

the catch moderated potential stock differential impacts--Coho off California were almost twice as large in 1984 as in 1983 while coho off the entrance to the Strait of Juan de Fuca and late-run Columbia River stocks were unusually small, and (3) abundance of resident components of Puget Sound production were far lower than expected.

For OPI coho, the 1984 unadjusted, forecasted run size was 806,600. The forecast, after an adjustment for El Nino, was 556,600. Preliminary data indicates that the actual size of the 1984 OPI will be about 659,000 coho, at 18% below the unadjusted estimate but also 18% above the adjusted estimate.

The SPDT indicates there is little data in which to quantify any adjustments for negative El Nino impacts in Chinook run returning in 1985, but it is anticipated that El Nino will have little or no effect on coho runs returning in 1985.

Interannual Shifting of the Subarctic Boundary and Some of the Biotic Effects On Juvenile Salmonids

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Introduction

Zoogeographic boundaries of regionally distinct species assemblages have been described for the Oceanic Pacific by McGowan (1971, 1972). These unique regional pelagic fauna groupings are maintained and preserved by physical mechanisms such as semi-enclosed gyres which tend to conserve water mass characteristics. In addition to these established assemblages there are species or species groups found "down-stream" from centers of stable populations which must respond to more transient environmental states to maintain themselves at their range boundaries. These groupings, in contrast to those maintained within distinct water types, experience dynamic and seemingly unpredictable fluctuations.

Extensive field programs in the 50s and 60s led to the definition of smaller oceanographic subdivisions or "domains" within the Pacific Subarctic water mass (Fig. 1) based on analysis of temperature, salinity and oxygen measurements (Dodimead et al. 1963; Favorite et al. 1976). The Subarctic current system (Fig. 2) divides as it crosses the North Pacific; one portion proceeds in a cyclonic direction to form the Alaskan gyre; the other portion flows in a anticyclonic direction to form the California current. Chelton (1984) postulated that much of the observed interannual variability of ocean climate in the Northeastern Pacific is related to the relative proportions of northward and southward flowing water. Wickett (1967) correlated the interannual variability of zooplankton volumes in the California Current system from 1951 to 1960 with the input of nutrients via the southerly component of Ekman transport at 50°N, 140°W, 1200 miles "upstream" in the previous year. He estimated that fifty to sixty percent of the observed variance of the annual concentration of zooplankton off California was due to advection of nutrients.

Within the Pacific Subarctic water mass each domain can be characterized by general biological features. In the Central Subarctic domain for example, phytoplankton standing crops are relatively low and phytoplankton production is believed to be

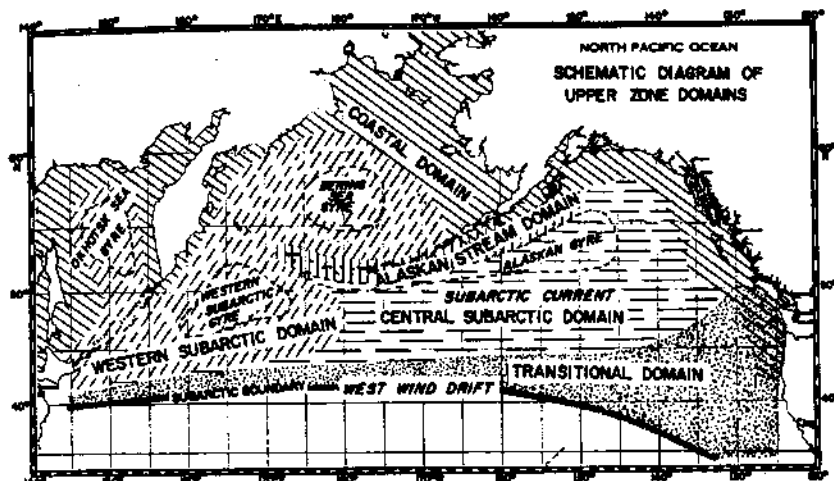


Figure 1. Schematic diagram of upper zone domains (from Dodimead et al. 1963).

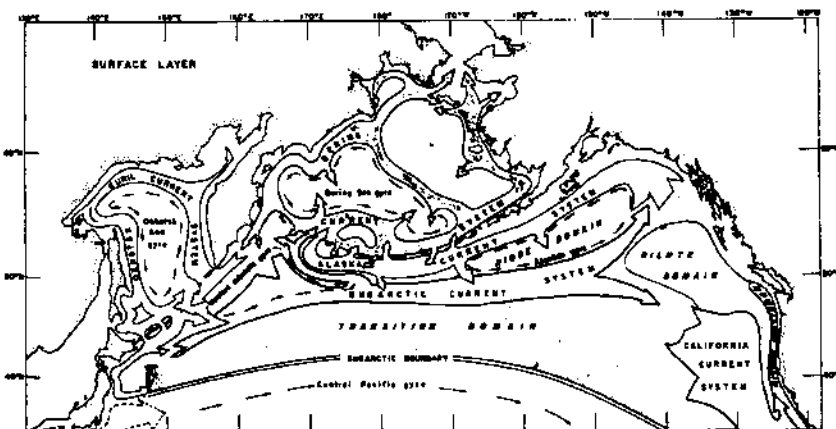


Figure 2. Schematic diagram of surface currents in the Subarctic Pacific region (from Favorite et al. 1976).

controlled by zooplankton grazing (McAllister et al. 1960; Frost 1983); two relatively large herbivorous copepods (*Neocalanus plumchrus* and *N. cristatus*) make up 70-80% of the coarse mesh (.350 mm) zooplankton (LeBrasseur 1965; Miller et al. 1984) and finally, the endemic commercially important carnivores in the system are anadromous fishes (salmon) which enter the ocean at a relatively

large size and change from planktivores to piscivores as they grow (LeBrasseur 1972). In contrast, in the California Current system which is made up of varying proportions of water from the transitional, Central Subarctic and Coastal domains, the phytoplankton standing crop may be high and is not limited by grazing; many species of small copepods (e.g. *Calanus* spp., *Mesocalanus* spp., *Paracalanus* spp., *Clausocalanus* spp., *Acartia* spp.) make up a relatively smaller portion of the zooplankton biomass which is generally lower than in the Subarctic (Fleminger, Issacs and Wyllie 1974); and the commercially important fish endemic to the system, the Pacific sardine (*Sardinops sagax*) and the northern anchovy (*Engraulis mordax*), are planktivorous (herbivorous and omnivorous).

This report illustrates some of the effects that variations in intensity of ocean circulation may have on some faunal distributions. Extreme northward shifting of the Subarctic boundary occurs during EL NINO years such as 1957-58. A number of Central Subarctic species are carried southward by the California current system during "normal" years; some exhibit relatively stable populations which may have become genetically or physiologically distinct from the parent population (eg. *Calanus pacificus* var. *californiensis*); some may form breeding populations which expand and retreat in unison with the strength of the southward transport (eg. *Euphausia pacifica*) (Brinton 1962); and still others rely on annual recruitment from the Central Subarctic water domain (eg. *Neocalanus cristatus* and *N. plumchrus*) (Bowman and Johnson 1973). This pattern of responses within the system is also supported by biomass data from large scale plankton surveys made between 1956 and 1963 (LeBrasseur 1965a). We postulate that planktivorous fish living in the open ocean adjacent to the west coast of North America) are affected by interannual fluctuations in southward transport of zooplankton biomass. We hypothesize major shifts in the particle size spectrum (see Parsons 1969) of the zooplankton community has a greater impact on planktivorous fish than do changes in biomass alone.

Methods

Approximately 5,000 zooplankton samples were collected during oceanographic and exploratory fishing surveys from 1956 to 1964. Vertical plankton hauls were made from 150 m to surface with a standard NORPAC net with a mouth opening of 0.16 m² and a mesh of .330-.350 m white nitex (Fulton 1983). Samples were preserved in 4% formaldehyde.

In the laboratory major taxa were identified and weights estimated as a percentage of the total sample weight. Organisms larger than 4 cm, including fish and squid, were weighted separately. The remaining sample was weighed to the nearest 0.1 g after draining and blotting on paper toweling. The estimated weight of phytoplankton, coelenterates, thalassia and detritus was subtracted from the sample wet weight to arrive at zooplankton wet weight. For plotting zooplankton biomass distributions data were pooled into time intervals covering the spring bloom (April through June).

We define the boundary between the Central Subarctic and the transitional domains (Dodimead et al. 1963) as a line which separates biomass estimates greater or lesser than 80 mg/m^3 during the time period encompassed by the spring bloom of zooplankton as observed at Ocean Station P (50°N , 145°W). The value of 80 mg/m^3 represents the minimum annual biomass peak observed at Station P over a 26 year period (Fulton 1983). We assumed that Station P was always within the Central Subarctic Domain (Fig. 1). Biomass estimates for the California current region were taken from Fleminger et al. (1974) but adjusted by subtracting the thaliacea biomass in order to be comparable with the present sampling protocol.

As a measure of the relative strength of southward transport of Central Subarctic water (Table 1) we have chosen the annual mean meridional Ekman transport at 50°N , 130°W (Ballantyne and Wickett 1978).

Table 1. Zooplankton biomass in the Northeastern Pacific during the period April through June, compared with April biomass in the CalCOFI region. Ekman transport is shown to indicate the relative volume of the southwards flow. Figures in brackets indicate the number of observations; N/S indicates no samples taken; ? indicates no distinct boundary conditions.

Year	Subarctic biomass mg/m^3	Transition biomass mg/m^3	April CalCOFI biomass* mg/m^3	Annual Mean Ekman transport @ 10° metric T/sec/km
1956	183(36)	14(6)	102(172)	-15.3
1957	155(168)	51(5)	69(205)	-10.0
1958	131(81)	45(6)	32(264)	-0.7
1959	218(65)	31(30)	34(247)	-18.4
1960	43(32)?	N/S		-12.0
1961	64(46)?	?		-12.8
1962	154(330)	38(50)		-13.9
1963	211(177)	N/S		-5.3
	$\bar{X}=147(854)$	$\bar{X}=35(97)$	$\bar{X}=72(888)$	$\bar{X}=-11.1$

*CalCOFI biomass is estimated from Fleminger et al. 1974 (Fig. 4) omitting THALIACEA biomass for comparison with sampling methods used in LeBrasseur (1965a).

@Annual mean Ekman transport at 50°N , 130°W is from Ballantyne and Wickett (1978). Negative values indicate southwards flow.

Results

For the spring bloom period between 1956 and 1963 (LeBrasseur 1965a)

we examined eight zooplankton biomass charts. The boundary between the Central Subarctic and the Transitional domains could be identified by the above criterion in six cases. The mean biomass within the area defined as the Central Subarctic was 147 mg/m^3 , for the Transition domain 35 mg/m^3 , and for the California Current System 72 mg/m^3 (Table 1). Biomass in 1960 and 1961 (the two years when no boundary could be defined) for all positions sampled in the Central Subarctic domain was generally as low as the average Transition biomass (35 mg/m^3). Biomass which we consider to be of Subarctic origin ($>80 \text{ mg/m}^3$) extended southward to the coasts of Washington and Oregon in 1957 (Fig. 3) and again in 1963 (Fig. 5).

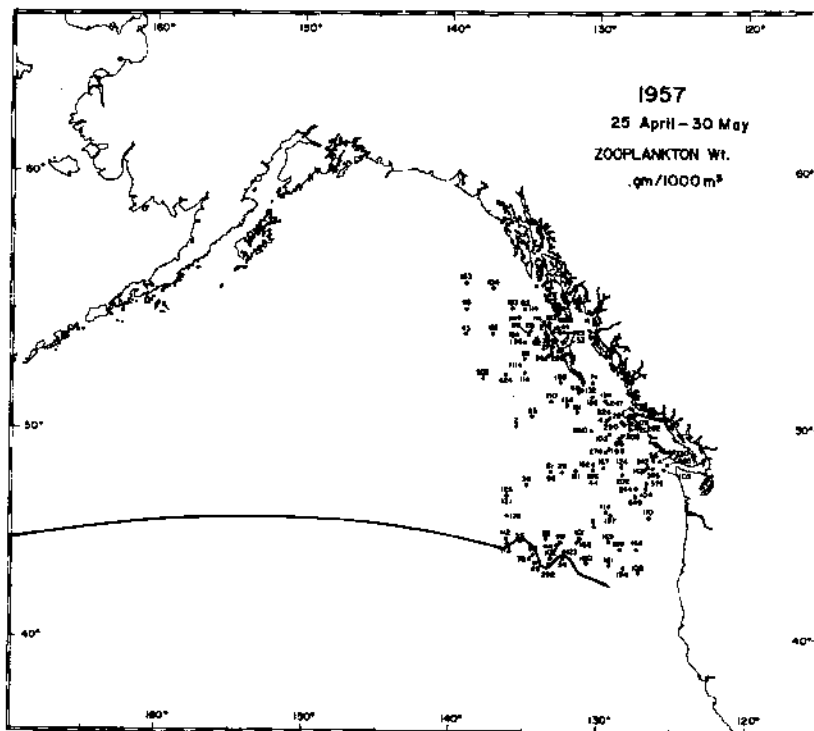


Figure 3. Distribution of zooplankton biomass - 1957.

In 1963 the Subarctic origin of this biomass was clearly identified by the presence of large numbers of *Neocalanus cristatus* and *N. plumchrus* which made up more than 80% of the wet weight; in 1956-61 zooplankton species were not identified. In 1958 during the period 22 May-10 June, biomass characteristic of Transitional water occupied a band about 500 km wide, extending northwards from about 45°N to the Queen Charlotte Islands (52°N) (Fig. 4). This northern extension of the Transitional domain was independently confirmed by physical measurements (Dodimead et al. 1963).

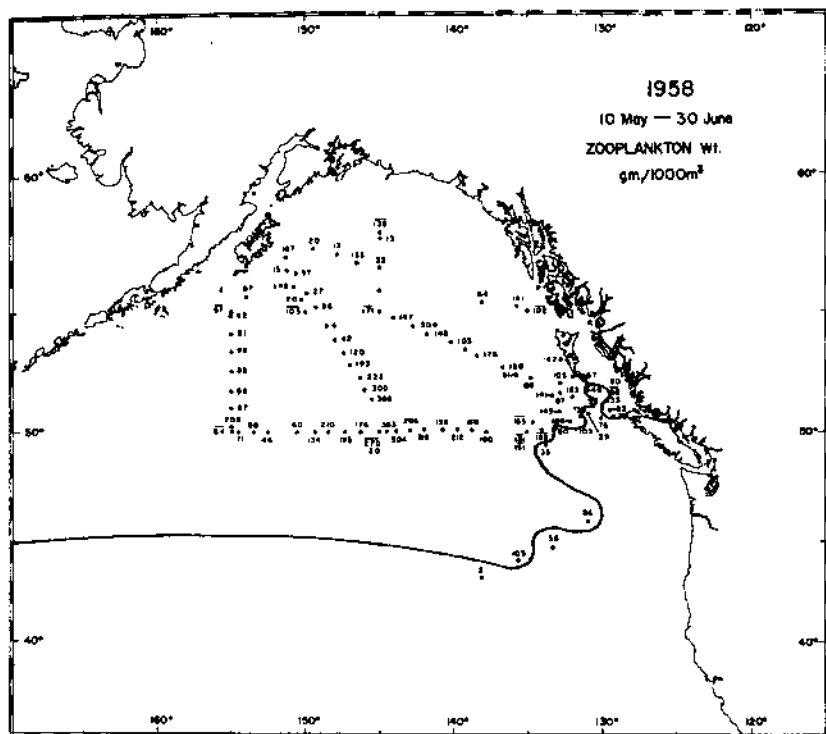


Figure 4. Distribution of zooplankton biomass - 1958.

Discussion

Greater than average southward transport of Central Subarctic water has been shown to affect secondary production in the California current system (Reid 1962; Wickett 1967; Colebrook 1977; Chelton et al. 1982). Suggested mechanisms have emphasized advection of nutrients from the Central Subarctic and entrainment of subsurface nutrients in proportion to the strength of the current. Nutrient transport appears to be accompanied by transport of Central Subarctic fauna and biomass. For example, *Neocalanus plumchrus* and *N. cristatus* both are present, sometimes in high numbers, south of Cape Mendocino (Fleminger 1964; Bowman and Johnson 1973). Our data show interannual variability of zooplankton biomass and, in the two years for which we have data which include species counts as well as biomass estimates (1962 and 1963), a corresponding shift in the species (size spectrum) of zooplankton along the coast of North America from at least the Queen Charlotte Islands to Cape Mendocino (Fig. 6).

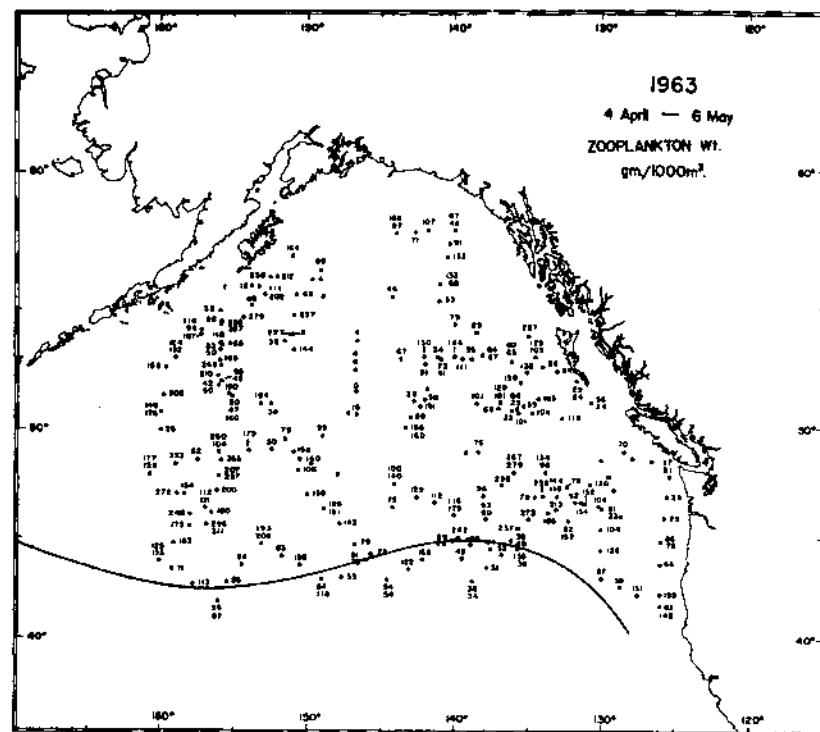


Figure 5. Distribution of zooplankton biomass - 1963.

Salmonids feed opportunistically in marine environments (see, for instance Healey 1980). In general, prey size is limited on the upper end by the gape of the mouth and on the lower end by the ability to detect and capture prey. It has been shown experimentally that juvenile pink salmon (*Oncorhynchus gorbuscha*) can meet their feeding requirements most efficiently on large food particles (Parsons and LeBrasseur 1970). Juvenile pink salmon fed rations of *N. plumchrus* (ca. 2.5 mg) obtained theoretical food requirements at prey concentrations of approximately 4,000 copepods/m³ (10,000 mg/m³) while those fed rations of *Pseudocalanus minutus* (ca. 0.1 mg) could not meet theoretical food requirements at prey concentrations of >670,000 copepods/m³ (>67,000 mg/m³). Although basic requirements of predator/prey models are violated by the restricted space in small aquaria (i.e. the predator should search an "infinite" optical field), these results indicate that *N. plumchrus* is closer to the optimal prey size for juvenile salmonids (ca. 5-10 g) than is *P. minutus* or other small copepods. We speculate that a decrease in biomass further exaggerated by a reduction in zooplankton particle size would cause reduced growth and, possibly, reduced survival of juvenile salmonids.

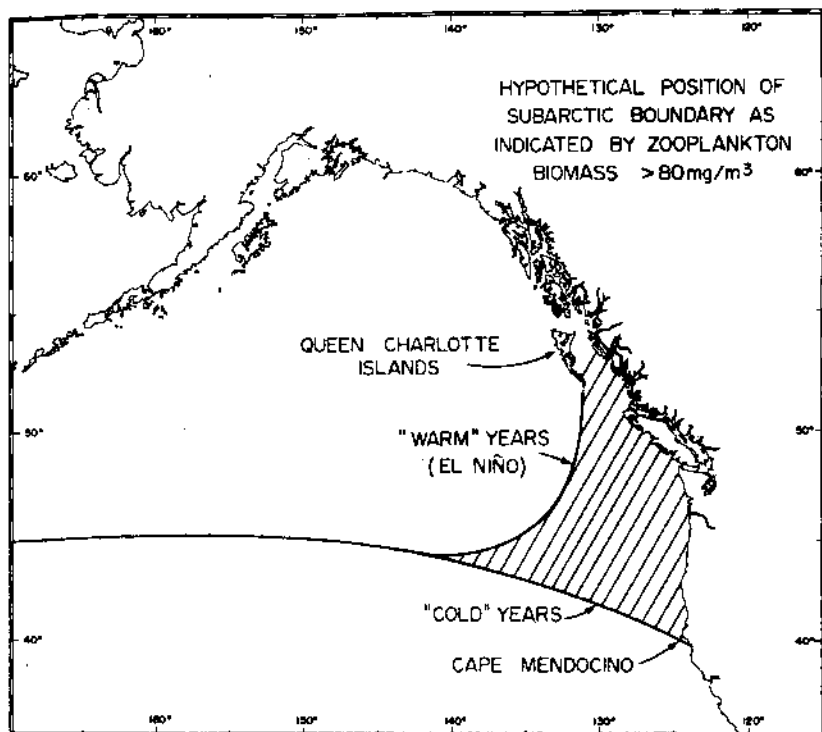


Figure 6. Schematic diagram of the area affected by shifting of Subarctic boundary.

Extreme northward shifting of the Subarctic boundary occurs during El Niño years such as 1957-58. We have attempted to show that one of the effects of such a shift is to alter the zooplankton community off the coast of North America for approximately 800 km from 40°N to 52°N by replacement of large copepods with small copepods. We have used hypothetical changes in feeding efficiency during the early sea life of juvenile salmonids as an example of one kind of effect that variations in ocean transport could have on a commercial fish stock. Effects of this type of environmental perturbation should increase from north to south, and should be mediated by the buffering action of nursery environments such as large bays, estuaries, and protected coastal waters. It will also vary between species and phenotypes.

The problem of linking a decline in commercial fish stocks to changes in ocean climate is difficult to resolve. Long term fluctuations in abundance of fish populations in the California Current system have been estimated from the examination of fish scales in the undisturbed sediments of the anoxic Santa Barbara

Basin (Soutar and Issacs 1974). Since these records extend back in time prior to commercial exploitation, they implicate changes in ocean climate as a cause of persistent instability. The existing data base is insufficient to provide any more conclusive analysis and we suggest a useful hypothesis relating ocean transport, prey size spectrum and biomass, and feeding success that could be field tested, considering the time and space scales identified here.

Acknowledgments

Suggestions from Drs. Kees Groot, Kim Hyatt, John Mason and Dan Ware substantially improved the manuscript. We gratefully acknowledge their helpful suggestions.

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Appendix: Summary of Unusual Sightings of Marine
Species Off British Columbia During the 1982-83 El Niño

Compiled by John D. Fulton

Species	Location	Time	Source of record and remarks
1) Extensions of Northern Range			
FISH			
<u>Synodus lucioceps</u> (California lizard fish)	Cape Beal (Bradys Beach)	Aug. 15	Bamfield Marine Station (Bergey)
<u>Xiphias gladius</u> (Swordfish)	47°01.1'N, 130°24'W	Sept 20/83	PBS, caught in gill net (Sloan)
= previous record	46°01.1'N, 128°39.4'W	June 30/82	Univ. of Victoria (Tunncliffe)
<u>Remora remora</u>	46°42'8 N, 131.25.0'W	Aug 4/83	PBS (Robinson)
PLANKTON			
(Copepod)			
<u>Acartia danae</u>	48°49.0'N, 128°37.4'W	Sept 20/83	105 plankton haul (Ashton)
= previous record	46°32'N, 125°57'W	Sept 1935	Davis (1949)
2) Isolated sightings			
FISH			
<u>Genyonemus lineatus</u> (White croaker)	Swanson Channel	March 83	B. C. Provincial Museum (Teden)
<u>Seriola lalandi dorsalis</u> (Yellowtail)	47°57.0'N, 130°50.0'W	Aug 5/83	B. C. Provincial Museum (Teden)
Species			
<u>Trachurus symmetricus</u> (Jack mackerel)	47°33.0'N, 131°12.4'W	Aug 2/83	B. C. Provincial Museum (Teden)
<u>Engraulis mordax mordax</u> (Anchovy)	Barkley Sound Quatsino Sound	July 12/83 Nov 18/83	(Bauer) B. C. Provincial Museum, young small specimens indicate spawning? (Teden)
2) Isolated sightings (cont'd)			
FISH			
<u>Sardinops sagax</u> (Pacific sardine)	Clayoquot Sound	Aug 83	Schooling with anchovy (Dawson)
INVERTEBRATES			
<u>Emerita analoga</u> (California sand crab)	Kyuquot Sound	Aug 83	Juveniles on Sand Beach (Austin)
BIRDS			
<u>Puffinus occidentalis</u> (Brown pelican)	Victoria Denman Island	July 24/83 July 27/83	(Hill) (Sparrowhawk)
<u>Puffinus bulleri</u> (New Zealand shearwater)	Cape Beal Cape Beal	Aug & Nov 1983 Aug-Nov/83	Bamfield Marine Station (Bergey) Bamfield Marine Station (Bergey)

Species	Location	Time	Source of Record and Remarks
<u>Puffinus creatopus</u> (Pink-footed shearwater)	Cape Beal	Aug-Nov/83	Bamfield Marine Station (Bergey)
<u>Thalasseus elegans</u> (Elegant tern)	Queen Charlotte Islands	Summer '83	(Phillips)
<u>Sterna caesia</u> (Caspian tern)	Queen Charlotte Islands	Summer '83	(Phillips)
<u>Steganopus tricolor</u> (Wilson's phalarope)	Queen Charlotte Islands	Summer '83	(Phillips)
REPTILES			
<u>Dermodochelys schlegelii</u> (Leatherback turtle)	Off Nootka Sound	July '83	(Cary)
PLANKTON			
1) Copepods:			
<u>Scottocalanus perseans</u>	Queen Charlotte Sound	May '83	(Ashton)
<u>Pleuromma xiphias</u>	50°43.0'N, 131°08.3'W	Aug '83	(Ashton)
2) Isolated sightings (cont'd)			
<u>Heterostylites longicornis</u>	54°43.0'N, 131°08.3'W	Aug '83	(Ashton)
<u>Arietellus plumifera</u>	50°43.0'N, 131°08.3'W	Aug '83	(Ashton)
<u>Aegisthus macronatas</u>	50°43.0'N, 131°08.3'W	Aug '83	(Ashton)

Species	Location	Time	Source of Record and Remarks
3) Widespread Sightings			
INVERTEBRATES			
<u>Velella velella</u> (By-the-Wind-Sailor)	B. C. Coast	Mar-Sept '83	Many sightings all summer on outer coast.
FISH			
<u>Mola mola</u> (Ocean sunfish)	B. C. Coast & Juan de Fuca Strait & Johnstone Strait	Mar-Nov '83	Numerous sightings
<u>Scomber japonicus</u> (Chub/Pacific Mackerel)	B. C. Coast & Strait of Georgia	June-Dec '83	Particularly abundant in Barkley Sound (486 fish in one seine set)
<u>Sarda chiliensis</u> (Pacific bonito)	B. C. Coast	July & Sept '83	Several sightings
<u>Brama japonica</u> (Pomfret)	Edge of Continental Shelf, Dixon Entrance	Aug '83	Catches on set lines
PLANKTON			
1) Copepods			
<u>Mesocalanus tenuicornis</u>	B. C. Coast	Spring & Summer '83	(Ashton)
<u>Lucicutia flavicornis</u>	" "	" "	" "
<u>Ctenocalanus vanus</u>	" "	" "	" "

<u>Euquirella curticaudata</u>	"	"	"
<u>Euquirella rostrata</u>	"	"	"
3) Widespread Sightings (cont'd)			
PLANKTON (cont'd)			
2) Molluscs:			
<u>Euclio pyramidata</u>		B. C. Coast	Spring & Summer '83 (Ashton)
3) Salps:			
<u>Salpa fusiformis</u>	"	"	"

Records and Sightings of Fish and Invertebrates in the Eastern Gulf of Alaska And Oceanic Phenomena Related to the 1983 El Niño Event

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This report presents records of sightings and captures of unusual marine species from the eastern Gulf of Alaska during the 1982-83 El Niño event and, where possible, relates the occurrence of the species to anomalous oceanographic conditions. Surface water temperatures of the locations were not reported at the time of observation or capture; therefore, specific oceanographic conditions synoptic with the biological data are unavailable.

General information on surface water temperatures may indicate the relationship between the mass of anomalously warm water and the occurrence of unusual marine species in the eastern Gulf of Alaska. Anomalously warm surface water began developing in southeastern Alaska and Prince William Sound by October 1982 (Fluharty, 1984). By March 1983, all of the eastern Gulf of Alaska and the Bering Sea were unusually warm ($>+0.5^{\circ}\text{C}$), with the warmest ($+1.5^{\circ}\text{C}$) off southeastern Alaska. The warm water anomaly continued in the eastern Gulf of Alaska and southeastern Alaska inside waters until August (Fluharty, Fig. 2 and Table 1, 1984). By August, the warmest cell of surface water in the Gulf of Alaska had moved westward to southeast of Kodiak (56°N , 148°W). A cooling of southeastern Alaska inside waters and the far eastern Gulf of Alaska followed in September and October. The warm water anomaly reestablished in the eastern Gulf of Alaska by March 1984.

Northwest shifts of warm water marine species have been reported in previous years (Radovich, 1961). Most reports have been linked to the occurrence of strong to very strong tropical El Niño events; 1941, 1957-58, 1977, 1982-83. Northward displacement of marine species has been envisaged as coincident with the northward displacement of usual sea surface temperatures (Hamilton and Mysak, in press) and northward shifts of major oceanographic features (French et al., 1971). General warming of northern surface waters and major shifts of oceanographic features are undoubtedly causative factors involved in biological displacements, but interannual variable development of eddies in the northeast Pacific Ocean (Mysak, 1985) may be an important factor in moving southerly species well north of the usual ocean