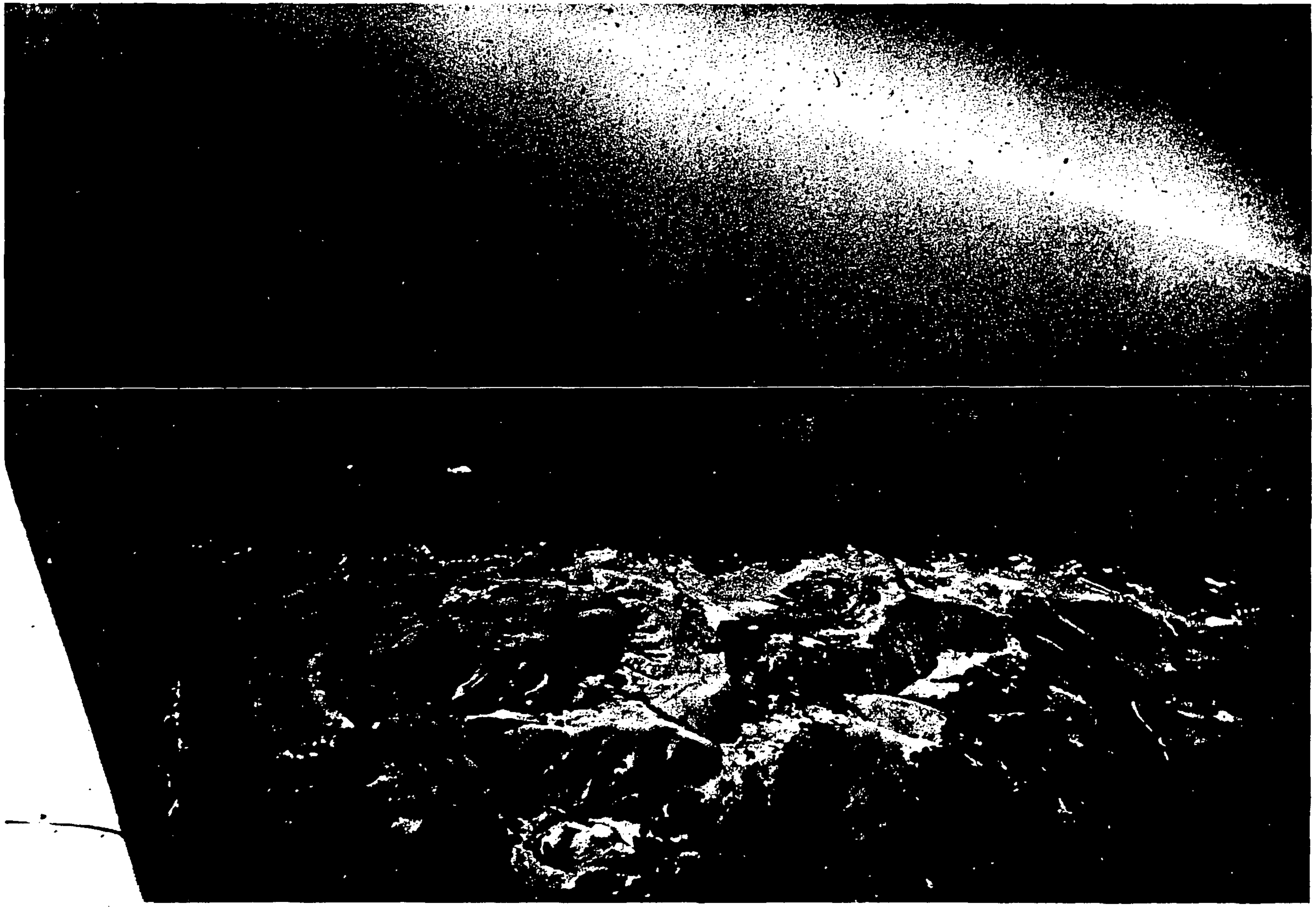

Figure 15. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) near Pecho Rock, October 10, 1966.

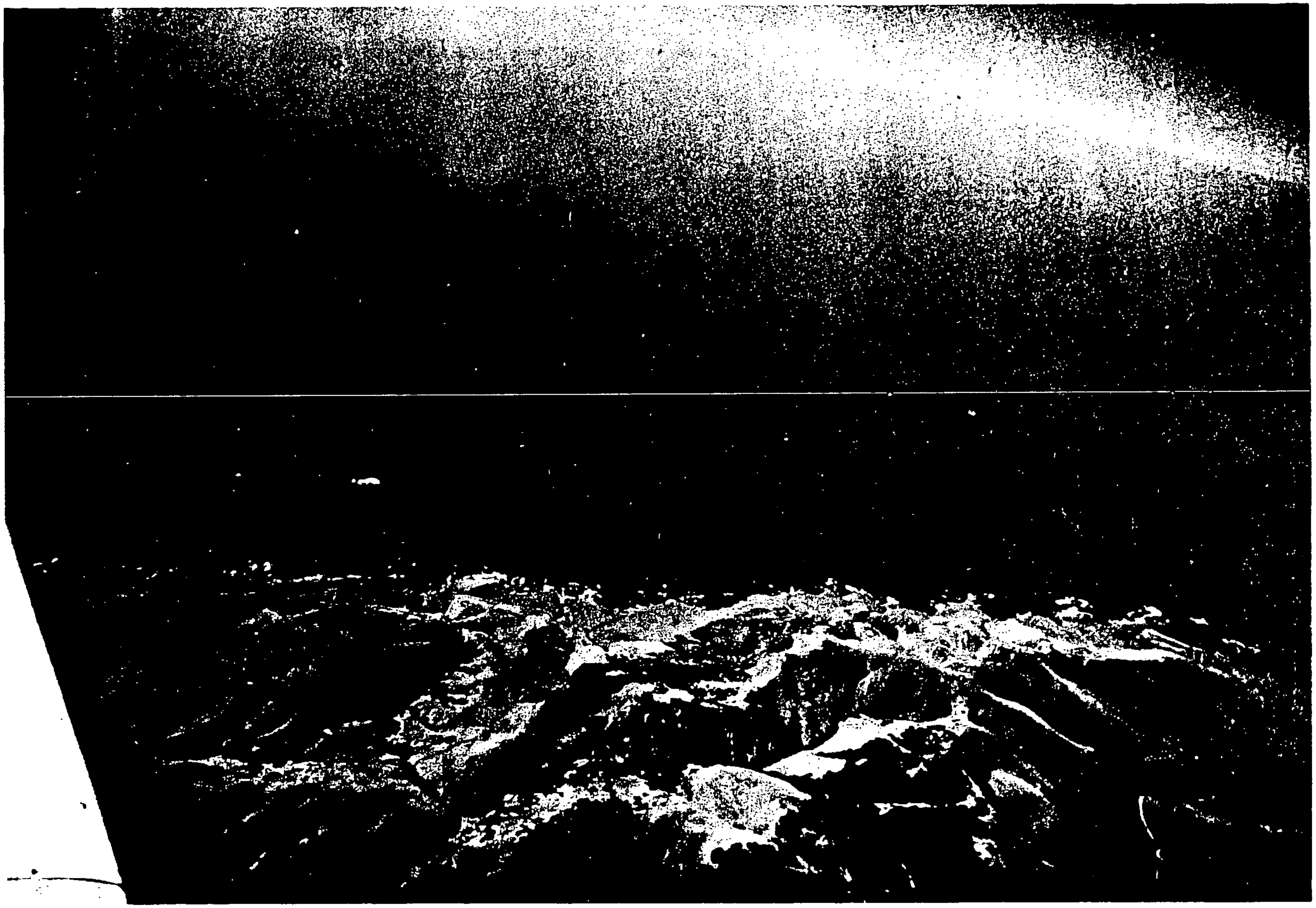

Figure 16. Black and white enlargement of a kodachrome slide showing offshore kelp near Pecho Rock (arrows), October 10, 1966.

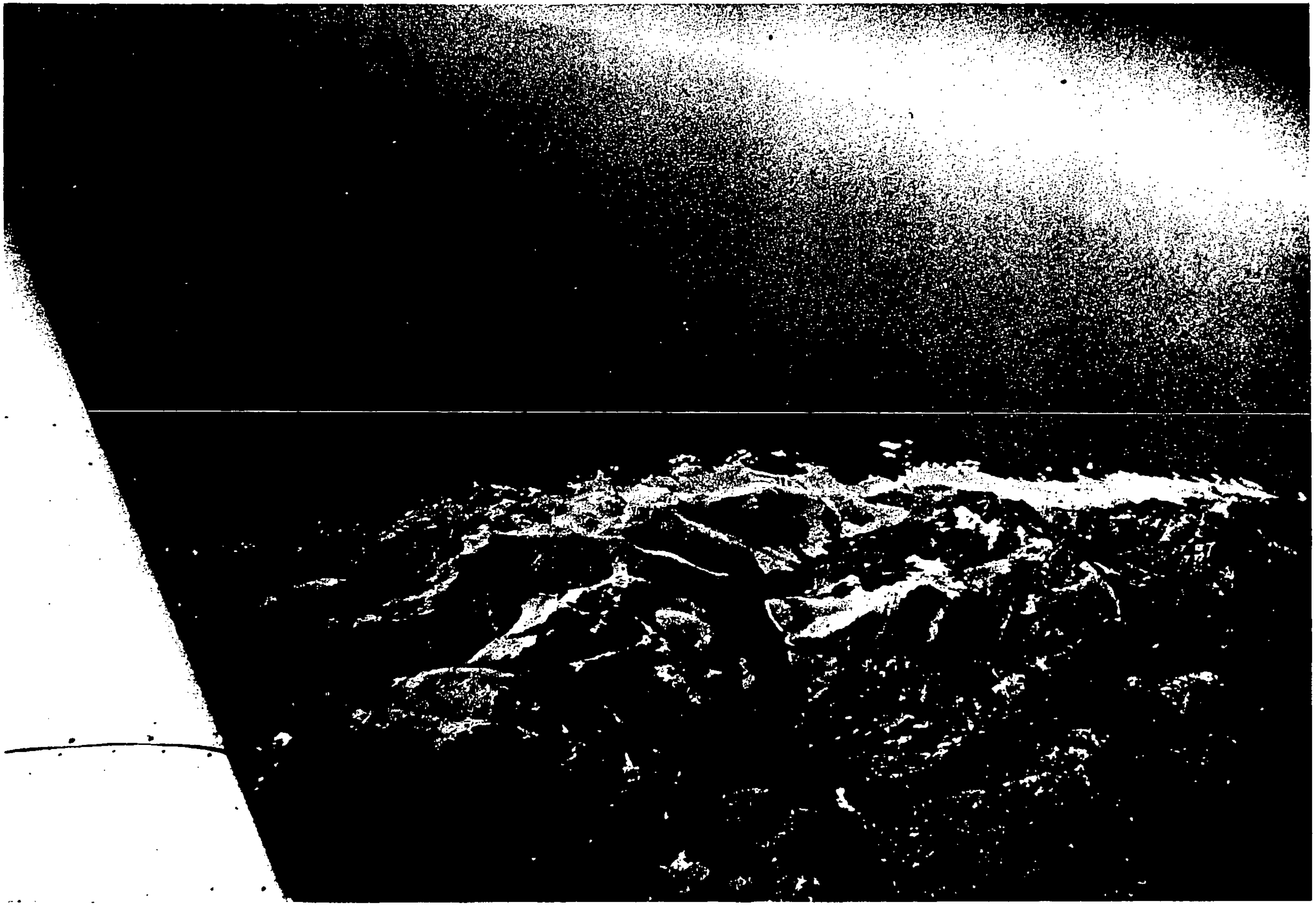

Figure 17. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) between Pecho Rock and Diablo Cove, October 10, 1966.

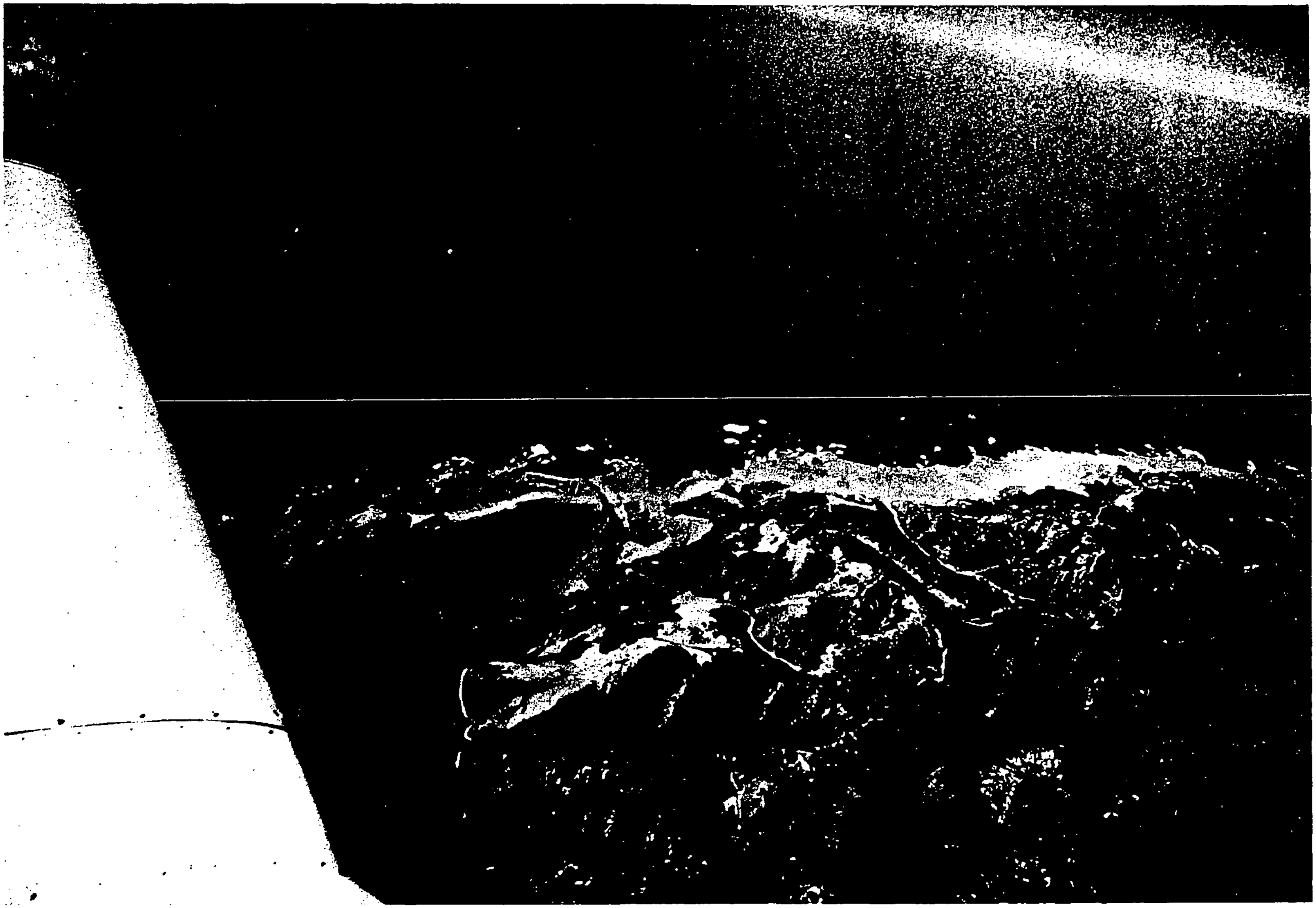

Figure 18. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) near Diablo Cove, October 10, 1966.

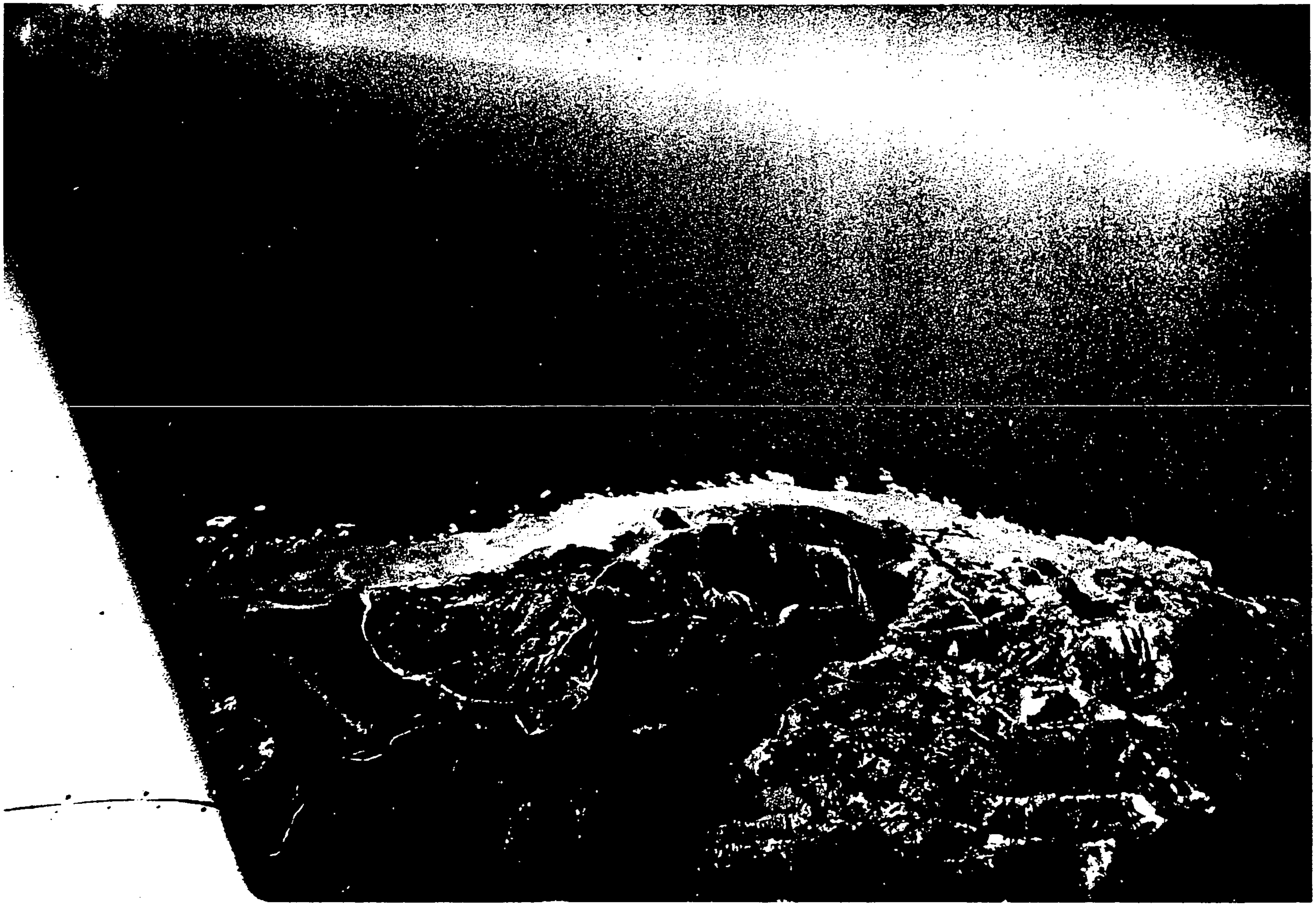

Figure 19. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) north of Lion Rock, October 10, 1966.

ACKNOWLEDGMENTS

The author gratefully acknowledges the cheerful assistance provided by James Adams of Pacific Gas and Electric Company. The amount of work that could be accomplished was significantly increased by Mr. Adams' efforts. Likewise, thanks are due to Barbara B. North for assistance in collecting and identifying, and in typing manuscript. The completeness of our algal species lists is largely due to her skill.

SUMMARY

1. Diablo Cove lies on an exposed rocky coast. Bottom topography is extremely irregular. Measurements and plant distributions indicated submarine illumination is probably good. Circulation and water movements are well developed.

2. A highly diversified species assemblage was found. Intertidally 44 plant and 64 animal species were observed while subtidally the numbers totaled 52 plants and 134 animals. It is believed that the list of plant species is fairly complete but possibly as few as half of all animal species present were recovered.

3. The high species diversity may result from an ecotonal effect and from the relative freedom the area has enjoyed from human influences.

4. Attached plants appear to be the chief source of organic productivity in the area. Grazing animals were much more abundant than filter feeders. Consequently considerable attention was given to identifying principal plants and their distributions within the Cove.

5. Five major zones were described. These were a "Deep Barren" zone, a "Brown Forest" zone (comprised principally of larger brown algae), a "Shallow Barren" zone (dominated by grazing urchins), a "Shallow Subtidal" zone, and an "Intertidal" zone.

6. The extent and consequences of a warm water discharge are discussed. The most likely result is believed to be a moderate decrease in species diversity and replacement of cold water forms by warm water organisms. Such changes may extend as deep as the Shallow Subtidal Zone. Of greater concern is the possibility of ecological imbalance. The consequences of upsetting trophic relations in the Cove are discussed.

7. Possibilities for avoiding species change and ecological imbalance are discusse It is suggested that control of urchins in the Shallow Barren Zone would be an excellent precaution for avoiding imbalance.

8. The need for establishing the positions and extent of nearby kelp beds is mentioned. It is believed that the beds constitute an excellent tool for monitoring adverse influences from a warm water discharge.