Impact of ENSO Events on Tuna Fisheries in the U.S. Affiliated Pacific Islands

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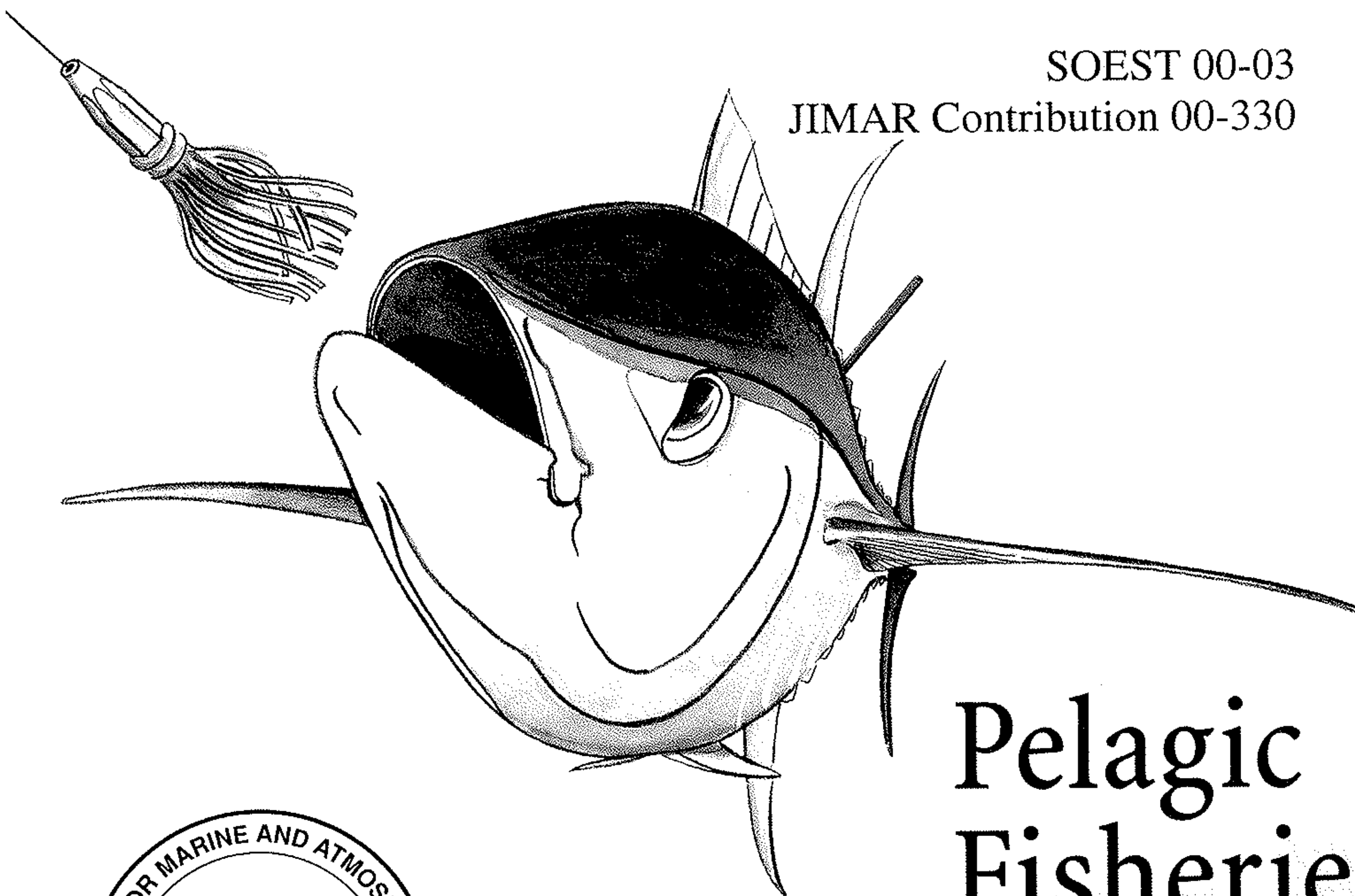

Joint Institute for Marine and Atmospheric Research ~UH-NOAA~

JIMAR

Pelagic Fisheries Research Program

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- The National Marine Fisheries Service
- The American Samoa Department of Marine and Wildlife Resources
- StarKist Samoa, Inc.
- StarKist Foods, Inc.
- Caribbean Fishing Company, Inc. (affiliate of Heinz and StarKist)
- Samoa Packing, Inc.
- Zolezzi Enterprises, Inc.
- Guam Department of Commerce
- Guam Department of Agriculture and Wildlife, Fisheries Division
- Marshall Islands Marine Resources Authority, Republic of the Marshall Islands
- Department of Resources and Development, Federated States of Micronesia National Government
    - Micronesian Maritime Authority, Federated States of Micronesia National Government
    - National Fisheries Corporation, FSM
    - Caroline Fishing Corporation
    - Micronesian Longline Fishing Company, Inc.
    - Yap Fishing Authority, Government of the State of Yap
    - Yap Fresh Tuna, Inc.
    - Casamar Yap
    - Division of Marine Resources, Government of the Republic of Palau
    - Palau Mariculture Demonstration Center
    - Palau Maritime Authority

Abstract

This report assesses the impact of El Niño-Southern Oscillation (ENSO) events on the tuna industry in the U.S.-affiliated Pacific Islands. It is the result of the first phase of a study on the impact of ENSO cycles on tuna fisheries throughout the Pacific Islands region. The first phase of the research project focused on interviews with fleet managers, vessel captains and crews, transshipment operators and cannery managers in American Samoa, Guam, and other Micronesian Islands. Anecdotal information obtained in the interviews and some regional catch data indicated that some correlation exists between climate and fisheries, and this warrants further study. In Phase Two, the project team plans to statistically analyze catch data for the countries served by the Pacific Community, formerly the South Pacific Commission, and provide a socioeconomic impact analysis.

Contents

INTRODUCTION

The increase of tuna catches during the last decade in the central and western Pacific have resulted from expansion and intensification of purse seine and longline fishing. A recent United Nations agreement encourages rational management of highly migratory species and straddling stocks, such as Pacific tuna. Knowledge of how environmental variability impacts the distribution and availability of tuna stocks in the exclusive economic zones (EEZs) of the Pacific Islands is essential for regional management of these fisheries; therefore, this study explores the relationship of climate variability and pelagic fisheries in the Pacific Ocean.

The effects of ENSO (El Niño-Southern Oscillation)[1] on the Pacific Coast fisheries of the Americas have been well documented; however, neither the media nor the scientific community have given much attention to the impact of ENSO events on Pacific tuna fisheries. Some anecdotal information has been available about the changes in tuna distribution during ENSO events. In 1992, boat captains and agents in American Samoa reported an eastward shift in skipjack stocks during an ENSO warm event, which began in 1991. During that year, StarKist Samoa and Samoa Packing cannery managers reported an oversupply of tuna resulting from purse seiners making short trips east of Samoa. This resulted in delays of up to 21 days for vessels waiting to off-load their catch in Pago Pago. Kiribati's government officials also reported a sharp decline in government revenues from access fees, which are distributed to regional governments under the U.S./Pacific Islands Tuna Treaty, largely on the basis of the amount of fish caught in each country's EEZ. With the eastward displacement of tuna and purse seine vessels during ENSO events, the potential for fishery interaction may increase as vessels are geographically closer to the Hawaii EEZ.

Anecdotal evidence indicates that ENSO events have an impact on tuna distribution. The determination that ENSO events have a significant impact on migratory patterns or catch-per-unit-effort for tuna would suggest that agencies who monitor the status of tuna stocks, assist in tagging studies, or manage fisheries resources and industries reliant upon tuna stocks should develop an understanding of the effects and patterns of ENSO events. As shown in this study, the observations and evidence of climate impacts on pelagic fisheries clearly necessitates further investigation, because the outcomes of the study would be beneficial to the fisheries industry, Pacific Island economies, and resource managers dependent on this knowledge.

Project Background

Upon receiving a grant for the first phase of research from the Office of Global Programs, National Oceanic and Atmospheric Administration (OGP/NOAA), the project team, in

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[1] The El Niño-Southern Oscillation (ENSO) phenomenon is an interannual perturbation of the climate system which occurs every 4-7 years and lasts 12-18 months. The impacts of ENSO events are strongest in the Pacific through disruption of the atmospheric circulation, generalized weather patterns, and fisheries. ENSO affects the ecosystem dynamics in the equatorial and subtropical Pacific by considerable warming of the upper ocean layer, rising of the thermocline in the west and lowering in the east, strong variations in the intensity of currents, low trade winds with frequent westerlies, high precipitation at the dateline and drought in the western Pacific. Anti-ENSO events (e.g. La Niña events) occur less frequently and are characterized by intense equatorial upwelling.

consultation with colleagues from the Pacific ENSO Applications Center (PEAC)[2] and Pacific Islands fisheries agencies, reviewed the work plan. Ideally, a study of this nature would investigate islands throughout the Pacific to determine the overall effects and changes of catch patterns and shifts in tuna stocks. Practically, the funding allowed for investigations at a limited number of sites. Should the evidence from the first phase of the project indicate that further investigations should be undertaken, the researchers were prepared to propose a second phase of research at an expanded number of sites with more in-depth investigations.

The project team chose American Samoa and Guam fisheries as the emphasis for the preliminary study, because these islands host major segments of the Pacific tuna industries. The StarKist Samoa and Samoa Packing canning plants in American Samoa supply about 39 percent of U.S. canned tuna production.[3] Pago Pago Harbor is the homeport for the majority of the U.S. purse seine fleet. Guam is a major transshipment point for longline-caught sashimi-grade tuna bound for the Japanese market. The Federated States of Micronesia and the Republic of Palau rely on Guam as their central point for transshipment, and feeder flights from these islands carry fish to Guam, where they are transferred to wide-body jets bound for Japan. Guam also provides management for some of the transshipment companies and gear repair operations stationed in Yap and other Micronesian Islands.

In addition, American Samoa and Guam have been involved with the project team in the development of the Pacific ENSO Applications Center (PEAC). With joint operations and management in Guam and Hawaii, PEAC provides public education about the El Niño-Southern Oscillation events (El Niño and La Niña), ENSO forecasts, and climate information products to the U.S.-affiliated Pacific Islands. PEAC helps link scientific information on climate variability with end-users. The ENSO forecasts have been used by decision-makers and resource managers in developing response plans for droughts and tropical cyclones associated with ENSO events. PEAC could expand their program to provide ENSO forecasts and the results of climate variability research to pelagic fisheries resource managers, fisheries industries, and organizations interested in fisheries, should the research reveal linkages between ENSO events and pelagic fisheries.

The Office of Global Programs awarded the grant to support the initial phase of the project prior to the onset of the 1997-1998 ENSO event. As this event developed, the Pacific ENSO Applications Center began to receive anecdotal reports of changes in Pacific tuna fisheries, such as changes in the location of stock, unusual current patterns and fishing conditions, and shifts in the foreign purse seine fleets. Many of these changes were attributed to the 1997-1998 ENSO

[2] The Pacific ENSO Applications Center began as a pilot project in 1994 with funding from the Office of Global Programs, NOAA. Its purpose was to test the feasibility of providing end-to-end climate variability research, forecast, and application services. Through newsletters, workshops, and personal communication, PEAC advised the U.S.-affiliated Pacific Islands about the impending drought associated with the 1997-98 ENSO warm event. PEAC has shown that the "end-to-end" concept can be used to reduce the suffering and cost of extreme climate events associated with the ENSO cycle (Hamnett, Anderson, Schroeder, Guard, Hilton, & Tanabe. April 1999. The Pacific ENSO Applications Center and the 1997-98 El Niño. In Human Dimensions & Economics Principal Investigators Meeting, Project Summaries).

[3] "Tuna Processing." April 1997. In Bank of Hawaii, *American Samoa Economic Report*. From the U.S. Department of Labor.

warm event. This, in turn, significantly increased interest in ENSO phenomena among people in the tuna industry.

The project team initially scheduled fieldwork to begin in mid-1997. They delayed visits to the islands to allow the impacts of the 1997-1998 ENSO event to develop. Instead, the project team conducted telephone interviews with tuna industry people in Guam and American Samoa during the latter half of 1997. From October through December 1997, the team reviewed tuna catch information provided by the South Pacific Commission (SPC) through its *Regional Tuna Bulletin*[4] and *Tuna Yearbook.*[5] These sources clearly indicated temporal variability in catch throughout the Pacific region. Since these documents report monthly catch data by fleet and gear type, and then aggregate the spatial distribution data on an annual basis, it was not possible to identify the kinds of ENSO related changes in the fisheries being reported anecdotally during telephone interviews. Therefore, the importance of compiling catch data on a sub-regional basis became clear.

The team began fieldwork in American Samoa in January 1998. The interviews had been seen initially as a method for investigating perceived impacts of past ENSO events. However, the emergence of the strongest ENSO in recorded history provided the project team with the unique opportunity to interview vessel captains and crews, fleet managers and agents, and cannery managers about the impacts of an on-going event.

Research Methods and Assumptions

An underlying assumption of the analysis contained in this paper is that ENSO events change ocean and climate conditions, prompting a movement of tuna stocks, and thereby affecting tuna catch. Unfortunately, very limited scientific research on the location and movement of tuna stocks in relation to ENSO events has thus far been conducted to support this assumption.[6] Like most research on tuna fishing and tuna stocks, the analysis discussed in this paper relies on tuna catch statistics and the perceptions of tuna fishers about the location of stocks.

The project team conducted interviews with more than fifty people associated with the tuna industry in the Pacific Islands. Interviews varied widely to capture the full extent of those involved in fisheries. The fishing fleets were most accessible in American Samoa for interviews, due to the cannery operations and presence of some of the U.S. purse seine fleet. In most other islands, transshipment operators and staff of fisheries management agencies provided the primary source of information in interviews.

The project team does not assume fishers have perfect knowledge about the location of stocks, but that they rely on skills, techniques, and experience to successfully find fish. Interviews with

[4] Oceanic Fisheries Programme, South Pacific Commission. Quarterly. *South Pacific Commission Regional Tuna Bulletin.* Noumea, New Caledonia: SPC.

[5] Oceanic Fisheries Programme, South Pacific Commission. 1993-96. *South Pacific Commission Tuna Fishery Yearbook.* Noumea, New Caledonia: SPC.

[6] P. Lehodey, M. Bertignac, J. Hampton, A. Lewis, and J. Picaut. (1997, October). El Niño Southern Oscillation and tuna in the western Pacific, (Letter to Nature). *Nature,* 389:715-718.

tuna fishermen[7] suggest that they have some familiarity with the influence of ENSO events on tuna stock movement. This knowledge probably accounts for the association between stock and catch location, reflected in these fishermen's perceptions, and the correlation with catch data discussed in this paper.

The interviews conducted for this project indicate that a great deal of learning has taken place over the past ten years, as captains and fleet managers have observed differences in the climate and ocean conditions resulting from the ENSO events. Therefore, some of the changes in catch patterns reflected in catch data may not reflect changes in the fishery.

Economic Importance of the Tuna Industries in American Samoa and Guam

StarKist Samoa and Samoa Packing are two of the largest tuna canneries operating within United States' territory, with annual shipments to the U.S. of over 200 thousand pounds of canned tuna worth over $300 million.[8] They are the largest private sector employer in American Samoa, with a combined workforce of over 4,000 workers (about one third of the wage labor force), most of whom are Western Samoans. A 1994 study showed the two canneries annually generate over $3 million in revenue for the American Samoa Government and purchase more than $17 million in local goods and services.[9] The same study found the purse seine fleet home-ported in American Samoa contributes an additional $66.8 to $147.7 million each year to the local economy through the purchase of goods and services.

The tuna industry in Guam contrasts sharply to that in American Samoa. Guam is a major transshipment point for sashimi-grade tuna bound for Japan.[10] Since 1986, longline vessels have been unloading sashimi-grade tuna in Guam for shipment to Japan on wide-body passenger planes. Landings through Apra Harbor have ranged from about 6,000 tons in 1986 to a high of about 15,000 tons in 1989. An earlier study estimated that longline vessels spent between $11.3 and $19.7 million in the Port of Guam in 1994, and the transshipment industry employed about 130 people.[11]

The tuna industry is a minor segment of Guam's economy, which is dominated by tourism. The transshipment industry in Guam constitutes an insignificant percentage of the gross island

[7] The term "fishermen" is used throughout the paper when referring to those interviewed to accurately reflect the gender of ALL those who fish in these islands that were interviewed. A few women work in the industry, as transshipment operation owners and marketers or as agency managers and staff; however, all of the fishers were male. Therefore, the commonly used term "fishermen" is used here to describe the interviewed population of fishers.

[8] According to U.S. Department of Labor statistics, American Samoa shipped 211.6 thousand pounds of tuna to the U.S. in 1994 worth $309 million. (Bank of Hawaii, April 1997, *American Samoa Economic Report*).

[9] Michael P. Hamnett and William Sam Pintz. 1996. The Contribution of Tuna Fishing and Transshipment to the Economies of American Samoa, Commonwealth of the Northern Mariana Islands, and Guam. Honolulu: Pelagic Fisheries Research Program, Joint Institute for Marine and Atmospheric Research, University of Hawaii.

[10] Guam also serves as a homeport primarily for foreign purse seine vessels and has a small, cannery-grade tuna transshipment operation. However, the scope of this study was limited to the longline fishery.

[11] Michael P. Hamnett and William Sam Pintz. 1996. The Contribution of Tuna Fishing and Transshipment to the Economies of American Samoa, Commonwealth of the Northern Mariana Islands, and Guam. Honolulu: Pelagic Fisheries Research Program, Joint Institute for Marine and Atmospheric Research, University of Hawaii.

product that was about $2.993 billion in 1996.[12] Those employed in transshipment probably represent about 0.0019% of the workforce. Nevertheless, the Government of Guam considers homeporting and transshipment important elements of its efforts to diversify an economy currently dominated by tourism and military expenditures.

THE PURSE SEINE FLEET AND TUNA CANNERIES IN AMERICAN SAMOA

Interviews with Vessel Captains and Crew, Fleet Managers, and Cannery Managers

In January 1998, the project team conducted interviews in American Samoa with tuna packing plant managers from Samoa Packing and StarKist, fleet managers, vessel owners, and captains and crews. Those interviewed were directly involved with a total of fifteen U.S. purse seine tuna vessels, or about one third of the U.S. purse seine fleet operating in the Pacific Islands.

During their interviews, the fishermen joked constantly about their reputation as "liars" and the difficulties for the project team in getting a "straight story" about changes in the location of stocks and fishing conditions. There was, however, considerable consistency in stories told by interviewees and in their perception of impacts from the 1997-1998 ENSO warm event.

Both fleet managers and cannery managers had anticipated some of the ENSO impacts they experienced during the event. These included changes in the size and species composition of the catch and geographical shifts in the location of the most productive fishing grounds.[13]

The local National Marine Fisheries Service officer corroborated these effects. He showed the project team monthly catch data that he had been compiling since July 1988. The data included species composition and the quantity and locations of catch (by FAO region) from U.S. purse seine vessels based in American Samoa. A cursory review of the data from July 1988 through December 1997 revealed that there were changes in both the location of the catch and species composition, some of which appeared be related to ENSO cycles.

This project piqued the interest of those interviewed, and they readily shared their perceptions on the impact of the current and past ENSO events on the tuna industry. Most knew something about ENSO cycles and obtained knowledge in advance about the emergence of the 1997-1998 warm event. Several anticipated general shifts in the location of the fish and changes in species composition of the catch. Two fleet managers secured access to scientific information on the current warm event in advance. One manager purchased monthly forecasts on the location of tuna stocks from a California-based climate modeler. Some interviewees considered these forecasts to be useless because they lacked the degree of spatial resolution required to locate tuna schools. Several interviewees considered that the effects of ENSO cycles on the climate, ocean conditions, and location of the stocks represented only a few of the challenges facing tuna fishermen. ENSO was, perhaps, no more important than the other factors. Nevertheless, almost everyone interviewed thought ENSO forecast information would be useful.

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[12] Gross Island Product figure for 1996 comes from the Bank of Hawaii, *Guam Economic Development Report*, September 1997. Total employment for 1996 was 68,440, quoted in the same report.

[13] Such shifts were consistent with reports the project team had been getting and what has been observed in other studies, such as an article published in *Nature* in October 1997 based on an analysis of skipjack tuna catch by the U.S. purse seine fleet.

In general, interview participants in American Samoa who had knowledge of previous ENSO events said the 1997-1998 event was unlike any they had experienced. Unfortunately, most of those interviewed had few years of fishing experience in the western Pacific. Some provided comparisons between the 1997-1998 event and previous ENSO events in the eastern Pacific, along the Californian, Central American, and South American coasts. Most of the interviewees could only describe impacts of ENSO events since 1990 in detail.

During the 1997-1998 event, the ocean, weather, and fishing conditions had all deviated from "normal" and past ENSO conditions. The seas were much rougher, due to the increased storms and from shifting currents. This contributed to smaller catches. One interviewee remarked on the strength of the 1997-1998 ENSO event, and equated it with that of an "adolescent," rather than a child, an "el niño." Only one of those interviewed was active in the western Pacific tuna fishery during the 1982-1983 warm event, but only during the second year of the event. Therefore, he could give few details about it. However, everyone interviewed said, based on either their own experience or from stories they had been told, that 1997-1998 event differed from the 1986-1987 event. One interviewee recalled excellent fishing during the 1991-1992 warm event. He expected similar conditions during 1997-1998 event, but fishing had been quite poor.

Aberrant weather and ocean conditions during the latter half of 1997 made fishing difficult for the purse seine fleet based in American Samoa. There were periods during the second half of 1997 when countervailing currents at and below the surface of the water near the equator made catching fish impossible. Nets could not be set in these conditions without severe risk of gear damage. During December 1997 and January 1998, vessels found schools of fish, but the seas were too rough to set nets.

During several periods in1997, fishermen had difficulty finding the fish because they could not find birds or surface-swimming bait that are normally associated with schools of tuna. In some instances, fishermen knew the tuna were under the surface of the water, and they could see the schools from helicopters, but the fish never surfaced. When they could not find fish or during periods when the schools remained too deep to catch, the fishermen "fished off logs." This is a common fishing practice in a number of fisheries, because logs and other floating debris serve as fish aggregation devices. Several fishermen also set out rafts with radio beacons and returned to fish on their rafts. According to vessel captains and crew, the size and species composition of the catch from sets on logs and rafts were much more heterogeneous than sets made on schools of fish feeding on bait. Normally, tuna caught in a single set while feeding on bait are mostly of the same species (skipjack or yellowfin) and are of a relatively uniform size and weight. Big eye tuna represent a very small percentage of the catch. The increases in bigeye tuna catch for some periods in 1997, most notably November, reflects the fact that vessels were fishing on logs or rafts.

Fishermen and fleet managers observed a general shift of tuna stocks to the east from mid- to late-1997. This is consistent with catch statistics provided by the National Marine Fisheries Service for the U.S. purse seine fleet based in American Samoa discussed below. Many of the Samoa-based vessels were fishing east of the Line and Phoenix Islands in the Republic of Kiribati during the 1997 (Northern Hemisphere) "summer." One interviewee said they were

fishing the area in March and April of 1997. Captains and crews reported an increase in "foreign" (non-U.S.) vessels fishing there by August, which they had not previously seen. Another interviewee had not witnessed such dramatic shifts in the location of tuna in the 1986-1987 or the 1991-1992 ENSO events, with the exception of skipjack catches in the area east of Samoa. Another interviewee recalled similar shifts to the east during the 1982-1983 event which were followed by shifts to the west during 1983 and 1984 as ENSO conditions returned to "normal." One of the fleet managers also remembered a similar shift in the location of fish to the east near Samoa during the 1986-1987 ENSO, and shifts to the west the following year.

Another major impact of this ENSO event was a discernible change in the species composition of the total catch of single vessels when they returned to port. Interviewees reported that "normally," purse seine vessels catch about 80% skipjack and 20% yellowfin. The proportion of yellowfin in the catch began to increase in July 1997 and by December 1997, some purse seiners were catching up to 87% yellowfin and 13% skipjack. By January 1998, some boats were reporting catches of 90% yellowfin and 10% skipjack. Increases in yellowfin catch meant more income to the vessels, because the higher quality of the yellowfin meat brings in higher prices at the canneries. The canneries, however, view yellowfin as more difficult to handle in processing, since they are generally larger fish.[14]

As early as February and March 1997, vessels were catching larger skipjack than usual. In the past, this has presented the vessels and canneries with a handling problem. "Mushy Tuna Syndrome" (MTS), or "belly burn," was found to be a problem in 1994. "MTS" occurs when the temperature of large skipjack cannot be brought down fast enough after the fish are caught to prevent enzymes from deteriorating the flesh. When the large skipjack caught in 1994 were thawed at the cannery, the texture of the flesh was "too mushy" to be canned. To address this problem, vessel captains and cannery managers received technical assistance from Hawaii-based consultants. Large skipjack, up to 35 pounds, were being caught late in 1997, but handling methods had been adapted to avoid MTS.

Cannery managers also said that the albacore catch, which is provided by jig and longline boats, had increased significantly over the course of the 1997-1998 ENSO event. This is consistent with data from the American Samoa Department of Marine and Wildlife Resources (DMWR), which reported a high local albacore catch for several months in mid- to late-1997. Since albacore is used in the premium white meat packs, they bring a relatively high price to the fishermen. Interviewees from both canneries reported that the fat content of albacore from the longline boats was higher than normal, and there were some problems with discoloration of the flesh. This meant that the albacore could not be canned as premium pack and would have to be marketed as a cheaper product.

Unusual schooling patterns were also observed in the second half of 1997. Vessel captains observed schools of tuna so large (500 tons) that nets could not be set without running the risk of damaging nets or sinking the vessel. Fishers could only locate schools of very small fish (under 3 pounds) near Solomon Islands and Papua New Guinea during the third quarter of 1997.

[14] The increase in yellowfin catch reported by those interviewed is consistent with a region-wide increase reported in the Tuna Fisheries Yearbook, 1997, Oceanic Fisheries Programme, Secretariat of the Pacific Community, Noumea: SPC.

Although they would not normally bother with tuna this size, some vessels received permission from fleet managers to set nets on the smaller tuna since they could find nothing else suitable to meet cannery demand. By the fourth quarter, however, fishermen discovered schools of somewhat larger fish (3-6 pounds) a little farther east.

Analysis of Catch Data from Purse Seine Vessels Based in American Samoa

In February, the project director received permission from the National Marine Fisheries Service (NMFS) Regional Office to use catch data from the U.S. purse seine fleet compiled in American Samoa. A preliminary analysis used catch data captured by month, species, and the FAO regions (Figure 1); it was presented to the *Workshop on the Consequences of Climate Variability and Change for the Hawaii-Pacific Region*[15] held in Honolulu, 3-6 March 1998.

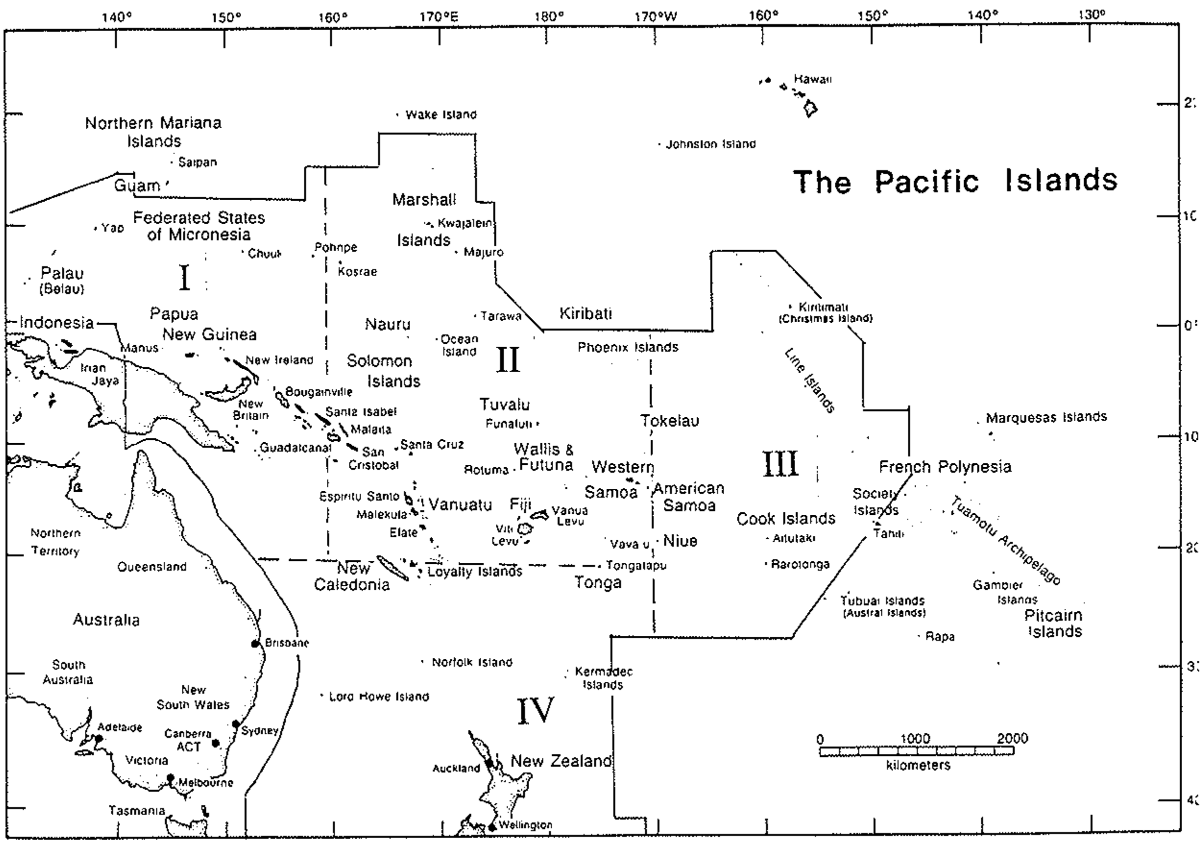

Figure 1: FAO Fisheries Zones (adapted from maps provided by National Marine Fisheries Service, American Samoa and by Publication Services, SOEST).

The graphs subsequently developed from the NMFS data show fairly dramatic shifts in the geographical distribution of catch by Food and Agriculture Organizations region over the entire period of the record (see Table 1 and Figures 2, 3, and 4 and Table 1). The association with

[15] The Center for the Application of Research on the Environment (part of the Institute of Global Environment and Society, Inc.) organized the workshop under the auspices of the White House Office of Science and Technology Policy (OSTP) and the U.S. Global Change Research Program (USGCRP).

ENSO events, however, remains unclear (Figures 5 and 6). The majority of the catch in the second half of 1988 was in the western-most FAO region (I), during the second year of a relatively strong ENSO cold event.[16] Beginning in October 1988, there was a gradual shift to the central region (II). In November 1989, catch shifted dramatically to the eastern region (III). By January 1991, the first year of the 1991-1992 ENSO warm event, catch started shifting to the central region (I), with a high volume of fish still caught in the west (I). In June 1991, fish were located primarily in the central region (II), and generally stayed there through January 1995 (during the 1991-1992 and start of the 1994-1995 ENSO warm event). Beginning in February 1995, the first year of an ENSO cold event, catch in the western region (I) increased significantly. During the period October 1995 through December 1998, most of the catch was in the central region (II).

Table 1: Catch Location by Year and ENSO

Year	ENSO Event	Catch Location
1988-1989	Strong Cold	(central)
1989-1990	None	(east)
1990-1991	None	(west) (central)
1991-1992	Strong Warm	(central)
1992-1993	None	(central)
1993-1994	None	(central)
1994-1995	Weak Warm	(east) then (central)
1995-1996	Weak Cold	(west)
1996-1997	None	(central)
1997-1998	Strong Warm	(east) then (central)

Source: Adapted from He, Barnston, & Hilton 1998, appendix, and from G. Yamasaki, NMFS, American Samoa.

As reported by vessel captains and fleet managers for the period of May 1997 through September 1997, the general decline in catch in the western region and the shift in the stocks to the eastern region is apparent in Figures 2, 3, and 4. The movement of tuna stocks and the shift in fishing effort to the western region during the 1995-1996 ENSO cold event is also clear. The increased catch in the western region beginning January 1991, the first year of the 1991-1992 ENSO warm event, may be a similar pattern to the western region, which recorded an increase in catch from September 1996 through May 1997; however, this is not clear from the data.

[16] The definitions of ENSO warm events (El Niño) and ENSO cold events (La Niña) used in this paper are drawn from Yuxiang He, Anthony G. Barnston and Alan C. Hilton, February 1998, *A Precipitation Climatology for Stations in the Tropical Pacific Ocean.* Camp Springs, Maryland: Climate Prediction Center, U.S. National Weather Service, pp. 15-20. This appendix has been reproduced as an appendix to this paper.

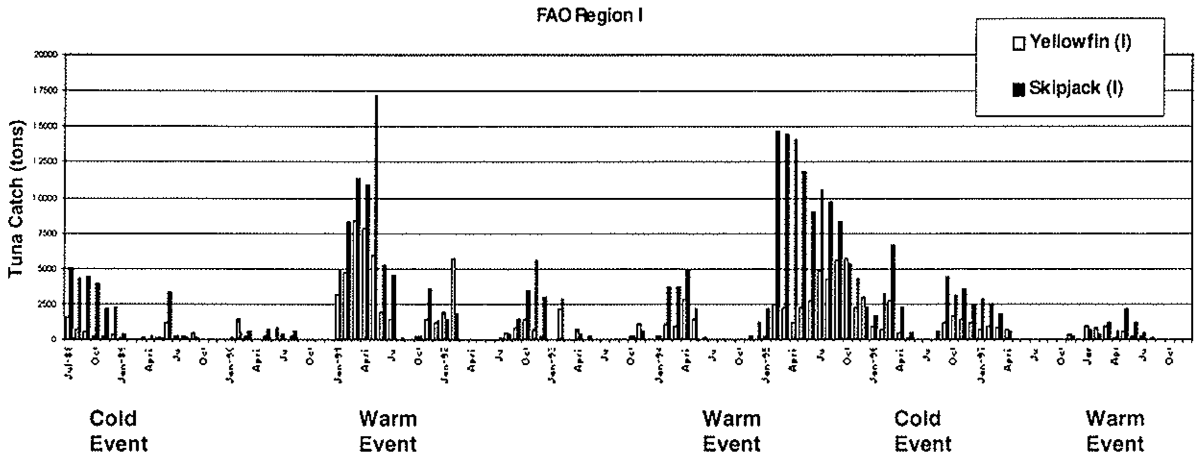

Figure 2: American Samoa Reported Tuna Catch in FAO Region I (1988-1998)

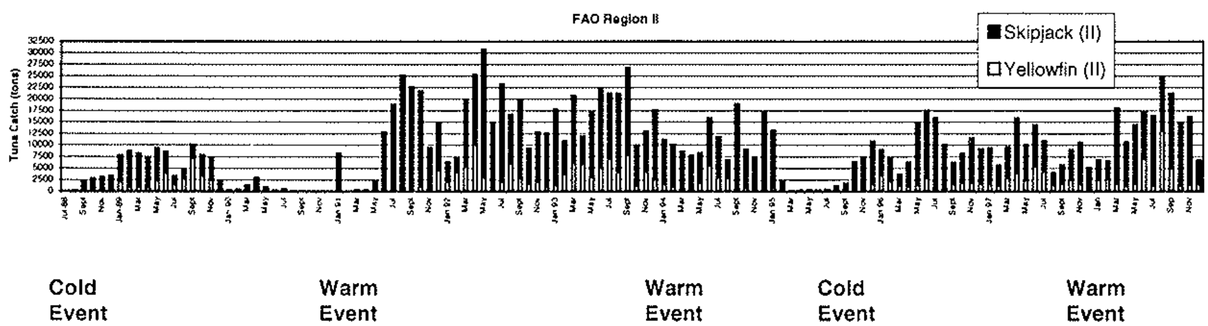

Figure 3: American Samoa Reported Tuna Catch in FAO Region II (1988-1998)

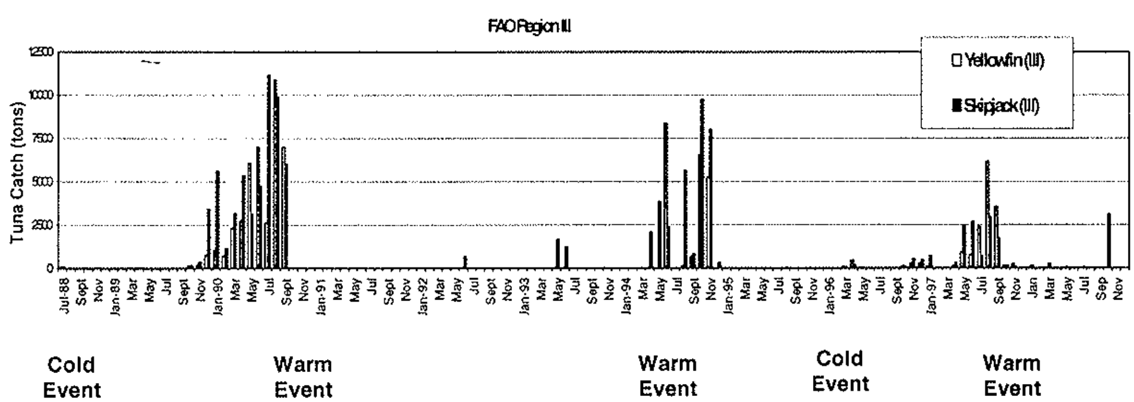

Figure 4: American Samoa Reported Tuna Catch in FAO Region III (1988-1998)

Figs. 2-4 Data Sourc*e:* G. Yamasaki, NMFS, American Samoa, 1998.

Although somewhat less apparent from the graphs shown in this paper, the National Marine Fisheries Service data (Table 2) indicate changes in the species composition of the catch. During August 1990 (a year preceding an ENSO warm event) and June 1994 (the first year of separate ENSO warm event), the yellowfin catch was relatively high as a proportion of total catch, most of which was caught in the eastern region. During February 1992, the second year of an ENSO warm event, the yellowfin catch showed an anomaly in the data. For that month, yellowfin catch in the west far exceeded the catch in species composition and in region. However, the general yellowfin catch during that period appeared more so in the central region. During 1997, there was a general decline in catch, but yellowfin catch in August 1997 constituted a relatively high proportion of the catch in both the eastern and central regions. Again, the time-depth of the catch data is too short to see a very clear pattern, but it appears that increases in the relative proportion of yellowfin catch occur in ENSO warm event years.

Table 2: High Yellowfin Catch and ENSO

Year	ENSO Event	General Population Location	Month of High Yellowfin Catch	Yellowfin Catch Location
1990-1991	None	I (west)	August	III (east)
1991-1992	Strong Warm	II (central)	February	I (west - anomaly) II (central)
1994-1995	Weak Warm	III (east) then II (central)	June	III (east)
1997-1998	Strong Warm	II (central)	August	III (east) & II (central)

Source: Adapted from He, Barnston, & Hilton, 1998, p. 15-20, and from G. Yamasaki, NMFS, American Samoa.

Economic Significance for Vessels, Processors, and Support Industries

The economic significance of shifts in stocks and catch patterns, previously discussed, differs among the purse seine fleet for vessels operating out of American Samoa, the canneries, vessel-support businesses, and the American Samoa Government. For vessel owners, shifts in the stocks to Region I (west) during the 1990-1991 ENSO warm event and the 1995-1996 cold event meant vessels had to travel significantly further west to catch fish. They then had to either land their fish in Guam (or another transshipment point) and pay for transshipment (about $130 per ton), or take additional time (seven to ten days) to return to American Samoa canneries. Conversely, when vessels can catch fish in Region III (east) – such as during 1989-1990, 1994-1995, and 1997-1998 – the distance traveled is shorter, which allows fishermen to spend more time fishing, if the catch is good. General declines in catch (like that experienced in 1997) impact vessel owners economically. When fish are difficult to find, fishermen spend the majority of their time searching for fish, and burning precious fuel reserves, rather than catching fish. Therefore, the fishing companies pay the costs of the crew salaries, gear, fuel, and other equipment, but the amount of fish caught will be less within a given time period, reducing the overall profits significantly.

From the canneries' perspective, tuna is a globally available commodity. Thus, as long as they maintain a steady supply of frozen fish, canneries can survive both catch declines for the American Samoa fleet and stock shifts to more distant waters. StarKist Samoa's parent company, however, owns interest in purse seine vessels supplying the cannery. Therefore, the company has a greater concern about catch declines and shifts in stocks to the western region than Samoa Packing and its parent company.

For both canneries, shifts in the stocks to the eastern region in 1990 caused logistical problems. The canneries had inadequate freezer space to accommodate fish off-loaded from quick turn-around trips. This had no direct economic impact on the canneries since the cost of waiting in port to off-load was borne by the vessel owners, not the canneries.

For businesses supplying fuel, salt, and other provisions and services to purse seine vessels in American Samoa, shifts in the purse seine fleet to the western region could result in lost revenues. For example, if vessels transship their fish, they purchase fuel and provisions in Guam, which results in less money being spent in American Samoa. This has a direct impact on the businesses, and results in a loss of tax income for the American Samoa Government.

THE LONGLINE FISHERY AND TRANSSHIPMENT INDUSTRY IN THE REPUBLIC OF THE MARSHALL ISLANDS, THE FEDERATED STATES OF MICRONESIA, AND THE REPUBLIC OF PALAU

The project team conducted interviews with government officials, vessel operators, and transshipment agents in the Republic of the Marshall Islands (RMI), Federated States of Micronesia (FSM), and the Republic of Palau (ROP) in August 1998. While the initial project plan only called for interviews in American Samoa and on Guam, the project team was able to expand the focus of the project to include the Freely Associated States as part of a ENSO impact assessment being conducted for the Pacific ENSO Applications Center. None of these islands have cannery operations, but they receive access fees for fishing within their exclusive economic zones and draw some income from port calls and transshipment services.

The Republic of the Marshall Islands lies in the easternmost region of the interviewed areas in this study. Four major currents are evident within the Marshall Islands' exclusive economic zone and the productivity of these oceanic waters have been considered relatively low compared to high islands in the western Pacific.[17] Nonetheless, catch in the region has increased with the development of the purse seine fishery. Most of the effort in fishing has been related to the availability of skipjack. The SPC Oceanic Fisheries Programme (OFP) has published a study that hypothesized that during ENSO events the skipjack are displaced eastward towards the Marshall Islands and Kiribati along with the shift in the warm water.[18] The managers have noticed relatively stable catches per unit of effort (CPUEs); however, there have been significant

[17] South Pacific Commission Oceanic Fisheries Programme (OFP). 1998. Republic of the Marshall Islands National Fisheries Assessment. p. 2.
[18] South Pacific Commission Oceanic Fisheries Programme (OFP). 1998. Republic of the Marshall Islands National Fisheries Assessment. p. 2.

declines in specific years, such as 1995-1996,which the OFP attributes possibly to an "El Niño effect on recruitment."[19]

Interviews in the Republic of the Marshall Islands were limited to government officials involved in managing fisheries access agreements for the Marshall Island government. In general, interviewees reported an increase in fishing activity in the Marshall Islands during the summer and fall of 1997. This resulted in greater tuna vessel access fees from the U.S. purse seine fleet---from about $1.5 million to about $3 million. The team uncovered no readily available data on vessel port calls or other indicators of increased fishing activity in the Marshall Islands Exclusive Economic Zone.

In the Federated States of Micronesia, the situation was quite different. The National Fishing Company (NFC) transships sashimi-grade tuna from the four states of the FSM to Guam, and then to Japan.[20] NFC operates six vessels. They transship tuna from those boats, and from an additional 60 Taiwanese and 10 Japanese longliners. NFC officials reported a dramatic drop in landings from January through May 1998, particularly in Yap and Chuuk States. This concerned NFC management tremendously, because they were incurring staff costs at transshipment points with little or no revenue.

The National Fishing Company (NFC) manager said that if they could have anticipated the decline in catch, they could have saved a great deal of money by laying off staff sooner than they did. These layoffs, however, would have coincided with the worst effects of the drought that resulted from the 1997-1998 ENSO warm event, which caused considerable economic hardship on farmers and national and state governments. Higher unemployment rates would only have exacerbated the hardship for everyone.

In an interview with the manager of the Micronesian Longline Fishing Company (MLFC) on Pohnpei, he indicated that they had suffered significantly from reduced catch. While no catch information was available, the management expressed great concern about the sharp decline in catch during the 1997-1998 ENSO warm event. Unlike the purse seine vessels operating in American Samoa, MLFC was not able to shift their fleet to more lucrative fishing grounds.

Fishing near Yap State, FSM declined dramatically (Fig. 5). Yap Fishing Authority (YFA) recorded landings for tuna and wahoo from July 1997 to June 1998 at about half the previous year during the same season. In May 1997, the landed catch for tuna was 2487.0 kg, almost double the amount caught during any month from May 1996. Then, only two months later, the landed tuna catch weighed merely 162.0 kg. The transshipment operation Yap Fresh Tuna, Inc. (YFTI) lost over 40 employees as a result of the decline in landings, and retained a skeleton staff of four people with decreased working hours. Casamar, a gear repair company based in Guam,

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[19] South Pacific Commission Oceanic Fisheries Programme (OFP). 1998. Republic of the Marshall Islands National Fisheries Assessment. p. 2.

[20] In 1992, several companies started transshipping tuna through the international airports in Guam and Saipan in the Commonwealth of the Northern Mariana Islands. Cargo planes carry fish from airports in the Federated States of Micronesia and the Republic of Palau to Guam on feeder aircraft, which are then put on jumbo jets to Japan. The operations transshipping tuna through the airport on Guam are not the same companies transshipping through Apra Harbor.

had just opened a field office in Yap when the ENSO event began. The company relied on one shared employee of YFTI to look after the office until fishing improved and fleets came back to Yap to use their services.

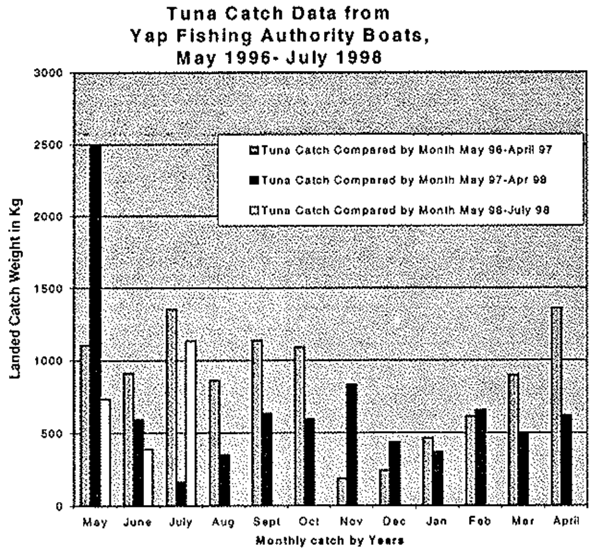

Figure 5. Tuna Catch from YFA, by Months and Years for May 1996 Jun 1998. Source: Yap Fishing Authority, August 1998, Yap State, Federated States of Micronesia.

The severe decline in catch meant that fishing companies could not meet basic costs of operations and could not make the needed revenue to cover extensive debts incurred in establishing a transshipment operation. In Yap, the tuna catch must exceed fifteen tons to make it profitable for freighter planes to transport the sashimi-grade tuna. When boats are catching only two to three tons, they head straight to Guam rather than stopping in Yap. To gain some revenue, YFTI rented their cold storage space and warehouse storage. At one point, YFTI had their power cut. To maintain basic power within their facility, the company made an agreement with the power utilities corporation to provide electricity while YFTI used their desalination units to supply freshwater to the hospital and town facilities during the drought. The only way that the companies remained in business was by finding alternative revenue sources until the fishing increased. Nonetheless, a number of workers were displaced and suffered from the lack of income during the ENSO warm event.

In the Republic of Palau, the fisheries managers reported that tuna catch had declined during the El Niño period. During the last quarter of 1997, there was a dramatic increase in the longline fish catch; however, the catch for the following quarter, the beginning of 1998 dropped severely. The managers recorded a decrease in revenues from fishing, but could not attribute this loss solely to ENSO-related impacts. Various gear types and methods used may have been problematic. In addition, the overall catch rates in Palau have been declining for five or six years because of overfishing, largely from foreign fishing fleets, and this made it difficult to isolate the impacts from climate variability. Incidentally, the nearshore fisheries managers reported a number of changes, including alterations in spawning cycles, habitat, and the location of fish,

some of which were attributed to the noticeably warmer temperature of the water in lower depths over coral reefs and closer to shore.

TRANSSHIPMENT OPERATIONS ON GUAM

Tuna transshipment on Guam has been a relatively volatile industry since it began in the mid-1980s. The tuna fishing and transshipment study, previously cited, found increases and decreases in the both the volume of tuna being transshipped through Guam and the number of port calls made by longline vessels. This volatility has been attributed to "good" and "bad" fishing conditions, the status of access agreements between fleets calling at Guam and the Federated States of Micronesia, and changes in the number of vessels operating in the region.

Interviews with Transshipment Agents and Brokers on Guam

Transshippers and agents interviewed on Guam in August 1998 said that beginning in February 1997, fishing for Guam-based longline vessels declined until May 1998. They also said that catch for Japanese vessels dropped from ten to twelve tons per trip to six to eight tons per trip, and then returned to "normal" catch rates. Longline vessels fishing for the sashimi trade can only stay at sea for several days before they must transship their fish to prevent loss of value in the market. Therefore, the drop in catch does not necessarily represent a drop in effort but may reflect a shift in the location of the stocks. Tuna transshipment agents attributed such a shift directly to the 1997-1998 ENSO warm event.

According to agents on Guam, tuna prices on the Tokyo market remained relatively high during 1997, and that may reflect the decline in catch. Interviews with transshipment agents on Guam revealed that tropical tuna prices in Tokyo had dropped from $10.99 per kilogram in 1994 to $5.99 per kilogram in 1996. Tuna prices had apparently risen again by mid-1997 with the average price per kilogram of $10.09 for the period from June 20 through July 3, 1997.[21] However, prices on the Tokyo market were fairly volatile throughout 1997 and 1998. A much more detailed analysis would be required to try and assess the ENSO event on prices.

Transshipment agents on Guam had heard that tuna catch in Palau had been "absolutely dry" from about February 1998 through August 1998. They also reported albacore catches in Solomon Islands had been quite good for about six or seven months. In addition, purse seiners that transship cannery-grade tuna through Guam had been catching larger yellowfin (20-30 kilograms) for almost two years. During the 1982-83 and the 1986-87 ENSO warm events, purse seine vessels calling at Guam had reported good catch in the high seas area called the "doughnut hole," north of the Federated States of Micronesia Exclusive Economic Zone.

Analysis of Transshipment Data from Government of Guam

Data on sashimi grade tuna transshipped through Apra Harbor compiled by the Government of Guam from January 1993 through November 1998 shows both the growth of the transshipment industry on Guam and the impact of the 1997-1998 ENSO warm event (Figs. 6 and 7). Port calls by fishing vessels and the number of vessels operating out of Guam increased from 1993 through

[21] National Marine Fisheries Service, http://www.nmfs.gov/trade/default.html.

1996. The volume of fish in metric tons also increased from 1993 through 1995 and then dropped slightly in 1996. In 1997, the first year of the 1997-1998 ENSO warm event, the volume of fish dropped to half of that reported in 1996, although the volume of fish transshipped per port call actually increased. This could be interpreted to mean that fishing effort dropped in 1997, resulting in a decline in the volume of fish transshipped. Interview data suggests that vessel captains responded quickly to the poor fishing conditions and moved elsewhere. Because of the unavailability of data on length of trip and catch per unit of effort, it is impossible to determine an actual decline in the stocks for Guam-based longline vessels.

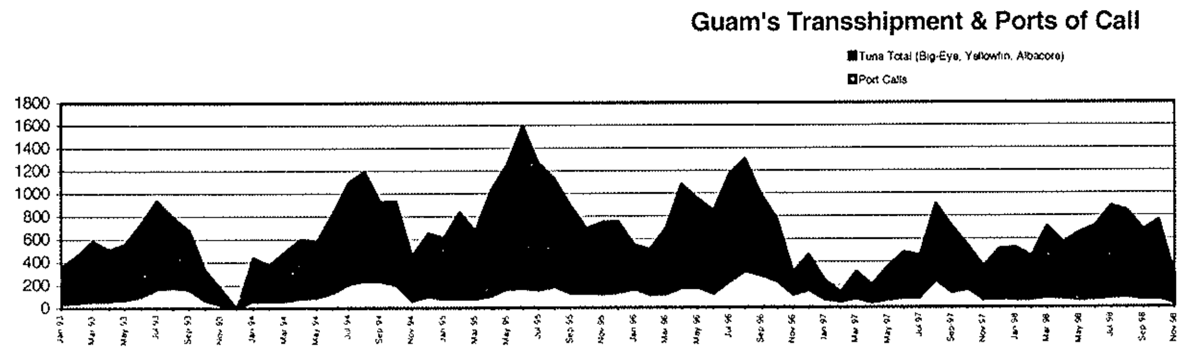

Figure 6. Guam's Transshipment and Ports of Call. Source: Department of Commerce, Government of Guam.

Monthly transshipment data from the Government of Guam show that the number of port calls and number of vessels operating out of Guam per month from 1993 through 1998 have an annual cycle (Figs. 6 and 7). This cycle peaks in the number of port calls and vessels operating out of Guam from May/June through October/November. The low season appears from December through March. During 1995 and 1996, this pattern was less pronounced, with a relatively high level of transshipment activity and numbers of port calls and vessels operating from June 1995

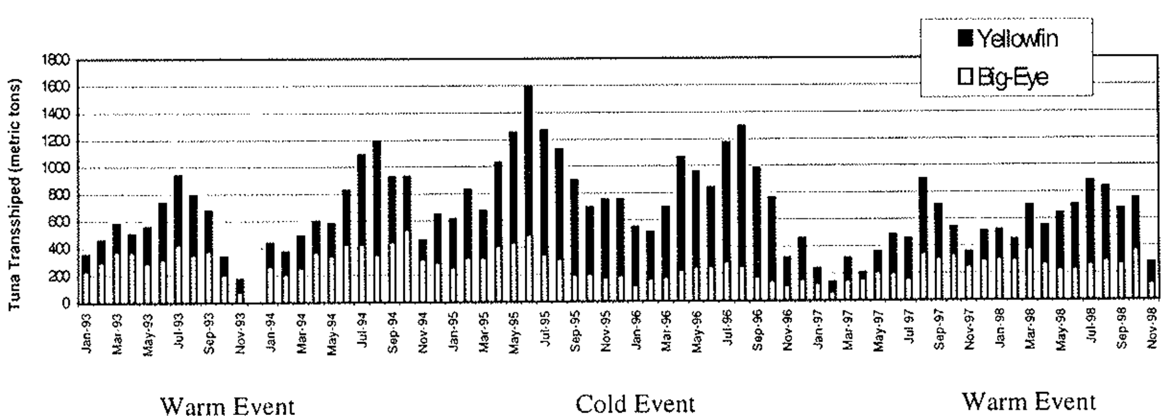

Figure 7: Guam Tuna Transshipment, January 1993-December 1998. Source Department of Commerce, Government of Guam.

through April 1996. This increase occurred after the 1993-1994 ENSO warm event, and it coincides with the 1995-1996 cold event. A record peak period of port calls and vessels operating during August and September 1996 followed.

As might be expected, the monthly volume of fish transshipped through Guam roughly parallels the annual cycle in the number of port calls and operating vessels, with a peak for landings from May/June through October/November. From 1993 through 1995, January transshipment volumes increased from 369.9 metric tons in 1993, to 463.4 metric tons in 1994, to 666.7 in 1995, and then dropped to 584.5 in 1996. The January 1997 volume dropped to 237.5 metric tons. This preceded the onset of the 1997-1998 El Niño.

The January 1998 volume returned to about 537.2 metric tons. Peak transshipment volumes for the same period increased from 977.2 metric tons in July 1993, to 1,221.9 in August 1994, and then to a high of 1,807 metric tons in June 1995. The annual peak in monthly landings declined to 1,410.6 metric tons in September 1996, and then to 748.6 metric tons in September 1997, the first year of the 1997-1998 ENSO warm event. In 1998, the peak monthly transshipment volume increased to 1,010.3 metric tons in July.

Economic Impact of Changes in the Longline Fishery and Transshipment in Guam

The economic impact of changes in the longline fishery for vessels transshipping out of Guam is unknown. As indicated earlier, the number of vessels operating out of Guam decreased by almost half from 1996 to 1997, and further declined in 1998. The decline in catch most likely had an economic and financial impact on those boats that left Guam. Without more detailed information on their plight since they left Guam, one can only speculate that they either left the fishery entirely or began transshipping in another port.

There are clearly more constraints on longline vessels to move with the stocks than there are on purse seine vessels. The longline vessels operating out of Guam do not freeze their fish and must operate in relatively close proximity to transshipment points with frequent and reliable air links to Japan. For these vessels, alternatives to Guam are probably limited to the Republic of Palau, Federated States of Micronesia, and the Republic of the Marshall Islands. And, fishing in Palau and most of the FSM declined at the same time as the areas fished by vessels calling in Guam.

For those vessels that continued to operate out of Guam in 1997 and 1998, the catch per port call actually increased in 1997 and more than doubled in 1998. Although expenditure data for these vessels is unavailable, it seems likely that their income actually increased from 1996 to 1998. This could mean that in gross economic terms, the fleet operating out of Guam became more efficient and profitable as a result of the disruption caused by the 1997-1998 ENSO warm event.

The decline in port calls had a clear economic impact on both transshipment operations and businesses that supply goods and services to those vessels. Total vessel expenditures are closely associated with the number of port calls made on Guam. A decrease in port calls results in a reduction in total vessel expenditures. The almost fifty percent fewer port calls from 1996 to 1997 could have resulted in a fifty percent decrease in vessel expenditures, with fuel consumption being an unknown variable. The rebound of port calls in 1998 would have resulted in a proportionate increase in the contribution of longline vessels to the Guam economy.

The financial and economic impacts related to changes in the Guam longline fishery in 1997 and 1998 appear to be more closely tied to the volume of fish landed than the number of port calls. Therefore, income for transshipment agents probably suffered about a fifty percent decrease from 1996 to 1997 and an increase of about fifty percent from 1997 to 1998.

CONCLUSIONS

Tuna vessel captains, fleet managers, transshippers, and tuna processors in the U.S.-affiliated Pacific Islands interviewed for the first phase of this project believe that ENSO events have an impact on the tuna industries in the region. The most direct effects of the 1997-1998 ENSO warm event appear to be shifts in the geographic location of tuna stocks for both the purse seine vessels operating out of American Samoa and the longline vessels operating in the Federated States of Micronesia, the Republic of Palau, and transshipping through Guam.

The 1997-1998 catch data for purse seine vessels operating out of American Samoa and longline vessels operating out of Guam are consistent with the results of interviews with vessel captains, fleet managers, transshippers, and tuna processors interviewed for this study. A cursory analysis of the catch data for the period June 1988 through November 1998 shows that there are clearly major geographical shifts in the catch by U.S. purse seine vessels operating out of American Samoa. These changes in the geography of the catch appear to be linked to shifts in the location of stocks associated with ENSO cycles. Unfortunately, the catch data record available from the National Marine Fisheries Service is too short to show a clearer association between ENSO events and the location of the stocks. It is possible that data with a finer spatial resolution for this limited period would show a clearer pattern.

Transshipment data from the Government of Guam also appear to reflect the impact of the 1997-1998 El Niño reported in interviews conducted by the project team with transshippers and agents on Guam. These data provide a useful means of assessing the economic impact of the 1997-1998 El Niño on Guam's tuna industry, but the data record is too short to see a consistent pattern. It is not clear, for example, if a less intense ENSO warm event would have had a similar impact on Guam's tuna industry. And, similar to the data obtained from American Samoa, the data used for Guam represent a limited number of vessels operating from one port.

In order to understand the impact of ENSO cycles on shifts in tuna stocks, catch data with much more time depths and greater spatial resolution will be required. The Pacific Community (formerly the South Pacific Commission) has catch data with a two-degree longitude and latitude resolution for all fleets operating in the EEZs of Pacific Island countries and territories. Analysis of these data has already shown a shift in catch per unit of effort for skipjack caught by the U.S. purse seine industry. Given the interest in understanding the relationship between ENSO cycles and the location of tuna stocks, further analysis of these data would be a worthwhile effort.

Shifts in tuna catch clearly have economic consequences for the vessels, the businesses that supply goods and services to vessels, and the governments that collect tuna access fees and taxes from vessel-support businesses. Moreover, those interviewed in the course of this study said that they could have minimized the negative impacts from shifts in the catch if they could have

anticipated the changes. This is undoubtedly also true for other jurisdictions. Therefore, additional research on the impacts of ENSO cycles on the Pacific Islands tuna industry, kinds of forecasts and information required to anticipate changes in the fishery resulting from ENSO events, and opportunities to apply ENSO forecasts for the tuna industry would also be warranted.

With catch statistics and fishermen as the only data sources, developing a complete understanding ENSO's effect on changes in the location of tuna stocks in the Pacific region is not possible. The discussion contained herein suggests that a more comprehensive analysis of catch data for the entire Pacific Islands region would yield a better understanding of the impact of ENSO events on tuna fishing. Further work on both tuna catch and the economic impact of ENSO events on the tuna industry may also suggest strategies for minimizing the negative impacts of ENSO events on tuna fishing, transshipment, support industries, and tuna processing.

The analysis conducted for this report suggests that without an understanding of the impact of ENSO cycles on fishing, the use of "catch per unit of effort" as a measure of the status of tuna stocks may not be possible. The interviews and analysis of catch and volume from transshipment indicate that ENSO events affect the location of the stocks, the weather and ocean conditions, and the schooling behavior of fish---all factors in the ability of vessels to catch fish. Based on these findings, there should be further investigation of the impacts from ENSO events that account for these factors.

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Appendix

From *A Precipitation Climatology for Stations in the Tropical Pacific Basin : Effects of ENSO*, by Yuxiang He, Anthony G. Barnston, and Alan C. Hilton. [Washington, D.C.] : U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, [National Centers for Environmental Prediction, Climate Prediction Center, 1998], 280 pp., (NCEP/Climate Prediction Center atlas ; no. 5), February 1998.

[6 broad-side pages follow]

Appendix

Procedure for Categorization of Boreal Winters as "Warm" or "Cold" ENSO Cases

In order for a boreal winter to qualify as a warm (El Niño) or cold (La Niña) case, the SST in the Niño 3.4 region must show an anomaly of the appropriate sign, and the Tahiti-minus-Darwin sea level pressure-based SOI must show a mean anomaly of the opposite sign. The SST anomaly must be of at least a critical magnitude and for a minimum duration prior to and including the boreal winter season. Only the months of October through February are included in the evaluation, because the aim is to classify boreal winters rather than entire 12-month periods centered at some specified time of the calendar year. The months of January and February period must pass a separate requirement to ensure that the episode does not largely dissipate prior to the winter season. While SST is considered more critical than SOI, the SOI cannot show a conflicting anomaly, and, unless the SST anomaly is strong, the SOI must show an agreeing anomaly of nonnegligible magnitude.

The procedure begins by forming 3-month means of the SOI and the Niño 3.4 SST. These are then standardized with respect to the mean and standard deviation of the individual 3-month period, based on 1950-1996. Use of the standard deviation of the individual 3-month period in question rather than of all twelve 3-month periods pooled does not follow the signal-to-noise enhancement consideration discussed in Trenberth (1984), but does ensure uniform interannual variances across the seasonal cycle. (Note that the five years of 1950-54 are used to get a more complete sampling of ENSO behavior despite their absence from the analyses in this atlas.) The **standardized anomalies** for the five 3-month periods centered on October (i.e. Sep-Oct-Nov), November (Oct-Nov-Dec), December, January and February are the data of interest. For ease of communication, these 3-month periods will be named by their center month in this discussion. The standardized anomalies for each of the five periods are shown in Tables A1 and A2 for SST and SOI, respectively. Anomalies for 1997 are shown for completeness (based on means and standard deviations of 1950-96), but only data for the 1955-96 period are directly applied to the analyses in this atlas. **The SOI values are sign-reversed** so that both SST and SOI are expected to be positive for a warm ENSO episode and negative for the cold ENSO case. To be classified as a non-neutral winter, the data must satisfy the following requirements:

SST Requirements:

1) Of the five periods, four-in-a-row must be ≥ 0.6, and Feb must be ≥ 0.4. Exemption #1: The winter can also qualify if $0.0 \leq \text{Feb} \leq 0.4$ when (Jan+Feb)/2 ≥ 0.6 or (Dec+Jan+Feb)/3 ≥ 0.6. Exemption #2: The winter can also qualify with only three-in-a row periods ≥ 0.6 when Jan and Feb <0.6 but Feb qualifies (possibly through exemption #1) and Jan is ≥ 0.5 when the SOI is ≥ 1.00 for at least four of the five periods.

2) At least one of the five periods must be ≥ 0.8, or three of the five must be ≥ 0.7.

SOI Requirements:

1) The average of the five periods must be ≥0.3, and either Jan or Feb must be ≥0.0. However, the winter can qualify if the average of the five periods is below 0.3 but at least 0.0, when the SST ≥1.0 for Feb, Jan or Dec, or for (Oct+Nov)/2.

In determining the sets of warm and cold winters as listed in Table 4, the following decisions are noted with respect to borderline winters, or non-borderline winters that have been classified differently by others. Note that 3-month periods are always being discussed, referred to by their middle month.

1956-57 (neutral): While the SOI qualifies as a cold winter, the SST fails, with Jan very weak and Feb actually slightly in the wrong (positive) direction.

1963-64 (warm): While the SOI qualifies as a warm winter, February SST is only 0.37. However, when averaged with January and December, 0.6 is exceeded, qualifying the winter. The (Dec+Jan+Feb)/3 SST is 0.70.

1964-65 (cold): While the SST qualifies as a cold winter, the SOI fails, with a five-period mean of -0.25 (recall that the SOI has been sign-reversed). However, the SST exceeds -1.00 when averaged over Oct and Nov, qualifying the winter.

1971-72 (neutral): While the SOI qualifies as a cold winter, the SST fails, with Jan weaker than -0.6 and Feb weaker than -0.4. The SST in Dec, Jan and Feb is not cold enough to override the Feb SST failure, and the SOI is not strong enough to override the Jan SST failure.

1976-77 (neutral): While the SST qualifies for a warm episode, the SOI shows no tendency toward a warm episode, with average values slightly in the opposite (cold) direction.

1977-78 (warm): The SOI strongly qualifies as a warm winter, but Jan SST slightly misses the 0.6 requirement. However, it does exceed 0.5, and at least four of the five periods (in fact, all five) have SOI>1.0, allowing for qualification.

1983-84 (neutral): While the SST qualifies as a cold winter, the SOI fails, with a five-period mean of -0.24 (recall that the SOI has been sign-reversed). The strongest SST over the five periods is -0.85, falling short of the -1.00 required to override the SOI failure.

1984-85 (cold): While the SST qualifies as a cold winter, the SOI fails, with a five-period mean of -0.07 (recall that the SOI has been sign-reversed). However, the SST exceeds -1.00 from Nov through Feb, qualifying the winter.

1987-88 (warm): The SST easily qualifies as a warm winter, and the SOI also narrowly passes with a five-period mean of 0.34 (recall that the SOI has been sign-reversed) and positive values for all five periods. Even if the mean SOI failed the 0.3 requirement (but was positive), the winter would qualify because the SST exceeds 1.00 for the Oct, Nov and Dec periods. Note that this winter represents the final stage of the strong 1986-87 event, and has not traditionally been classified as a warm episode case. (The 1986-87 event actually peaked in the middle of 1987 rather than boreal winter 1986-87.)

1992-93 (neutral): The SOI meets requirements for a warm winter. However, the SST falls short, never exceeding 0.4 until February. While the SST from March through August 1993 definitely depicts a warm episode (with continued unequivocal support from the SOI), it occurs during the portion of the annual cycle that prevents it from qualifying for either 1992-93 or 1993-94 winters. This is the only clear case within the 1955-96 period of an ENSO episode that does not lap over at least one boreal winter season. A similar situation occurred in boreal spring-summer of 1987, except that the warm event was so strong that both 1986-87 and 1987-88 qualified for moderately strong events, though *mid*-1987 had the outstandingly strong El Niño.

1994-95 (warm): Both the SOI and SST qualify for a warm winter.

1995-96 (cold): While the SST unambiguously qualifies as a cold winter, the SOI fails the 5-period mean, falling between 0.0 and the -0.3 requirement (recall that the SOI has been sign-reversed). However, the SST in Nov, Dec and Jan periods exceeds -1.00, creating an exemption for the SOI failure.

As it turns out, the same list of warm and cold winters as that shown in Table 4 would emerge if the criterion for qualification were simply to average the standardized SOI values for the five months of Oct to Feb, do the same for SST, and then form a weighted average the two results with a 0.85 weight for SST and 0.15 weight for the SOI. A winter qualifies if its weighted average exceeds ±0.7. However, this simpler criterion may not always result in the same list in the future or before 1955, and risks accepting cases that are strong in boreal fall but dissipate too rapidly as winter begins. The weighted average provides a relative strength score for all winters. The following table lists the strength score for the winters analyzed here, with qualifying winters shown in bold. Qualifying winters with score magnitudes of 0.70 to .99 can be considered standard, 1.00 to 1.49 moderately strong, and ≥1.50 strong.

1954-55	**-.89**	1960-61	-.23	1970-71	**-1.49**	1980-81	-.03	1990-91	.29
1955-56	**-1.46**	1961-62	-.43	1971-72	-.68	1981-82	.01	1991-92	**1.64**
1956-57	-.38	1962-63	-.54	1972-73	**1.64**	1982-83	**2.61**	1992-93	.25
1957-58	**1.37**	1963-64	**.82**	1973-74	**-1.76**	1983-84	-.64	1993-94	.20
1958-59	.37	1964-65	**-.72**	1974-75	-.58	1984-85	**-.91**	1994-95	**.98**
1959-60	-.20	1965-66	**1.43**	1975-76	**-1.52**	1985-86	-.45	1995-96	**-.77**
		1966-67	-.31	1976-77	.66	1986-87	**1.22**	1996-97	-.41
		1967-68	-.49	1977-78	**.74**	1987-88	**1.00**		
		1968-69	**.80**	1978-79	-.01	1988-89	**-1.88**		
		1969-70	**.77**	1979-80	.47	1989-90	-.03		

Table A1. Standardized anomaly of 3-month mean SST in region Niño 3.4

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1950	-1.73	-1.55	-1.65	-1.74	-1.73	-1.50	-0.99	-0.98	-0.92	-0.97	-0.84	-0.97
1951	-0.64	-0.72	-0.36	-0.42	-0.06	0.14	0.56	0.78	0.87	0.79	0.78	0.59
1952	0.47	0.12	0.26	0.07	-0.08	-0.48	-0.36	-0.11	0.08	0.00	-0.15	-0.04
1953	0.17	0.45	0.72	0.70	0.74	0.64	0.55	0.77	0.59	0.68	0.25	0.30
1954	0.27	0.39	0.03	-0.20	-0.59	-0.83	-1.20	-1.35	-1.23	-0.99	-0.85	-1.01
1955	-0.89	-1.03	-1.00	-1.43	-1.47	-1.45	-1.23	-1.42	-1.71	-2.01	-1.78	-1.52
1956	-1.01	-0.97	-1.07	-0.90	-0.72	-0.68	-0.99	-1.09	-0.78	-0.70	-0.47	-0.48
1957	-0.12	0.07	0.47	0.66	0.75	0.90	1.21	1.20	1.11	0.98	1.25	1.55
1958	1.70	1.82	1.56	1.20	0.88	0.72	0.69	0.20	0.11	-0.05	0.28	0.40
1959	0.58	0.46	0.46	0.35	0.20	-0.22	-0.54	-0.65	-0.42	-0.26	-0.08	-0.07
1960	-0.16	-0.13	-0.03	0.09	-0.04	-0.13	-0.03	0.12	0.02	-0.18	-0.29	-0.27
1961	-0.17	-0.18	-0.05	0.08	0.42	0.29	0.06	-0.49	-0.60	-0.57	-0.37	-0.28
1962	-0.29	-0.38	-0.52	-0.64	-0.58	-0.34	-0.05	-0.16	-0.30	-0.50	-0.52	-0.58
1963	-0.59	-0.40	-0.12	0.01	0.05	0.50	0.98	1.33	1.21	1.08	1.02	0.92
1964	0.80	0.37	-0.28	-0.96	-1.42	-1.36	-1.19	-1.09	-1.07	-1.09	-0.99	-0.94
1965	-0.66	-0.33	-0.07	0.28	0.69	1.32	1.68	1.88	1.85	1.74	1.67	1.49
1966	1.36	1.24	1.27	0.88	0.69	0.49	0.51	0.23	0.00	-0.09	-0.19	-0.28
1967	-0.31	-0.51	-0.88	-0.89	-0.48	-0.07	-0.09	-0.41	-0.51	-0.49	-0.39	-0.42
1968	-0.67	-0.87	-0.92	-0.83	-0.49	-0.01	0.45	0.48	0.40	0.48	0.64	0.89
1969	1.05	1.24	1.17	1.25	1.11	0.95	0.71	0.73	0.95	0.89	0.90	0.86
1970	0.79	0.58	0.57	0.43	0.02	-0.74	-1.16	-1.31	-1.28	-1.31	-1.45	-1.51
1971	-1.59	-1.56	-1.73	-1.47	-1.29	-0.90	-0.82	-0.75	-0.76	-0.82	-0.81	-0.78
1972	-0.55	-0.33	0.12	0.59	1.08	1.48	1.73	1.85	1.95	1.95	2.00	1.88
1973	1.70	1.40	0.78	0.02	-0.83	-1.32	-1.56	-1.55	-1.49	-1.53	-1.63	-1.76
1974	-1.76	-1.75	-1.63	-1.54	-1.18	-0.91	-0.61	-0.55	-0.62	-0.70	-0.77	-0.65
1975	-0.49	-0.56	-0.75	-1.08	-1.45	-1.66	-1.72	-1.61	-1.67	-1.50	-1.48	-1.51
1976	-1.51	-1.35	-1.19	-1.03	-0.77	-0.27	0.15	0.53	0.85	0.99	0.91	0.81
1977	0.63	0.61	0.28	0.34	0.31	0.56	0.41	0.42	0.53	0.72	0.73	0.72
1978	0.56	0.46	-0.07	-0.33	-0.70	-0.64	-0.75	-0.64	-0.49	-0.23	-0.08	-0.03
1979	0.01	0.22	0.35	0.43	0.31	0.07	-0.02	0.28	0.53	0.66	0.40	0.48
1980	0.56	0.45	0.37	0.34	0.59	0.64	0.39	0.10	-0.05	0.05	0.14	0.03
1981	-0.20	-0.45	-0.57	-0.49	-0.45	-0.44	-0.65	-0.55	-0.23	0.08	0.08	0.06
1982	0.09	0.07	0.18	0.66	1.33	1.75	1.83	1.87	2.13	2.28	2.36	2.46
1983	2.71	2.86	2.75	2.47	1.89	1.16	0.35	-0.12	-0.39	-0.58	-0.83	-0.85
1984	-0.70	-0.59	-0.47	-0.51	-0.74	-0.77	-0.79	-0.46	-0.51	-0.65	-1.08	-1.14
1985	-1.22	-1.23	-1.41	-1.29	-1.16	-0.88	-0.67	-0.47	-0.43	-0.41	-0.37	-0.45
1986	-0.65	-0.83	-0.74	-0.52	-0.19	0.12	0.43	0.74	0.97	1.12	1.10	1.16
1987	1.31	1.61	1.85	1.95	2.10	2.44	2.67	2.64	2.28	1.85	1.35	1.05
1988	0.78	0.55	0.08	-0.80	-1.74	-2.36	-2.36	-2.03	-1.94	-1.93	-2.08	-2.01
1989	-1.82	-1.83	-1.81	-1.62	-1.26	-0.85	-0.67	-0.48	-0.41	-0.32	-0.25	-0.14
1990	0.03	0.21	0.43	0.59	0.47	0.40	0.32	0.38	0.41	0.32	0.32	0.32
1991	0.35	0.28	0.30	0.61	1.04	1.37	1.25	0.99	0.95	1.09	1.41	1.58
1992	1.89	2.16	2.50	2.51	1.94	1.33	0.55	0.25	-0.06	-0.05	0.01	0.12
1993	0.23	0.38	0.87	1.45	1.62	1.36	0.75	0.51	0.39	0.43	0.32	0.18
1994	0.02	-0.05	0.02	0.28	0.48	0.54	0.62	0.62	0.80	0.94	1.13	1.14
1995	1.02	0.80	0.63	0.33	0.10	-0.05	-0.21	-0.46	-0.77	-0.89	-0.91	-0.84
1996	-0.88	-0.87	-0.80	-0.65	-0.51	-0.31	-0.19	-0.16	-0.30	-0.31	-0.39	-0.45
1997	**-0.53**	**-0.38**	**-0.04**	**0.74**	**1.67**	**2.49**	**3.02**	**3.02**	**3.15**	**3.00**	**2.73**	**2.53**

Table A2. Standardized anomaly of 3-month mean of SOI - multiplied by -1

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1950	-1.13	-1.61	-1.96	-1.64	-1.92	-2.00	-2.15	-1.44	-1.33	-1.29	-1.91	-1.74
1951	-1.63	-0.54	0.23	1.02	0.89	1.06	0.80	1.11	1.07	1.20	1.05	0.88
1952	0.83	0.45	0.30	-0.25	-0.42	-0.70	-0.32	-0.01	0.05	-0.01	0.35	0.39
1953	0.59	0.32	0.43	1.29	1.20	1.09	0.79	1.14	1.11	0.60	0.28	0.06
1954	0.10	-0.05	0.03	-0.21	-0.13	-0.11	-0.40	-0.55	-0.50	-0.25	-0.66	-0.41
1955	-0.88	-0.48	-0.46	-0.24	-0.74	-1.57	-1.71	-1.67	-1.62	-1.68	-1.55	-1.35
1956	-1.30	-1.33	-1.26	-1.43	-1.49	-1.42	-1.25	-0.84	-1.13	-0.84	-1.18	-0.62
1957	-0.48	-0.08	0.05	0.41	0.45	0.41	0.35	0.62	0.66	0.76	0.54	1.15
1958	0.98	0.86	0.15	0.40	0.42	0.33	-0.40	-0.27	-0.12	0.35	0.45	0.71
1959	1.04	0.43	0.00	-0.66	-0.02	0.28	0.53	0.30	-0.03	-0.58	-0.88	-0.75
1960	-0.32	-0.30	-0.57	-0.75	-0.36	-0.19	-0.34	-0.67	-0.50	-0.53	-0.55	-0.46
1961	-0.46	0.64	0.18	0.41	-0.41	-0.04	0.08	-0.05	0.19	-0.12	-0.61	-1.44
1962	-1.06	-0.48	0.11	-0.51	-0.82	-0.63	-0.36	-0.33	-0.71	-0.69	-0.58	-0.53
1963	-0.58	-0.83	-0.81	-0.71	0.07	0.48	0.60	0.42	0.85	1.07	1.31	0.89
1964	0.61	-0.16	-0.86	-0.91	-0.86	-0.41	-1.00	-1.24	-1.53	-1.08	-0.46	0.20
1965	0.19	-0.09	0.00	0.11	0.77	1.33	1.66	1.67	1.26	1.51	1.00	1.03
1966	0.54	1.08	0.78	0.98	0.41	0.23	-0.19	-0.08	-0.02	0.14	0.20	-0.42
1967	-0.93	-1.45	-0.92	-0.28	-0.09	-0.09	-0.45	-0.46	-0.42	-0.03	0.42	0.25
1968	-0.31	-0.48	-0.27	-0.40	-0.98	-1.18	-0.66	-0.15	0.15	0.26	0.12	0.54
1969	0.70	0.69	0.35	0.40	0.52	0.58	0.46	0.79	0.95	0.83	0.33	0.24
1970	0.66	0.70	0.40	-0.08	-0.39	-0.20	-0.29	-0.41	-0.96	-1.53	-1.76	-1.49
1971	-1.41	-1.51	-2.25	-2.14	-1.41	-0.48	-0.70	-1.16	-1.76	-1.51	-1.00	-0.44
1972	-0.49	-0.54	-0.35	0.87	1.50	2.02	1.46	1.50	1.21	1.03	0.95	0.66
1973	1.08	0.48	0.45	-0.18	-0.51	-0.77	-1.09	-1.15	-1.20	-1.88	-2.07	-2.57
1974	-2.10	-2.24	-1.90	-1.88	-1.11	-1.05	-0.80	-1.13	-1.01	-0.73	-0.31	0.21
1975	-0.09	-0.54	-1.21	-1.28	-1.38	-1.60	-2.11	-2.35	-2.22	-2.05	-1.96	-1.72
1976	-1.72	-1.48	-1.19	-0.94	-0.38	0.26	0.89	1.27	0.73	0.01	-0.29	-0.02
1977	-0.05	0.13	0.33	1.21	1.57	1.63	1.63	1.26	1.19	1.30	1.41	1.04
1978	1.48	1.20	1.31	-0.21	-0.57	-0.91	-0.44	-0.28	0.10	0.16	0.24	0.16
1979	-0.10	-0.07	-0.07	0.05	-0.28	-0.94	-0.53	-0.38	0.20	0.20	0.53	0.32
1980	0.09	0.16	0.73	0.98	0.78	0.33	0.16	0.19	0.16	0.35	0.22	0.07
1981	0.06	0.58	0.83	0.43	-0.79	-1.16	-1.00	-0.63	-0.13	-0.02	-0.05	-0.64
1982	-0.63	-0.55	-0.19	0.12	1.03	1.70	2.28	2.20	2.23	2.54	2.73	3.10
1983	3.30	3.51	2.93	1.46	0.43	0.14	0.45	-0.05	-0.50	-0.53	-0.19	-0.06
1984	-0.30	-0.07	-0.21	0.02	0.13	0.28	0.20	-0.16	0.04	-0.03	0.14	0.06
1985	-0.14	-0.38	-0.94	-0.59	-0.07	0.48	0.10	-0.24	-0.11	0.27	0.21	-0.30
1986	0.02	0.01	0.23	0.02	-0.27	-0.23	-0.12	0.39	0.21	0.46	0.77	1.27
1987	1.24	1.26	1.78	2.22	2.49	2.16	1.87	1.50	1.07	0.59	0.37	0.19
1988	0.41	0.13	0.03	-0.63	-0.44	-0.78	-0.92	-1.67	-1.79	-2.03	-1.75	-1.68
1989	-1.33	-1.20	-1.43	-1.72	-1.72	-1.16	-0.35	-0.31	-0.26	-0.40	-0.03	0.30
1990	0.85	0.96	0.88	-0.31	-0.69	-0.76	-0.03	0.25	0.35	0.38	0.22	0.12
1991	-0.14	0.10	0.73	1.50	1.39	0.86	0.52	0.90	1.33	1.34	1.40	1.83
1992	1.98	2.18	1.79	1.52	1.11	0.75	0.69	0.20	0.55	0.89	1.18	0.80
1993	0.86	0.84	1.16	1.14	1.56	1.21	1.49	1.14	1.23	0.77	0.48	0.01
1994	-0.04	0.36	1.05	1.66	1.74	1.51	1.67	1.84	1.72	1.35	1.18	0.78
1995	0.66	0.05	0.39	0.68	0.95	0.21	-0.12	-0.30	-0.11	-0.11	0.22	-0.15
1996	-0.14	-0.69	-0.73	-0.96	-1.17	-0.94	-0.94	-0.69	-0.65	-0.42	-0.50	-0.47
1997	**-0.98**	**-0.40**	**0.11**	**1.59**	**2.07**	**2.06**	**1.93**	**1.61**	**1.81**	**1.61**	**1.49**	**1.68**

Note: 1997 data (shown in bold), expressed relative to the 1955-96 base period statistics, are not analyzed in this atlas. They are included here for completeness and to show the powerful 1997-98 ENSO episode which may or may not end up being stronger than the famous 1982-83 episode.

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