7. Marine Biological Resources

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7.1 Introduction

The fisheries of the Bering Sea region are among the most productive in the world (Tables 7.1, 7.2, 7.3, and 7.4). Over 28% of recent world total landings of fish, mollusks, and crustaceans have been harvested from the extended region (North Pacific Ocean, Bering Sea, Sea of Okhotsk, Chukchi Sea, and Gulf of Alaska). These fisheries support a variety of seabird and marine mammal populations and an array of commercial, subsistence, and recreation harvest effort. The ex-vessel value of Alaska's commercial fisheries alone exceeded $1.4 billion in 1995 (NPFMC 1996a). Processing contributes additional value to the fisheries sector. In addition to highly productive marine fisheries, the region includes extensive freshwater systems with important fisheries.

The marine and freshwater resources of the region have been used for subsistence for thousands of years. Whales, seals, sea lions, walrus, sea cows, various seabirds, Pacific salmon, Pacific halibut, Pacific herring, whitefish, pike, and burbot figured prominently in the pre-contact diets of native peoples. The initial commercial activities in the region focused on the harvest of fur seals and other pinnipeds, sea otters, and baleen whales. Incidental harvests of sea cows led to their extinction in the mid-19th century. The commercial fisheries for Pacific cod, Pacific salmon, Pacific herring, and Pacific halibut developed in the late 1800's. Large-scale harvest of most other region groundfish stocks did not begin until after the Second World War.

The productivity and sustainability of fisheries in this region is controlled by the interplay of biological, oceanographic, hydrological, and human processes. For example:

- the stock levels of any given species are affected by changes in primary productivity, inter-specific competition for resources, complex predator-prey relationships, and reproductive success;
- changes in the velocity and direction of ocean currents affect the availability of nutrients and the disposition of larval and juvenile organisms, thereby influencing recruitment, growth, and mortality;

Table 7.1. Eastern Bering Sea (US EEZ) catches (1,000t).

	Pollock	Cod	Flatfish	Rockfish	Sablefish	Atka Mackerel	Herring	Halibut	Salmon (Total)	King Crab	Tanner Crab	Snow Crab
1970	1,256.6	70.4	230.8	76.8	13.0	1.0			157.8	3.9	0.5	
1971	1,743.8	45.1	313.6	31.6	18.0				117.4	5.9	0.1	
1972	1,874.5	43.3	216.8	38.9	16.3	6.0			78.0	9.9	0.0	
1973	1,758.9	54.4	198.9	15.5	8.9	2.0			65.6	12.2	0.1	
1974	1,588.4	63.8	182.1	36.4	6.7	1.0			61.3	19.2	2.3	
1975	1,356.7	54.4	174.4	25.2	4.5	13.0			63.5	23.3	3.2	
1976	1,177.8	54.7	159.8	28.9	4.6	13.0			111.8	29.1	10.2	
1977	986.0	36.6	113.7	14.1	4.6	21.0		0.6	139.8	31.8	23.4	
1978	985.7	45.8	211.3	11.0	2.0	24.0		0.6	177.1	39.8	30.3	0.8
1979	923.4	39.4	174.8	13.8	2.2	23.3		0.6	199.6	49.0	19.3	14.6
1980	1,016.4	52.0	180.0	7.0	2.0	16.0	21.6		232.5	68.3	17.1	18.0
1981	1,029.0	62.0	194.0	6.0	3.0	17.0	17.7	0.5	278.2	18.0	14.1	24.0
1982	1,013.9	57.0	184.0	3.0	4.0	20.0	24.9	0.7	255.3	4.6	5.6	13.4
1983	1,041.4	93.0	201.0	2.0	3.0	12.0	30.8	2.0	282.4	1.3	2.8	11.9
1984	1,180.6	133.0	236.0	2.0	3.0	36.0	22.9	1.4	300.5	2.7	0.7	12.2
1985	1,237.5	145.0	321.0	1.0	4.0	38.0	30.2	2.0	304.4	2.5	1.6	30.0
1986	1,235.1	141.0	302.0	1.0	7.0	32.0	23.7	2.7	277.0	5.7	0.1	44.5
1987	1,266.3	158.0	261.0	3.0	8.0	30.0	20.5	3.3	231.2	6.3	0.1	46.3
1988	1,271.0	198.0	396.0	4.0	7.0	22.0	20.1	2.2	243.0	4.2	1.2	60.9
1989	1,386.0	169.0	254.0	6.0	5.0	15.0	17.8	2.3	317.4	5.3	3.3	68.0
1990	1,426.0	171.0	162.0	21.0	4.0	22.0	20.3	2.6	314.4	9.7	29.4	73.5
1991	1,346.5	172.0	199.0	8.0	3.0	22.0	20.3	3.0	331.5	8.3	14.5	149.4
1992	1,438.4	206.0	248.0	18.0	2.0	47.0	26.0	3.1	312.6	4.2	16.0	143.3
1993	1,358.8	167.0	216.0	18.0	3.0	66.0	22.8	3.0	384.5	7.1	8.0	104.9
1994	1,421.4	197.0	262.0	20.0	2.0	69.0	30.7	2.6	393.7	0.2	4.1	68.1
1995	1,329.5	233.0	231.0	17.0	2.0	81.0	35.5	2.2	451.9	0.2	2.8	34.2
1996	1,218.2						32.5	2.5	409.1	3.9	0.9	29.9

Table 7.2. Western Bering Sea (Russian EEZ) catches 1,000t).

	Pollock	Pacific Cod	Flatfish	Rockfish	Saffron Cod	Herring	Halibut	Salmon	Crabs
1970	34.7	9.0	29.1		6.8			14.2	7.2
1971	18.9	6.5	11.6		2.7	4.7	0.3	20.9	2.7
1972	422.1	10.5	17.5		9.5	0.3		9.0	3.1
1973	364.9	21.0	10.2		9.5	0.0	0.1	13.0	
1974	427.0	17.4	9.9		13.4			17.7	
1975	265.2	7.3	7.8		1.7			26.1	2.0
1976	551.6	9.8	6.0	0.3	1.5			18.9	
1977	394.0	5.8	7.5		5.9	25.0	0.1	5.9	
1978	481.6	7.0	17.4	0.2	13.9	8.9	3.2	18.7	
1979	615.5	3.7	8.5	0.6	9.3	13.9	4.2	55.6	0.9
1980	928.0	14.2	20.8	1.2	14.0	12.8	0.3	14.8	0.8
1981	890.9	33.1	10.6	1.8	13.4	14.9	6.6	55.5	2.0
1982	1,019.1	62.2	12.0	0.5	12.9	12.9	2.9	18.8	3.0
1983	971.0	63.6	17.2	0.1	15.4	16.3	2.0	47.6	3.5
1984	785.9	97.5	8.0	0.1	16.1	17.4	2.6	29.4	3.2
1985	712.8	94.9	33.5	0.0	10.3	31.3	2.9	38.4	3.2
1986	936.7	117.7	39.9	0.0	8.9	21.0	5.0	24.1	4.8
1987	1,108.3	72.4	24.0	0.2	9.6	20.2	4.4	52.4	3.2
1988	1,291.7	70.3	27.9	1.0	10.5	15.3	2.5	21.8	5.8
1989	1,213.8	62.0	24.0	0.0	9.8	9.5	2.8	65.5	4.5
1990	928.4	89.2	26.8	0.1	15.2	16.3	3.0	16.5	4.3
1991	631.5	61.8	29.0	0.0	7.5	12.2	1.5	96.1	3.9
1992	702.7	110.0	25.5	0.0	13.5	2.4	1.4	29.9	0.6
1993	768.8	62.1	11.4	1.1	5.2	2.0	0.3	59.1	1.4
1994	369.3								
1995	407.1								
1996	510.5								

Table 7.3. Eastern Bering Sea (US EEZ) biomass estimates (1,000t).

	Pollock	Cod	Flatfish	Rockfish	Sablefish	Atka Mackerel	Halibut
1980	6,660	636	4,149	142	73	848	35
1981	10,820	1,058	4,595	142	82	982	35
1982	11,470	1,393	4,987	139	90	830	36
1983	12,280	1,608	5,290	141	121	747	37
1984	11,810	1,638	5,545	154	143	640	38
1985	14,330	1,577	5,406	192	166	551	41
1986	13,540	1,538	5,662	232	166	516	42
1987	13,990	1,496	5,914	270	135	599	43
1988	12,900	1,466	6,378	277	98	700	45
1989	10,880	1,339	6,340	294	131	866	49
1990	8,670	1,220	6,642	349	86	836	53
1991	7,030	1,063	6,818	334	58	1,045	56
1992	9,320	891	7,064	381	51	1,119	58
1993	9,240	857	7,252	381	35	950	59
1994	8,260	943	7,477	373	52	829	61
1995	8,080	1,060	7,068	395	43	699	63
1996	6,672	1,129	7,101	359	26	578	64
1997	6,500	1,590	6,873	589	36	450	65

Table 7.4. Status of Eastern Bering Sea fish stocks (1,000t).

	Mean Biomass	1997 Biomass	OFL	ABC	TAC	3-year Trend
Pollock	10,438	6,778	2,062.0	1,190.0	1,159.0	Down
Pacific Cod	1,364	1,590	418.0	306.0	270.0	Up
Yellowfin Sole	1,979	2,530	339.0	233.0	230.0	Stable
Greenland Turbot	448	118	23.0	12.0	9.0	Down
Arrowtooth Flounder	280	587	167.0	108.0	21.0	Stable
Rock Sole	1,187	2,390	427.0	296.0	97.0	Stable
Flathead Sole	403	632	145.0	101.0	44.0	Stable
Other Flatfish	595	616	150.0	98.0	51.0	Stable
Sablefish	95	37	5.6	2.7	2.3	Down
Pacific Ocean Perch	331	397	31.0	16.0	16.0	Up
Other Rockfish	161	193	10.0	7.0	7.0	
Atka Mackerel	699	450	82.0	67.0	67.0	Down

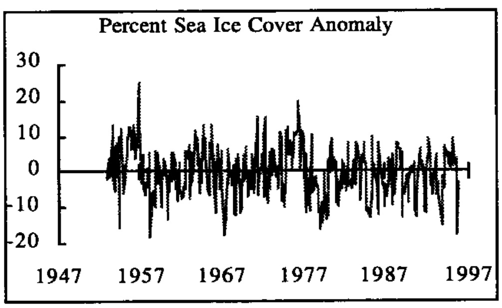
- changes in rainfall and runoff affect stream flow conditions which influence freshwater species as well as the freshwater portions of the life cycles of important anadromous species such as salmon;
- and, overall economic conditions and changes in demand for fish and fish products in key markets (e.g., Japan) can affect commercial fishing pressure and viability with attendant consequences for resource availability for subsistence and recreational interests.

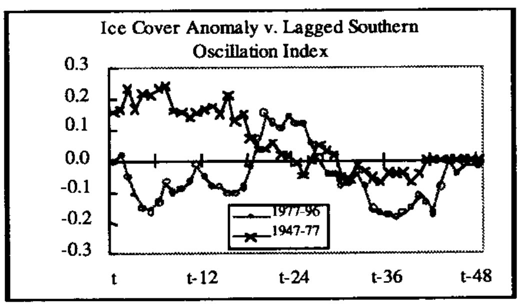
A review of historical records also indicates that this region is subject to considerable year-to-year variability in climatic conditions, dominated by changes in ocean-atmosphere interactions associated with the El Niño-Southern Oscillation (ENSO) cycle. Resulting changes in temperature, ocean circulation and productivity, sea ice, atmospheric circulation, and rainfall/runoff are associated with sometimes-dramatic changes in critical fisheries stocks and marine mammal populations. Information about the impacts of these natural climate swings can provide valuable insights into the vulnerability of the ocean ecosystem and fisheries (and other economically-important sectors) to climate change--where vulnerability is defined to include considerations of the sensitivity of a given system to an observed change and the flexibility of that system to adapt to or mitigate the effects of those changes. Some evidence indicates that, since the late 1970's, the region has been subject to a prolonged period of warm conditions—often referred to in the literature as a climate "regime shift"—associated with a strengthening and eastward displacement of the Aleutian Low. This "regime shift" may be a local manifestation of a multi-decadal cycle of natural variability (for example in ENSO). This extended period of warmer than average temperatures may reflect a long-term, secular warming trend. The current conditions may represent a long-term warming trend superimposed on a natural cycle of climate variability. Independent of their cause, the changes in atmospheric circulation and oceanic conditions associated with this "regime shift" have discernible consequences for critical ecosystems and populations, including fisheries and marine mammals.

This chapter provides an overview of the consequences of climate variability and change on the physical, biological, and human systems that characterize the Alaska-Bering Sea ocean ecosystem. For the purposes of this discussion, in addition to the open ocean and continental shelf regions, the ocean ecosystem is defined to include the freshwater rivers and streams, estuaries and coastal habitats which support critical fisheries, marine mammals and sea bird populations and the human communities which depend on them. After providing a description of current conditions and stresses, this chapter discusses the impacts of climate change in the context of several important species representing open ocean, anadromous, and freshwater species as well as selected marine mammals and sea birds. Following this exposition of specific impacts, we highlight some of the existing uncertainties and the research required to fill these critical information needs. Finally, we explore the need to integrate consideration of the current and anticipated changes in climate in a variety of resource management and economic development decisions both within the fisheries sector itself and in the context of the other ecosystems and sectors addressed at the June 1995 Workshop.

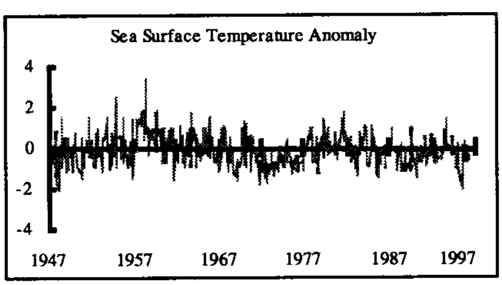
Alaska and Bering Sea. Shifts in temperature in the Bering Sea seem related to the location and intensity of the Aleutian low-pressure cell. In the Gulf of Alaska, periods of warm-ocean conditions appear to be associated with an eastward displacement and intensification of the Aleutian low and downwelling in coastal waters. Recent work by Trenberth and Hurrell (1994) suggests that the entire 1977-1988 period differs markedly from the 1946-1976 and 1989-1992 periods. The Aleutian Low was more intensive than normal in the 1977 though 1988. The deepening of the Aleutian Low is usually associated with warm coastal waters and high sea level (Emery and Hamilton 1985, Roden 1989). Another data series shows that the average pressure in an area 27.5° N to 72.5° N; and 147.5° E to 122.5° W was 1010.8 mb from 1976 to 1988; down from an average of 1012.9 mb, 1946 through 1975 (Pearcy 1992). In addition, sea surface temperature and temperature at depth showed an unusually strong and rapid increase in 1977 and 1978 in the northern Gulf of Alaska off Seward (Royer 1989) as well as off Kodiak and Bristol Bay (Rogers 1984).

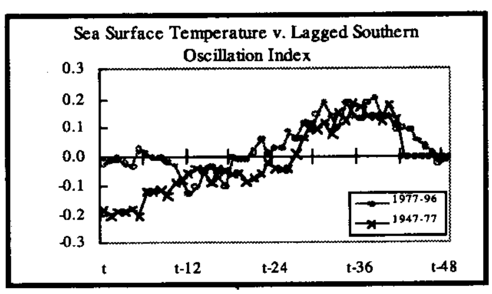
Several measures can be related to the decadal scale of changes that are important to biological oceanography (Niebauer 1988). Percentage of ice cover has changed from the 1970s through the 1990s. In addition, the correlation at short lags between percent sea ice cover and SOI has switched from positive (anti-El Niños associated with above average ice cover) to negative (El Niños associated with above average ice cover).



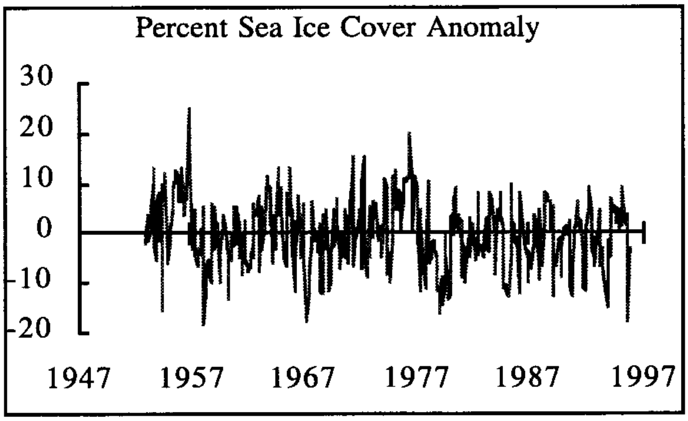


Also there is a long record of sea surface temperature (SST) from ship of opportunity data taken with a square centered on the Pribilof Islands. The newer part of the time series is from satellite charts. The SST record shows a similar pattern. Prior to the mid-1970s, El Niños were associated with increased SST at short (< 1-year) lags and decreased SST at long (30 to 42-month) lags. In recent years, the correlation structure has broken down at short lags, with El Niños often associated with depressed SST.





These general surface circulation patterns, in combination with freshwater inputs, contribute to upwelling processes that make nutrients abundantly available on the Bering Sea's continental shelf, leading to high levels of biological productivity. The strength of these upwelling processes, the direction of nutrient transport, and the extent and duration of sea ice coverage are influenced by the location and intensity of the Aleutian Low–a prominent atmospheric pressure feature. The Aleutian Low is a persistent low-pressure cell that is dynamically centered to the south of the Aleutian Islands. The mean position of the Aleutian Low is influenced by the position and intensity of climate events, including El Niño-Southern Oscillation (ENSO).

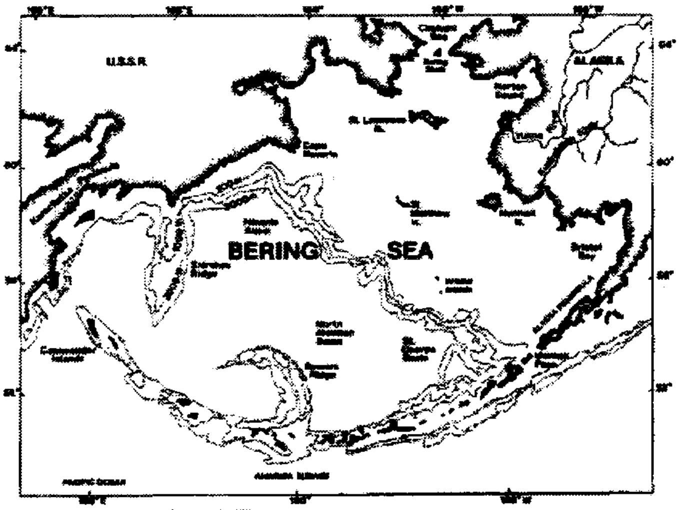


The El Niño-Southern Oscillation (ENSO) is a coupled ocean-atmosphere process characterized by periodic oscillations in ocean temperature and atmospheric pressure conditions in the tropical Pacific. Under usual conditions, westward trade winds tend to keep warm surface waters "stacked up" in the western Pacific Ocean, resulting in strong coastal upwelling along the eastern edge of the equatorial Pacific Ocean. El Niño refers to the "warm phase" of the ENSO cycle during which warm surface waters normally confined to the western Pacific expand eastward toward the coast of South America. These conditions are associated with a depression in the thermocline in the eastern Pacific which significantly curtails the usually strong upwelling of nutrient-rich waters. El Viejo or La Niña describe the "cold phase" of the ENSO cycle when ocean temperatures in the eastern Pacific are cooler than normal. These changes in oceanic conditions are coupled to a see-saw in atmospheric pressure gradients across the Pacific Basin known as the Southern Oscillation. An index, called the Southern Oscillation Index (SOI), provides a measure of the difference in sea level atmospheric pressure between Tahiti and Darwin, Australia. Negative values for the SOI are associated with an El Niño warm event, while positive SOI values are associated with cold phases of the ENSO cycle. These changes in the exchange of energy between the ocean and the atmosphere in the tropical Pacific produce changes in patterns of temperature and precipitation globally with effects felt in the Bering Sea (e.g., Niebauer 1988).

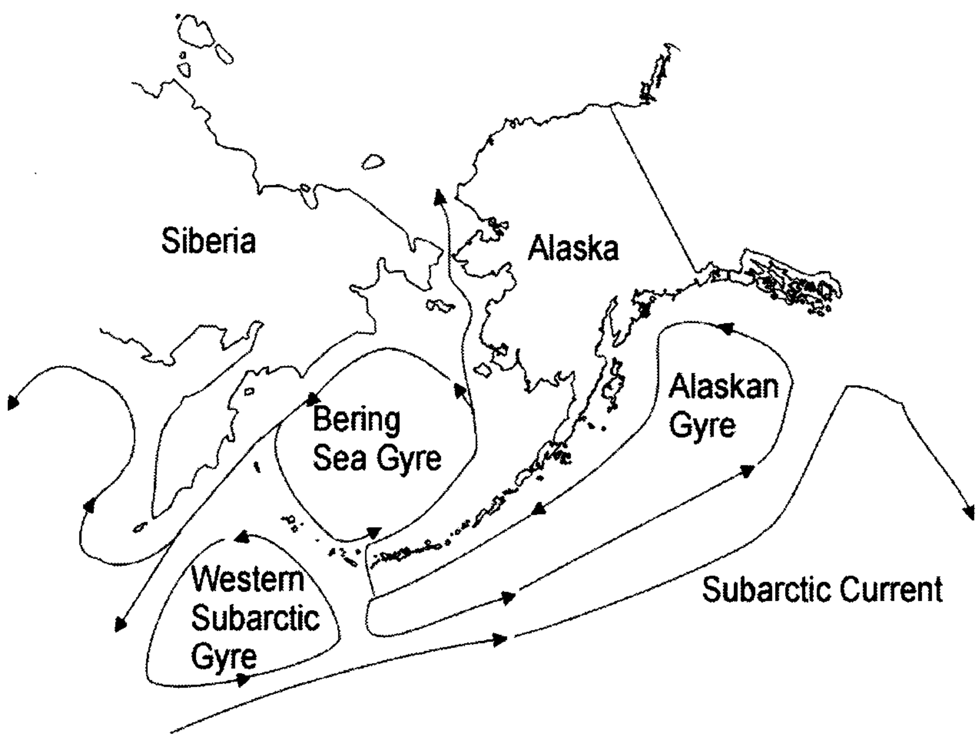
Decadal scale changes in ocean physics in the Bering Sea and Alaska Gyre— Evidence from several sources indicates that a strong climatic change occurred in the mid-1970s that influenced ocean dynamics and biological productivity. Strong shifts in atmospheric measures during the late 1970s resulted in warmer winter conditions that continued through the early 1980s. Consequently, the regime shift involved a general warming of waters in the Gulf of

7.2 Physical System

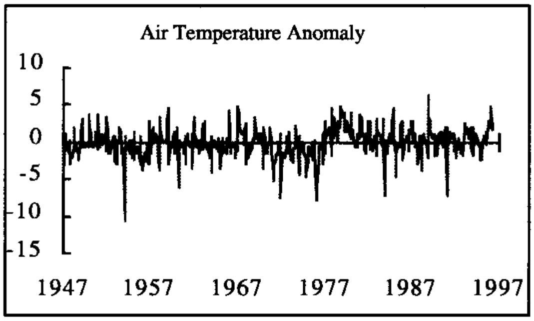
A broad shallow continental shelf covers the northeast half of the Bering Sea while the southwest half consists of a deep basin rimmed by a narrow shelf. The primary freshwater inputs are provided by the Yukon and Kuskokwim rivers, which drain over 400,000 square miles in Alaska and Canada.

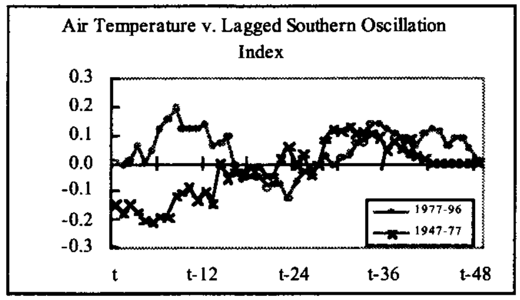


Surface circulation patterns include the eastward flowing Subarctic Current, and the counterclockwise Western Subarctic, Alaskan, Bering Sea gyres. North Pacific waters feed into the Bering Sea through breaks in the Aleutian Islands. Surface waters flow from the Bering Sea into the Chukchi Sea to the north, and along the Kamchatka Peninsula into the North Pacific.

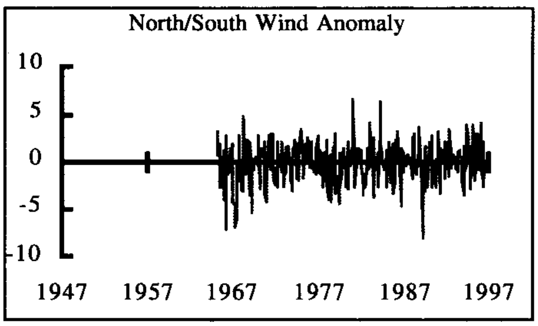


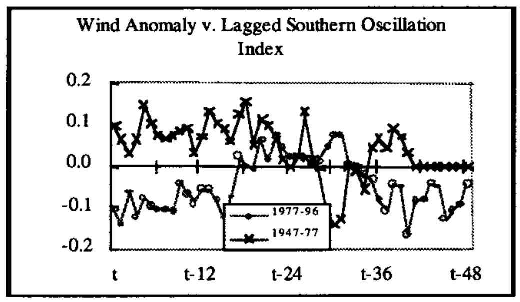
An air temperature time series from the St Paul Island airport in the Pribilofs also supports the hypothesis of a mid-1970s regime shift.





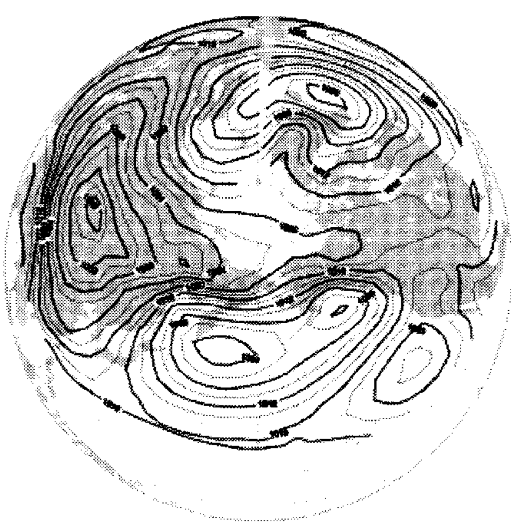
Similarly, an index of wind direction (derived from wind components from the north and south) at the St. Paul Island airport suggests that a regime shift occurred in the mid-1970s.

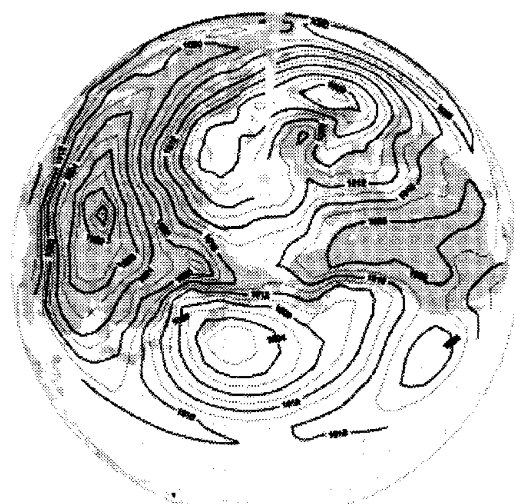




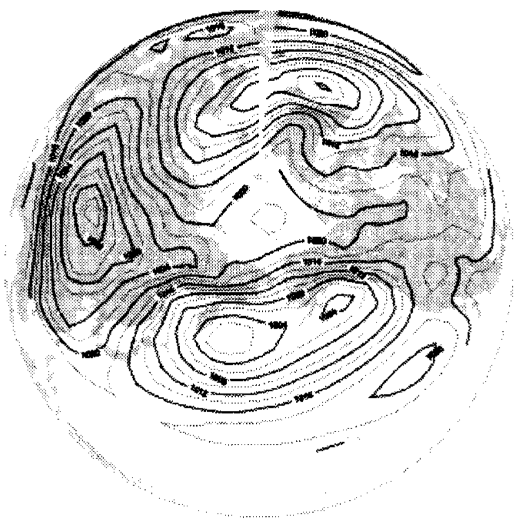
Anti-El Niño 1947-77 (Niebauer 1997)

Anti-El Niño 1977-96. (Niebauer 1997)

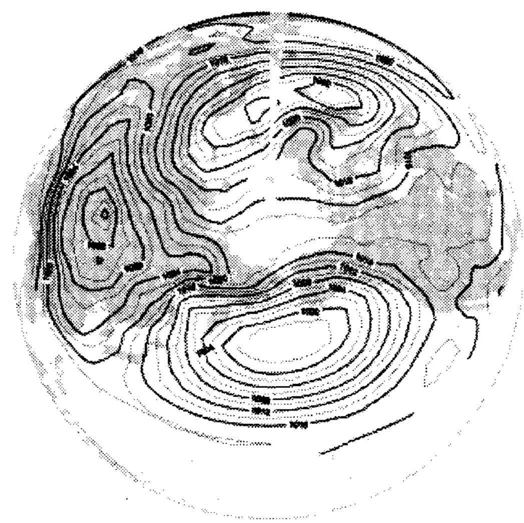




El Niño 1947-77 (Niebauer 1997)



El Niño 1977-96 (Niebauer 1997)



In the mid-1970s, the ENSO event coincided with a change in the 18-year lunar tide-cycle that is related to temperatures in the Gulf of Alaska (Royer 1993). Royer has developed a time series of CTD casts at the mouth of Resurrection Bay in the northern Gulf of Alaska going back to the early 1970s. This series indicates that an 18-year temperature cycle at depth that is correlated to the tidal (lunar) cycle of this period (Royer 1993). In the mid-1970s the ENSO event was coincident with the high temperature period of the 18-year cycle. The two events acting together caused unusually warm water.

Because changes in the frequency and intensity of El Niño events have a critical role in determining the impact of climate change on marine resources of the Bering Sea region, it is important to understand how climate change is likely to affect ENSO. Bakun (1996) hypothesizes that ENSO is driven by the temperature differential between the tropics and the poles. He speculates that global warming will decrease the temperature differential and may reduce basin-scale oceanic and atmospheric circulation, possibly reducing the productivity of the Bering Sea ecosystem.

7.3 Biological Resources & Processes

The productivity of fisheries is controlled by the interplay of biological and oceanographic processes. Changes in the velocity and direction of ocean currents affect the availability of nutrients and the disposition of larval and juvenile organisms, thereby influencing recruitment, growth, and mortality. However, while the influence of abiotic processes is undeniable, the exact nature of the mechanisms involved is largely unknown or unobservable. Moreover, the influence of oceanographic processes may vary across life stages and through space and time, and may depend on the conflicting or compounding interplay of multiple processes.