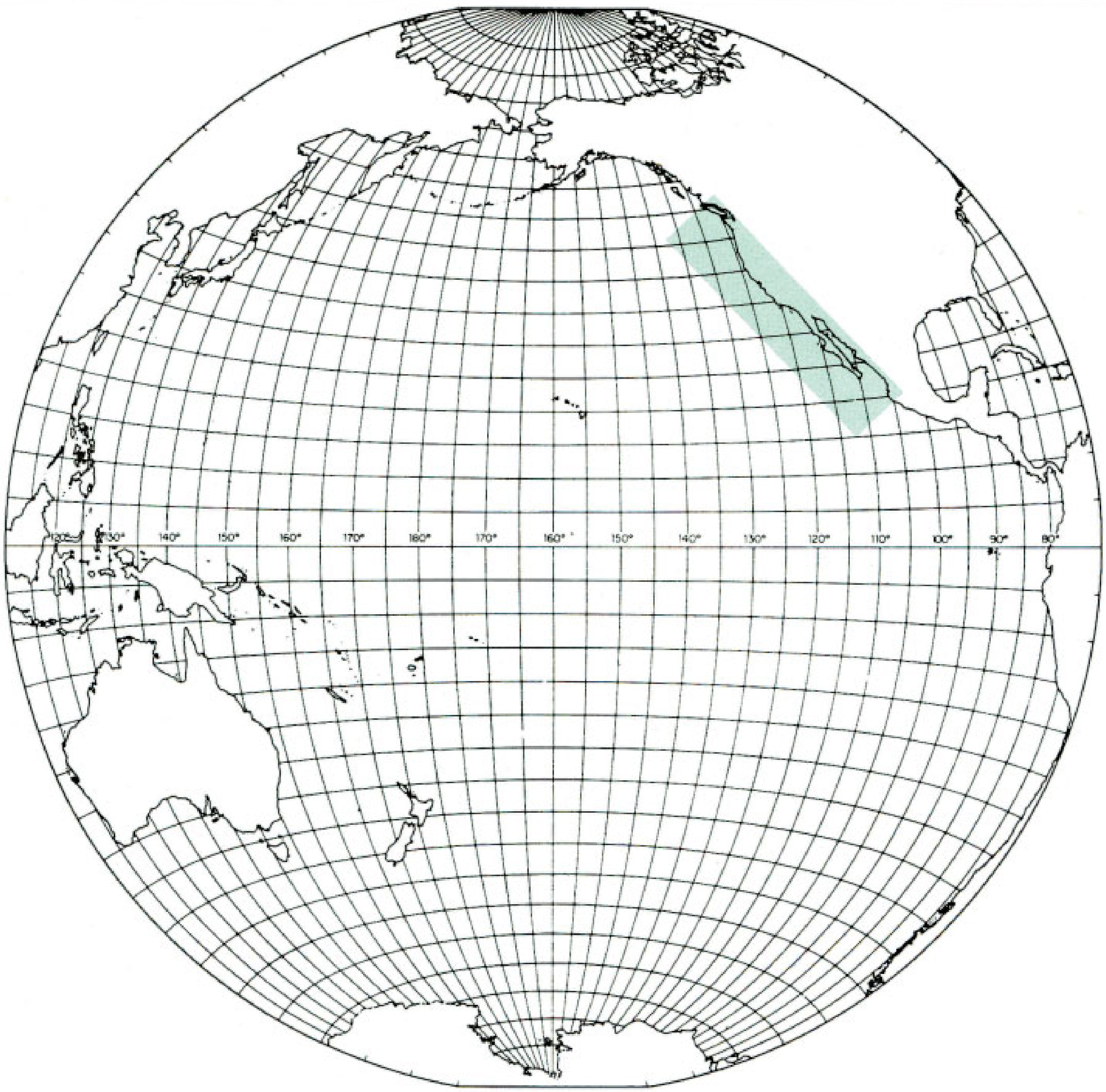

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UNIVERSITY OF CALIFORNIA, SCRIPPS INSTITUTION OF OCEANOGRAPHY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, NATIONAL MARINE FISHERIES SERVICE

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Part I

REPORTS, REVIEW, AND PUBLICATIONS

REPORT OF THE CALCOFI COMMITTEE

CALCOFI LEGENDS RETIRE

John Hunter "Weighs Anchor"

After more than 40 years as a scientist and administrator for CalCOFI, Dr. John R. Hunter retired from the Southwest Fisheries Science Center (SWFSC) of the National Marine Fisheries Service (NMFS) in the summer of 2003. He began his CalCOFI career as a laboratory scientist defining the progress of egg and larval development and particularly the development of schooling and feeding behavior of aggregations of larvae preying on patches of motile plankters. He started this phase of his career after studying tuna and porpoise field behavior; one of his contributions was to define the behavior of tuna near flotsam. Tropical tuna fisheries now take advantage of the aggregation of tuna around artificial floating devices. Hunter's doctoral dissertation concerned nest parasitism of sunfishes by minnows. These divergent areas of study prepared him for the diversity of scientific approaches he has used to understand and manage the coastal pelagic species of the CalCOFI program interests. About a third of his numerous publications concern the details of spawning and the importance of that knowledge in evaluating fish resources; these are published under the pseudonym J. Roe Hunter.

Hunter's international recognition as a scholar was furthered by his research conducted under a Rockefeller Foundation Fellowship during which he and J. H. S. Blaxter wrote the definitive work on Clupeoid biology, published in *Advances in Marine Biology* 20 years ago. This work constituted the unification of field and laboratory studies that have been grist for field, laboratory, and modeling works to this day. The scholarly demands on Hunter have multiplied through his interactions with faculty and graduate students at Scripps Institution of Oceanography (SIO) and other important centers around the world. Through these important activities, he has carried the CalCOFI process into his supervision and planning of research for the U.S. Agency for International Development, U.S. Global Ocean Ecosystem Dynamics (GLOBEC), and International GLOBEC. Hunter used the CalCOFI format in the design of the International Geosphere-Biosphere Programme in relation to Small Pelagics and Climate Change. Hunter founded this project a decade ago, and it is carried on by his colleagues, led by Dr. Juergen Alheit.

Recently, following the massive recovery of the sardine population and its expansion from small habitats in the Southern California Bight to dominance of the pelagic biota from Mexico to Canada and Alaska, Hunter proposed a multi-institutional program to overcome the parochial geography of CalCOFI and expand biological and oceanographic measurements through the entire California Current System from British Columbia to Baja California, Mexico. This is a work in progress (now called Pacific Coastal Observing System, PaCOS; formerly known as Alliance for California Current Ecosystem Observation, ACCEO) and, fortunately, we can rely on his guidance for several more years to expand the CalCOFI grid beyond its present scope.

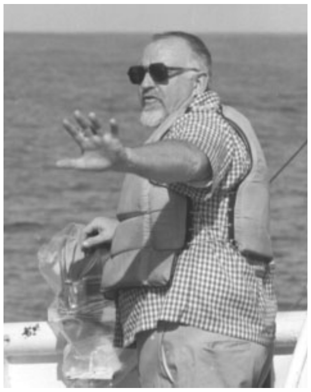
Hunter is best at careful observation. Flaws in traditional observation systems stimulated him to design rapid and incisive methods for those times when the ocean, and particularly its biota, would not stand still for patient observation. His first contribution was to assemble a group of scientists to adapt and modernize river and coastline methods for tagging fish that could be used in the open ocean habitat, especially for tuna scanned by satellites. Hunter was a pioneer in the study of archival tags nearly two decades ago when the existing technology was far behind researchers' needs. Now the age of miniature computer tags has brought these techniques into functional prominence. Hunter has been spreading the understanding and application of daily egg production methods for the rapid and precise assessment of the spawning biomass of multiple spawning schooled fishes around the world. He recently added continuous sampling by the Checkley egg-pump sampler, which in its first use on the West Coast forced the revision of our time-honored opinions about the life and geography of the Pacific sardine. Lastly, Hunter forged airborne LIDAR technologies to assess schooling surface fishes, which are resistant to normal acoustic surveys. As a result, the upper areas of the ocean are now rapidly observable, and these methods are the methods of choice for slow-schooling fishes and virtually the only methods for rapid-swimming fishes like mackerel. Hunter's research exemplifies how basic research can be combined with applied research to address management needs. His paper on ultraviolet radiation damage to surface-living anchovy larvae, co-authored with John Taylor and Geoff Moser, has been cited 43 times in the 25 years since its publication. A quarter of these citations relate to invertebrate and fish damage and appear in works published in the last three years, long after his personal involvement.

In his scholarly wake, he has also left us the definitive handbook on fisheries science writing, *Writing for Fishery Journals*. (And, although it contains no signal for when to stop writing about a top scientific and scholarly career, I trust the editors who have been brought up with its sage advice will exercise the necessary controls over those of us who need it [editors' note: we did]). While Hunter is leaving the field of science administration, we are confident that there will be issues in CalCOFI that will rise to his standard for giving guidance and consideration.

Great job, well done, and thanks for the extra labor on CalCOFI's behalf.

Paul Smith "Casts Off"

Dr. Paul E. Smith, leading fisheries research biologist at SWFSC and adjunct professor at SIO, retired in January 2003 after 40 years of service. Smith came to the SIO campus as a postdoctoral student in ecology with Professor E. W. Fager, who pioneered the use of modern statistics in oceanography. Smith soon developed a close working relationship with Dr. Garth Murphy, CalCOFI Coordinator, and Dr. Elbert Ahlstrom, director of the La Jolla Laboratory of the Bureau of Commercial Fisheries (BCF). His interest in plankton and sardine biology led to his appointment as fisheries research biologist at BCF, later to become NMFS. Smith's interest in sampling design and techniques led to several important papers on plankton net performance and efficiency. This research was, and continues to be, a major contribution to the CalCOFI field surveys and to the quality of the plankton data derived from them. His classic monograph, "Standard Techniques for Pelagic Fish Egg and Larva Surveys," co-authored with Dr. Sally Richardson, published by the UN Food and Agriculture Organization in 1977, remains the international standard manual for plankton field surveys. Smith's early interest in acoustic biological sampling led him to Norway, where he worked closely with Simrad engineers in the design and installation of acoustic instrumentation aboard the newly commissioned RV *David Starr Jordan*. Scientists throughout the world have continued to call on Smith for his expertise in the design of acoustical samplers and in the biological interpretation of data derived from them. His core research interest has centered on coastal pelagic fisheries (sardines, anchovies, mackerels, and hake), and he has published numerous classic papers on all of these. His career has bridged the period of the Pacific sardine collapse, the explosive growth of northern anchovy, and the recovery of the sardine population during the past decade. His leadership in the establishment of a harvest moratorium for Pacific sardine was critical to the population's recovery. He played a similar advisory role in the conservation and management of coastal pelagic fisheries in Mexico, Chile, Peru, Spain, Japan, and South Africa through the introduction of scientific advances developed in the CalCOFI program. His studies of larval fish assemblages in re-



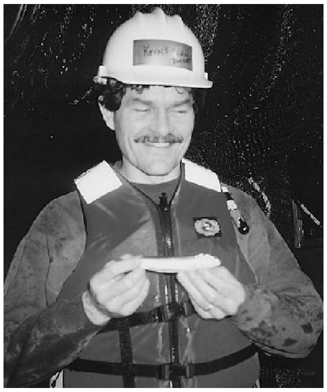
lation to changes in the ocean environment form a basis for ecosystem management of the California Current System. One of Smith's most important roles has been as a graduate student advisor and postdoctoral mentor. Many of his students have become leaders in their research fields and have made major contributions to fisheries and ecological science. Following his retirement, Smith has continued his research projects, service on scientific committees, and student advising, and he remains a vital resource for CalCOFI and SIO. Just as one of his ancestors opened new vistas and opportunities as a member of the Lewis and Clark expedition, Smith's career continues to be a truly remarkable series of explorations in fisheries science and ocean ecology.

Ronald Lynn "Rides the Ebb Tide"

Ronald J. Lynn retired in January 2003 after 40 years of service with BCF and its successor agency NMFS. Lynn was a rare specimen at NMFS, being the only physical oceanographer at La Jolla's SWFSC through most of his career. His unique expertise, contagious enthusiasm, and kind, unassuming demeanor made Lynn's office a popular spot for the center's scientists. (Not to mention the great view!) His talents are reflected in his extensive and diverse body of work, which includes seminal papers on subjects ranging from abyssal water properties (with Joe Reid), to California Current physical dynamics, to West Coast fisheries oceanography. CalCOFI was always a focal point of Lynn's career: he participated in planning, in data collection at sea, and, of course, in the analysis of CalCOFI's vast data set. He was a regular contributor to *CalCOFI Reports*, and his *CalCOFI Atlas* no. 30 remains a classic and much-referenced guide to the CalCOFI hydrographic data set.

Lynn's career spanned two climate regimes, from the period of Nansen bottle casts and hand annotation of data to CTDs and real-time satellite imagery. He was always at the forefront of technological advances and always approached problems with simple curiosity and logic. Four decades of productive research have earned Lynn a well-deserved reputation as a leading expert in fisheries oceanography and the physical oceanography of the California Current. He will be missed in the CalCOFI community, but his ideas and accomplishments will continue to guide our work. We wish Lynn well in his retirement.

Kevin Hill "Steps Down and Jumps Ship"



Dr. Kevin T. Hill has stepped down as CalCOFI coordinator and has left the California Department of Fish and Game (CDFG) to work with SWFSC in La Jolla as part of its population dynamics research team. He served as CalCOFI coordinator from 2000 to 2003. He organized the annual CalCOFI conference from 2000 to 2002 and oversaw production of volumes 41 to 43 of *CalCOFI Reports*. For the past three years, Hill was the project leader for CDFG's pelagic fisheries assessment unit and was responsible for conducting stock assessments and biomass evaluations for Pacific sardine and Pacific mackerel. He also represented CDFG on the Pacific Fisheries Management Council's Coastal Pelagic Species Management Team and the Scientific and Statistical Committee. Hill worked for CDFG for over eight years, spending his entire tenure at SWFSC in La Jolla collaborating with federal scientists working on coastal pelagic fish stocks. Hill's expertise, professionalism, and enthusiasm will be missed by CDFG. As coordinator of CalCOFI, Hill's exceptional organizational skills made it a pleasure for the committee to conduct CalCOFI business, gave us the ability to track financial transactions easily, and kept us on track. As organizer of the conferences, he attended to every detail and ensured that participants were well cared for; his closing remarks were always exceptionally gracious and warm and made both him and CalCOFI shine. On behalf of the entire CalCOFI community, we thank Hill for his dedication and tireless energy, which have helped CalCOFI move forward into the twenty-first century.

SIO HIGHLIGHTS

CalCOFI personnel from SIO have devoted considerable time and energy to finding operating funds to replace those that until recently were provided by the University of California. In the summer of 2002, the state of California imposed stringent budget cuts throughout the university system. University of California, San Diego, elected to absorb much of its cut by decreasing allotments for research. This ultimately translated into a $1.3 million cut in state-supported research at SIO. Approximately $1 million of those funds represented SIO's contribution to CalCOFI, for technicians and two of the quarterly research cruises.

SIO/CalCOFI has since received emergency funding from NOAA and the Office of Naval Research. These, together with other carry-forward funds, will provide technicians' salaries through early summer 2004 and research vessel support through the fall cruise in 2004. The emergency funds would not have been realized without the support of SIO's director, Charlie Kennel, and miraculous efforts on the part of Kathleen Ritzman, Kennel's director of government relations. Additional outside funds are being sought to fill the funding gaps beyond 2004.

A bright spot during the past year was the April CalCOFI cruise. The Office of Naval Research supported the use of the RV *Roger Revelle* for an expanded cruise, providing space and time for several navy-supported programs and a few additional days for extra CalCOFI-dedicated research. This gave us the opportunity to demonstrate the value of CalCOFI as a research platform. During the three-week cruise, there were 25 "ancillary" personnel with 23 different projects. Onboard were researchers from three foreign countries and three California institutions (in addition to SIO). Most programs met or exceeded their expectations. By all criteria, the objective of demonstrating CalCOFI's value as a research platform was fully met.

The additional research occurred on the third leg of the cruise; we conducted a closely spaced hydrographic survey along the perimeter of the CalCOFI area while returning to San Diego from station 77.49. At the same time, the RV *David Starr Jordan*, which had completed a larval fish and egg survey up to San Francisco, was able to do a similar hydrographic survey around the northern area. We hope that this increased sample density will enable us to estimate a flux budget for the CalCOFI area from a single cruise. Previous efforts (Roemmich 1989 in Deep-Sea Res. I, vol. 36; and Bograd, Chereskin, and Roemmich 2001 in J. Geophys. Res., vol. 106) have been forced to average over several cruises to reduce the error bars. If we obtained sufficient sample spacing on this cruise, we will be able to compare fluxes of numerous properties between cruises and between areas; this will open approaches to a number of ecological questions concerning off-shore transport and advective versus in situ processes.

CDFG HIGHLIGHTS

CDFG established the largest marine reserve on the West Coast in 2002, setting aside 12 areas (175 square miles) within the Channel Islands National Marine Sanctuary where fishing is not allowed. CDFG will convene workshops to review the best methods for monitoring the newly established marine reserves. The next phase would expand the network of reserves into federal waters—those lying beyond the 3-mile boundary of state waters that surround each island. The full system of marine reserves would cover 426 square miles and once adopted by the federal government would make California the home of the largest network of marine reserves in the continental United States.

A cooperative program involving state, federal, and university researchers is being assembled to provide information needed to manage nearshore fish and invertebrates under the authority of the California Fish and Game Commission. Specifically, the Cooperative Research and Assessment of Nearshore Ecosystems program (CRANE) will develop a fishery-independent sampling program to provide density and size frequency information on marine invertebrates, fishes, and kelps in nearshore rocky subtidal habitats (5–100 m depth). CDFG will conduct aerial kelp bed surveys annually to measure the distribution and abundance of kelp habitat and resources.

PACOS AND THE FUTURE OF CALCOFI

At the CalCOFI conference in November 2001, Dr. John Hunter, SWFSC, proposed that CalCOFI begin strengthening communication and data exchange between existing pelagic surveys along the west coast of North America. Existing programs, if effectively coordinated, could ultimately serve as the framework for an expanded program of observation covering the entire California Current System. This idea was enthusiastically received and discussed by conference participants. Hunter and other CalCOFI personnel conducted three workshops along the West Coast (in Moss Landing, California; Portland, Oregon; and Seattle, Washington) to assess support for this concept; support was enthusiastic from Baja California to British Columbia.

The concept has been favorably received by NOAA Fisheries. Early in April, a workshop was held at SWFSC in La Jolla, attended by Michael Sissenwine and Bill Fox from NOAA Fisheries headquarters, scientists from

NMFS laboratories in La Jolla and Seattle, and representatives from CDFG and SIO. NOAA pledged support for a broad view of the alliance, which would include not only CalCOFI and allied programs but also all the biological observing systems presently in place in the Exclusive Economic Zone (for instance, the MBARI/NPS Line 67 near Monterey, California, and the line off Newport, Oregon, that is repeatedly surveyed by Oregon State University and NWFSC). The program has been named Pacific Coastal Observing System (PaCOS). A workshop of key federal, state, and university institutions will occur on 1 June and 30 July 2003. Those attending the April workshop also agreed on the importance of maintaining the CalCOFI program, which will be a key component of any expanded alliance.

CALCOFI REPORTS GOES ONLINE

In an effort to keep up with the information age, reach the largest possible audience, and reduce costs, *CalCOFI Reports* is now available on the Internet. Articles from the entire series (volumes 1 to 44) may be downloaded, free of charge, as Adobe Acrobat™ (pdf) files. See the CalCOFI Web site, www.calcofi.org, for details. Volumes 43 and 44 files were generated electronically during the final layout process. Volumes 1 through 42 were scanned and electronically archived in a searchable format thanks to the efforts of Information Technology Services of the SWFSC. The CalCOFI Committee is especially grateful to Rob Bistodeau for offering his time and expertise to this worthy cause!

KUDOS

The seagoing personnel of SIO's Integrative Oceanography Division, the SWFSC's Fisheries Research Division, and CDFG's Marine Region all contributed, through their dedication and diligence, to the success of CalCOFI's quarterly fieldwork. The CalCOFI Committee thanks the officers and crews of the research vessels that have served us well as platforms for our observations during the past year: NOAA's RV *David Starr Jordan*, University of California's RV *New Horizon* and RV *Roger Revelle*, and CDFG's RV *Mako*.

We thank H. Geoffrey Moser, Steven J. Bograd, Ronald C. Dotson, Franklin B. Schwing, and Dale Sweetnam for their assistance in preparing this report. We also thank the reviewers of contributed papers in this volume: Larry Allen, Steven Bograd, Larry Breaker, Kurt Buck, Gregor Cailliet, Aloysius Didier, Jr., John Geibel, John Hunter, Eric Knaggs, Milton Love, Baldo Marinovic, Jerrold Norton, Richard Parrish, Paul Reilly, Franklin Schwing, Gary Sharp, Mary Silver, Cindy Thomson, Sam Herrick, William Watson, and Mary Yoklavich. We are especially grateful to Joni Harlan for her professional style in editing this volume of *CalCOFI Reports* and to Barry Age and Simone Llerandi for their exceptional efforts in producing it.

Finally, we would like to thank Brad Neuschwanger (CDFG), Mary Ellsworth (CDFG), Corey Chan (CDFG), and Diane Foster (NMFS) for providing invaluable assistance to the CalCOFI Committee throughout the year.

The CalCOFI Committee:
Kevin Hill, CalCOFI Coordinator
John Hunter, NMFS
Laura Rogers-Bennett, CDFG
Elizabeth Venrick, UCSD

REVIEW OF SOME CALIFORNIA FISHERIES FOR 2002: MARKET SQUID, SEA URCHIN, DUNGENESS CRAB, PRAWN, COASTAL PELAGIC FINFISH, ALBACORE, OCEAN SALMON, NEARSHORE LIVE-FISH, PACIFIC HERRING, AND RECREATIONAL

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SUMMARY

In 2002, commercial fisheries landed an estimated 177,627 metric tons (t) of fishes and invertebrates from California ocean waters (fig. 1). This represents a decrease in landings of nearly 12% from the 200,996 t landed in 2001, and a 28% decrease from the 247,122 t landed in 2000. The preliminary ex-vessel economic value of commercial landings in 2002 was $104 million, slightly higher than the $103 million in 2001 and a decrease of 22% from the $133 million in 2000.

The top three grossing fisheries in the state were invertebrate fisheries. Market squid was once again the top grossing fishery, with ex-vessel value of $18.2 million, an 8% increase in value even though landings declined by 15%. Regional shifts in availability and landings due to El Niño conditions and strong international demand for California squid due to poor landings in other international squid fisheries were responsible for the reduced landings and higher revenues. Dungeness crab was the second highest grossing fishery, with $13.4 million in revenue, an increase of 49% over 2001, which had the lowest landings in over 25 years. Sea urchin was the third highest grossing fishery, with $10.1 million in revenue, a decrease of 13% from 2001 revenues, even though landings were 6% higher. Weakening prices due to expansion of new Japanese fisheries was not offset by increased domestic demand. Chinook salmon ranked fourth in value, with $7.6 million in revenues, an increase of 60% from 2001 ($4.8 million). And swordfish ranked fifth in value with $6.3 million in revenues, a 28% decline from 2001 ($8.7 million). The remaining top-ten grossing fisheries included Pacific sardine ($5.8 million), California spiny lobster ($4.5 million), albacore ($3.9 million), sablefish ($3.6 million), and spot prawn ($3.3 million). Groundfish revenues (all groundfish species combined) in 2002 were $16.1 million, slightly lower than in 2001 ($16.2 million), although landings were 3% higher in 2002 (12,273 t) than in 2001 (11,862 t).

Spot prawn revenues decreased by 10% in 2002 ($3.3 million) from 2001 ($3.7 million), continuing a decline in landings for the past 4 years. Over three-quarters of spot prawn were landed live, with an average price of $8.22/lb. In recent years, there has been a shift from the use of traps to trawls in the fishery. However, concerns about bycatch of overfished rockfish species led to a ban of spot prawn trawling in 2003.

Landings of Pacific sardine ranked second in 2002 (58.3 t) and increased 11% from 2001 (51.8 t) despite a closure for domoic acid, export bans due to viral hemorrhagic septicemia, and a regional closure of northern California, Oregon, and Washington fisheries due to attainment of the harvest guideline. Pacific mackerel landings in 2002 (3,366 t) declined 51% from 2001 and 84% from 2000, prompting a reduction in the harvest guideline for 2003. Landings of jack mackerel and northern anchovy also decreased substantially in 2002 compared to 2001, with declines of 72% and 76%, respectively.

Commercial landings of albacore declined 13% in 2002, whereas recreational landings increased 30% compared to 2001. The majority (60%) of the recreational catch was landed in Mexico. Nearshore commercial finfish landings totaled 352t in 2002, with 73% identified as live landings. Ex-vessel value of nearshore landings was $2.7 million, of which $2.3 million was paid for live fish. This represents a slight decrease from 2001 in total nearshore landings and in value.

In 2002, nearly 700,000 recreational anglers aboard commercial passenger fishing vessels (CPFVs) landed nearly 3.17 million fishes, 6.5% more than in 2001 (2.97 million) and 2% less than in 2000 (3.23 million). Southern California anglers accounted for 81% of total landings. The ten top species landed in southern California were barred sand bass (27% of total), albacore tuna (12%), unspecified rockfishes (12%), kelp bass (10%), California barracuda (9%), sanddab (5%), ocean whitefish (4%), California scorpionfish (4%), halfmoon (3%), and yellowtail (3%). In central and northern California, a total of 1,164,767 fish were landed. The ten top species included unspecified rockfishes (37% of total), blue rockfish (23%), Chinook salmon (13%), gopher rockfish (6%), flatfishes (unspecified; 5%), lingcod (4%), albacore tuna (4%), California halibut (2%), striped bass (1%), and brown rockfish (1%).

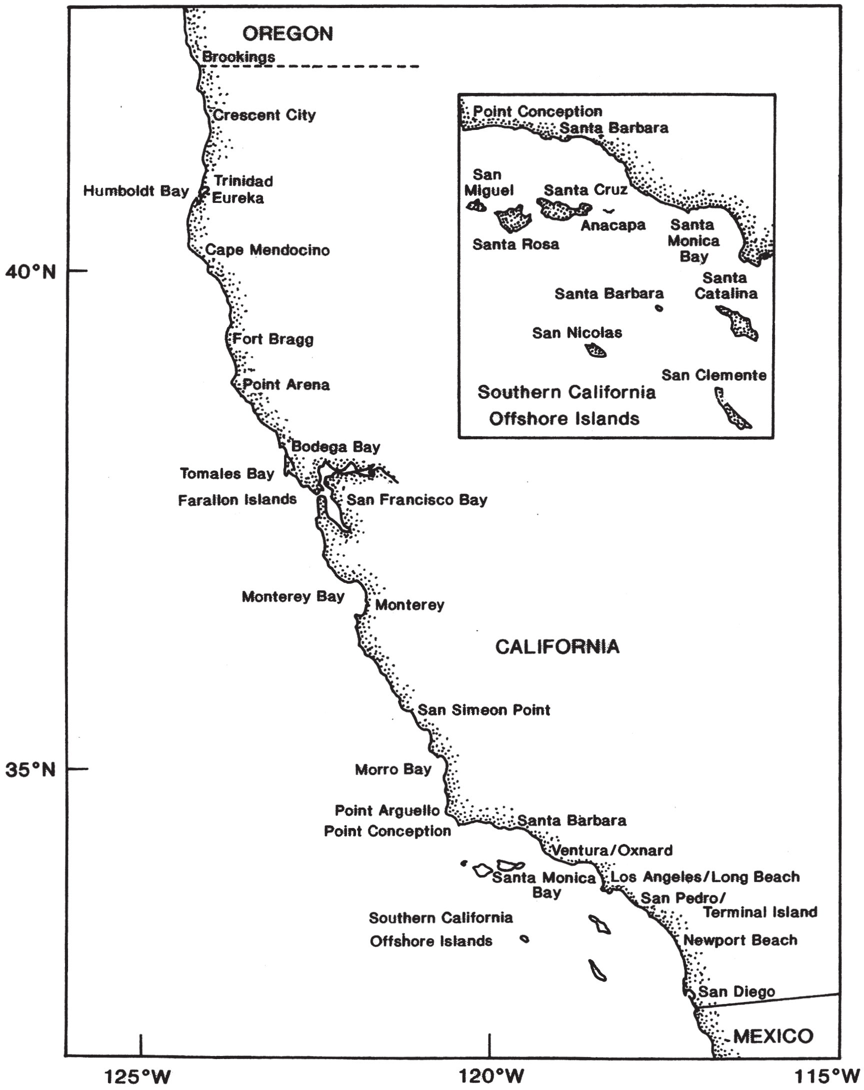

Figure 1. California ports and fishing areas.

In 2002, the California Fish and Game Commission undertook 28 rule-making actions that address marine and anadromous species. New regulations for offshore and nearshore rockfish and lingcod stocks were prompted by action taken by the Pacific Fishery Management Council (PFMC). PFMC voted to decrease the bag and possession limits of certain rockfish species found in federal waters to help rebuild overfished stocks of bocaccio, canary, cowcod, yelloweye rockfishes, and lingcod. Because many of these species are found in both state and federal waters, the Commission adopted similar state laws to comply with the federal regulations for these species. New management areas for rockfish and lingcod include:

- Northern Rockfish and Lingcod Management Area—waters from Cape Mendocino (40°10'00"N lat.) to the California-Oregon border.
- Central Rockfish and Lingcod Management Area—(formally known as the Northern Rockfish and Lingcod Management Area) waters from Cape Mendocino south to Point Conception.
- Southern Rockfish and Lingcod Management Area and Cowcod Closure Areas—remain the same; between Point Conception (34°27'00"N lat.) and the U.S.-Mexico border.

Rockfish, lingcod, and sculpin fisheries were closed for eight months (March–June and September–December, inclusive) in offshore waters (deeper than 20 fathoms) of the central management area, and closed for 4 months in offshore waters (January–February and November–December) in the southern management area. No closures occurred in the northern management area.

In October 2002, the Commission voted to adopt a series of marine protected areas (MPAs) within the

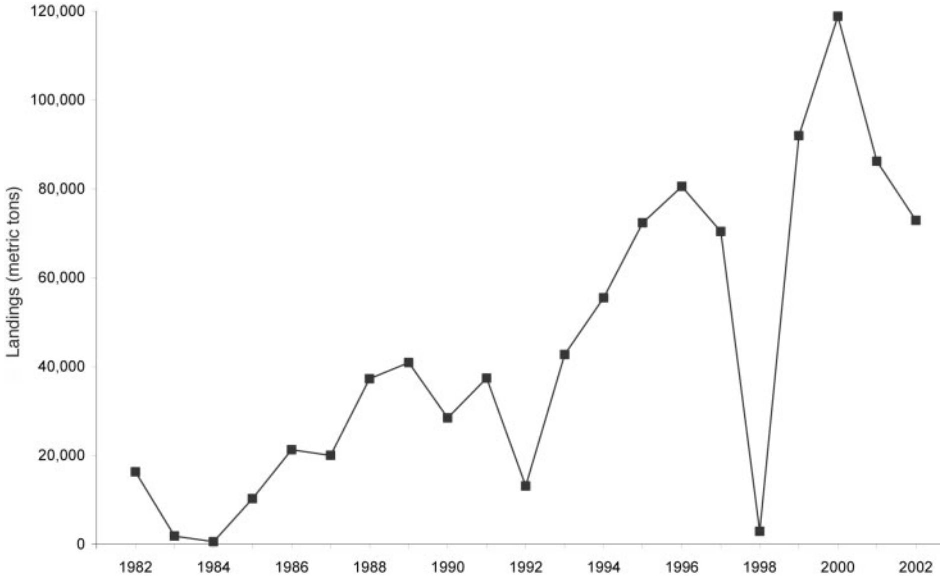

Figure 2. California commercial market squid landings, 1982–2002.

Channel Islands National Marine Sanctuary. The decision came after 4 years of public meetings and deliberations. The network of MPAs consists of 12 distinct areas around four of the northern Channel Islands covering 175 mi^2. The Commission also adopted the Nearshore Fishery Management Plan, which provides a management strategy for 19 of the nearshore species targeted by the nearshore live-fish fishery. The plan integrates a framework of management measures intended to meet the goals and objectives of the Marine Life Management Act and provide for sustainable nearshore stocks and fisheries.

INVERTEBRATE FISHERIES

Market Squid

Market squid (*Loligo opalescens*) was the largest fishery in the state by volume and ex-vessel value in 2002. A total of 72,879 t of market squid was landed, 15% less than in 2001 (86,202 t) and 39% less than the record high set in 2000 (118,825 t) (fig. 2). The 2002 ex-vessel value was approximately $18.2 million, an 8% increase over 2001 ($16.9 million). The average ex-vessel price was $250/t, a 40% increase from 2001. The fishery was poor due to El Niño weather conditions, and market demand was strong due to poor landings in other international squid fisheries.

The fishing season for market squid runs from 1 April through 31 March of the following year. A northern fishery occurs during the spring and summer and is centered on the southern bight of Monterey Bay. A southern fishery occurs during the fall and winter off the Channel Islands and coastal locations from Point Conception south to San Diego. Both declines in total landings (fig. 2) and regional shifts in landings (fig. 3) highlight the impacts of the El Niño weather conditions on the squid fishery. During the 2002–2003 season, 42,596 t were landed, 54% less than the 2001–2002 season (92,573 t) and 63% less than the peak 1999–2000 season (115,437 t).

The northern fishery experienced a significant expansion and record-setting year. A total of 25,224 t was landed (fig. 3), a 58% increase over the previous record of 15,950 t set in the 1994–95 season. Squid were harvested from areas as far south as Morro Bay and as far north as Fort Bragg. The length of harvest time was also unusually long. Landings began in mid-February and continued through November. Typically, landings in the northern fishery occur around mid-April and end around September. Usually squid are concentrated and harvested at night with the use of high-powered lights. This year there was an increase in daytime activity. During the day, squid remained concentrated enough to allow for vessels using sonar to detect and capture them.

Contrary to most seasons (but prevalent in El Niño years), the southern fishery did not surpass the northern fishery in 2002–2003 (fig. 3), with 17,372 t landed (41% of the catch). Catches were light most of the season with boats working hard for very few tons landed per fishing day. These poor southern California landings were concurrent with the mild El Niño that occurred earlier in the summer. After the El Niño condition subsided, southern catches remained poor. With very high international demand, coupled with low availability, the ex-vessel price of squid increased from $220/t to $550/t.

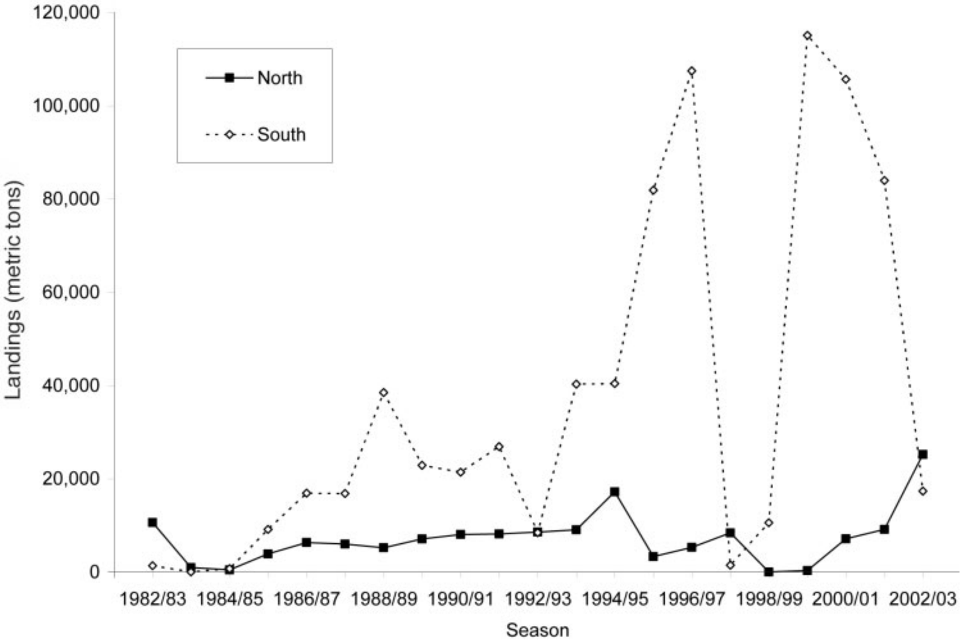

Figure 3. Comparison of market squid landings for northern and southern fisheries by fishing season (1 April to 31 March of the following year), from the 1982–83 season to the 2002–2003 season.

Market squid has become an important international commodity. While some squid are used domestically for consumption and bait, most are packed and processed for export. In 2002, 41,224 t were exported for a value of $30.9 million. Export to China accounted for approximately 40% of this trade.

In May 2002, the preliminary draft of the Market Squid Fishery Management Plan was released for public review and comment. The goal of the plan is to provide a framework and set of procedures to ensure a sustainable fishery and to reduce the potential for overfishing. Due to other fishery issues and implementation of other fishery management regulations, the California Fish and Game Commission postponed adoption of the plan until the fall of 2003, with scheduled implementation in the 2004–2005 fishing season.

Sea Urchin

Statewide landings in 2002 were estimated at 6,260 t with an ex-vessel value of $10.1 million (fig. 4). This is a 6% increase from 2001 landings (5,930 t) and a 13% decrease from 2001 ex-vessel value ($11.53 million). In recent years, a strengthening domestic market has helped offset a world market weakened by increased production from new overseas fishing grounds. Sea urchins from the recently exploited Kuril Islands off northern Japan have made an impact on the more lucrative sea urchin grades, taking some of the market share traditionally captured by California's product.

The majority of southern California sea urchin landings came from the northern Channel Islands off Santa Barbara, where large and accessible stocks supplied the fishery in its early growth years. From 1973 to 1977, 80–90% of red urchin landings originated from these islands. Since the late 1990s, landings have decreased from the northern Channel Islands as fishing effort shifted south to San Clemente Island, San Nicolas Island, and the San Diego area. More recently there has been a reported reversal of this trend as northern Channel Island kelp beds have rebounded from the 1997–98 El Niño. In 1990, the southern California sea urchin catch peaked at over 12,250 t and has declined steadily to 3,810 t in 2002 (preliminary totals). In the 1990s, the fishery was impacted by two El Niño events (1992–94 and 1997–98) and a weakening Japanese economy reflected in decreased demand and lower ex-vessel prices; both factors contributed to reduced fishing effort and catches.

The northern California fishery has been characterized by rapid growth to 13,850 t in 1988 and then a decline and apparent stabilization at about 1,360–2,270 t since the late 1990s (fig. 4). The 2002 catch was estimated at 2,440 t. The number of sea urchin permits issued has slowly but steadily declined during the last decade, dropping to 361 for 2002. The target number of permits remains at 300 for this limited-entry fishery.

Legislation authorizing the Sea Urchin Fishery Advisory Committee (SUFAC) went into effect in 2002. Several members of the Director's Sea Urchin Advisory Committee (DSUAC) have been appointed to the

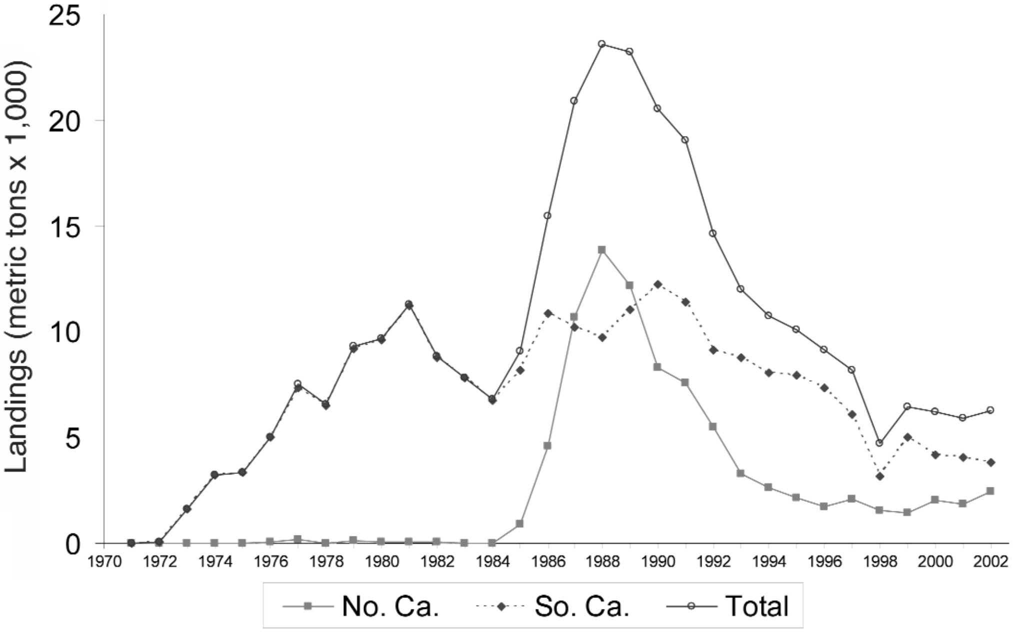

Figure 4. Comparison of red sea urchin landings for the northern and southern fisheries, 1971–2002.

restructured SUFAC. CDFG and the California Wildlife Foundation (CWF) completed a memorandum of understanding to allow the transfer to the CWF of remaining sea urchin enhancement funds that were collected from a self-imposed sea urchin landing fee during the DSUAC era. The transfer was for accounting purposes, and SUFAC retains control of fund distribution. Although the landing fee expired in 2001, the industry account has approximately $250,000 remaining. The funds currently support a study of sea urchin settlement, and additional studies are actively being sought to support and augment CDFG's efforts to manage the resource and associated fishery.

SUFAC recently developed a proposal for using international consultants to write an industry-based monitoring plan. The industry and CDFG are working on interim regulatory changes for consideration by the California Fish and Game Commission. One proposed change could reduce overall catch by repealing the minimum landing requirement to maintain an urchin permit. Another proposal would increase fishing and product marketing opportunities during the summer months by reducing the number of days the fishery is closed.

Dungeness Crab

Landings of Dungeness crab (*Cancer magister*) in 2002 are estimated at 3,286 t, a 105% increase in landings over 2001 (1,604 t) (fig. 5). This reverses the trend of decreasing landings since 1998. Landings in 2001 were the lowest in over 25 years. Ex-vessel revenues for 2002 were $13.4 million, a 49% increase in value over 2001 ($9 million), and slightly below 2000 revenues ($13.7 million). The average price/lb dropped 28% from $2.54 in 2001 to $1.84 in 2002.

The Dungeness crab fishery in California is managed under a regimen of size, sex, and season. Only male Dungeness crabs are harvested commercially, and the minimum commercial harvest size is 6.25 in., measured by the shortest distance across the back immediately in front of the posterior lateral spines. The minimum size limit is designed to protect sexually mature crab from harvest for one or two seasons, and the timing of the season is designed to provide some measure of protection to crabs when molting is most prevalent. California implemented regulations prohibiting the sale of female Dungeness crabs in 1897. Minimum size regulations were first implemented by California in 1903 and have remained substantially unchanged since 1911. The commercial season runs from 1 December to 15 July from the Oregon border to the southern border of Mendocino County and from 15 November and 30 June in the remainder of the state. This basic management structure has been stable and very successful over time. Legislation to authorize a pre-season soft shell testing program in California was introduced during 1994, and industry-funded pre-season testing began prior to the 1995–96 season. The testing is monitored by the Pacific States Marine Fisheries Commission and a minimum meat recovery of 25% is required. Each year, around 1 November, the program is initiated; if the crab meat recovery is less than 25%, another test is mandated. Two weeks later the second

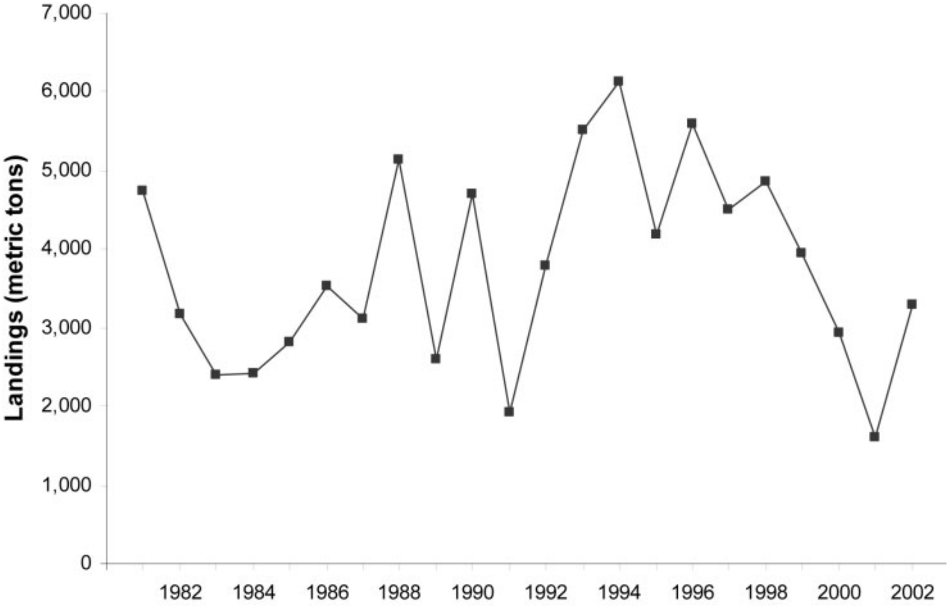

Figure 5. California commercial landings of Dungeness crab, 1981–2002.

test is made, and if the pick out is still below 25%, the season opening is delayed 15 days. This procedure can continue until 1 January, when no more tests can be made and the season must be opened on 15 January. The first test produced a 27.3% pick out for the 2001–2002 season.

Summarizing 2001–2002 commercial season landings rather than the annual totals presented above results in much lower landings, since 79% of the 2002 landings occurred in November and December, the start of the 2002–2003 season. Landings for the 2001–2002 season totaled 1,634 t, a 36% decline from the 2000–2001 season and the lowest since the 1974–75 season. Southern Oregon suffered the same type of season, whereas northern Oregon and Washington reported their best catches in years. The average statewide price per pound was $2.14, a decrease of $0.09/lb over the 2000–2001 season. No one in central California went fishing on the 15 November 2001 opening date due to a strike over price. The fishers and processors finally settled for $2.00/lb on 6 December, but the price jumped to 2.25/lb within two days. The northern California opening date of 1 December 2001 was also bypassed due to a strike over price. The strike ended after 12 days, and the crabbers brought in the first crabs at $1.60–1.80/lb. The price jumped to $2.10/lb within a few days due to poor catches. A total of 385 boats made landings during the 2001–2002 season, down from 424 the previous season and the smallest number of boats since the mid-1970s. Even with the coastwide strike, which lasted until mid-December, the majority of crab boats had quit fishing by February.

Spot and Ridgeback Prawn

Preliminary 2002 spot prawn (*Pandalus platycerous*) landings were 178 t, a 7% decrease from 2001 (192 t). In the last two years, both trap and trawl landings have increased in the Monterey area but declined in the Santa Barbara area. Overall, this is the fourth consecutive year of decreasing landings.

Spot prawn are caught with both trawl and trap gear. Sixty-six boats fished for spot prawn in 2002 (37 trawl and 29 trap) with landings in seven port areas (tab. 1). Nearly 50% of landings were made in the Santa Barbara area. In the past, boats using trap gear were the major contributors to the fishery. Since the mid-1970s, however, boats using trawl gear have increased in number, and their landings now dominate the fishery. Since 1990, the number of spot prawn trawlers increased as vessels forced out of groundfish fisheries by new quotas, seasonal closures, and restrictions sought other sources of income. Many trawlers alternate between targeting spot prawn and ridgeback prawn, fishing for spot prawn during the closed season for ridgeback prawn, and conversely, targeting ridgeback prawn during the spot prawn closed season. In 2001, trap landings were greater than trawl landings for the first time since 1984; however, in 2002, trawl landings were once again greater by 19 t.

In 2002, trawlers harvested 99 t of spot prawn, while trap landings decreased to 80 t (tab. 1). The median ex-vessel price for spot prawn was $8.22/lb, and 76% of all spot prawn landed were sold live. Live prawn had a median price of $9.28/lb with a range of $2.75–11.25/lb. Fresh dead spot prawn sold for a median price of $3.81/lb with a range of $0.10–7.00/lb.

TABLE 1
Landings of California Spot Prawn by Port Area and Gear Type, 2002

	No. of fishing vessels		Landings (metric t)			
Port Area	Trap	Trawl	Trap	Trawl	Total	% of total
Eureka	1	2	<1	3	3	2
San Francisco	1	8	<1	24	24	13
Monterey	5	5	26	11	37	21
Morro Bay	2	10	5	<1	5	3
Santa Barbara	7	24	16	61	78	43
Los Angeles	11	1	19	<1	19	11
San Diego	9	0	14	0	14	8
Total			80	99	179	100

During 2002, the trap and trawl permit fisheries in southern California operated under concurrent closures from 1 November to 31 January. Up to 50 lb of incidentally trawled spot prawn could be retained during the closure. This southern California closure was enacted in 1997 to provide more protection for gravid females. North of Point Arguello, the spot prawn trap season was closed from 1 May to 31 July.

Bycatch concerns in the fishery led CDFG and the California Fish and Game Commission to mandate an on-board spot prawn observer program in 2000. Trawl and trap fishermen landing spot prawn were required to purchase an observer stamp; the stamp funds were used to hire, train, and deploy observers on spot prawn vessels to monitor the bycatch. Based on results from the observer bycatch study, an analysis of spot prawn logs by depth, and because of strict restrictions in landings of incidentally caught bocaccio rockfish (designated as an overfished species), the California Fish and Game Commission implemented a ban on all spot prawn trawling starting 1 April 1 2003. There is still a 50 lb allowance of spot prawn while trawling for ridgeback prawn, but spot prawn are now prohibited as bycatch to pink shrimp trawling. Provisions are being made to allow some spot prawn trawlers to convert their permits to the restricted-access trap fishery.

Preliminary ridgeback prawn (*Sicyonia ingentis*) landings totaled 200 t in 2002, a 22% increase from 2001 (165 t). However, this is only a slight recovery from the 77% decline in 2001 from record landings in 2000 (710 t).

Ridgeback prawn are taken entirely by trawl gear. Closed season is 31 May to 1 October, but 50 lb of incidentally caught prawn are allowed. Thirty boats landed prawn in 2002, a decrease of one from 2001. All landings were made in southern California ports, primarily in the Santa Barbara area, and caught mostly in the Santa Barbara Channel.

The median ex-vessel price for ridgeback prawn in 2002 was $1.62/lb. Nearly half (48%) was landed live; however, most ridgeback prawn is frozen whole for export and domestic markets. Live prawn had a median price of $1.57/lb, and fresh dead prawn sold for a median price of $1.35/lb.

Until recently, market demand and the number of dealers who could process large quantities of prawns limited ridgeback prawn landings. Within the last 6 years, several dealers were able to process up to 300,000 lb annually; however, following peak landings in 2000, the number of processors has dropped. In 2002, nine dealers purchased between 16,000 and 101,000 lb, with 22 dealers purchasing over 500 lb. Lack of market and lack of prawn availability have been given as reasons for the decline.

Ridgeback prawn trawl logs, required since 1986, also show that catch per unit of effort (CPUE) in pounds per tow hour increased from a low of 32 lb/tow hour in 1992, to a high of 213 lb/tow hour in 1999. During 2000, when record landings of ridgeback were made, CPUE had already begun decreasing with 160 lb/tow hour. CPUE further decreased to 70 lb/tow hour in 2001 and 68 lb/tow hour in 2002.

No biomass estimates or maximum sustainable yield calculations exist for ridgeback prawn. However, the potential for expansion of this fishery, the growing demand for ridgeback prawn, and this species' wide fluctuation in availability, warrants continued monitoring and analysis to keep harvest levels sustainable.

FINFISH FISHERIES

Coastal Pelagic Finfish

Pacific sardine (*Sardinops sagax*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), and northern anchovy (*Engraulis mordax*) are known as coastal pelagic species (CPS) finfishes. These species are jointly managed by the Pacific Fishery Management Council (PFMC) and the National Marine Fisheries Service (NMFS).

Pacific Sardine. The Pacific sardine fishery extends from British Columbia, Canada, southward to Baja California, Mexico; however, the bulk of the catch is landed in southern California and Ensenada, Baja

California, Mexico (BCM). The Pacific sardine harvest guideline (HG) for each calendar year is determined from the previous year's spawning biomass estimate. The 2002 Pacific sardine HG was set at 118,442 t using the 2001 spawning biomass estimate of 1.1 million t. Sixty-six percent (78,961 t) of this HG was allocated to the southern California fishery (south of Point Piedras Blancas, 35°40'00"N lat.), and the remaining 33% (39,481 t) was allocated to the northern California, Oregon, and Washington fisheries. The PFMC took emergency action to reallocate the remaining sardine resource in September after the northern fishery reached its HG in late August and the fishery was closed. The PFMC has planned a formal review of the reallocation process for 2003.

In southern California, Pacific sardine was the dominant CPS finfish until May 2002, when a domoic acid health advisory went into effect. Domoic acid is produced by a species of diatom and works its way up the food chain; it can cause disorientation, central nervous system damage, and death. Many vessels, except those that had orders for bait, stopped fishing. In addition, the expansion of the Australian sardine fishery and a temporary ban on U.S. imports due to concerns over viral hemorrhagic septicemia (VHS) reduced orders from Australian importers for sardines from California. Even so, California landings of Pacific sardine in 2002 totaled 58,296 t, an 11% increase from the previous year (tab. 2). Since 1995, the overall trend for California's sardine landings has been upward (fig 6). The ex-vessel value in 2002 exceeded $5.8 million; a 7% decrease from 2001. Most (71%) of the catch was landed in southern California. Fifty-eight percent (33,661 t) of California's sardine catch was exported in 2002 with most (84%) of the fish going to Australia (50%) and Japan (34%). Although the tons exported increased by only 1%, the export value of sardine, which exceeded 20.5 million dollars, was 13% higher in 2002 than in 2001.

Oregon's Pacific sardine fishery landed 23,126 t in 2002, with an ex-vessel value of more than $2.8 million dollars; and Washington's landings totaled 15,832 t with an ex-vessel value of more than $1.9 million dollars (tab. 2). A significant portion of Oregon and Washington's sardine catch was exported to Japan in 2002. The commercial Pacific sardine fishery in Ensenada, BCM, had landings totaling 43,437 t in 2002; a 49% increase over 2001 (tab. 2).

Pacific Mackerel. Although Pacific mackerel are occasionally landed in Washington and Oregon, the majority of landings are made in southern California and Ensenada, BCM. During 2002, schools of Pacific mackerel were not abundant in southern California and were rare north of Point Conception. In addition, the domoic acid health advisory led to a ban on Pacific mackerel for human consumption during the spring and summer of 2002. California landings of Pacific mackerel in 2002 totaled 3,366 t; down 51% from 2001 and 84% from 2000 (fig. 6). The ex-vessel value of the 2002 catch in California was $486,683. Export data on Pacific mackerel alone were not available; however, a comparison of exports of all mackerel species for the years 2001–2002 showed mackerel products exported from California decreased by 98% in 2002. Ensenada's commercial Pacific mackerel fishery had landings totaling 7,962 t in 2002; a 51% increase from 2001. Oregon's 2002 landings of Pacific mackerel totaled 127 t with an ex-vessel value of $6,453. Figures for Washington's Pacific mackerel landings were not available.

TABLE 2
Commercial Landings (metric tons) of Pacific Sardine by Region and Ex-vessel Value

Region	Landings (metric t)	% change from 2001	Ex-vessel value (US$)	% change from 2001
Canada	703	−56	—	—
Washington[a]	15,832	30	1,936,900	36
Oregon[b]	23,129	45	2,839,110	44
California[b]	58,296	11	5,835,824	−7
Ensenada[c]	43,437	49	—	—

[a] Data from Pacific States Marine Fisheries Commission.
[b] Data from California Fishery Information System.
[c] Data from Nacional de la Pesca, Ensenada, Baja California, Mexico.

The fishing season for Pacific mackerel runs from 1 July through 30 June. The HG for the July 2001–June 2002 season was set at 13,837 t, based on a biomass estimate of 90,418 t. The HG for the July 2002–June 2003 season was set at 12,456 t, based on a biomass estimate of 77,516 t.

Jack Mackerel. Landings of jack mackerel in California totaled 1,006 t, a decrease of 72% from 3,615 t in 2001. Ex-vessel revenues totaled $202,000, a 64% decrease from $560,000 in 2001. There were no reported landings of jack mackerel in Mexican waters in 2002.

Northern Anchovy. Landings of northern anchovy in California decreased substantially in 2002 to 4,643 t, down from 19,187 t in 2001. This represents a 76% decline from 2001 landings and a 60% decline from 2000 landings (11,504 t). Ex-vessel revenues were $550,000 in 2002, a 62% decline from $1.4 million in 2001. There were no reported landings of northern anchovy in Mexican waters in 2002.

Albacore

Commercial albacore (*Thunnus alalunga*) landings decreased in 2002 from the previous year, and recreational catches increased. Commercial landings decreased by 13% (2,596 t) from 2001 (2,968 t), and ex-vessel value decreased 27% ($3.76 million) from 2001($5.14 million). The average price per metric ton paid to fishers for

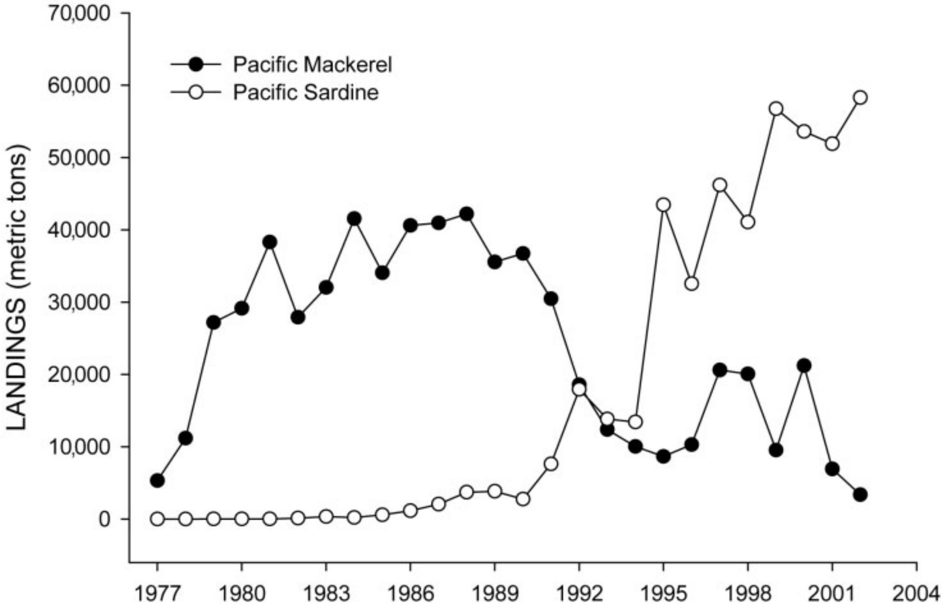

Figure 6. California commercial landings of Pacific sardine (*Sardinops sagax*) and Pacific mackerel (*Scomber japonicus*), 1977–2002.

albacore dropped 16% from $1,580 in 2001 to $1,320 in 2002. The decline in commercial harvest does not necessarily reflect a decline in the albacore population. However, it does reflect a down year for the market value. Commercial landings for albacore have varied dramatically over the last decade, ranging from a high of 5,590 t in 1999 to a low of 818 t in 1995. These landings are still significantly lower than the peak decades of the 1950s and 1960s when commercial landings were routinely over 27,000 t. During the 1950s there were over 3,000 vessels in the commercial fleet; now there are fewer then 500. Also, during those early years the fleet used pole-and-line gear, trolling gear, longlines, purse seines, and drift gillnets. Since the 1980s, trolling operations have dominated the fishery, taking 90% of the annual albacore catch.

Beginning in the 1980s, the albacore fisheries off California have typically operated within 900 miles of the U.S. Pacific coast. California commercial fishers concentrate on the North Pacific albacore stock during the summer and fall as the fish migrate through the northeastern Pacific Ocean. In recent years, during the winter months, some vessels have also targeted the western Pacific albacore stocks off the east coast of New Zealand.

Landing figures for CPFVs for 2002 were impressive. Logbook data indicate a total catch of 312,903 albacore, a 23% increase over the previous record high catch of 254,983 fish in 1999. This is also a 30% increase over 2001, in which CPFVs reported landing 240,181 albacore. In 2002, 151 CPFVs reported 5,351 trips in which at least one albacore was caught. It took a total of 105,693 angler trips to land the 312,903 (catch per unit angler = 2.96) albacore.

In California there are no size or bag limits on albacore, but California CPFVs fishing in Mexican waters must adhere to Mexican regulations. Mexican law permits the take of only 5 albacore per day, and according to CPFV logbooks 60% of the 2002 catch was harvested from Mexican waters. Typically the majority of fish are landed in July and August when the bulk of the stock travels through the range of the southern California CPFV fleet. However, the arrival and departure times associated with albacore migration can vary from early spring arrivals to late winter departures.

The Marine Recreational Fisheries Statistics Survey (MRFSS) only includes fish taken in U.S. waters. Because of this, albacore landings for CPFV and private boat anglers decreased from the previous year. An estimated 99,000 albacore were landed by sport anglers in 2002, whereas the final 2001 estimate was 146,000 fish. The average weight of all albacore sampled by MRFSS field personnel showed a 6% increase (7.39 kg compared to 6.97 kg) from 2001. Using MRFSS average weight and landings data, recreational catches by weight (732 t) accounted for 22% of all landings in California. Using the CPFV logbook data for landings, the CPFV catch by weight (2,312 t) for 2002 amounted to approximately 47% of all albacore landed in California.

In October 2002, PFMC adopted the Highly Migratory Species Fishery Management Plan, which includes albacore as a managed species. According to PFMC's report, the North Pacific albacore stock is healthy

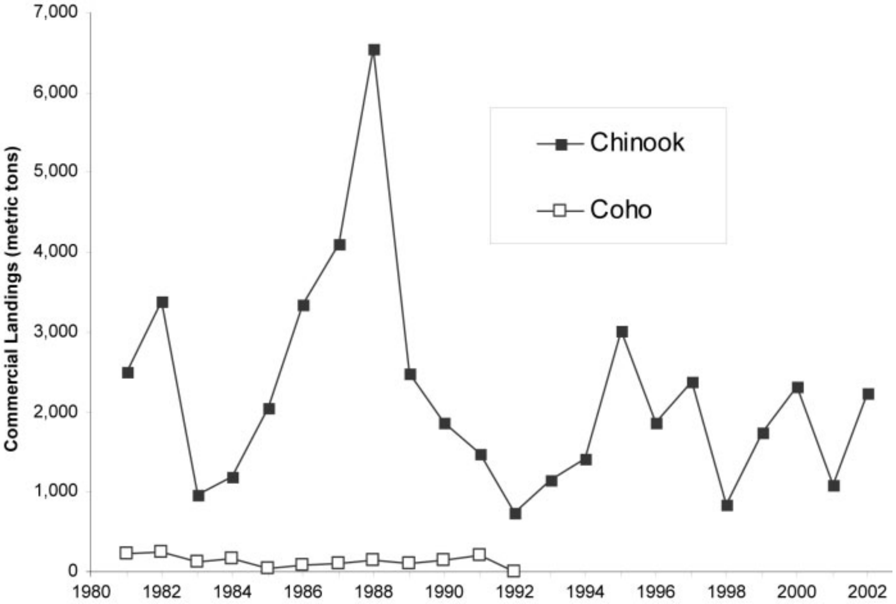

Figure 7. California commercial landings of ocean salmon, 1981–2002.

and not being overfished. Stock size and catches are increasing as the high, productivity oceanic regime, first noted 3 years ago, continues. The maximum sustainable yield for the North Pacific stock has been estimated at 80,000–110,000 t. Total catches are now over 100,000 t and the stock is still increasing. In recent years, West Coast catches have accounted for about 16% of the total North Pacific harvest. The PFMC is not considering implementing limited access or quota management at this time.

Ocean Salmon

In 2002 the commercial troll fishery landed approximately 2,241 t (386,700 fish) of dressed chinook (fig. 7), and fished approximately 17,000 boat days. Ex-vessel prices for dressed salmon averaged $1.55/lb, and the total ex-vessel value of the fishery exceeded $7.6 million.

Statewide recreational landings totaled 179,300 chinook during 206,900 angler days (catch per angler day = 0.87) (fig. 8). Anglers were limited to two salmon per day (all species except coho). South of Horse Mountain (near Cape Mendocino) the minimum size limit was 20 in. total length (TL), through 30 April and 24 in. TL thereafter. Anglers fishing with bait and by any means other than trolling in the area between Point Conception and Horse Mountain were required to use barbless "circle" hooks. In the Klamath management zone (KMZ) the bag limit was two salmon per day with no more than six salmon in 7 consecutive days and a minimum size limit of 20 in. TL. In the California portion of the KMZ, anglers landed 16,100 chinook during 21,500 angler days.

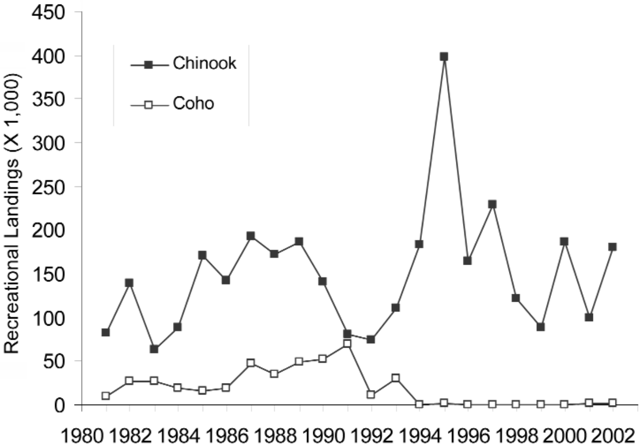

Figure 8. California recreational landings of ocean salmon, 1981–2002.

In 2002, the PFMC enacted commercial and recreational ocean salmon regulations in California to meet the following objectives:

- The NMFS Sacramento River winter chinook (*Oncorhyncus tshawytcha*) 2002 Biological Opinion requirement that the duration and timing of the 2002 commercial and recreational fisheries south of Point Arena not change substantially relative to the 2000 and 2001 seasons.
- The Oregon coast natural (OCN) coho (*Oncorhynchus kisutch*) maximum allowable exploitation rate (marine and freshwater combined) of 15% under Amendment 13. For 2002, the PFMC elected to constrain fishing so that the OCN exploitation rate would not exceed 12.5% in accordance with Oregon Department of

Fish and Wildlife's recommendation to provide additional protection for lower Columbia River natural coho, which are listed as endangered under the Oregon Endangered Species Act.

- Conservation and allocation objectives for Klamath River fall chinook as follows: a spawner escapement to natural areas of 35,000 adults; a minimum adult natural spawner escapement rate of 33–34%; 50% of the allowable adult harvest for federally recognized tribal subsistence and commercial fisheries; 15% of the non-Indian harvest to the Klamath River recreational fishery; 17% of the ocean harvest to the KMZ (Horse Mountain, California, to Humbug Mountain, Oregon) recreational fishery.
- The California coastal chinook jeopardy standard of no greater than a 16% age-4 ocean harvest rate on Klamath River fall chinook.
- The Sacramento River fall chinook escapement goal range of 122,000–180,000 hatchery and natural adults.
- The prohibition of retention of coho in California as required under the NMFS 1999 biological opinion for threatened central California coast coho.

In response, a series of regulations were enacted to achieve these objectives. Harvest impacts on northern California coastal chinook are a primary management concern for commercial ocean fisheries from Pigeon Point, California, to Florence, Oregon, and for recreational fisheries in the KMZ (from Horse Mountain, California, to Humbug Mountain, Oregon). To meet the jeopardy standard on California coastal chinook and achieve the management objectives for Klamath River fall chinook, the adopted regulations were designed to result in: (1) a maximum ocean fishery exploitation rate on age-4 Klamath River fall chinook of 12.9% (for fisheries from 1 September 2001 through 31 August 2002); (2) a Klamath River run target of 132,600 fall chinook adults, resulting in a spawner escapement of 35,000 fish in natural areas and taking into account a projected in-river harvest impact of 70,900 adults and returns to basin hatcheries; (3) 50% (50,400) of the allowable adult harvest for tribal subsistence and commercial fisheries; (4) 40.6% (20,500) of the non-tribal harvest to the Klamath River recreational fishery; and (5) 11% of the ocean harvest to the KMZ recreational fishery. These harvest allocations were expected to result in a 49–51% California-Oregon sharing of Klamath River fall chinook ocean troll harvest. The projected California-Oregon troll shares were the result, in part, of the PFMC decision to constrain fisheries so that the OCN exploitation rate would not exceed 12.5% in 2002 rather than the maximum of 15% allowed under Amendment 13.

OCN constraints prevented full access to the allowable harvest of Klamath River fall chinook under both the FMP and NMFS jeopardy standards, and included a 29-day and 12-day closure in the July recreational fishery in the KMZ and Fort Bragg (Horse Mountain to Point Arena) areas, respectively. Nonetheless, there was for the first time in many years a July (10,000 chinook quota) and August troll fishery in Fort Bragg and an August commercial fishery (3,000 chinook quota) in the California portion of the KMZ (Oregon-California border to Humboldt south jetty). Commercial fishing remained open in both areas during September (California-KMZ 10,000 chinook quota).

For more complete information, see PFMC's Web site, <www.pcouncil.org>, where you will find "Review of the 2002 Ocean Salmon Fisheries," compiled by the Salmon Technical Team and PFMC staff.

Nearshore Live-Fish

Preliminary summaries of 2002 California nearshore commercial finfish landings totaled 352 t. Of that, 257 t were recorded as live landings and 95 t as dead landings of nearshore finfish. Preliminary ex-vessel value of the total landings for year 2002 was $2.7 million, of which $2.3 million was paid for live fish (fig. 9). This represents a slight decrease from 2001 in total nearshore landings and in value.

Management of the Fishery. The nearshore fishery, as defined in the California Code of Regulations (Title 14, Sec. 1.9) concerns a select group of finfish: black rockfish (*Sebastes melanops*), black-and-yellow rockfish (*S. chrysomelas*), blue rockfish (*S. mystinus*), brown rockfish (*S. auriculatus*), cabezon (*Scorpaenichthys marmoratus*), calico rockfish (*Sebastes dallii*), California scorpionfish (*Scorpaena guttata*), California sheephead (*Semicossyphus pulcher*), china rockfish (*Sebastes nebulosus*), copper rockfish (*S. caurinus*), gopher rockfish (*S. carnatus*), grass rockfish (*S. rastrelliger*), kelp greenling (*Hexagrammos decagrammus*), kelp rockfish (*S. atrovirens*), monkeyface prickleback (*Cebidichthys violaceus*), olive rockfish (*S. serranoides*), quillback rockfish (*S. maliger*), rock greenling (*H. lagocephalus*), and treefish (*S. serriceps*). These 19 species represent those most commonly captured in the nearshore live-fish fishery. They are primarily found in association with kelp beds or rocky reefs within 3 mi of shore and in waters less than 20 fathoms. All but three (California sheephead, monkeyface prickleback, and rock greenling) of the 19 species are designated as groundfish species under the PFMC fishery management plan for Pacific coast groundfish. This review focuses on the nearshore finfish species most commonly captured and sold live.

The Nearshore Fishery Management Plan (NFMP), adopted in 2002, is a framework plan that identifies a management strategy for many of the nearshore species targeted by the nearshore live-fish fishery. The five integrated management measures (fishery control rule, re-

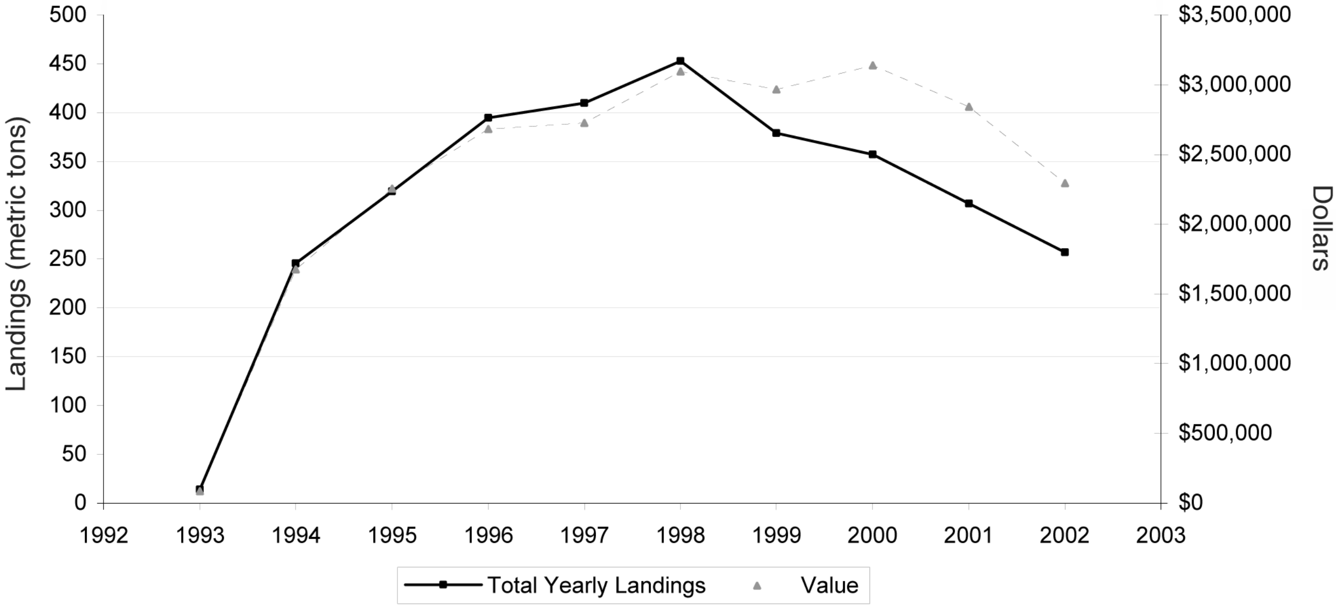

Figure 9. California nearshore live-fish landings and ex-vessel value, 1993–2002.

gional management, resource allocation, marine protected areas, and restricted access) together, over time, will meet the goals and objectives of the Marine Life Management Act and provide for sustainable nearshore stocks and fisheries. The 19 designated nearshore species are territorial, slow-growing, and long-lived, which makes them vulnerable to overfishing even at low exploitation rates.

The nearshore live-fish fishery began in the mid-1980s. Initially, the fishery supplied live fish for the California Asian community. The live-fish market has since expanded and now supplies markets nationally, and in some cases, internationally. The primary gear types used to capture live fish in nearshore waters include various hook-and-line methods and trap gear. Hook-and-line gear includes rod-and-reel, vertical longlines, horizontal longlines, and weighted "stick gear" and is limited to no more than 150 hooks per vessel or 15 hooks per line. Most of the hook-and-line and trap vessels range from 6 m to 12 m in length. The fishery is generally short range, relying on day trips to deliver live fish to market or to dockside holding bins. This small scale also enables operations to quickly redirect effort from reef to reef.

Before market demand for live fish increased, the ex-vessel value (wholesale value) for rockfishes, cabezon, California sheephead, and greenlings was low. An increase in consumer demand for premium, live fish and continued recognition as a specialty product caused the value of live fish to increase dramatically. For example, the average ex-vessel value of cabezon (landed dead) was less than $.50/lb in 1989. In 2002, the average price for live cabezon was $4.02/lb (down 5% from $4.25/lb in 2001). At any time, however, prices vary widely depending on port region, species, size, and marketability of fish. In 2002, prices for live, premium fish ranged from $0.65 to $10.00/lb.

Landing receipts, commonly called market receipts, are the primary CDFG resource for quantifying commercial fishing activity. By law, a fish buyer must complete a landing receipt at the time fish are delivered. Basic information such as weight of the landing, price paid, gear type used, and the condition of the fish (e.g., live) must be provided. Considerable effort is spent reviewing and editing landing receipts to ensure that critical information such as market category and condition code are accurately reported. Condition information of ambiguous landings can often be obtained by examining the ex-vessel price: a substantially higher price often indicates a live landing. The data used for this report are preliminary, and live-fish landing weights provided in this review should be interpreted as low estimates of the actual live-fish landings. Condition (live or dead) of fish being landed was not required on landing receipts prior to 1993 and, therefore, was not used for this review.

Landings information reported by market category provides very little information on the species composition of the catch. Market categories on which this review is based likely contain several different species similar in appearance or market value. For example, the "group gopher" market category often includes gopher, brown, black-and-yellow, grass, kelp, copper, China, and quillback rockfishes. Information on the species composition provided by port sampling was not available for inclusion in this review.

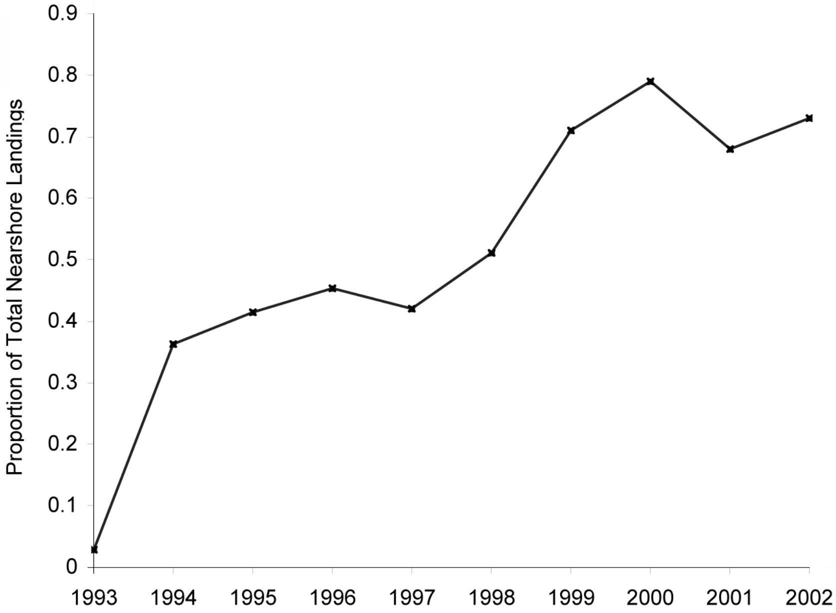

Figure 10. Proportion of fish landed live in the nearshore fishery, 1993–2002.

Regional Landings. As in recent years, California sheephead and California scorpionfish were the primary market categories landed live in southern California. In central and northern California, from Point Conception to Cape Mendocino, the dominant market categories of the live-fish landings were more diversified: gopher and brown rockfish market categories (and the multiple species they contain) were by far the most common rockfish landed live in the two central California regions. In the northern region, the black rockfish market category was predominant, followed by the relatively "clean" cabezon market category. Statewide, 73% of nearshore fish were landed live (fig. 10). This is up slightly from 69% in 2001 and reflects the value of the "live" condition. Prices and dominant landings varied by management region, ports within a region, and season. Below is a regional summary for 2002.

Landings in the North Coast Region (Oregon border to Cape Mendocino; port complexes of Eureka and Fort Bragg) totaled 57 t of dead and 87 t of live nearshore market categories. Total landings in this region (144 t) made up 41% of nearshore fish landings statewide, with a preliminary ex-vessel value of $0.72 million. Approximately 34% of the state's live fish were landed in the North Coast Region for a value of $0.55 million. In this region, live landings were dominated by the black rockfish market category (49 t landed) followed by cabezon (8 t landed). These two market categories accounted for 66% of the North Coast Region's landings of live fish. Hook-and-line gear was used to catch 88% of the live catch in the North-Central Coast Region, and trap gear was used to take approximately 12%.

North-Central Coast Region (Cape Mendocino to Point Año Nuevo; port complexes of Bodega Bay and San Francisco) landings totaled 12 t of dead and 10 t of live nearshore market categories. Total landings in this region (22 t) made up 6% of nearshore fish landings statewide, with an ex-vessel value of $0.18 million. Roughly 4% of the state's live fish were landed in the North-Central Region for a value of $0.10 million. For 2002, live landings were primarily bolina (brown rockfish) market category (4 t landed), followed by gopher market category (ca. 1 t landed). These two market categories accounted for 54% of the North-Central Coast Region's landings of live fish. Hook-and-line gear was used exclusively to catch live fish in this region (finfish traps are prohibited).

South-Central Coast Region (Point Año Nuevo to Point Conception; port complexes of Monterey and Morro Bay) landings totaled 14 t of dead and 86 t of live nearshore market categories. Total landings in this region (100 t) made up 28% of nearshore fish landings statewide with an ex-vessel value of $1.0 million. Approximately 33% of the state's live fish were landed in this region for a value of $0.97 million. In this region, live landings were dominated by gopher and brown rockfish market categories (38 t landed) and were followed by cabezon (27 t). Together, these market categories accounted for 76% of the south central coast region's landings of live fish. Hook-and-line gear was used to catch 76% of the live fish in the south-central coast region. Trap gear took approximately 23% of live fish in this region.

South Coast Region (Point Conception to Mexico border; port complexes of Santa Barbara, Los Angeles, and San Diego) landings totaled 12 t of dead and 75 t of live nearshore market categories. Total landings in this region (87 t) made up 25% of nearshore fish landings statewide with an ex-vessel value of $0.73 million. About 29% of the state's live fish were landed in the South Coast Region for a value of $0.68 million. In 2002, live landings were dominated by California sheephead (47 t) and were followed by California scorpionfish and cabezon (16.5 t). These landings together accounted for 85% of the South Coast Region's landings of live fish. Trap gear was used to catch 57% of the live fish in the South Coast Region, and hook-and-line gear and trawl (California scorpionfish) gears were also used.

Recent Trends in the Fishery. Landings have declined for the fourth straight year from a peak in 1997–98 (947 t landed). The total value of the fishery has also declined, although somewhat disproportionately due to the continued strong demand for live fish (fig. 9). It is anticipated that statewide landings will continue to decline in the upcoming year due to a planned reduction in fishing effort. Concerns over increased pressure on nearshore finfish stocks, primarily from displaced federally managed shelf fishery participants, have been given specific attention from both federal and state managers. Current nearshore interim regulations (implemented in 2000) reflect a reduced "allowable catch" of nearshore species equivalent to 50% of historical annual harvest levels. This precautionary approach provides a "de facto" contingency for such shifts in effort.

In addition to the size limits on certain nearshore species and recently implemented limited entry program, there remains in place a two-month fishery closure and gear restrictions on the fishery, which are used to achieve the catch limitations set under interim regulations and to conform state regulations to PFMC regulations for fishing activity conducted in state waters. CDFG and the California Fish and Game Commission are also developing regional total-allowable-catch limits, recreational and commercial sector allocation parameters, and cumulative trip limits. The initial phase of this work is being directed toward cabezon, kelp, and rock greenlings, and California sheephead. These upcoming management measures are consistent with the Nearshore Fishery Management Plan and the nearshore regulatory implementation process.

Pacific Herring

California's Pacific herring (*Clupea pallasi*) fisheries had mixed success in 2002. Statewide landings for the 2001–2002 sac roe season (December 2001–March 2002) totaled 3,339 t, an increase of 9.5% from the 2000–2001 season's landings of 3,049 t; however, permittees did not meet quotas. The San Francisco gill net fleet, composed of three platoons (401 active permits), landed 2,981 t, 20.4% under the 3,744 t quota. The Tomales Bay fishery (35 permits) landed a total of 321.3 t of the 454 t quota. A total of 6.1 t was landed in Crescent City (six permits) from the 27.2 t quota, and Humboldt Bay landings (two permits) totaled 31.3 t, 42.5% below the 54.4 t quota. Annual sac roe landings, January to December 2002 increased from 2,715 t to 3,290 t, up 21.2% from the previous year.

Catch value in the herring sac roe fishery is based on roe recovery rates. Ex-vessel prices for herring with 10% roe recovery averaged an estimated $500 per short ton for gill net landings with an additional $50 paid for each percentage point above 10%. The ex-vessel price per ton was lower than the previous season, reflecting the continuing volatility of the Japanese economy. Statewide ex-vessel value of the sac roe fishery was an estimated $1.8 million, a 38.7% decline from last season, and was well below the average for the previous 17 seasons (US$8.6 million) For the fifth consecutive season, the San Francisco Bay herring eggs-on-kelp fishery landings were below average. Landings totaled 41.1 t, which was 10.3% less than the 66.4 t quota, but a 66.4% increase from last season's landings of 25.0 t. Total estimated value of the 2001–2002 eggs-on-kelp harvest was $634,000 based on an average ex-vessel price of $7.00/lb. Price paid varies with the product's grade, with grade 1 receiving approximately $10/lb, and grade 5 bringing $3–4/lb.

CDFG conducted research surveys in three bays to estimate spawning biomass of each herring stock. Hydroacoustic and spawn deposition survey estimates were used in San Francisco Bay. Spawn deposition estimates were used exclusively to assess the Tomales Bay and Humboldt Bay populations.

The 2001–2002 herring spawning biomass estimate for the San Francisco Bay population was 32,109 t, a 5.1% decline from the previous season. Although there was a return of favorable oceanic conditions, and herring returning to the bay were in good physical condition, an apparent displacement or loss of older-year-class fish, namely 5-year-olds and older, continued this season. The Tomales Bay herring spawning biomass continued to demonstrate a tendency to fluctuate widely. The 2001–2002 spawning biomass estimate was 6,570 t, which represents an increase of 72.6% from the previous season's estimate (3,807 t). This season's biomass is the highest since the 10,014 t El Niño season of 1982–83. In Humboldt Bay, CDFG conducted spawning ground surveys and monitoring of the herring gill net fishery for the second consecutive season. An estimate of 560 t of herring spawned in south and north Humboldt Bay. No surveys were conducted in Crescent City Harbor.

A mild to moderate El Niño is forecasted for 2002–2003. Its impact is not expected to be on the same scale as the 1997–98 El Niño, yet it is uncertain how

TABLE 3
Southern California CPFV Landings in 2002, 2001, and 2000

	2002 landings				2001 landings		2000 landings	
Species/Species Group	No. of fish	Rank	% change from 2001	% change from 2000	No. of fish	Rank	No. of fish	Rank
Barred sand bass	629,722	1	+5	−15	598,083	1	737,944	1
Albacore tuna	291,681	2	+35	+156	215,516	5	113,971	7
Rockfishes, unspecified	287,799	3	−18	−12	350,596	2	326,918	2
Kelp bass	234,675	4	−23	−15	304,169	3	277,191	3
California barracuda	208,865	5	−22	−19	266,634	4	256,887	4
Sanddab*	122,217	6	+239	+2,291	36,013	13	5,111	21
Ocean whitefish	100,164	7	−27	−30	138,052	7	144,055	6
California scorpionfish	88,343	8	−46	−48	162,302	6	169,417	5
Halfmoon	80,514	9	−17	+149	97,363	9	32,399	14
Yellowtail	69,904	10	−12	−34	79,556	11	105,896	9
Pacific mackerel	69,276	11	−36	−38	108,408	8	111,627	8
Bluefin tuna	32,558	12	+54	+57	21,083	15	20,696	15
California sheephead	27,361	13	−30	−16	39,163	12	32,684	13
Bocaccio rockfish*	21,725	14	+252	+662	6,176	21	2,853	24
Yellowfin tuna	18,572	15	−40	−79	31,118	14	88,302	11
Lingcod	12,939	16	+491	+938	2,189	28	1,246	26
Blue rockfish*	8,598	17	+400	—	1,721	30	0	—
White seabass	8,571	18	−14	−51	9,996	17	17,470	16
Copper rockfish*	7,802	19	+118	—	3,583	25	0	—
Pacific bonito	7,525	20	−56	−83	17,121	16	44,610	12
Blacksmith	7,019	21	+254	+693	1,985	29	885	28
California halibut	5,259	22	−36	−50	8,219	19	10,471	18
Surfperch, unspecified	4,266	23	+32	+339	3,235	26	971	27
Gopher rockfish*	3,349	24	+43	—	2,343	27	0	—
Wahoo	3,012	25	−19	−35	3,730	24	4,647	22
Dolphinfish (dolphin)	2,700	26	−32	−84	3,963	23	16,469	17
Skipjack tuna	2,681	27	−69	−12	8,738	18	3,030	23
Canary rockfish*	2,512	28	+61	—	1,559	31	0	—
Opaleye	2,371	29	+142	+1594	980	33	140	35
Flatfishes, unspecified	2,278	30	−98	−98	96,210	10	95,896	10
Fishes, unspecified	9,137		+2	−49	8,999		17,790	
Sharks, unspecified	1,470		+74	+98	847		743	
Jumbo squid	195,406		—	+2,351	0		7,972	
Total no. kept	2,570,271		−2	−3	2,629,650		2,648,291	
No. of anglers	540,063		−3	−7	558,550		581,972	
Reporting CPFVs	204		−1	0	205		206	

*Fields added on new logbook form in July 2001.

it may influence herring fisheries for the season. The December 2002 fishery in San Francisco Bay opened to a slow start with limited fishing activity through mid-month.

The herring roe product, “kazunoko,” remains an integral part of traditional Japanese New Year’s festivities. However, changes in the Japanese culture and economy have also resulted in changes to the sac roe market. Demand for kazunoko is expected to wane by industry observers as younger Japanese become more westernized. Ex-vessel prices are expected to decline with concern for the Japanese economy, and, as a result, herring buyers have been proceeding cautiously and offering similar prices in the 2001–2002 season.

Recreational Fishery

Southern California. Hook-and-line saltwater recreational fishing is conducted from private vessels, piers, shorelines, and CPFVs in southern California. Specific information about these recreational fisheries is collected through phone surveys and field sampling under the MRFSS survey by the Pacific States Marine Fisheries Commission. In addition, CDFG collects and maintains a database derived from mandatory logbook information supplied by CPFVs. Much of our knowledge of CPFV recreational fishing in southern California is based on these logbook data. Landings by CPFVs represent approximately 21% of the total landings by recreational fishers.

Traditionally, the taxa targeted south of Point Conception by CPFVs in southern California and Baja California waters include California barracuda (*Sphyraena argentea*), serranids or sea basses (*Paralabrax clathratus*, *P. nebulifer*), scorpaenids or scorpionfishes (*Scorpaena guttata*, *Sebastes* spp.), scombrids or mackerels (*Scomber japonicus*), tunas (*Katsuwonus pelamis*, *Sarda chiliensis*, *Thunnus alalunga*, *T. albacares*), wahoo (*Acanthocybium solanderi*), California halibut (*Paralichthys californicus*), ocean whitefish (*Caulolatilus princeps*), white seabass (*Atractoscion nobilis*), yellowtail (*Seriola lalandi*), halfmoon (*Medialuna californiensis*), and California sheephead (*Semicossyphus pulcher*). The taxa being targeted can vary with season and also by year. Occasionally, El Niño conditions greatly increase the availability in southern California waters of species normally found off Mexico. Conversely, La Niña conditions increase the number of colder-water species. CPFVs are typically quick to exploit the fishing opportunities provided by these changing oceanographic conditions.

The top-ten species or species groups in 2002 in southern California (by number of fishes in landings) were barred sand bass, albacore tuna, rockfishes (unspecified), kelp bass, California barracuda, sanddab (*Citharichthys* spp.), ocean whitefish, California scorpionfish, halfmoon, and yellowtail (tab. 3). These species or species groups include eight of the top ten groups from 2001 and 2000. One of the exceptions for both 2001 and 2000 was flatfishes (unspecified). In those years, this category was in the top ten, but in 2002 it dropped to rank 30. This can be explained by the new revised logbooks distributed to CPFV operators in July 2001. By early 2002, most CPFV operators were using the new logbooks. The revised logbooks contained several new fields not in the older version. The new fields included several specific rockfish species: blue (*Sebastes mystinus*), bocaccio (*S. paucispinis*), canary (*S. pinniger*), copper (*S. caurinus*), cowcod (*S. levis*), gopher (*S. carnatus*), and yelloweye (*S. ruberrimus*), and sanddab. Previously, all rockfish species were grouped into the category "rockfishes (unspecified)" and most sanddabs were in the category "other flatfishes." Several fields were removed in the new version, including blue shark, mako shark, jack mackerel, wahoo, and "other flatfishes." All sharks caught are now individually written in the blank fields on the logbook. These are all accounted for in the field "sharks (unspecified)" (tab. 3). CPFV operators also have the option to write in specific species not pre-printed on the logbook form.

Other changes in the top-ten species included Pacific mackerel, which dropped from eighth in 2001 and 2000 to eleventh in 2002. Yellowtail jumped from eleventh in 2001 to tenth in 2002, and halfmoon from fourteenth in 2000 to ninth in 2002. The order of abundance also changed for nine of the top-ten species or species groups each year, except for barred sand bass, which remained number one for all 3 years (tab. 3).

In 2002, 540,063 anglers aboard 204 reporting CPFVs landed 2,570,271 fishes south of Point Conception (tab. 3). These southern California landings represent 81% of the total landings by CPFVs statewide (3,166,234 fishes). The number of fishes landed statewide in 2002 was 6.5% higher than in 2001 (2,974,239 fishes) and 2% lower than in 2000 (3,232,852 fishes). Landings in 2002 in southern California decreased by 2% compared to 2001 and by 3% compared to 2000. The number of anglers using southern California CPFVs dropped by 3% and 7%, respectively, compared to 2001 and 2000. The southern California anglers represented 79% of the anglers using CPFVs statewide.

Decreased landings were reported in 2002 for flatfishes (unspecified) and rockfishes (unspecified), but these can be explained by the new logbook categories. Many of these fishes are now accounted for by individual species fields. Other landings that deceased in 2002 compared to 2001 and 2000 were skipjack tuna, Pacific bonito, California scorpionfish, yellowfin tuna, Pacific mackerel, California halibut, dolphinfish (*Coryphaena hippurus*), California sheephead, ocean whitefish, kelp bass, California barracuda, wahoo, yellowtail, white seabass, and halfmoon (2001 only) (tab. 3). Decreases in some of the more southerly species or species groups (e.g., skipjack tuna, yellowfin tuna, dolphinfish) can be primarily attributed to decreased availability. Cooler oceanic waters moved onshore along the California coast in late 2002, shifting the summer distribution of some of these species southward. Decreased landings of Pacific mackerel and Pacific bonito may have been related to decreased availability, but reduced biomass may also have been a factor.

In response to the decreased availability of southerly species in 2002, the southern California CPFVs shifted their efforts to other species or species groups, including albacore tuna, bluefin tuna, and a number of nearshore species (tab. 3). Albacore landings increased by 35% and 156% compared to 2001 and 2000, respectively, and bluefin landings increased by 54% and 57%, respectively. Increased landings were also reported for a number of nearshore species, including opaleye (*Girella nigricans*), surfperch (unspecified), blacksmith (*Chromis punctipinnis*), and lingcod.

The number of reported jumbo squid (*Dosidicus gigas*) landings in 2002 by CPFVs operating in the Los Angeles area and south increased greatly from the previous 2 years but was similar to 1999 landings (104,549). The 2002 landings jumped to 195,406 from zero in 2001 and 7,972 in 2000. This is in contrast to the central and northern California area, where the reported numbers of jumbo squid remained zero or low all 3 years (tabs. 3, 4). An El Niño was predicted for 2002, but it was weak and dissipated early. Jumbo squid are often seen during El Niño conditions, so there may have been an influx of warm water from the south to bring the jumbo squid into southern California waters. Mass strandings of jumbo squid were seen in La Jolla in July. Tissue samples were taken for analysis to determine if domoic acid poisoning was responsible for the strandings. A large bloom of

TABLE 4
Central and Northern California CPFV Landings in 2002, 2001, and 2000

	2002 landings				2001 landings		2000 landings	
Species/Species Group	No. of fish	Rank	% change from 2001	% change from 2000	No. of fish	Rank	No. of fish	Rank
Rockfishes, unspecified	208,967	1	−23	−54	271,159	1	457,833	1
Blue rockfish*	130,192	2	+85	+685,121	70,203	2	19	—
Chinook salmon	74,625	3	+73	−3	43,221	3	76,744	2
Gopher rockfish*	36,291	4	+10	+1,209,600	32,931	4	3	—
Flatfishes, unspecified	27,982	5	+1,618	+641	1,629	15	3,776	7
Lingcod	24,449	6	+165	+159	9,242	8	9,441	5
Albacore tuna	21,238	7	−14	+59	24,665	5	13,382	4
California halibut	10,148	8	−19	+88	12,525	6	5,394	6
Striped bass	6,611	9	−39	−64	10,889	7	18,501	3
Brown rockfish	6,602	10	+132	—	2,841	14	0	—
Copper rockfish*	6,498	11	−14	+4,413	7,587	10	144	19
Bocaccio rockfish*	4,478	12	−41	+152	7,630	9	1,779	9
Canary rockfish*	2,577	13	−60	+36	6,443	11	1,900	8
Sanddab	2,489	14	+6,627	+398	37	34	500	14
Vermilion rockfish	1,782	15	+268	+2,375	484	20	72	21
Cabezon	1,180	16	−75	−32	4,673	12	1,730	10
Kelp greenling*	886	17	−72	+132	3,137	13	382	17
Olive rockfish	853	18	+940	—	82	29	0	—
Sablefish	479	19	+464	+296	85	27	121	20
White croaker	477	20	+151	−3	190	24	493	15
Fishes, unspecified	875		−23	−72	1,130		3,128	
Sharks, unspecified	283		−31	−60	412		710	
Dungeness crab*	25,335		+12	+29	22,566		19,608	
Jumbo squid	666		—	+11	0		600	
Total no. kept	595,963		+12	−3	533,761		616,260	
No. of anglers	141,302		+3	−7	136,674		152,547	
Reporting CPFVs	109		0	−1	109		110	

*Fields added on new logbook form in February 2001.

the domoic acid-producing diatoms occurred in the spring off central and southern California.

Central and Northern California. North of Point Conception, CPFV anglers traditionally target rockfishes (*Sebastes* spp.); salmon (*Oncorhynchus* spp.); lingcod (*Ophiodon elongatus*); and, opportunistically, albacore tuna (*Thunnus alahunga*). Cabezon (*Scorpaenichthys marmoratus*) and other nearshore species are also taken. California halibut (*Paralichthys californicus*), striped bass (*Morone saxatilus*), sturgeon (*Acipenser* spp.), and leopard shark (*Triakis semifasciata*) are primarily taken from within San Francisco Bay. In addition, more southerly species such as bluefin tuna (*Thunnus thynnus*), white seabass (*Atractoscion nobilis*), skipjack tuna (*Katsuwonus pelamis*), and yellowtail (*Seriola lalandi*) may be targeted in warm-water years.

The top-ten species or species groups taken in 2002 by central and northern California CPFVs (by number of fishes in landings) were rockfishes (unspecified), blue rockfish (*Sebastes mystinus*), chinook (king) salmon (*Oncorhynchus tshawytscha*), gopher rockfish (*Sebastes carnatus*), flatfishes (unspecified), lingcod, albacore tuna, California halibut, striped bass, and brown rockfish (*Sebastes auriculatus*) (tab. 4). These top-ten species included eight of the top ten in 2001 and seven of the top ten in 2000. New revised logbooks were distributed to CPFV operators in February 2001, which explains the absence of the blue and gopher rockfishes in the top-ten species for 2000. Quantities of bocaccio and canary rockfish landings in 2002 decreased from 2001, despite the introduction of the new logbook form. This is likely due to new fishing regulations put in place in 2001 and 2002 limiting the number of certain rockfish species that could be caught. In contrast, the number of brown, vermillion, and olive rockfish reported landed in 2002 increased from previous years, possibly due to the limits on other species of rockfish and subsequent redirected efforts.

By early 2002, most CPFV operators were using the new logbooks. The revised logbooks contained several new fields not in the older version. The new fields included several specific rockfish species—blue (*Sebastes mystinus*), bocaccio (*S. paucispinis*), canary (*S. pinniger*), copper (*S. caurinus*), cowcod (*S. levis*), gopher (*S. carnatus*), and yelloweye (*S. ruberrimus*)—kelp greenling (*Hexagrammos decagrammus*), and Dungeness crab (*Cancer magister*). Unlike the new southern California logbook form, a separate field for sanddabs was not added on the new central and northern California logbook form, but some CPFV operators provided an account of the sanddabs they landed. There has always been the option for operators to write in specific fish species, so some of these species have occurred in the logbooks in small quantities in previous years. Fields were removed for California barracuda and "other sharks."

Rockfishes (unspecified) was ranked the number one species group for 2002, 2001, and 2000. The top four ranks in 2002 and 2001 were the same, but all other ranks were shuffled between the years (tab. 4). The number of reported flatfishes (unspecified) was extremely high in 2002 compared to earlier years, possibly due to less fishing opportunities for shelf rockfish and more CPFV trips targeting sanddabs.

In 2002, 141,302 anglers aboard 109 reporting CPFVs caught 595,963 fish north of Point Conception, a 12% increase from 2001 and a 3% decrease from 2000 (tab. 4). The increase in the landings between 2002 and 2001 may in part be due to the increased quantities of flatfishes (unspecified), salmon, sanddab, lingcod, and brown rockfish landed. Total landings for 2002 and 2000 are similar. The central and northern California landings accounted for 19% of the state's total landings (3,166,234 fishes). The number of anglers using central and northern California CPFVs increased by 3% compared to 2001 but decreased by 7% from 2000. Central and northern California anglers represented 21% of the anglers using CPFVs statewide. Decreases in 2002 were seen in California halibut, albacore tuna, striped bass, and kelp greenling compared to 2001 (tab. 4). In addition, fewer than 50 individuals of ocean whitefish, California barracuda, white seabass, and yellowtail and no Pacific bonito, skipjack tuna, or dolphinfish were landed in central and northern California ports in 2002. Lower landings of species such as Pacific mackerel, jack mackerel, and Pacific bonito may be due to a decrease in availability as well as a reduction in biomass.

Albacore tuna landings decreased by 14% to 21,238 in 2002 compared to 24,665 in 2001, but increased by 59% from 13,382 in 2000. Increased landings were also reported for flatfishes (unspecified), sanddab, lingcod, Chinook salmon (2001 only), white croaker (2001 only), sablefish, and various rockfish species (blue, brown, gopher, olive, and vermillion) (tab. 4). Landings of Dungeness crab increased 12% between 2002 and 2001 and 29% between 2002 and 2000. No jumbo squid (*Dosidicus gigas*) were caught by CPFV anglers in this region in 2001, and very low numbers were reported in 2002 and 2000 compared to the large numbers reported in southern California for 2002.

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P. Collier, Dungeness crab
S. Crooke, albacore tuna
W. Dunlap and D. Aseltine-Neilson, recreational
A. Grover, ocean salmon
J. Kashiwada, sea urchin
L. Laughlin, spot and ridgeback prawn
K. O'Reilly, coastal pelagic finfish
K. Oda, herring
D. Osorio and R. Leos, nearshore live-fish
T. Tanaka, market squid

THE STATE OF THE CALIFORNIA CURRENT, 2002–2003: TROPICAL AND SUBARCTIC INFLUENCES VIE FOR DOMINANCE

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ABSTRACT

This report summarizes conditions in the California Current system between February 2002 and spring 2003 from Oregon coastal waters nearly to Cape Lazaro in Baja California. A moderate El Niño peaked early in 2003 and began to decline. In the northern portion of the region the effects of El Niño were overshadowed by a large anomalous intrusion of subarctic water that was evident from British Columbia to the U.S.-Mexico border. First described off Oregon in July 2002, the anomalous mass was still evident off Oregon and Southern California in April 2003. At the time of this writing (July 2003) there is some evidence for La Niña conditions developing in the tropical Pacific.

INTRODUCTION

This segment of *CalCOFI Reports* was initiated in 1994 to provide preliminary summaries of the major observations from the past year's CalCOFI surveys. It has since expanded to include IMECOCAL to the south, observations by numerous groups in central California, and the GLOBEC LTOP (U.S. Global Ocean Ecosystem Dynamics Long-Term Observation Program) off Oregon. Topics have expanded from hydrography, chlorophyll, and macrozooplankton biomass to include near-surface fish eggs and avifauna. We continue this tradition of enhanced coverage. We hope that this foreshadows a more formal alliance between pelagic survey programs along the West Coast of North America that would form the basis for expanded observation of the entire California Current system. The concept of a West Coast alliance, first proposed by John Hunter at the 2001 CalCOFI Conference, has continued to be developed by Hunter and others (Schwing et al. 2002a). For further information, see the Web site for the proposed alliance (currently known as Pacific Coastal Observing System, PaCOS, formerly as ACCEO): http://swfsc.nmfs.noaa.gov/FRD/acceo/acceo1.htm.

Justification for this alliance was clearly demonstrated during the summer of 2002 when an anomalously strong intrusion of subarctic waters was observed off Oregon. It was quickly confirmed off Vancouver Island, and was evident off southern California. A flurry of e-mails between West Coast oceanographers (see Appendix) was proof that oceanography can still be exciting. This feature is discussed in the sections that follow and is the subject of several recent publications, cited in relevant sections below.

The present State of the California Current report covers primarily the period between April 2002 and

February–March 2003. Some data from April 2003 cruises are included. The moderate El Niño predicted last year developed and faded again. Late fall and winter of 2002–2003 was the only warm period in four consecutive cool years, and there is evidence for a return to cooler conditions in the near future. Evidence for a large-scale climate change in 1998–99, a reversal of that observed in the mid-1970s, is still being evaluated.

DATA SETS AND METHODS

Large-scale anomalies for the North Pacific Ocean are summarized from the National Center for Environmental Prediction reanalysis fields (Kistler et al. 2001) from the NOAA-CIRES Climate Diagnostics Center, http://www.cdc.noaa.gov. The reanalysis fields are monthly gridded (approximately 2° × 2°) anomalies of sea-surface temperature (SST) and surface winds. The base period is 1968–96. Ocean temperature anomalies at 100 m depth were computed from the Global Temperature-Salinity Profile Program database, monthly averaged on a 1° spatial grid. Anomalies were computed by subtracting the 1° monthly climatologies (base period 1945–96) of the World Ocean database 1998 (Levitus et al. 1998) from the gridded observations and were averaged into 5° × 5° boxes.

Monthly upwelling indexes and their anomalies for the west coast of North America (21°−52°N) are calculated relative to 1948–67. The daily alongshore wind component and SST are from the NOAA National Data Buoy Center (NDBC). Values from six representative buoys from the California Current system are plotted against the harmonic mean of each buoy.

The northern portion of the California Current system has been sampled seasonally by the Northeast Pacific Long-term Observation Program (LTOP) of the U.S. GLOBEC program since 1997. Observations are made five times a year along the Newport Hydrographic (NH) line at 44.65°N, and three times a year along a set of four or five zonal sections between 42°N and 45°N. Cruise reports and data from this program are available on the LTOP Web site, http://ltop.oce.orst.edu/~ctd/index.html. The NH line was previously occupied regularly from 1961 to 1971, and long-term seasonal averages have been calculated from these historical data (Smith et al. 2001).

The CalCOFI program and the Investigaciones Mexicanas de la Corriente de California program (IMECOCAL) conduct closely coordinated, quarterly surveys off Southern California (fig. 1) and Baja California (fig. 2), respectively. Cruises covered in this report include April, July, and October–November 2002 and January–February 2003. Partial results for April 2003 are also included. Measurements by both programs include conductivity-temperature-depth (CTD) casts to 500 m (CalCOFI) or 1,000 m (IMECOCAL), depth permitting. Water samples are routinely collected to determine dissolved oxygen, nutrients, and chlorophyll. Standard (.505 mm mesh) oblique bongo tows are conducted to 210 m depth. Continuous underway measurements of near-surface temperature, salinity, fluorescence, and acoustic Doppler current profilers (ADCP) are made. Additional samples and sampling methods are discussed

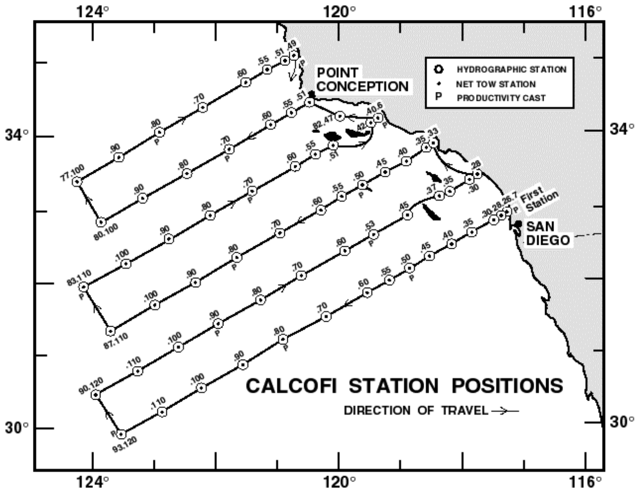

Figure 1. Standard CalCOFI cruise pattern.

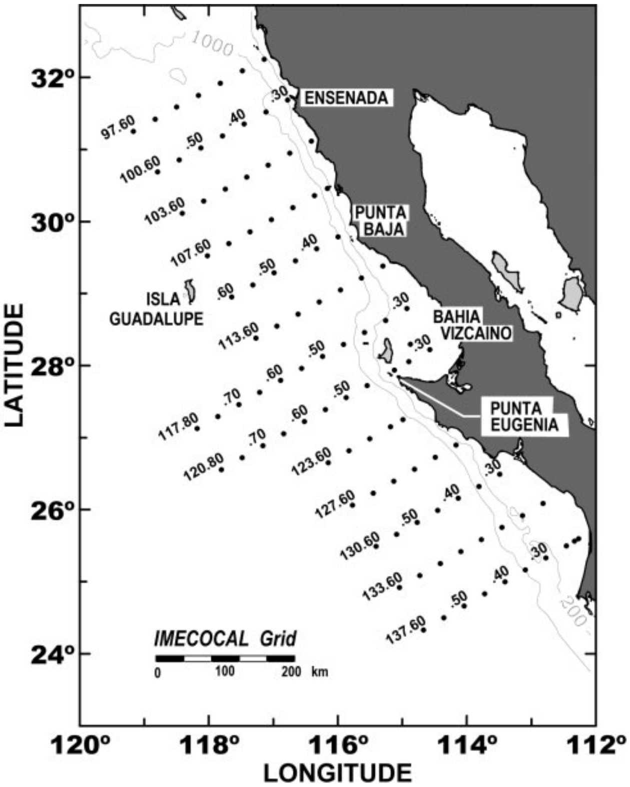

Figure 2. Standard IMECOCAL cruise pattern and station locations (*solid dots*). Line 97 is sampled during the spring cruise only. The 200 m and 1,000 m depth contours are shown.

in data reports and on Web sites (e.g., http://www-mlrg.ucsd.edu/calcofi.html and http://imecocal.cicese.mx).

CalCOFI cruises 0204, 0302, and 0304 were extended north of the usual pattern. The following discussion only includes observations from the standard CalCOFI grid. Data from cruises 0302 and 0304 are preliminary.

In October 2002 IMECOCAL performed CTD casts to 400 m only because of limited hydrographic cable. During April 2002 the IMECOCAL grid was extended to sample stations along line 97.

A continuous underway fish egg sampler (CUFES; Checkley et al. 1997) collects eggs near the surface on the winter and spring CalCOFI cruises and on all IMECOCAL cruises. When the Real-time Flow Imagining and Classification System (REFLICS; Iwamoto et al. 2001) is fully developed, it will image objects collected by CUFES and classify them as sardine eggs, copepods, bubbles, and so on.

Systematic surveys of the distribution and abundance of pelagic birds have been made on CalCOFI cruises since 1987. Personnel from the Point Reyes Bird Observatory (PRBO) Marine Science Program have assessed the reproductive performance of seabird populations at the Farallon Islands since the early 1970s.

BASINWIDE PATTERNS

The Multivariate El Niño/Southern Oscillation (ENSO) Index (MEI; Wolter and Timlin 1998) assesses the relative magnitude of El Niño and La Niña events based on six tropical Pacific variables. Following several years of negative MEI values, representing weak-to-moderate La Niña conditions in the tropics, the MEI became positive in spring 2002 and peaked in December 2002–January 2003 (fig. 3). This was the first El Niño since the large 1997–98 event, and it was considerably weaker. The 2002–2003 El Niño was comparable in intensity and duration to the 1965–66 event and produced an MEI value similar to the events of 1963–64, 1977–78, 1979–80, and 1994–95, that is, a moderately strong event. However, it did not evolve, or dissipate, like the canonical El Niño. Strong thermal anomalies did not fully develop on the South American coast, and the rapid decline in early 2003 contrasts to most strong El Niños, which often strengthen from winter to spring.

The Northern Oscillation Index (NOI; Schwing et al. 2002c) is an ENSO-related index that reflects the intensity of interannual climate events in the northeast Pacific. After four consecutive years of positive values (indicating La Niña-like conditions), the NOI reversed its sign in summer 2002 (fig. 3). It has remained positive through April 2003 but, like the MEI, is poised to change its sign again in summer 2003 as a La Niña develops. The Pacific Decadal Oscillation (PDO; Mantua et al. 1997) reflects multidecadal climate variability in the northeast Pacific, with positive (negative) values indicating warm (cool) SST anomalies in the California Current system. As with the other indexes, the PDO switched sign in mid-2002, reflecting a reversal to warm upper-ocean thermal anomalies in the California Current system from the pattern of cool anomalies that had persisted for several years (fig. 3). As with the MEI and NOI, the PDO appears to have reached its peak in early 2003 and may again reverse sign later this year.

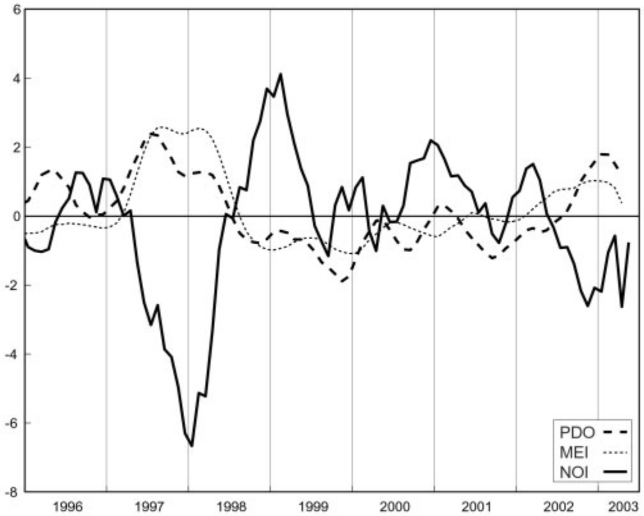

Figure 3. Monthly time series of the Pacific Decadal Oscillation (PDO), Multivariate ENSO Index (MEI), and Northern Oscillation index (NOI) for January 1996 through April (May) 2003 for PDO and MEI (NOI). Series have been smoothed with a 5-month running mean, except the last two months, which are raw values.

An unusually strong Aleutian Low in summer 2002 resulted in a large cyclonic wind anomaly over most of the northeast Pacific (fig. 4a). This pattern persisted through early 2003 (figs. 4b,c), contributing to weakened upwelling or downwelling conditions in the northern California Current system. The strongest cyclonic wind anomalies (January 2003; fig. 4c) occurred near the peak of the El Niño development, a pattern commonly observed when El Niño conditions are predominant in the equatorial Pacific (Schwing et al. 2002b). By April 2003, the cyclonic wind anomalies had broken down, replaced by a relatively stronger North Pacific High and anomalously high equatorward winds in the California Current system region (fig. 4d).

The patterns of SST anomaly represent a direct ocean response to anomalies of the prevailing wind stress. Although positive temperature anomalies had developed in the tropics by summer 2002, and peaked in fall-winter at ~1.0−1. 5°C, the eastern North Pacific remained cool at this time (fig. 4a), continuing a pattern that had been seen since the 1998 La Niña. In the central North Pacific, however, positive temperature anomalies had developed by summer 2002; these spread throughout the northeast

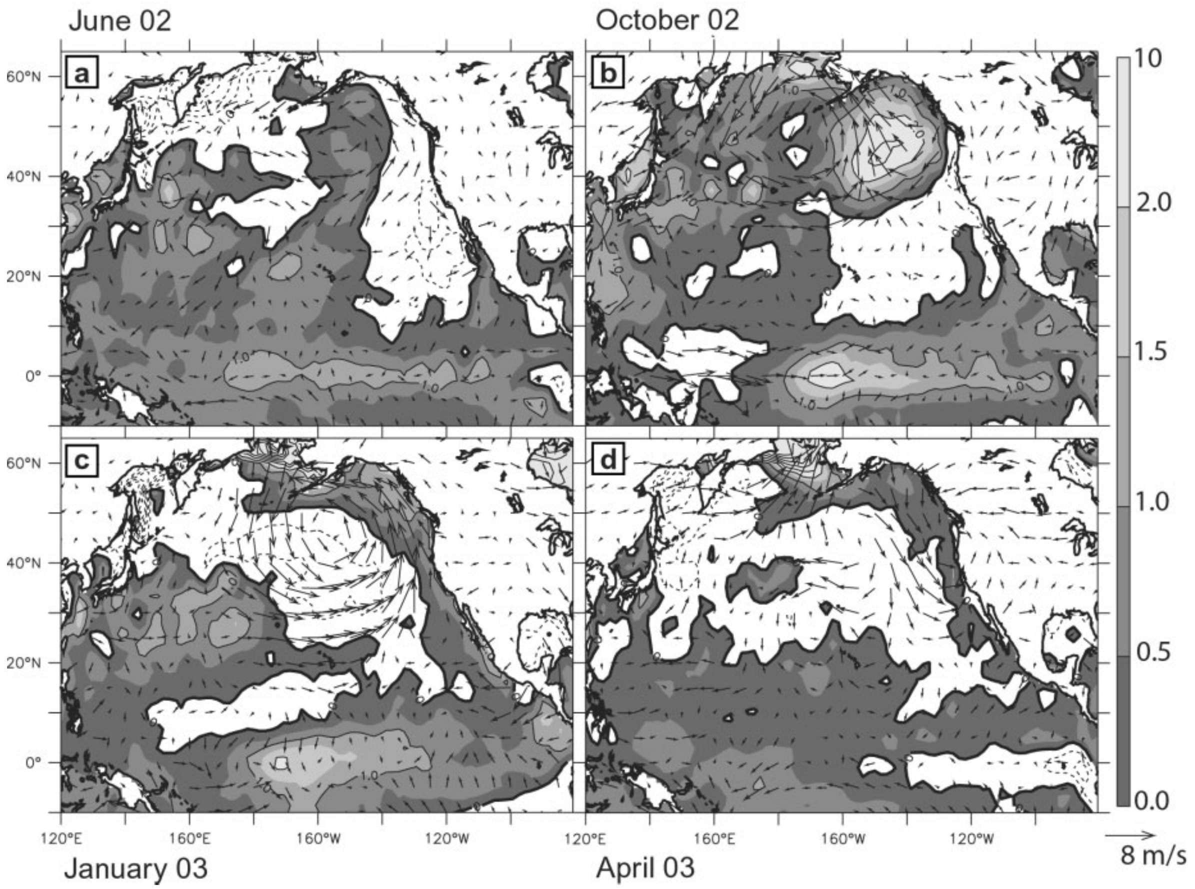

Figure 4. Anomalies of surface wind velocity and SST in the North Pacific Ocean for (*a*) June 2002, (*b*) October 2002, (*c*) January 2003, and (*d*) April 2003. Arrows denote magnitude and direction of wind anomaly. Contours denote SST anomaly. Contour interval is 1.0°C. Positive (warm) SST anomalies are shaded. Wind climatology period is 1968–96. SST climatology period is 1950-79. Monthly data obtained from the NOAA-CIRES Climate Diagnostics Center.

Pacific by October 2002 (fig. 4b). Strong positive temperature anomalies were seen all along the California Current system and into the northern Gulf of Alaska as the El Niño peaked in early winter 2002–2003, when anomalous downwelling-favorable winds covered much of the California Current system (fig. 4c). As in past El Niños, warm waters in the eastern North Pacific were primarily related to the local cyclonic wind stress anomalies (Schwing et al. 2002b).

The breakdown of the weak-to-moderate 2002–2003 El Niño was fairly rapid and somewhat unusual. Even as the western tropical Pacific remained anomalously warm, the eastern equatorial Pacific began to cool in early spring (figs. 4c,d). By April 2003, cool anomalies appeared to be spreading from east to west along the equator, and the thermocline had shoaled (not shown), signaling the end of the El Niño and possibly the initiation of yet another La Niña. If the La Niña develops through summer 2003, as it is predicted to do, this would be the fifth year of the past six with cool anomalies in the eastern tropical Pacific.

The large-scale wind stress anomalies in the Northeast Pacific during winter 2001–2002 (Schwing et al. 2002) set the conditions for the unusual water property and productivity observations made throughout the California Current system in summer 2002 (Murphree et al. 2003). Anomalously strong southward Ekman transport of subarctic waters into the North Pacific Current (NPC), as well as strong eastward flow of the NPC toward the North American coast, provided the source of subarctic waters into the California Current system. Additionally, unusually strong coastal upwelling in spring 2002 (fig. 5) and enhanced equatorward transport helped spread the anomalous waters throughout the California Current system during 2002.

COASTWIDE CONDITIONS

Monthly coastal upwelling indexes (Bakun 1973; Schwing et al. 1996) indicated stronger-than-normal upwelling through most of the California Current system in spring-summer of 2001 and 2002 (fig. 5), continuing the pattern of strong upwelling and cool SSTs

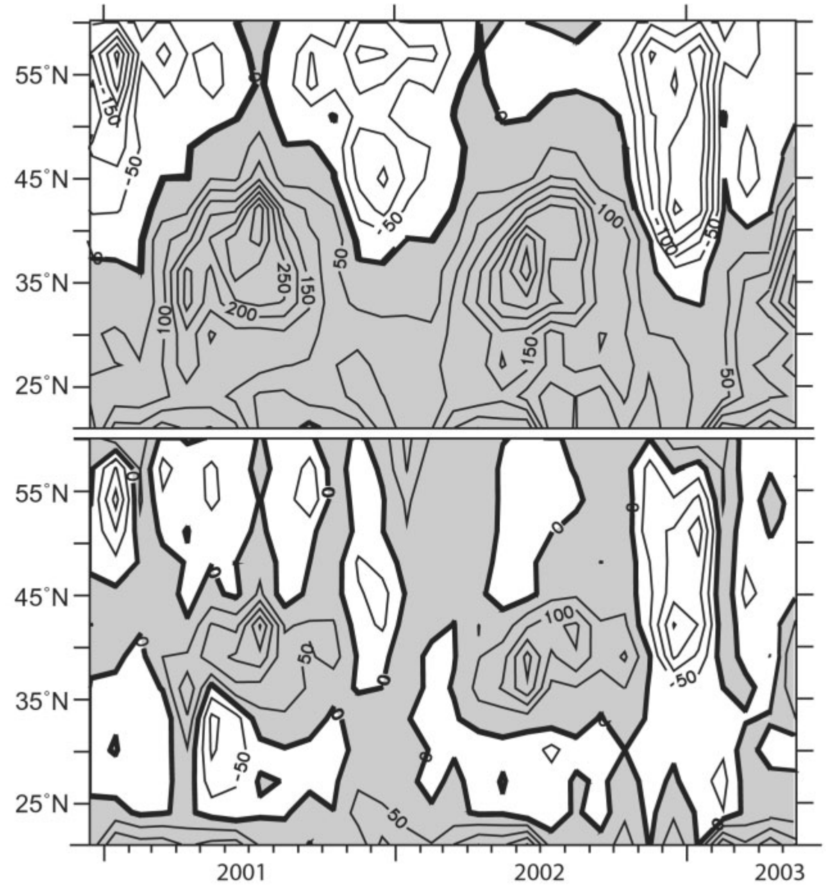

Figure 5. Monthly upwelling index and upwelling index anomaly for January 2001–May 2003. Shaded areas denote positive (upwelling) values in upper panel, and positive anomalies (greater-than-normal upwelling) in lower panel. Anomalies are relative to 1948–67 monthly means. Units are in m^3/s per 100 km of coastline.

since the onset of the 1998 La Niña (Hayward et al. 1999; Bograd et al. 2000; Durazo et al. 2001; Schwing et al. 2002a). Strongest upwelling occurred around 36−40°N in both years, while weak upwelling (negative anomalies) occurred off Baja. The 2002 upwelling period again extended this extraordinary period of persistently strong upwelling seasons (Schwing et al. 2002a). However, strong downwelling prevailed in the California Current system north of Point Conception during winter 2002–2003, reflecting the prevailing cyclonic wind anomalies (fig. 4c). Upwelling was strongest in the southern California Current system in early 2003, while downwelling persisted in the northern California Current system at least through April. Anomalously strong upwelling had returned to the California Current system, from Baja California to Washington, by May 2003.

National Data Buoy Center (NDBC) coastal buoy winds reveal synoptic-scale variability of atmospheric events in the California Current system, superimposed on the annual climatological cycle of generally southward winds in summer and northward or weak southward winds in winter (fig. 6). Coastal winds in 2001 showed the typical pattern of stronger magnitudes and higher variability off northern California and Oregon, and weaker magnitudes with less variability off southern California (Schwing et al. 2002a). The 2002 coastal winds were somewhat more variable throughout the California Current system. There were a number of anomalously strong southward wind events during the first half of 2002 over this part of the California Current system, contributing to the strong upwelling and cool coastal temperatures. In the latter half of 2002, there were a number of strong northward wind events, contributing to downwelling and warmer SSTs. The cyclonic wind anomalies seen around this time (figs. 4b,c) represent the integrated effect of a number of these synoptic events.

The buoy SSTs reflect these changes in alongshore wind forcing, with cool temperatures persisting through spring and summer 2002 (fig. 7). However, a sharp transition occurred around October–November 2002 as the strong downwelling episodes resulted in positive SST anomalies. This transition was particularly obvious

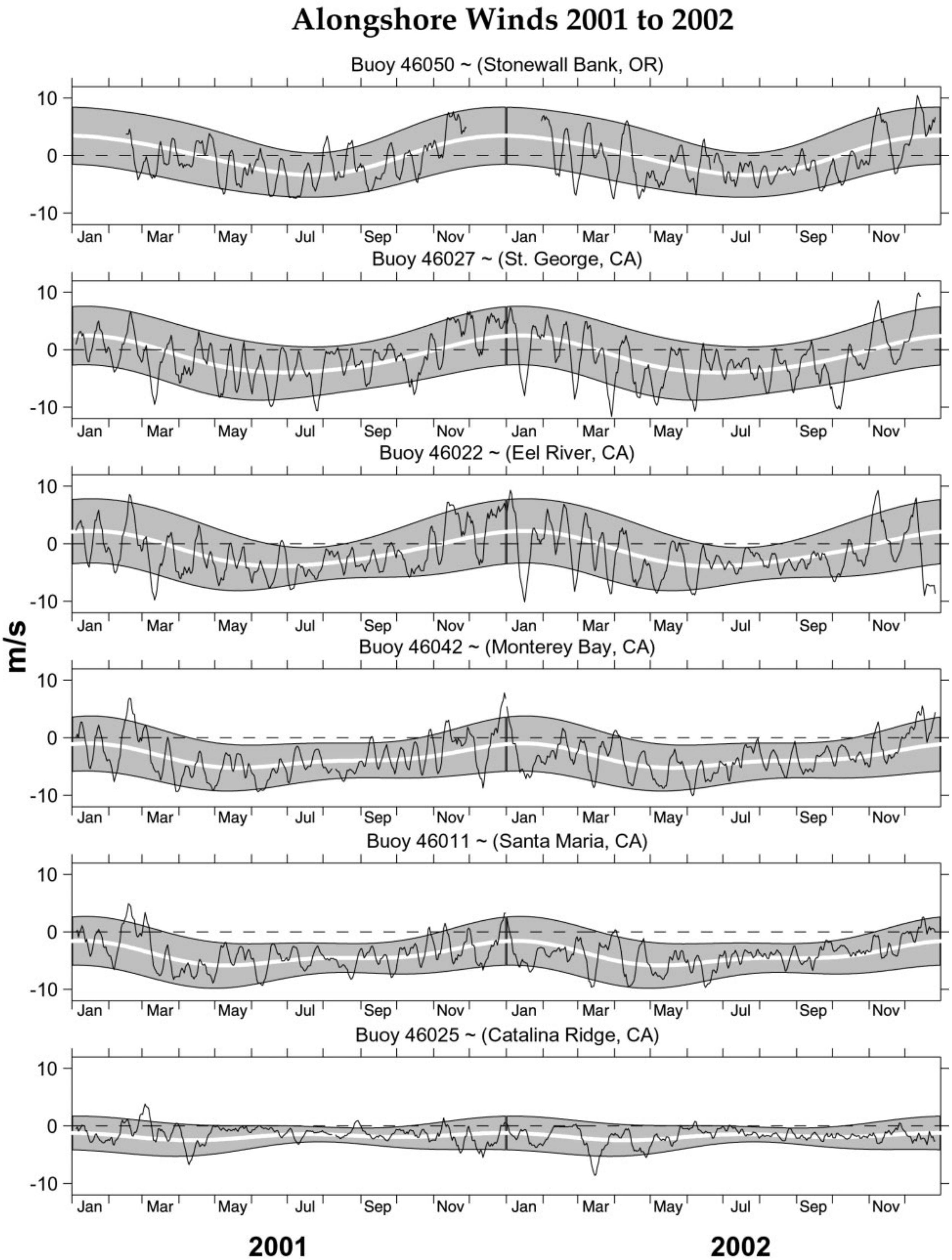

Figure 6. Time series of daily-averaged alongshore winds for January 2001–December 2002 at selected National Data Buoy Center coastal buoys. Bold lines are the biharmonic annual climatological cycle at each buoy. Shaded areas are the standard errors for each Julian day. Series have been smoothed with a 7-day running mean. Data were provided by NOAA NDBC.

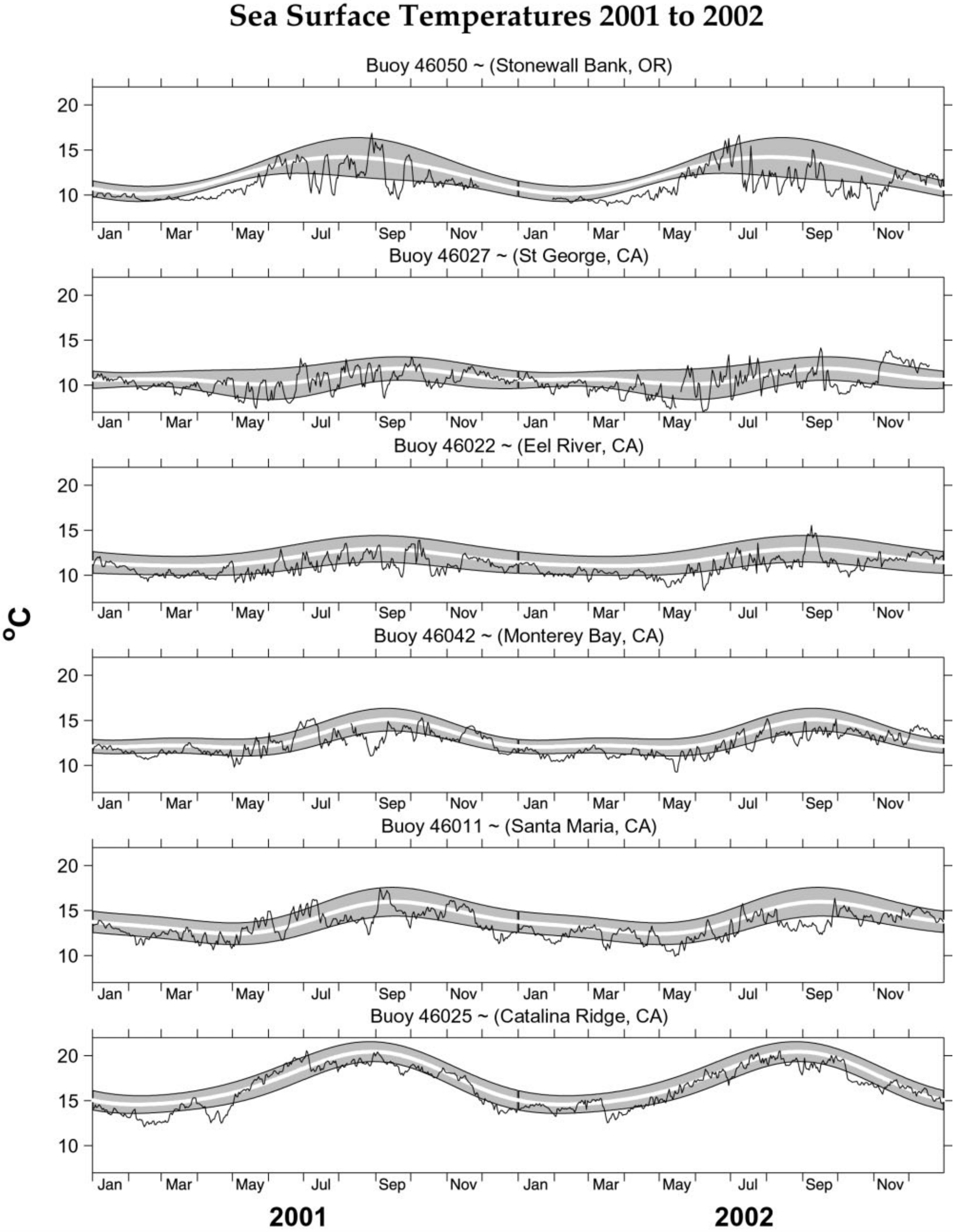

Figure 7. Time series of daily-averaged SST for January 2001–December 2002 at selected NDBC coastal buoys. Bold lines are the biharmonic annual climatological cycle at each buoy. Shaded areas are the standard errors for each Julian day. Data provided by NOAA NDBC.

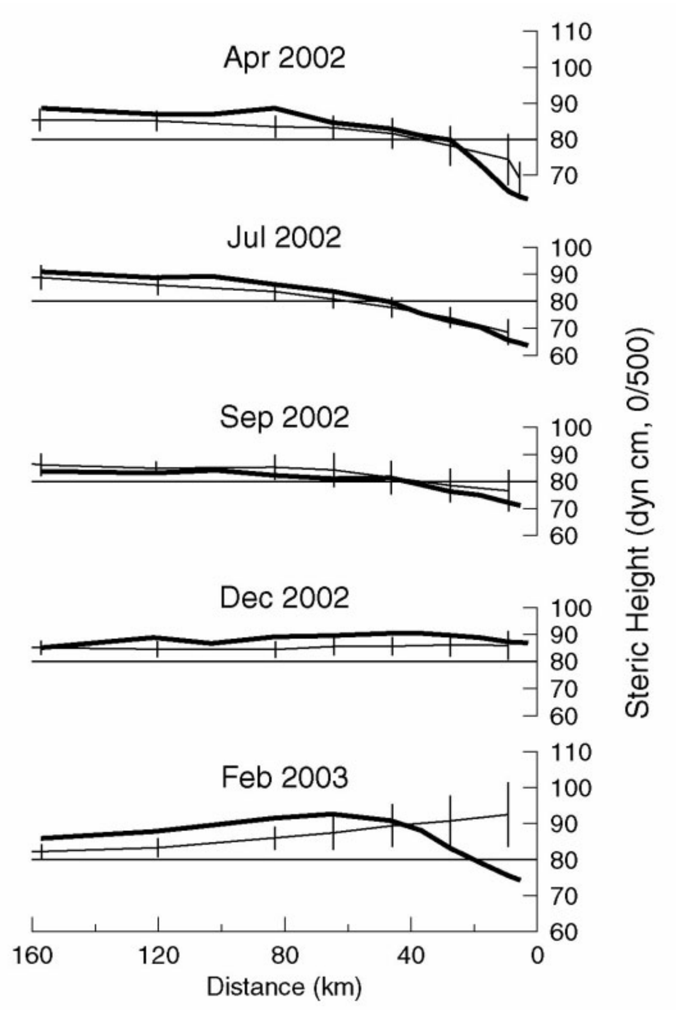

Figure 8. Steric height profiles of the sea surface relative to 500 dbar along the NH line at 44.65°N since April 2002 (*thick line*) shown with the long-term (1961–71) seasonal or monthly average provided by Smith et al. (2001). Vertical bars indicate 1 standard deviation above and below the average. Values over the shelf and upper slope were calculated by the method of Reid and Mantyla (1976).

off northern California (St. George buoy). With the collapse of the 2002–2003 El Niño event, it might be expected that coastal temperatures will return to the cool values seen in recent years.

REGIONAL STUDIES

Oregon Coast: GLOBEC LTOP Cruises

Observations off the Oregon coast suggest that El Niño had a relatively minor impact while the anomalous intrusion of subarctic water dominated the ecosystem.

Water temperatures off central Oregon were near normal during the La Niña of 1998–2001 (Schwing et al. 2002a), except that waters over the continental slope tended to be above normal at depths of 30–100 m in summer (fig. 27 in Schwing et al. 2002a). By February 2002, the entire section was colder than normal, and steric height was lower than normal (Schwing et al. 2002a).

Steric heights along the NH line remained near normal through spring and summer 2002 (fig. 8), though the gradient over the shelf was steeper than normal, indicating enhanced southward flow. By early December, steric heights were slightly above normal along most of the section. Steric heights offshore were still elevated in February 2003, but inshore values were very low, indicating strong southward flow over the shelf, presumably because of upwelling-favorable winds during the first ten days of February.

Temperature sections along the NH line in 2002–2003 (fig. 9a) show the usual seasonal cycle in the upper ocean: deep mixed layers and weak horizontal gradients in winter, and very strong stratification with temperature decreasing toward shore in summer. There are also some striking anomalies: very cold (< 7.5°C) subsurface waters over the outer shelf in July 2002, and complex inversions in fall and winter. Each section contains both positive and negative anomalies that differ from the seasonal average by more than one standard deviation. Positive anomalies are seen at depths between 200 m and 500 m in all sections, and in the surface layer in winter. These positive anomalies are probably associated with the 2002–2003 El Niño.

The remarkably cold water (<7.5°C) over the outer shelf in July 2002 (fig. 9) occurred in the upper halocline and was the coldest in this salinity range yet observed off Newport (fig. 10). This anomaly was part of a large-scale subarctic intrusion that also affected water masses off Vancouver Island (Freeland et al. 2003) and southern California (Bograd and Lynn 2003).

This water mass anomaly can be explained by enhanced southward advection, which was detected by moorings (Kosro 2003) and satellite-tracked drifters (Barth 2003) and in satellite altimeter data (Strub and James 2003). The cold halocline had relatively high nutrient concentrations (Wheeler et al. 2003), and upwelling of these nutrient-rich waters produced higher-than-normal chlorophyll concentrations off Oregon and northern California (Wheeler et al. 2003; Thomas et al. 2003). These anomalous conditions apparently resulted from large-scale atmospheric forcing in the northeast Pacific Ocean (Murphree et al. 2003). The cold halocline anomaly was already present off central Oregon in April 2002, and was still present in February 2003 when its peak amplitude occurred at a depth of 110 m, 100 km from shore (fig. 9b).

Regional surveys were made in April, July, and September 2002. As in recent years (Durazo et al. 2001; Schwing et al. 2002a), surface temperatures were nearly homogeneous in April 2002 (fig. 11a), though there was

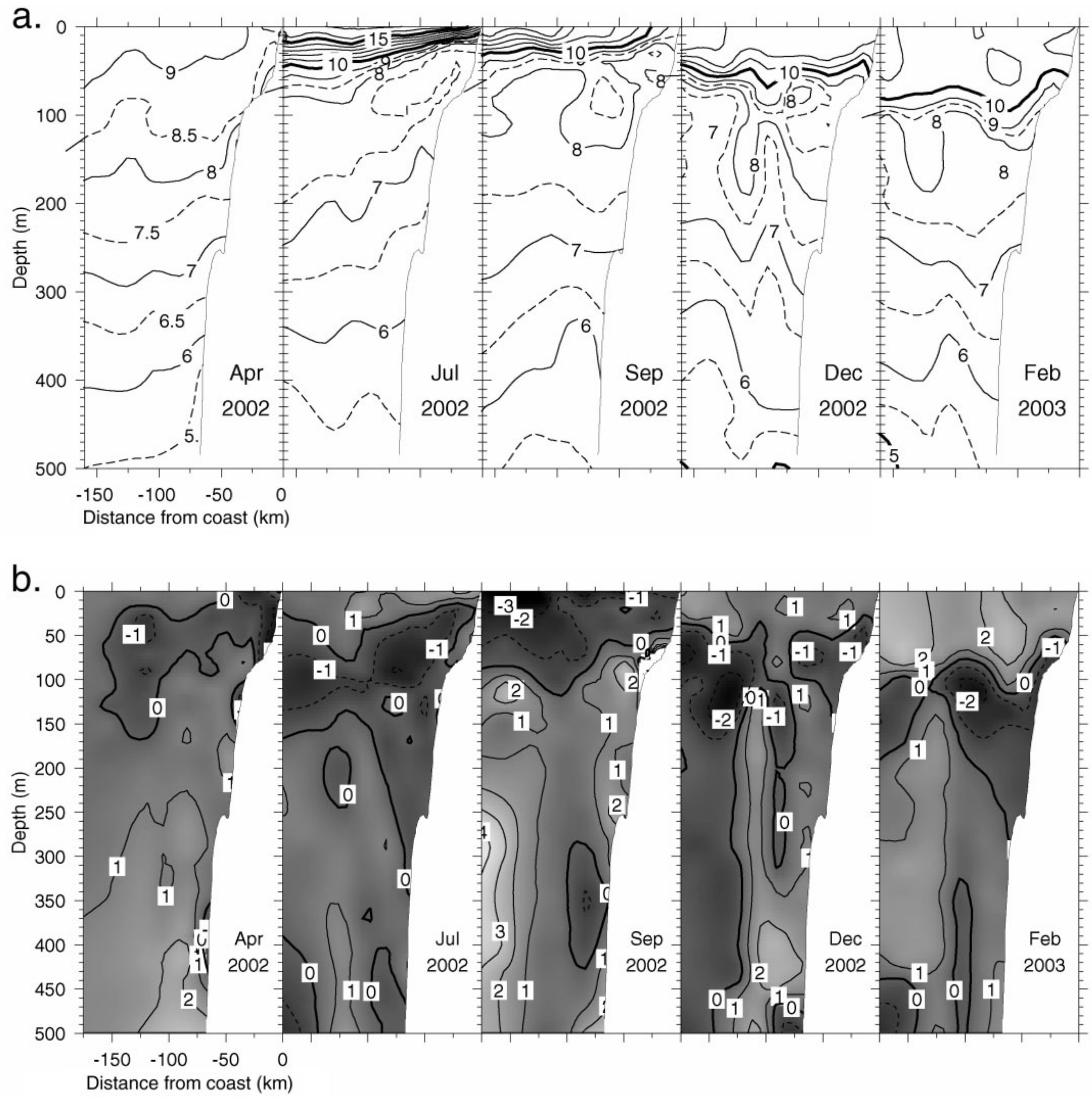

Figure 9. Temperature along the NH line at 44.65°N, for sections since April 2002. (*a*) Temperature, in °C (*dashed lines* are intermediate contours). (*b*) Temperature anomalies normalized by historical standard deviations; positive (negative [*dashed lines*]) anomalies indicate that present values are warmer (colder) than the historical (1961–71) seasonal or monthly averages; values greater than 1 (2, 3) are significant at the 90% (95%, 99%) level.

a strong, narrow equatorward jet near the coast (fig. 11b). A narrow low-salinity tongue (fig. 11c) coincided with the core of the jet, indicating southward advection of Columbia River plume water. By July 2002, there were strong surface temperature gradients: inshore waters were 6–7°C colder than offshore waters, and offshore waters were 1–2°C warmer off Newport than off Crescent City (fig. 11a). Geostrophic flow at the surface, relative to 500 dbar, was equatorward throughout the survey region (fig. 11b), and low-salinity Columbia River plume waters (salinity < 32.5) covered all but the inshore portion of each section (fig. 11c). By late September, zonal

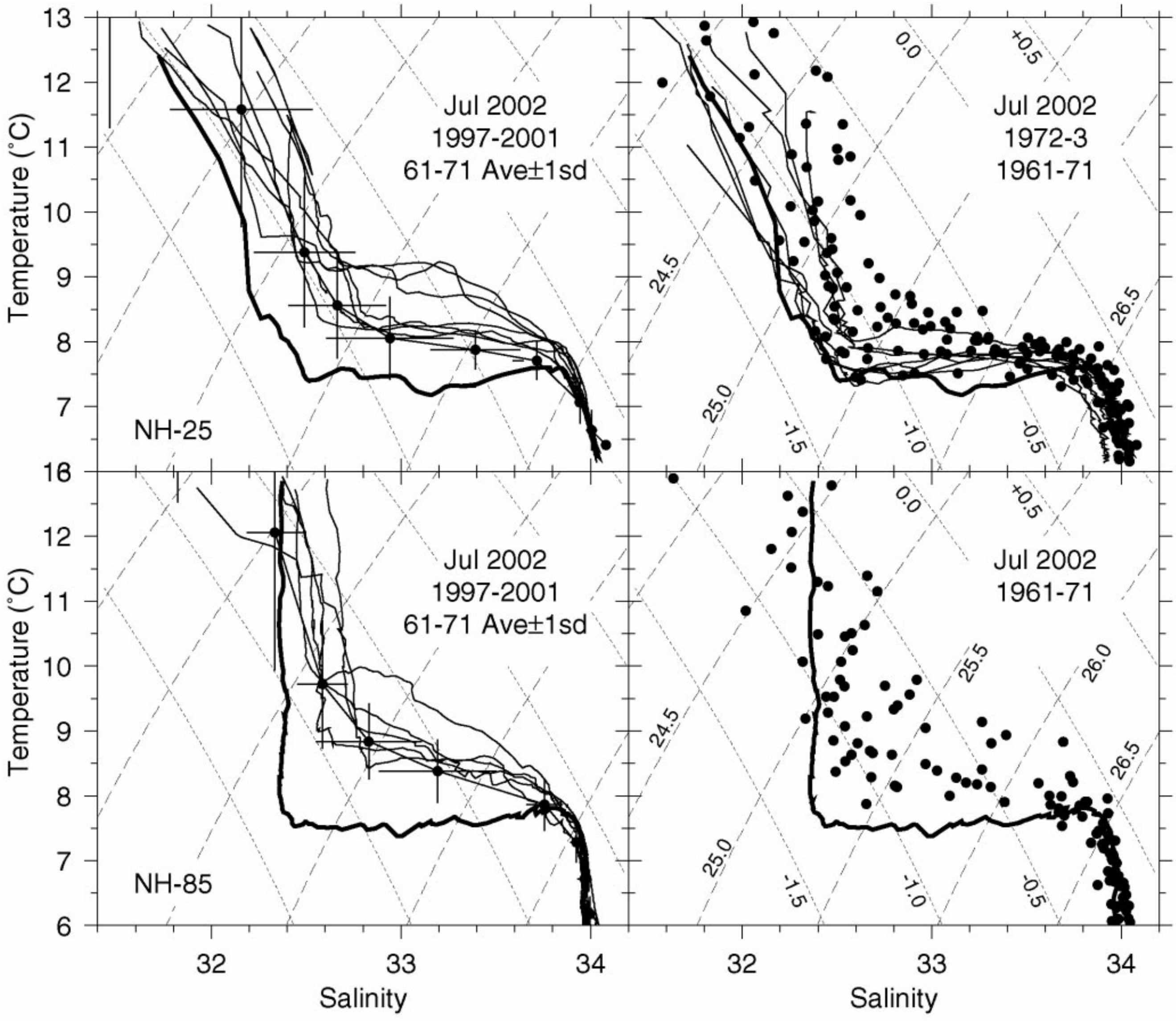

Figure 10. Temperature and salinity diagrams for the shelf-break station (NH-25, *upper panels*), and the offshore station (NH-85, *lower panels*). *Left*, continuous CTD data from July 2002 (*thick line*) compared to recent summers (*thin lines*) and the mean (±1 SD) of historical data (*cross bars*); *right*, data from July 2002 (*thick line*) compared to historical continuous (*thin lines*) and discrete (*dots*) summer data.

gradients of surface temperature and dynamic topography fields had weakened, and there seemed to be some eddies off Crescent City (which were not resolved because we did not have enough time to sample our standard section at 42.5°N). Low-salinity Columbia River plume waters (salinity < 32.5) were observed only in the northwest corner of our grid; these low salinity surface waters were still 2–4°C warmer than the offshore waters at Crescent City. Winds had continued to be favorable for upwelling through most of September—that is, longer than usual—and this continued upwelling was reflected in the cold, dense waters observed in the coastal strip at the end of September.

Chlorophyll *a* concentrations on all three 2002 surveys were generally high, exceeding 4 µg/l over most of the shelf in both April and July. Even at the end of September, most of the inner shelf region had values > 4 µg/l. These high chlorophyll values apparently reflect the enhanced subarctic influence (Wheeler et al. 2003).

As of this writing, the weak-to-moderate El Niño in the equatorial Pacific seems to be fading, though the most recent value (for Feb.–Mar. 2003) of the MEI (Wolter and Timlin 1998) is still positive. Our results suggest that this El Niño has had only a minor impact on the northern California Current system, expressed in higher-than-normal surface temperatures in late winter, and isolated

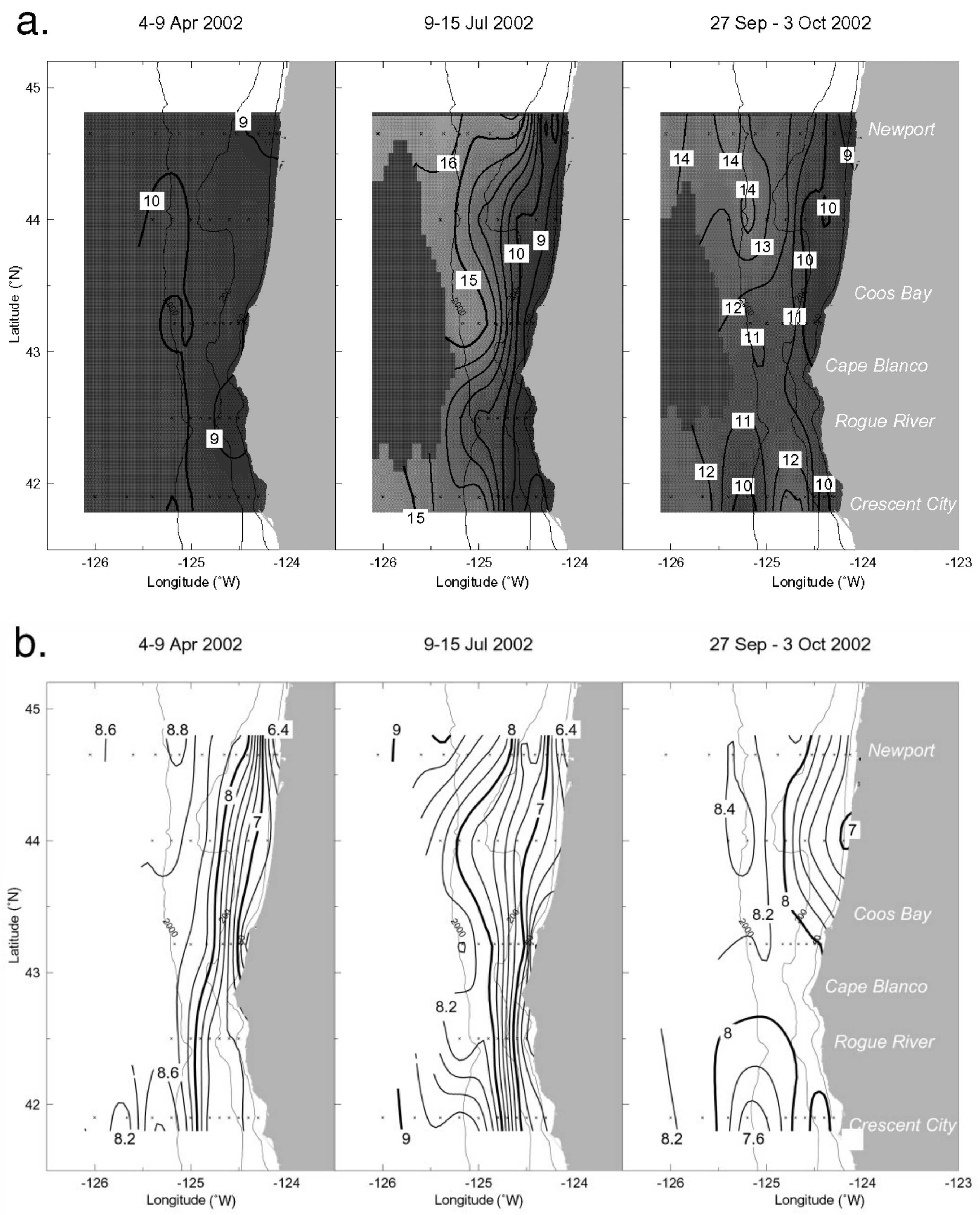

Figure 11. Spatial patterns for GLOBEC LTOP cruises: (*a*) 10 m temperature (˚C), (*b*) geopotential anomaly (J/kg) of the sea surface relative to 500 dbar.

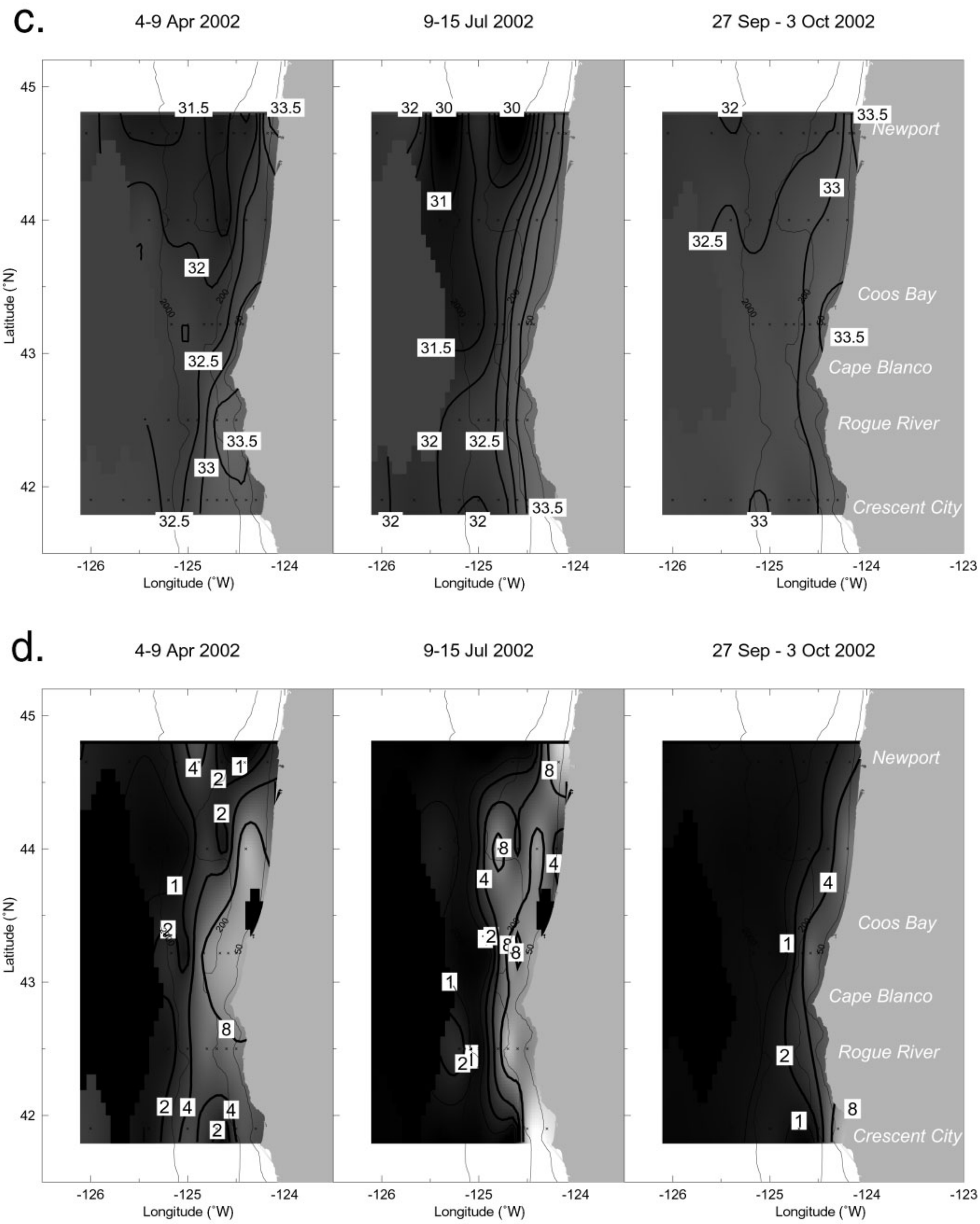

Figure 11 (*continued*). (c) 10 m salinity, (*d*) 10 m chlorophyll (µg/l).

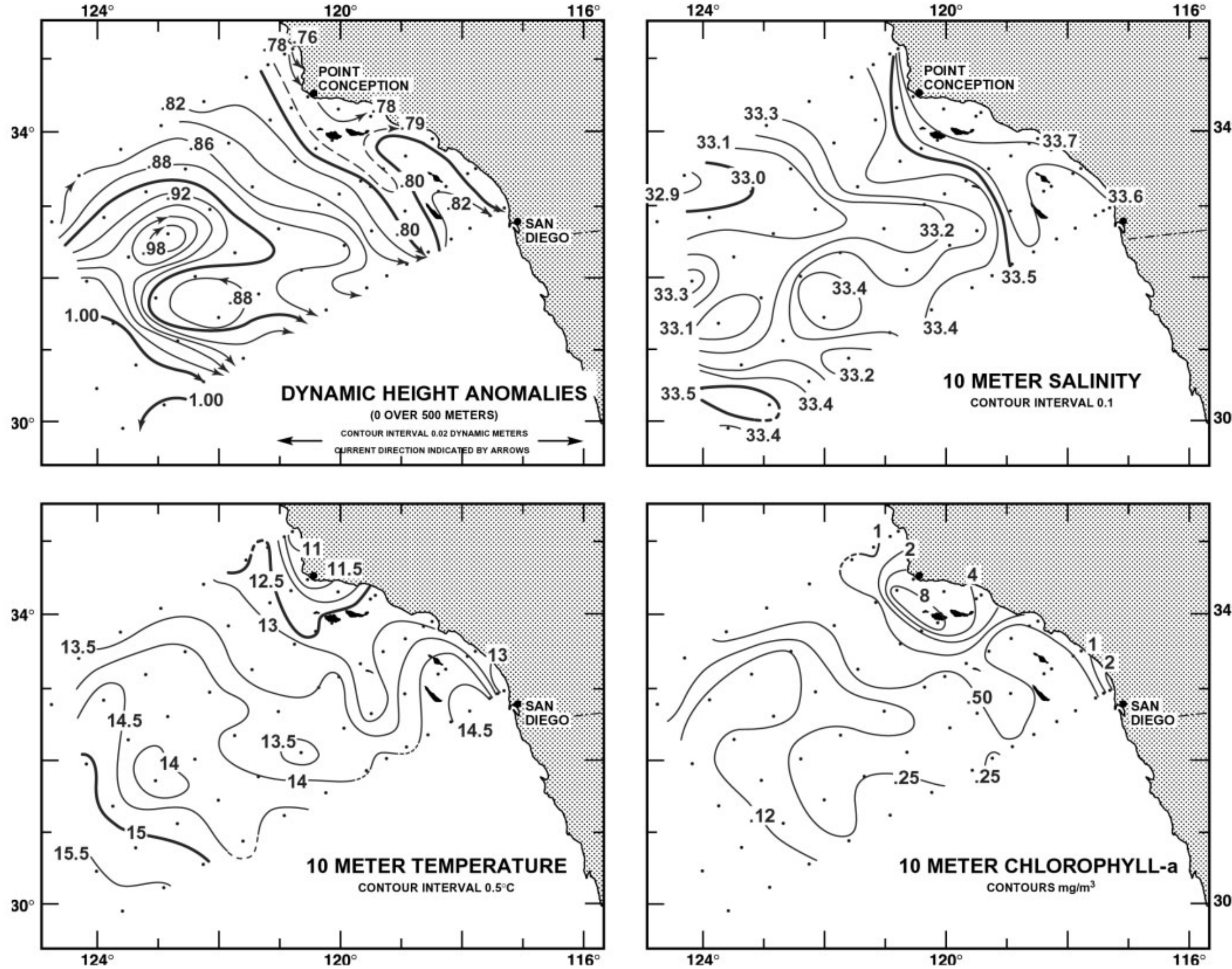

Figure 12. Spatial patterns for CalCOFI cruise 0204 (27 Mar.–12 Apr. 2002) including upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*.

warm anomalies at depths of 200–500 m. In contrast, the subarctic intrusion of cool freshwater has had a significant ecosystem impact, causing elevated nutrient concentrations, high chlorophyll concentrations, and even hypoxic waters over the inner shelf off Oregon (Wheeler et al. 2003). Whether and to what extent the subarctic influence will continue through 2003 remains to be seen.

Southern California Bight: CalCOFI Cruises

0204 (27 Mar.–12 Apr. 2002). The dynamic height map shows pronounced onshore-offshore meanders in the outer half of the cruise pattern (fig. 12). The uniform southward flow on the continental shelf and cool temperatures and high salinities close to shore are indicative of coastal upwelling. Chlorophyll levels were highest in the northeast quadrant of the cruise, but maximum values did not reach the values usually seen in spring. In retrospect, the first occurrence of anomalously cold, fresh subarctic waters could be seen at four offshore stations (tab. 1).

0207 (2–18 July 2002). The California Current still showed strong meanders, but these had shifted somewhat southward compared to 0204 (fig. 13). The cyclonic eddy that was centered between stations 87.90 and 90.90 on 0204 strengthened and moved to station 90.110. The narrow Southern California Eddy seen on 0204 had broadened, and the northward flow on the inshore side had strengthened, proceeding through the Channel Islands past Point Conception. At 10 m, the center of the elongated Southern California cyclonic eddy had cool temperatures and higher salinities, characteristic of water from below. There was also a clockwise warm-core eddy around and north of San Clemente Island. Chlorophyll levels decreased from those on the spring cruise.

TABLE 1
Selected Hydrographic Parameters Summarized for the Most Recent Six CalCOFI Cruises, Showing the Development and Decline of the 2002–2003 El Niño and the Presence of the Anomalous Intrusion of Subarctic Waters

Cruise	10 m mean temperature anomaly (˚C)	10 m mean salinity anomaly	Estimated number of stations with cold, fresh anomaly
0201	−0.6	+0.09	N.A.
0204	−0.5	+0.05	4
0207	0.0	−0.03	15
0211	−0.04	−0.13	26
0302	+1.0	−0.16	28
0304	−0.03	−0.18	20

Note: The subarctic anomaly was considered to be present when the minimum salinity was less than 0.3 salinity units from the long-term station mean and generally occurred at depths between 50 m and 125 m at offshore stations.

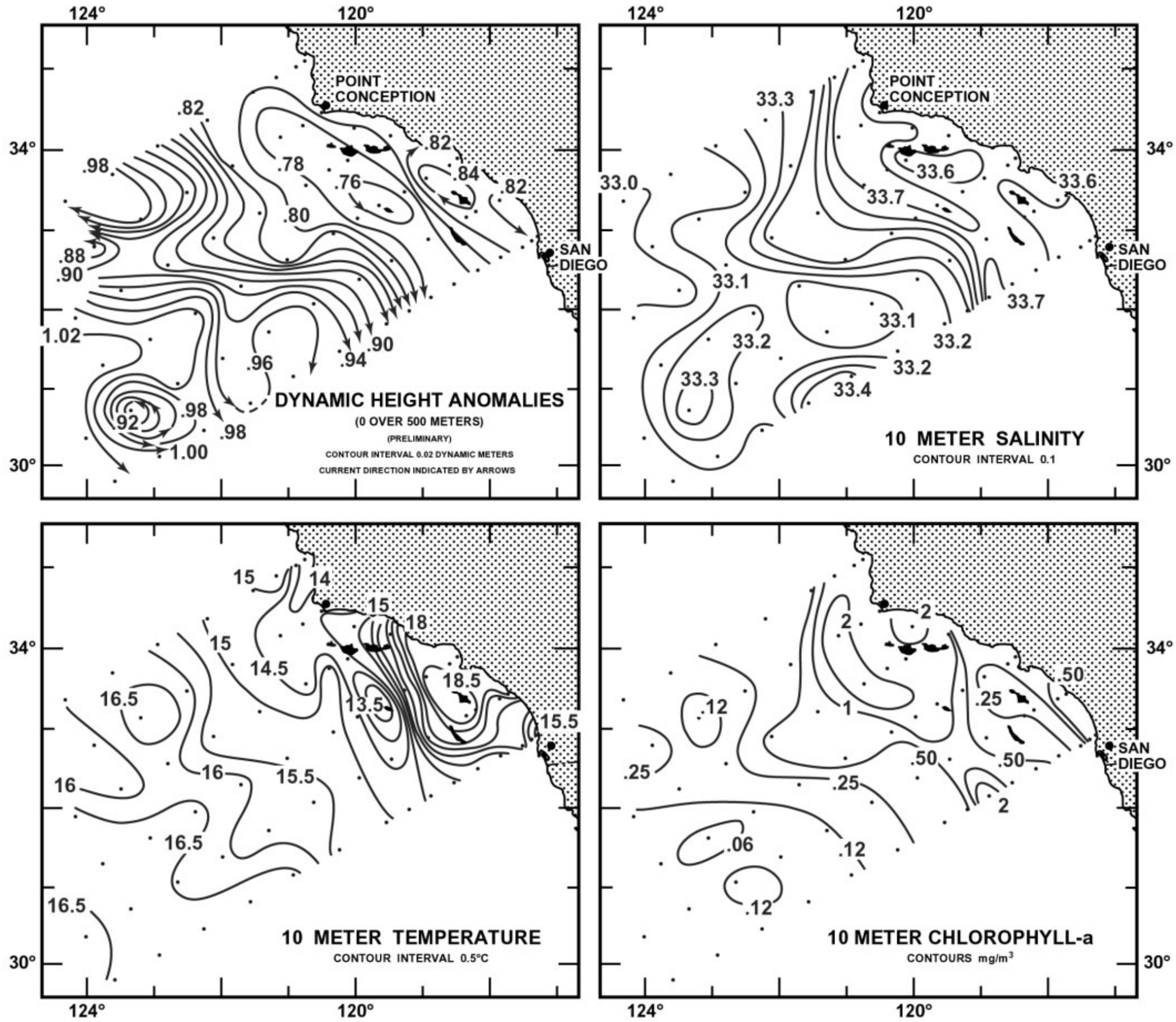

Figure 13. Spatial patterns for CalCOFI cruise 0207 (2–18 July 2002) including upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*.

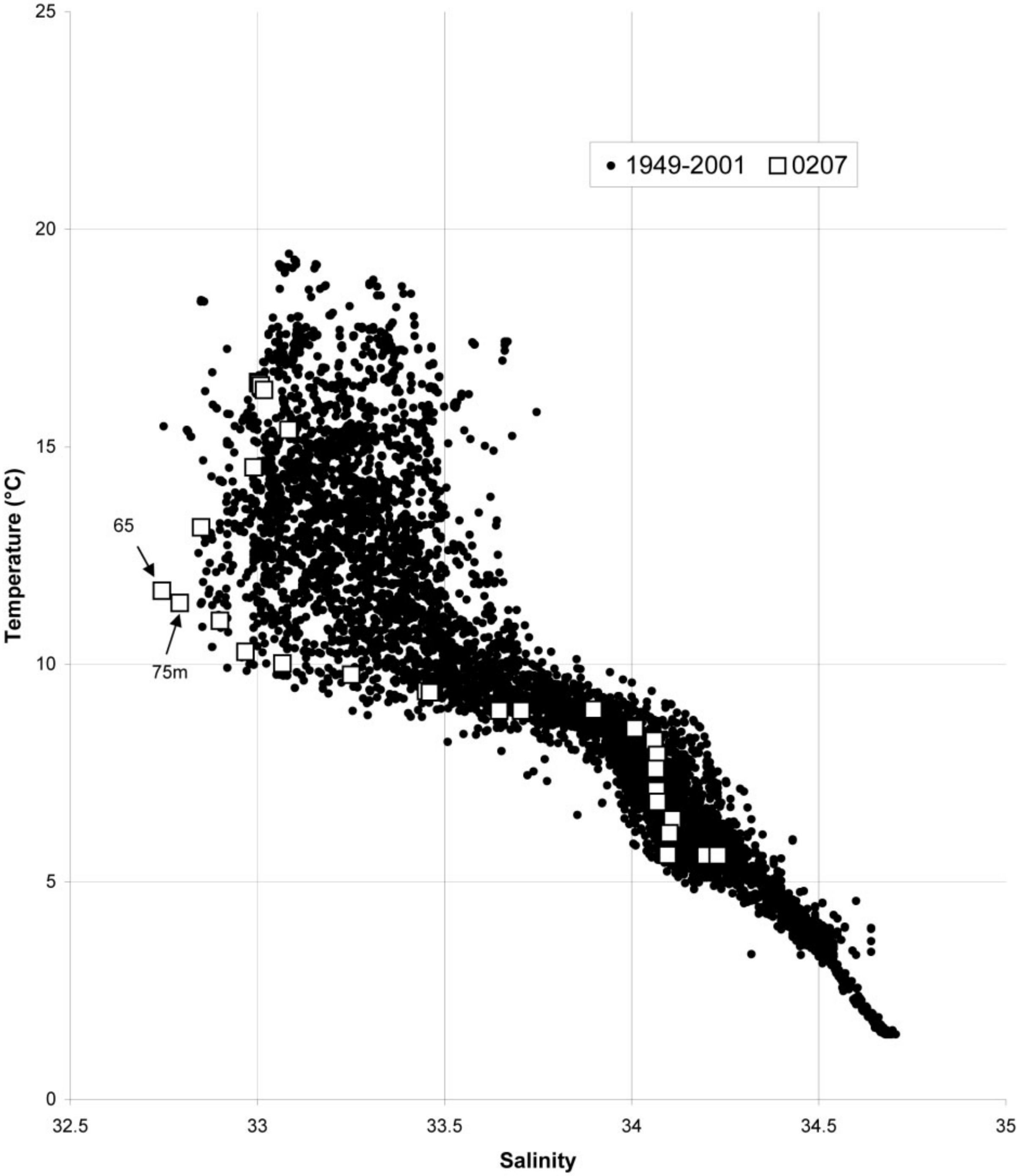

Figure 14. Temperature/salinity plot for station 80.80 on CalCOFI cruise 0207 against T/S point from all hydrographic casts at that station since 1941.

During this cruise, the unusually cool and low-salinity layer, first reported off Oregon, was seen in the upper pycnocline in our region. The feature was strongest at stations 80.80 and 80.90 as well as 83.110 at depths of 65–90 m. Temperature and salinity values were outside the range of all previous observations at these stations (fig. 14).

0211 (10–26 Nov. 2002). The big zonal offshore meander of the previous cruise moved southward and was centered along lines 87 to 93; the cyclonic eddy that was present in the last two cruises in the southwest quadrant was no longer within the cruise pattern (fig. 15). The Southern California Eddy was present, with northward coastal flow from La Jolla to Avila Beach. Some

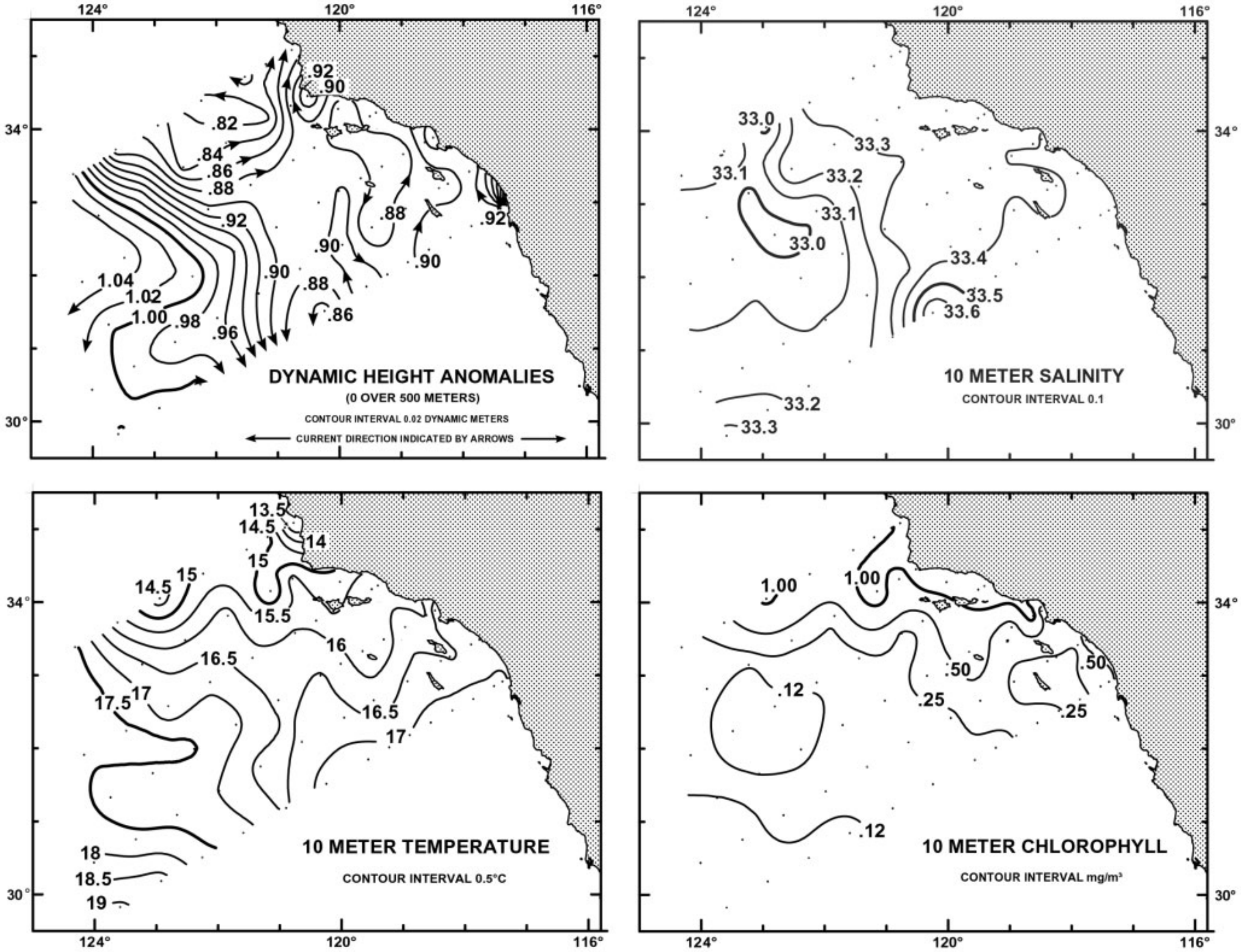

Figure 15. Spatial patterns for CalCOFI cruise 0211 (10–26 Nov. 2002) including upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*.

upwelling was seen off Avila Beach, but overall the SSTs were close to normal. Surface chlorophyll levels decreased; they were highest in the Santa Barbara Channel and at the northern edge of the pattern.

The anomalously low subsurface temperature and salinity feature seen during the summer was still strong, especially at stations 90.100, 90.110, and 93.90. In contrast, the deeper SE coastal waters had a layer of warmer and more saline water at depths between 125 and 300 m, an indication of an enhanced northward subsurface coastal countercurrent.

0302 (30 Jan.–25 Feb. 2003). These data are still at a preliminary stage of processing at the time of this writing (fig. 16). Maps of surface flow show a strong surface coastal countercurrent all the way from La Jolla to at least Monterey. This is a common winter circulation feature, but it appeared to be stronger than usual on this cruise, consistent with the coastwide, poleward wind-stress anomalies (fig. 4). The poleward flow resulted in downwelling at the coast. The main California Current jet remained far offshore. A strong clockwise eddy was present in the southwest corner of the cruise pattern, where there had been an inshore, offshore meander the previous July. The minimum in surface salinity, which is generally a good indicator of the location of the California Current jet, can be seen to enter the region from the outer end of line 80. Surface chlorophyll levels were generally low, as is typical of fall and winter cruises. This cruise continued to document the progressive change from cold, saline waters the previous winter (0201) to warmer and less saline waters (tab. 1). In March, SST averaged about 1°C above normal, after a long period of cooler-than-normal SSTs, reflecting the arrival of the moderate El Niño state of the ocean locally.

The sub-surface anomaly was similar to that seen on the fall cruise, cooler and much less saline than normal at about 75–100 m on some of the offshore stations (especially 83.110), near the $\sigma_t = 25$ surface, and warmer

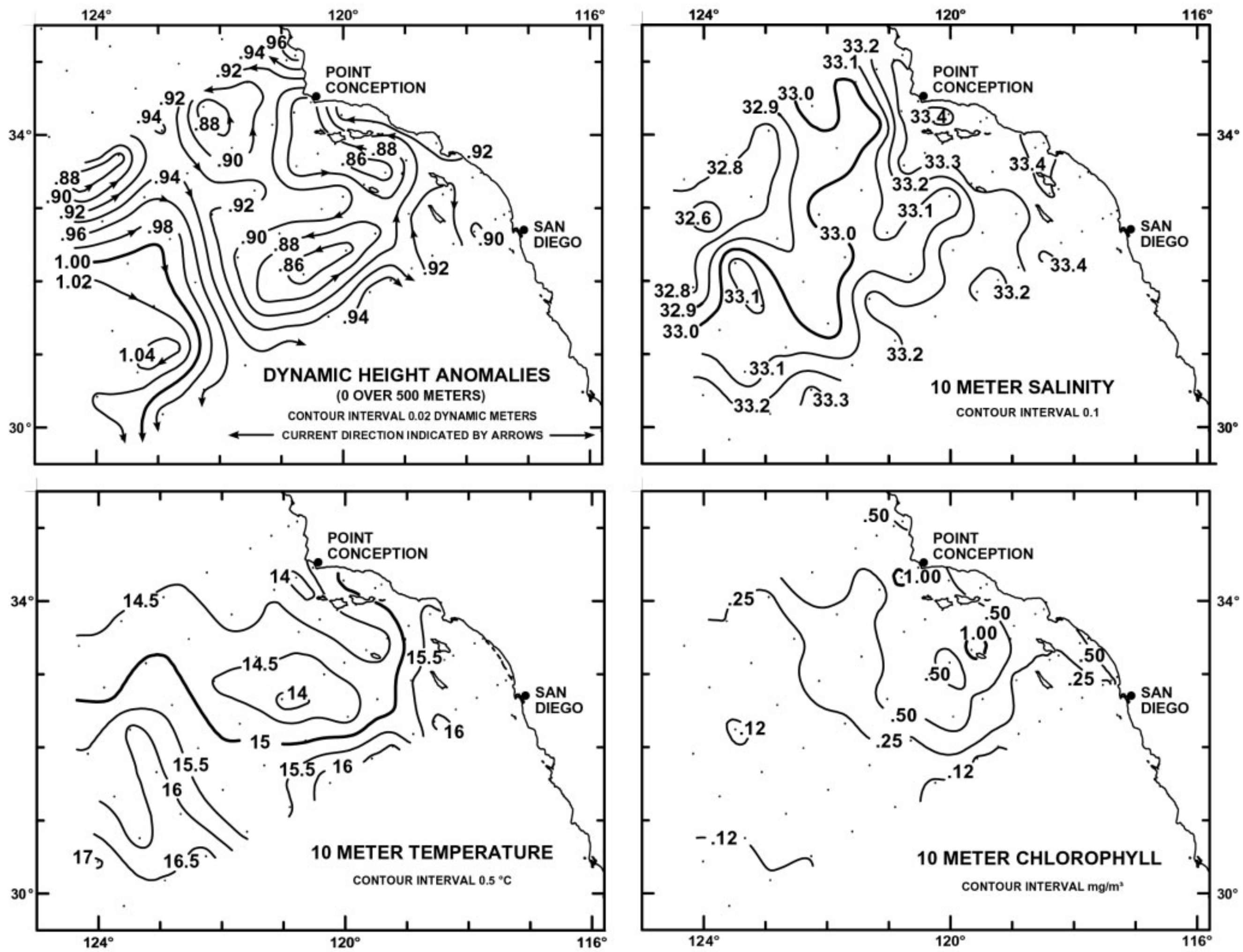

Figure 16. Spatial patterns for CalCOFI cruise 0302 (30 Jan.–25 Feb. 2003) including upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*.

and more saline than normal at deeper depths in the southeastern stations. It was observed at fewer stations (tab. 1), which might be a sign of weakening, or movement offshore.

0304 (4–25 Apr. 2003). These data are also still at a preliminary stage. The map of nearsurface flow reveals the main jet of the California Current at the outer edge of the pattern, confirmed by the lowest salinities found there (fig. 17). A clockwise eddy was present in the southwest corner, and a pair of cyclonic eddies occurred on the inshore edge of the California Current jet. There was another ribbon of meandering flow down the center of the pattern, but it was not as strong as the outer band of flow.

At 10 m, the shelf stations had cool temperatures and higher salinities, characteristic of upwelling. The 10 m temperature anomalies (not shown) were cooler than normal, suggesting stronger-than-normal upwelling. The 10 m chlorophyll levels were quite high all along the shelf stations, as well as in a band just beyond the outer Channel Islands. The cold, low-salinity upper thermocline feature seen on previous cruises was still present at the offshore stations, again near the $\sigma_t = 25$ surface.

Baja California: IMECOCAL Cruises

0204 (19 Apr.–9 May 2002). Geostrophic currents were equatorward with slight meandering, conditions typical of a spring transition (fig. 18). With the exception of two weak, small-scale gyres between Isla Guadalupe and Punta Eugenia, no conspicuous eddy structures were noticeable. The core of the California Current, as depicted by the salinity minimum at 10 m and 50 m (not shown), was near the coast on sections 97 and 100 but south of these lines it was displaced southwestward. Three coastal, low-temperature upwelling regions were present south of coastal prominences: Ensenada, Punta Baja, and Punta Eugenia. These inshore locations were associated with high chlorophyll *a*

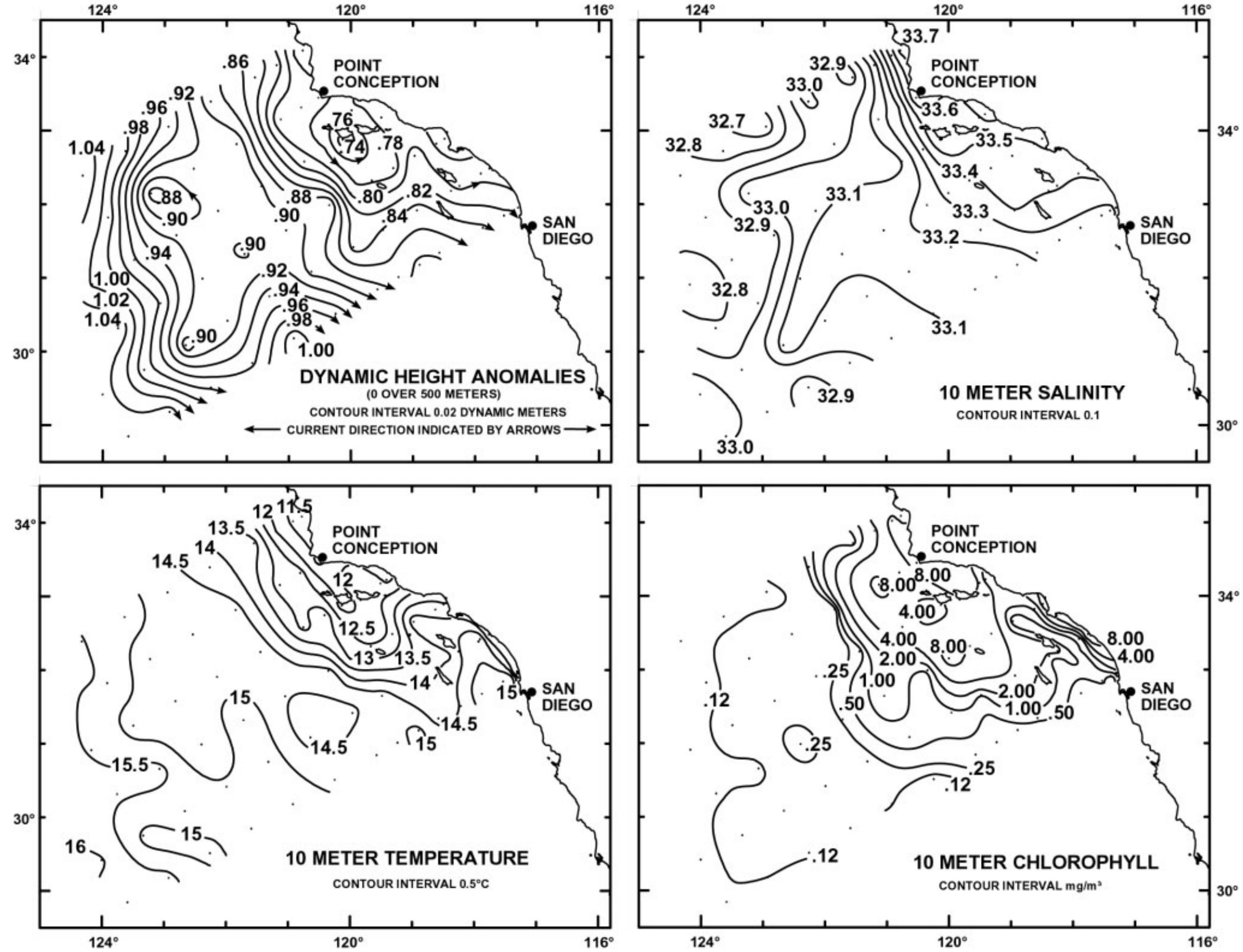

Figure 17. Spatial patterns for CalCOFI cruise 0304 (4–25 Apr. 2003) including upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*.

values (> 8 mg/m^3). Chlorophyll *a* patterns followed those of geostrophic currents and were similar to those described for April 1999 by Lavaniegos et al. (2002) during La Niña conditions, that is, high coastal concentrations associated with upwelling centers and diminishing concentrations offshore.

0207 (12 July–2 Aug. 2002). An eddy-rich California Current was characteristic of this summer season, the most noticeable feature being the quite energetic anticlockwise gyre west of Punta Eugenia (fig. 19). The California Current entered the survey region from the outermost part of sections 100 and 103 and divided into two branches; the northern branch gave rise to a return flow that was part of the Southern California eddy (fig. 13). The other branch flowed southeastward towards Vizcaino Bay and was entrained into the mesoscale cyclonic gyre off Punta Eugenia. South of this gyre, the California Current reappeared as a southward flow along the outer part of sections 127 to 137. Inshore, lower temperatures indicated upwelling off Ensenada, Punta Baja and Punta Abreojos (27°N) related to higher values of chlorophyll *a*. High concentrations of chlorophyll *a* were also present around Vizcaino Bay where contours suggest these rich waters were transported offshore by the northern limb of the gyre. Low values of chlorophyll *a* were associated with the outer clockwise circulation. South of Punta Eugenia, the cyclonic circulation off the Gulf of Ulloa (26°N) and the high salinity wedge nearshore indicated the presence of a poleward near surface coastal flow.

0210 (23 Oct.–13 Nov. 2002). Near surface geostrophic currents and the salinity distribution at 10 m (and 50 m, not shown) indicate that the California Current core entered the survey region from the west at Guadalupe Island (fig. 20). A branch of this core flowed north on what appeared to be the southern limb of the Southern California eddy (fig. 15), which extends further south during this season (Lynn and Simpson 1987).

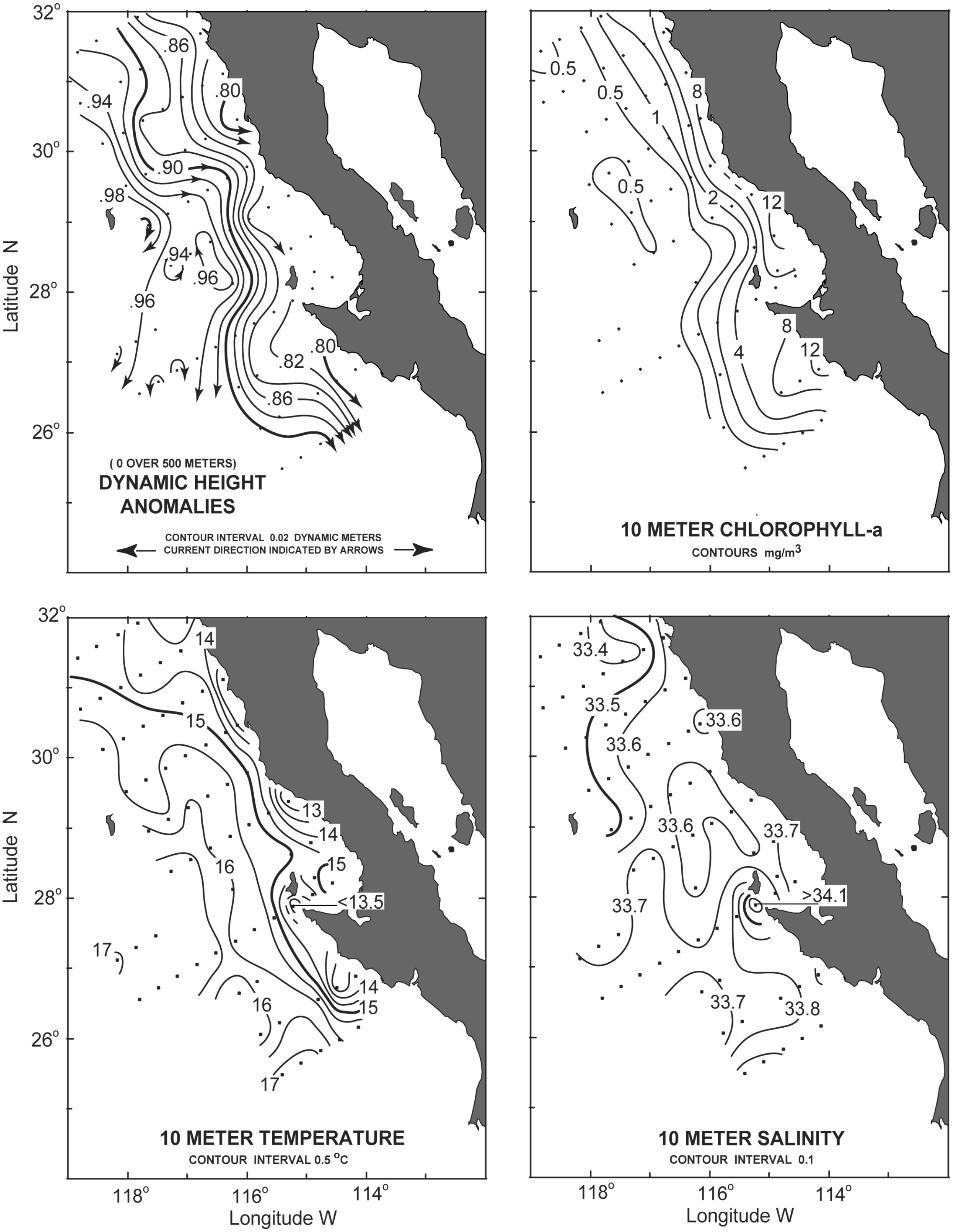

Figure 18. Spatial patterns for IMECOCAL cruise 0204 (19 Apr.–9 May 2002) including upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m chlorophyll *a*, 10 m temperature, and 10 m salinity.

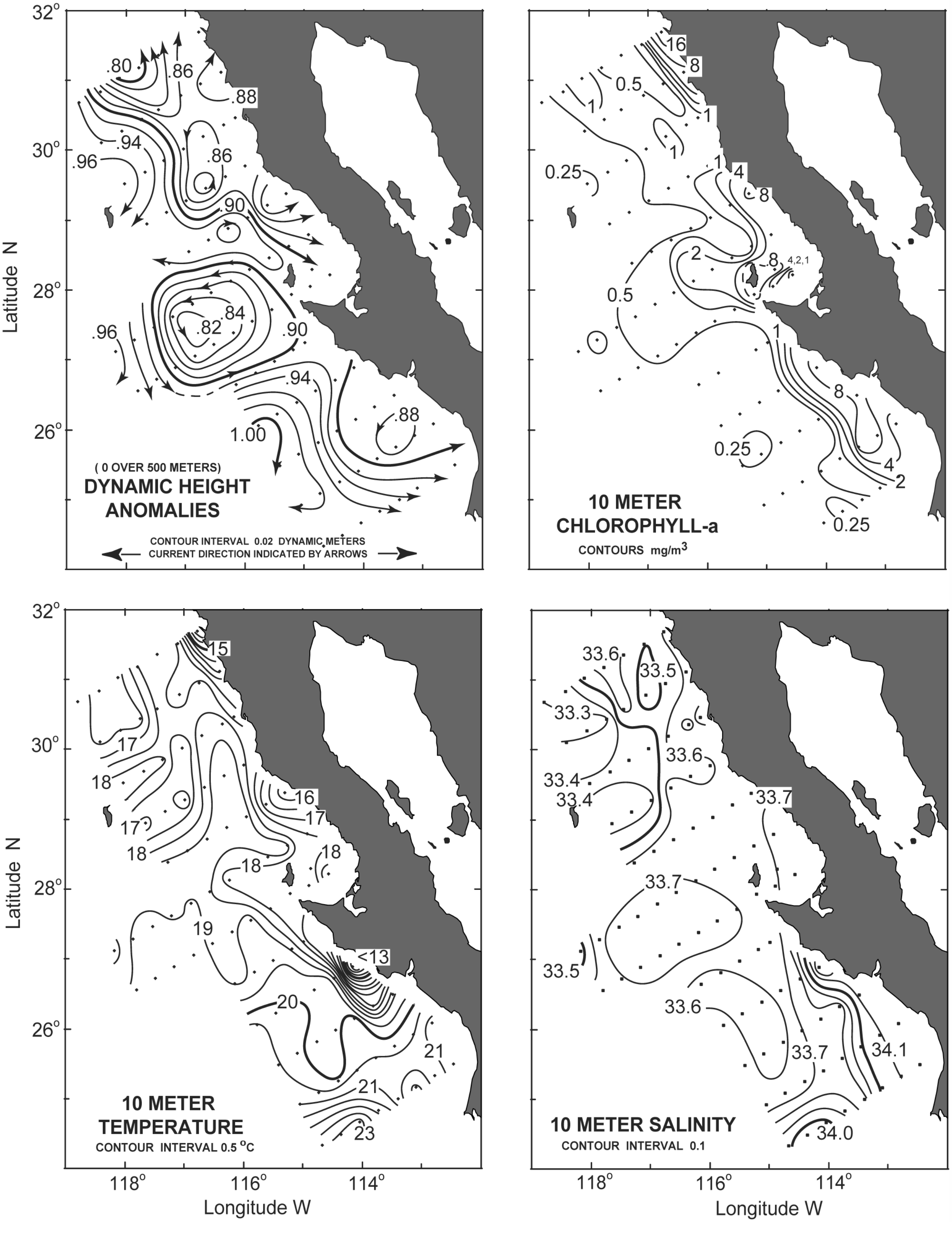

Figure 19. Spatial patterns for IMECOCAL cruise 0207 (12 July–2 Aug. 2002) including upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m chlorophyll *a*, 10 m temperature, and 10 m salinity.

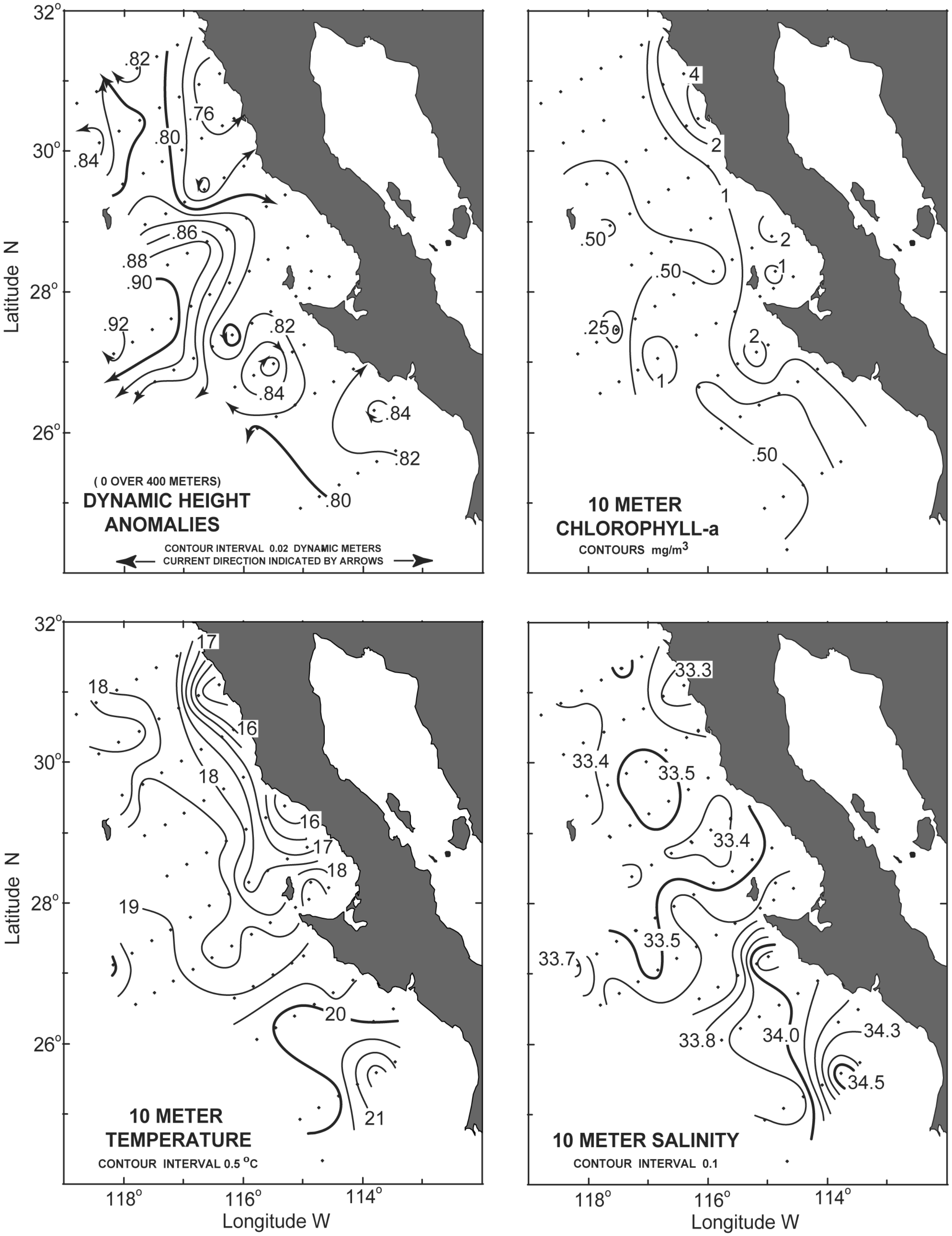

Figure 20. Spatial patterns for IMECOCAL cruise 0210 (23 Oct.–13 Nov. 2002). Note that upper-ocean geostrophic flow was estimated from the 0/400 dbar dynamic height field. Also included are the 10 m chlorophyll *a*, 10 m temperature, and 10 m salinity.

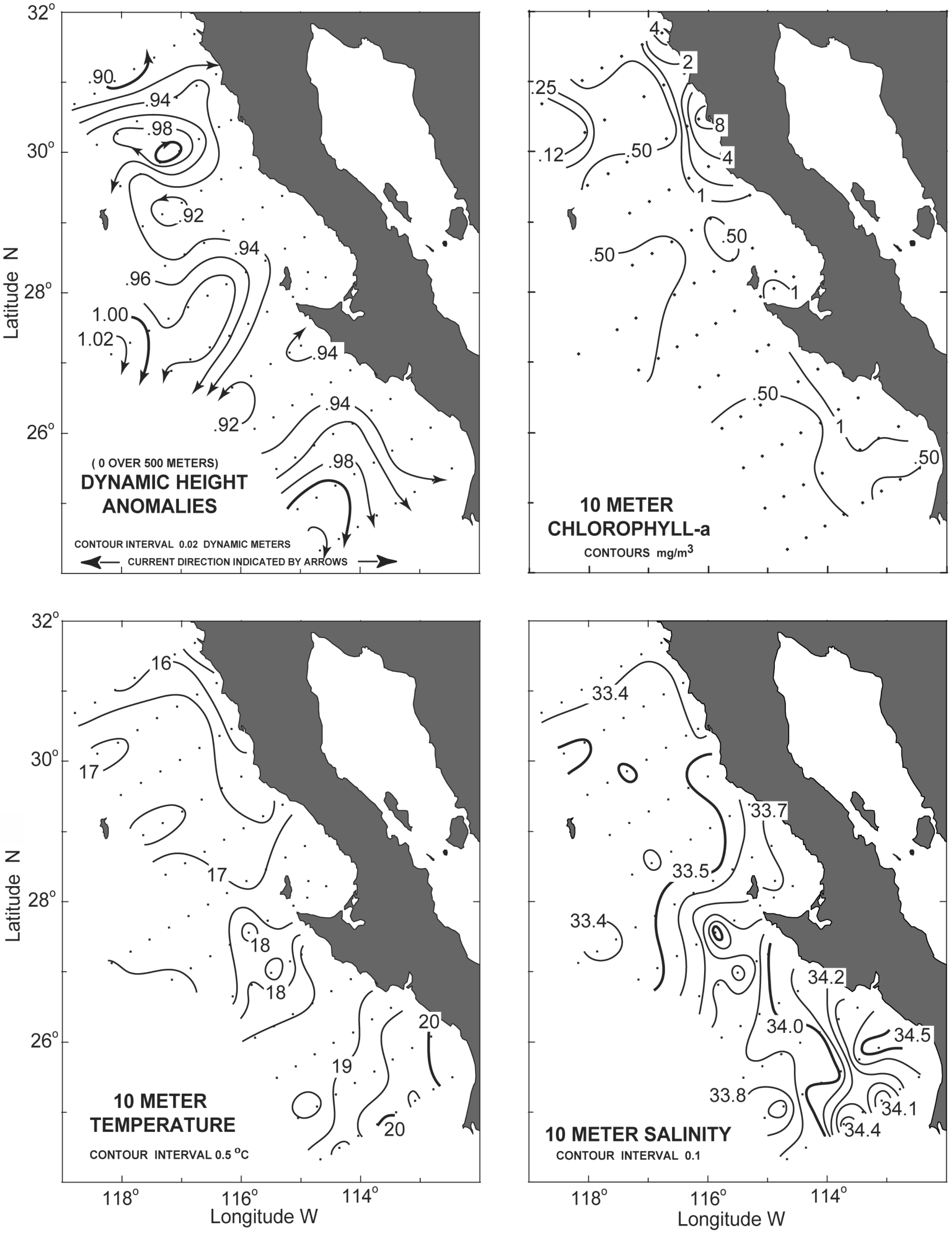

Figure 21. Spatial patterns for IMECOCAL cruise 0301 (30 Jan.–20 Feb. 2003) including upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m chlorophyll *a*, 10 m temperature, and 10 m salinity.

The other branch moved east to merge with an upwelling, high chlorophyll *a* coastal southward flow. Both flows veered south and circulated around the clockwise eddy centered at 28°N and exited the survey area as an offshore jet at 26.5°N. This gyre was a typical structure of the season as it appears in the climatological means of Lynn and Simpson (1987). The gyre also delimited low chlorophyll *a* concentrations (~0.5 mg/m^3). In general, mesotrophic conditions prevailed (chlorophyll *a* < 0.5 mg/m^3) in offshore areas. Nearshore, low temperatures centered at station 103. 30 were associated with southward flow, low salinities, and the highest concentrations of chlorophyll *a* observed during this cruise. Note that part of this coastal southward flow returned as a coastal poleward current as indicated by dynamic height anomaly contours. South of Punta Eugenia a wedge of high temperatures and salinities (T > 20°C, S > 34) suggest the entrainment of transitional waters as a near surface coastal poleward flow.

0301 (30 Jan.–20 Feb. 2003). During this winter season, the California Current entered the survey area as an eastward flow on the northernmost portion of the survey grid (fig. 21). Upon reaching the coast near Ensenada, it flowed equatorward meandering along cyclonic and anticyclonic gyres while remaining offshore. The California Current left the survey region off Punta Eugenia. South of 26°N, geostrophic currents indicated the presence of an eastward flow carrying waters from the southwest (T > 18°C, S > 34). Salinity contours suggest that this flow was later constrained to the coastal region. Low chlorophyll *a* concentrations were observed throughout the cruise, with high values (> 4 mg/m^3) at some inshore locations. Chlorophyll *a* concentrations of 0.5 mg/m^3 followed closely the meandering of the current.

BIOLOGICAL PATTERNS

Chlorophyll *a*

Off Southern California, integrated chlorophyll values fell well within the range of past values (fig. 22). The seasonal cycle was depressed in 2002, but this may have been partly due to timing if the April cruise missed the peak bloom period. However, the low upwelling index off southern California that spring (fig. 5) suggests that the reduced springtime maximum of chlorophyll *a* may be partially real. Mean cruise chlorophyll values have not been very sensitive to El Niño conditions in the past. Nevertheless, it is tempting to attribute the low value observed in February 2003 to El Niño. The 0302 value was lower than the fall-winter values observed during the 1994–95 event (38.4 µg/l and 36.8 µg/l, respectively), which was of comparable magnitude and timing. In contrast, the chlorophyll *a* concentrations observed on the following cruise, in April 2003, were elevated, the third highest concentration in the past 20 years.

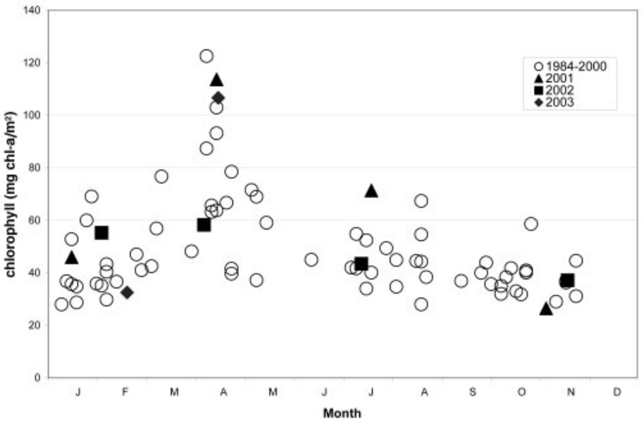

Figure 22. CalCOFI cruise mean integral chlorophyll concentrations. Concentrations observed in 2001, 2002, and February and April 2003 (preliminary) compared with concentrations observed since 1984.

It is unlikely that this elevated chlorophyll *a* concentration was the result of the intrusion of subarctic water, unlike the situation in waters off Oregon. The intrusion appeared to be too far offshore and too deep to influence coastal upwelling or regional productivity or biomass. The depth of the anomaly coincided with the start of the nutricline, and the nutrient content was not noticeably elevated.

One unusual aspect of the phytoplankton in April 2002 was the dominance of *Pseudo-nitzschia australis* in the vicinity of Point Conception. The contours of abundance followed those of chlorophyll *a* quite well (Schwing et al. 2002a, fig. 12). This species is one of the major producers of domoic acid, responsible for deaths of marine mammals and birds and even humans. Pelagic fish species, which are less susceptible to the toxin, act as vectors. Subsequent reports indicated that the 2002 bloom was widespread; samples from Monterey Bay also showed a bloom in April,[1] and there were numerous marine mammal strandings reported up and down the coast later that summer. Although *P. australis* occurs frequently in CalCOFI samples, especially in the northern inshore region, it is unusual for it to dominant the flora.

Elevated abundances of *P. australis* were again seen in the Santa Barbara Channel on 0304, but the flora was dominated by the more typical spring-bloom species of hyalochaete *Chaetoceros*. High concentrations of domoic acid were detected that spring and summer between Santa Barbara and Santa Cruz, and the toxin was present as far south as northern San Diego County.[2]

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[1] M. Silver, pers. comm.

[2] G. Langlois, pers. comm.

Macrozooplankton Biomass

In 2002, the cruise mean zooplankton biomass off Southern California (fig. 23) was markedly elevated in April and a bit so the previous February. However, values in July and November were below the recent monthly averages for 1984–2001, and the February 2003 value (not shown) was the sixth lowest on record; all volumes lower than this also occurred during El Niño events, as is characteristic of the El Niño conditions.

The complete IMECOCAL zooplankton series from September 1997 to February 2003 shows the highest variability in fall and winter (fig. 24). As to the north, values in February 2003 were low; this was the second consecutive winter with mean values lower than the historical mean for the period 1951–84 (CalCOFI cruises in the Baja California region). These low values contrasted strongly with the warm winter of 1998. The rest of the 2002 cruises had mean biomass values within the confidence interval of the period 1951–84. The largest biomass for the IMECOCAL series occurred in July 2002, but this appeared to be typical for that time of year in the historic context.

Mean tendencies in macrozooplankton biomass among regions (fig. 25) showed that during February and April 2002 biomass was highest off Southern California (CalCOFI lines 80–93) and lowest off northern Baja California (IMECOCAL lines 100–110), with values off central Baja California (lines 113–133) falling between these. From July 2002 to February 2003 the three regions showed similar mean values. Considering previous years, the regions have been responding in coherence from July 2000, with the exception of winter and spring 2001 and 2002, when low volumes off northern Baja California were the rule. During the period September 1997–April 1999, when the California Current was influenced by a strong warming and a subsequent cooling (El Niño and La Niña), the regions had very different values and trends.

Fish Eggs

In spring 2002, egg concentrations of sardine, anchovy, and jack mackerel were, in general, typical of recent spring values (fig. 26). Sardine eggs occurred broadly between the California Current and nearshore waters and were most abundant between Point Conception and Monterey Bay, although they also occurred on the southern- and northernmost lines. Anchovy eggs were confined to the Southern California Bight, and jack mackerel eggs were offshore of the sardine eggs, with relatively little overlap. Overall, sardine eggs were far more abundant than anchovy or jack mackerel eggs, but peak abundances were less in spring 2002 than in the prior two springs and in the spring of 2003 (preliminary; for more information, see http://swfsc.nmfs.noaa.gov/FRD/CalCOFI/CurrentCruise/currentcruise.htm).

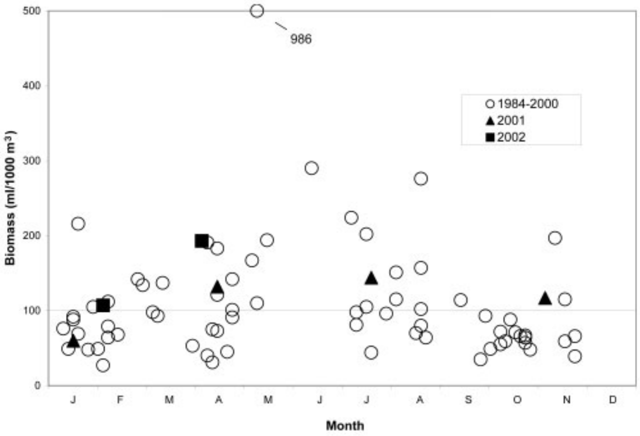

Figure 23. CalCOFI cruise mean macrozooplankton biomasses. Biomass values observed in 2001, 2002, and February 2003 compared with those observed since 1984.

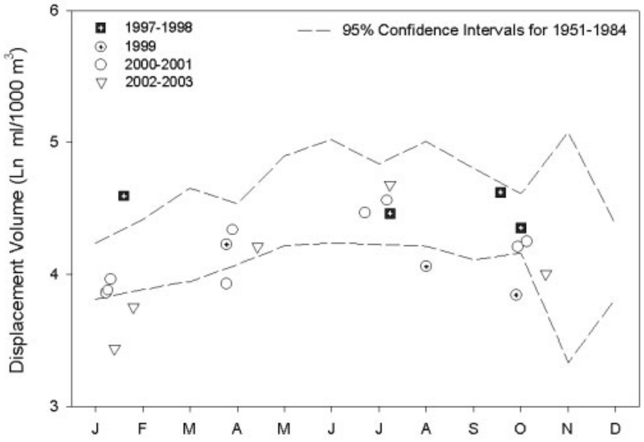

Figure 24. Mean macrozooplankton biomass of 21 IMECOCAL cruises from September 1997 to February 2003. Dashed lines indicate 95% confidence intervals for the historical mean of 1951–84 for the CalCOFI cruises in the region off Baja California. Data have been transformed to logarithms.

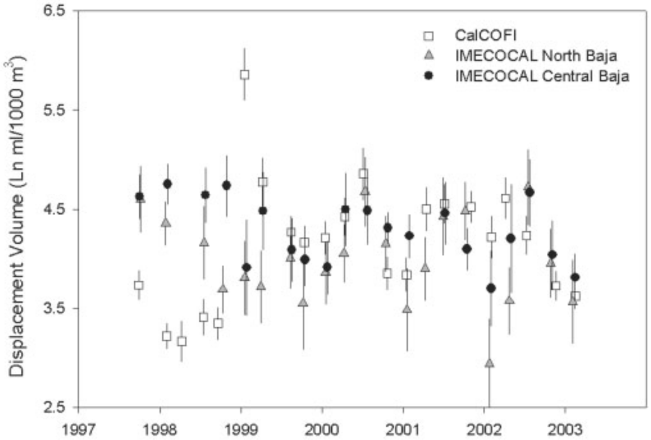

Figure 25. Mean macrozooplankton biomass in three regions of the California Current: Southern California (lines 80–93), northern Baja California (lines 100–110), and central Baja California (lines 113–133).

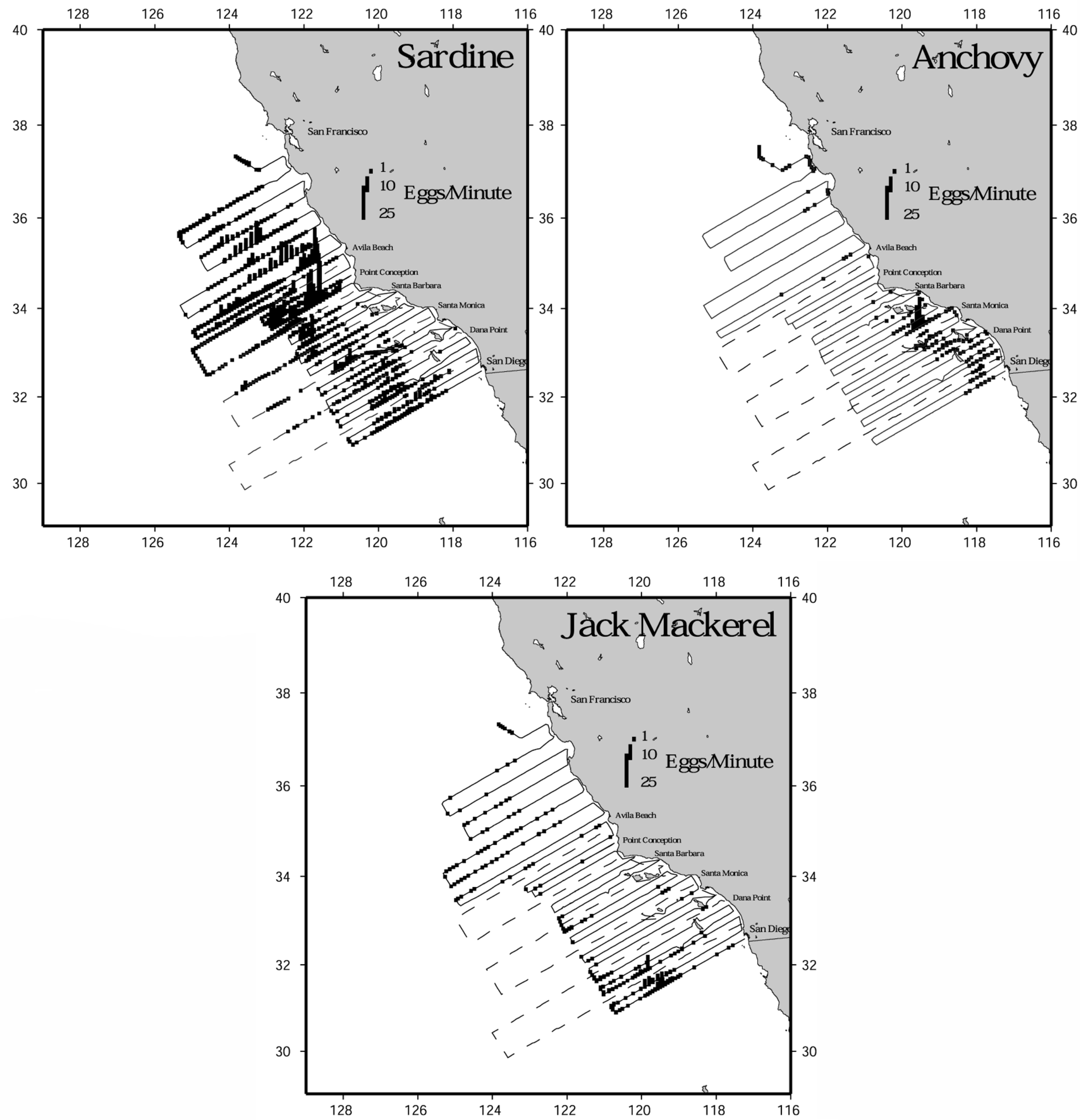

Figure 26. Rate of occurrence of eggs of Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), and jack mackerel (*Trachurus symmetricus*) sampled with the continuous underway fish egg sampler (CUFES) in April-May 2003. Dashed line represents RV *New Horizon* cruise; solid line represents RV *David Starr Jordan* cruise. One egg per minute corresponds to approximately 1.4 eggs per cubic meter.

Avifauna

In this report we describe observations of marine bird populations collected during 2002–2003 and compare these observations to data from the CalCOFI and PRBO time series. Our objective is to assess the response of marine bird communities off the west coast of North America to the 2002–2003 El Niño event and to interpret these short-term fluctuations within the context of the hypothesized 1998–99 shift to a cold-water regime (Bograd et al. 2000; Durazo et al. 2001; Schwing et al. 2002a). Observations of marine bird populations provide information on the response of upper-trophic preda-

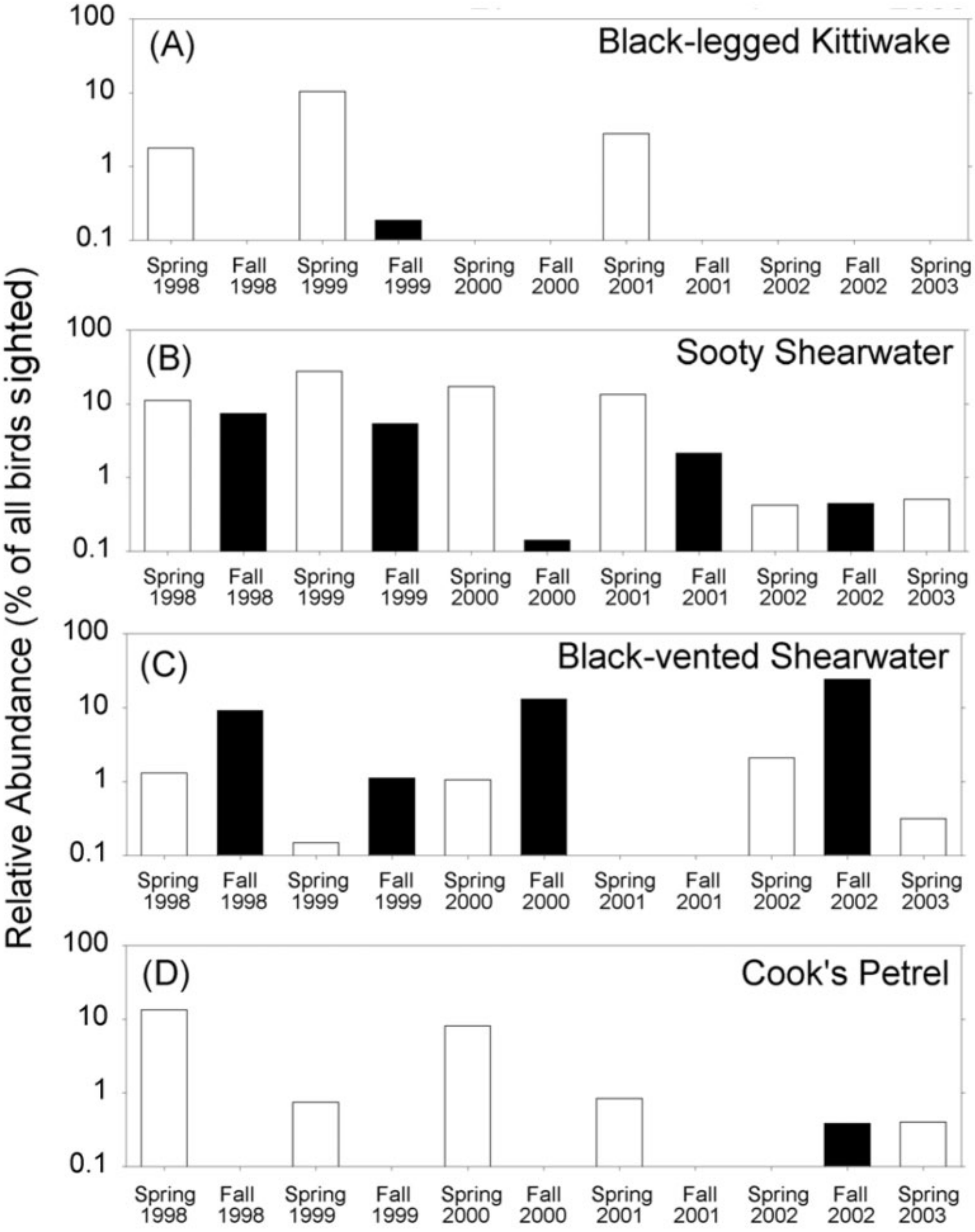

Figure 27. Relative abundance of four indicator seabirds with an affinity for distinct water temperature and biogeographic domains: (*a*) and (*b*) subarctic/cold water taxa, (*c*) and (*d*) subtropical/warm-water taxa. Importance was computed by dividing the number of individuals of a given species by the total number of seabirds sighted during each cruise. The white histograms depict spring cruises, and the black, fall cruises.

tors to interannual and longer-term oceanographic variability. Previous CalCOFI observations have documented fluctuations in seabird community structure in response to changes in the physical and biological properties of the California Current system (Veit et al. 1996; Hyrenbach and Veit 2003). Colony-based studies of seabird diet, demography, and population dynamics underscore the conclusions of at-sea surveys. These time series have revealed that locally breeding bird populations are sensitive to shifts in ocean productivity and prey availability over short (interannual) and long (decadal) temporal scales (Ainley et al. 1995; Sydeman et al. 2001; Abraham and Sydeman, in press).

To examine short-term (interannual) fluctuations in the composition of marine bird communities at sea, we describe changes in the relative abundance of four species with different water mass preferences and biogeographic affinities (fig. 27). The subtropical black-vented shearwater (*Puffinus opisthomelas*) shifts its distribution northward into the CalCOFI study area in the fall, particularly during warm-water years. The Cook's petrel (*Pterodroma cooki*) is a pelagic spring-summer visitor that moves shoreward during warm-water periods and has increased significantly in abundance off southern California between 1987 and 1998. The once numerically dominant cold-water species, the sooty shearwater (*Puffinus griseus*), is a spring-fall visitor that has declined by 74% between 1987 and 1998. Finally, the black-legged kittiwake (*Rissa tridactyla*) is a subarctic winter visitor that becomes more numerous during cold-water years, particularly in spring (Lynn et al. 1998; Hayward et al. 1999; Hyrenbach and Veit 2003).

Surveys of marine bird communities at sea between the fall of 1998 and the spring of 2003 failed to detect clear and persistent signals of a shift to a cold-water regime. After the transition from one of the strongest El Niño events in the twentieth century to La Niña conditions in the summer and fall of 1998, 1999 was characterized by a prolonged period of cool water and enhanced upwelling along the west coast of North America (Hayward et al. 1999; Bograd et al. 2000; Schwing et al. 2000). The two cold-water indicators (black-legged kittiwake and sooty shearwater) occurred off southern California in high numbers during 1999. The kittiwake reached its highest relative abundance (approximately 10% of all birds sighted) in the spring of 1999, when the sooty shearwater accounted for over 27% of all birds observed (fig. 27a,b). Interestingly, the kittiwake was also observed in the fall of 1999, a period when the subtropical black-vented shearwater had almost completely vanished from the region (fig. 27c).

However, during the spring cruise of 2000, we observed no kittiwakes and fewer sooty shearwaters compared with their relative contribution during 1999 (fig. 27a,b). Additionally, there was a rebound in the importance of the two warm-water species, to levels similar to those observed during the spring of 1998 (fig. 27c,d). The return to a warm-water avifauna was particularly evident in the fall of 2000. At this time, the black-vented and the sooty shearwater accounted for 13% and < 1% of all the birds sighted, respectively (fig. 27b,c).

During 2001 and 2002, persistent moderate to strong (1–4°C) negative SST anomalies were observed off the west coast of North America (El Niño Watch January 2001–December 2002 advisories, http://coastwatch.pfel.noaa.gov/elnino.html) (fig. 4). Once more, the avifauna responded to these new oceanographic conditions, and a shift toward a cold-water community was evident by spring 2001. At this time, the combined relative contribution of the two warm-water indicators declined to < 1% of all the birds sighted, whereas the importance of the sooty shearwater and the kittiwake increased but remained below the number observed during 1999 (fig. 27a,b). The fall cruise revealed a bird community dominated by phalaropes (*Phalaropus* spp.) and devoid of warm-water indicators (fig. 27c,d).

Starting in the fall of 2002, positive temperature anomalies developed offshore (west of 125°W; fig. 4). Subsequently, anomalously warm water (1–2°C) was apparent along the southern California coast and off Oregon and central California starting in December 2002 (fig. 4; El Niño Watch January 2002–March 2003 advisories, http://coastwatch.pfel.noaa.gov/elnino.html). The fall CalCOFI cruise revealed a large northward incursion of the subtropical black-vented shearwater, which accounted for ~25% of sightings (fig. 27c). The other warm-water indicator, the Cook's petrel, was also observed in large numbers at this time, when it reached the highest fall-time relative abundance since 1997. Notably, conditions during spring 2003 were indicative of a transitional community with both warm-water and cold-water indicator species present but numerically dominated by phalaropes and other spring migrants.

In contrast to the fluctuating seabird communities at sea, marine birds at the Farallon Islands, central California (37°N), revealed record high reproductive success in 2002 (fig. 28). In particular, mean annual productivity reached the highest value in the entire 30+ year time series for the Cassin's auklet (*Ptychoramphus aleuticus*), 1.18 chicks fledged per breeding pair; pelagic cormorant (*Phalacrocorax pelagicus*), 2.59 chicks fledged per breeding pair; and pigeon guillemot (*Cepphus columba*), 1.46 chicks fledged per breeding pair. In fact, when all six breeding species are considered, 2002 represents the fourth consecutive year of positive seabird anomalies. Notably, this period of high and sustained Farallon seabird productivity started after the hypothesized regime shift of 1998–99 (tab. 2).

To further consider whether seabird demography is indicative of a new cold-water regime, we compared annual seabird productivity values during the warm-water (1990–98) and cold-water (1999–2002) periods before and after the 1998–99 regime shift (tab. 2). The seabird productivity data from 2002 supports the preliminary evidence of enhanced seabird productivity after 1998 (see also Durazo et al. 2001; Schwing et al. 2002a). In particular, the breeding-success data revealed significant increases in the productivity of four species (Cassin's auklet, pelagic cormorant, pigeon guillemot, and rhinoceros auklet [*Cerorhinca monocerata*]), and the marginally significant ($0.10 < p < 0.05$) increase in the reproductive success of the Brandt's cormorant (*Phalacrocorax penicillatus*). For the common murre (*Uria aalge*), we did not detect a significant increase in productivity starting in 1999.

In order to evaluate the impact of the developing 2002–2003 El Niño on seabird productivity patterns we reanalyzed a hierarchical clustering analysis of the seabird productivity data between 1990 and 2001, including data

TABLE 2
Comparison of the Productivity of Six Seabird Species Breeding at the Farallon Islands (off Central California), in Conjunction with the 1998–99 Regime Shift

	Productivity (chicks fledged/pair)				
Seabird species	1990–98	1999–2002	Proportional change (%)	Mann-Whitney U	*p* value
Brandt's cormorant	1.38 (±0.93)	2.17 (±0.20)	+57	6	0.064
Cassin's auklet	0.62 (±0.24)	0.97 (±0.17)	+56	2	**0.013**
Common murre	0.66 (±0.27)	0.81 (±0.02)	+22	14	0.531
Pelagic cormorant	0.54 (±0.64)	1.84 (±0.69)	+239	2	**0.013**
Pigeon guillemot	0.54 (±0.38)	1.28 (±0.15)	+138	2	**0.013**
Rhinoceros auklet	0.48 (±0.16)	0.63 (±0.02)	+32	4.5	**0.037**

Note: Numbers in parentheses are mean standard deviation. The proportional change in seabird productivity was quantified as PC = 100% * [(after) − (before) / (before)]. Positive and negative PC values indicate increasing and decreasing productivity, respectively. Boldfacing denotes statistical significance.

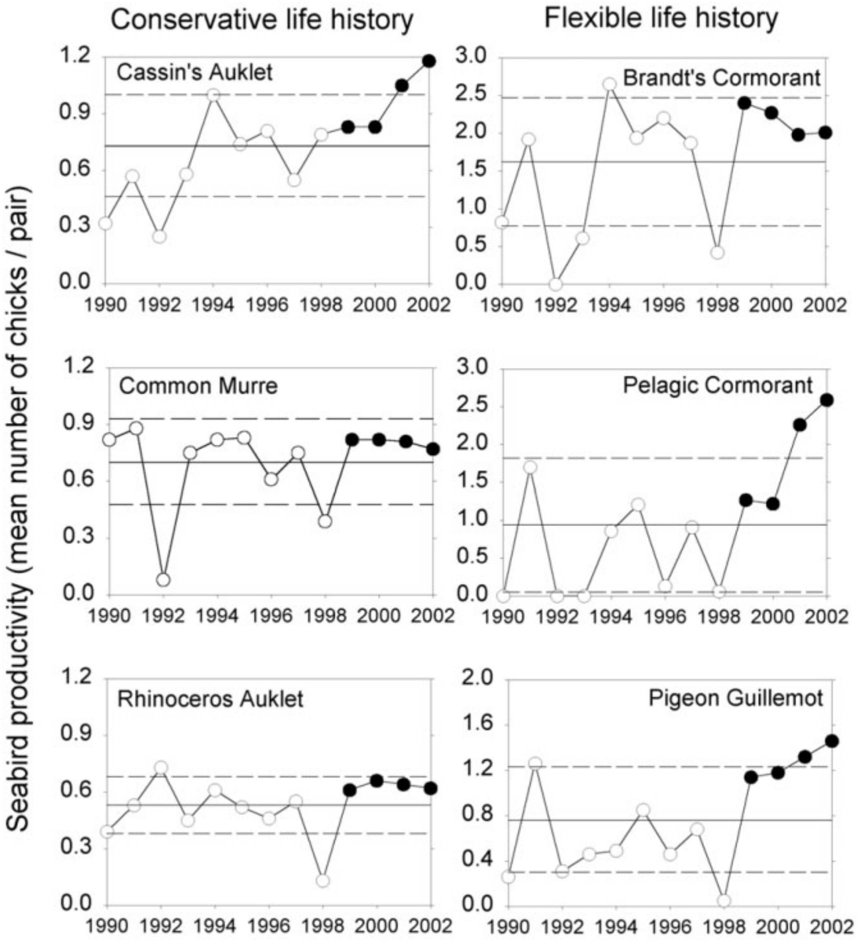

Figure 28. Anomalies of productivity for six seabird species breeding at southeastern Farallon Island (central California). Solid horizontal lines represent long-term averages (1990–2002); hatched lines represent the variability (mean ±SD); solid dots highlight productivity anomalies after the hypothesized regime shift during the winter of 1999.

from the 2002 breeding season. The previous analysis revealed three distinct clusters of years, corresponding to time periods of high, intermediate, and low productivity, respectively (Schwing et al. 2002a). The reanalysis indicated that 2002 was somewhat of a peculiar year between the intermediate productivity (2 years: 1994 and 1996) and the high productivity (6 years: 1999–2001, as well as 1991, 1995, and 1997) clusters. Interestingly, while three species yielded the highest productivity values in the time series, the reproductive success of the common murre declined slightly to 0.77 chicks fledged per breeding pair (fig. 28). This is within the normal range of variation found for this species.

Also, we evaluated changes in the chick diet compo-

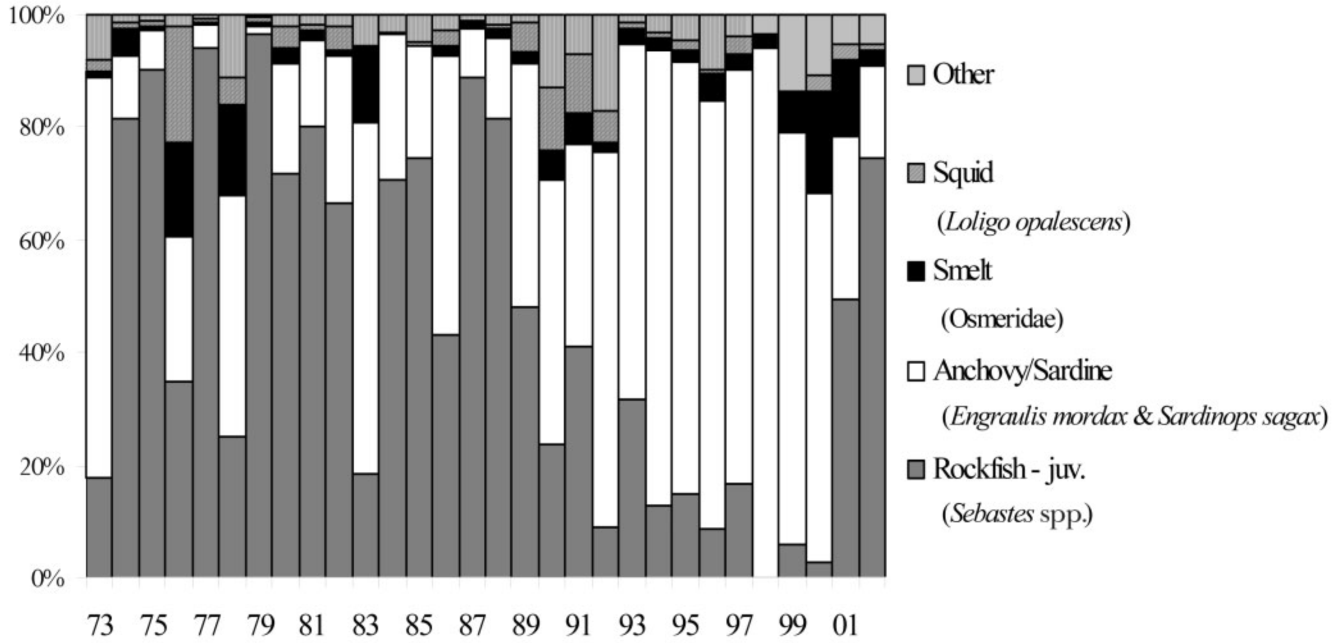

Figure 29. Interannual diet composition of common murre chicks at SE Farallon Island (central California, 1973–2002), based on the number of prey items of each species consumed. The "other" category includes Pacific butterfish (*Peprilus simillimus*), juvenile salmon (*Oncorhynchus* spp.), flatfishes (*Bothidae* and *Pleuronectidae*), juvenile lingcod (*Ophiodon elongatus*), señorita (*Oxyjulis californica*), and other fish species comprising less than 5% of the diet in any given year.

sition for the common murre from 1973 to 2002 (fig. 29). These data are indicative of a decline in the take of rockfish (*Sebastes* spp., mostly *Sebastes jordani*) by murres and other breeding seabird species after 1989 (Sydeman et al. 2001). However, starting in 2001 and continuing in 2002, there was an increase in the proportion of rockfish in the murre diet. In 2002, approximately 74% of the chick diet was composed of juvenile rockfish, a level comparable to those observed in 1987–88. The murre diet is indicative of changes in the abundance of young-of-the-year (i.e., 0-age-class) rockfish in the Gulf of the Farallons and adjacent waters (Sydeman et al. 2001). Indeed, midwater trawl surveys conducted by NOAA Fisheries in the vicinity of the Farallon Islands in 2002 documented an increase in juvenile rockfish abundance over the preceding years,[3] thereby corroborating the conclusions drawn from the study of diets of breeding seabirds.

Together these results strongly suggest that the Farallon Island ecosystem has responded to the 1998–99 regime shift, with four consecutive years of elevated seabird productivity across the board, and the recovery of one of the bird's primary prey resources, juvenile rockfish. It is worth noting, however, that seabird reproductive success during the 2002 breeding season appeared intermediate between the conditions characteristic of high and intermediate productivity years (Schwing et al. 2002a). Namely, while some species reached the highest productivity levels recorded to date, others declined slightly (fig. 28). We note that the sooty shearwater, a transequatorial migrant that dominated the avifauna in the late 1980s, has yet to recover. Modeling studies of prey consumption and energetic requirements may provide insights into the shearwater's numerical response to changing ocean climate and prey availability in the California Current system.

Colony-based and at-sea observations during 2002–2003 have provided additional evidence that marine birds respond to short-term (interannual) and longer-term (decadal) changes in the conditions of the California Current system. However, locally breeding populations and at-sea communities differ in the magnitude and persistence of their responses.

DISCUSSION

Three large-scale events claimed the attention of West Coast oceanographers between April 2002 and April 2003: the anomalous intrusion of subarctic water, the predicted El Niño, and the possible interdecadal climate shift in 1998–99. All of these interacted in some way or another, and interpreting the various signals is not certain.

The anomalous intrusion of cold, fresh water was clearly seen from the Gulf of Alaska to the latitude of southern California. It was not evident from the IMECOCAL surveys. It may have lost its unique characteristics by these latitudes or occurred offshore of the survey area. The intrusion was characterized by elevated nutri-

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[3] Mills, K. L., S. R. Ralston, T. Laidig, and W. J. Sydeman. Functional response curves and the use of top predator diet as indicators of pelagic juvenile rockfish (*Sebastes* spp.) abundance in the California Current system. (manuscript)

ent levels and upwelling of these waters off Oregon and northern California and resulted in enhanced chlorophyll concentrations. A similar impact further south was not noticed. The effects of this intrusion were opposite those of the predicted El Niño and appeared to dominate conditions, at least in the northern portion of the region. As of the most recent cruises (April 2003) the feature was still present off Oregon and Southern California. Further development and dissipation of this cold, fresh anomaly will be closely followed.

The effects of the El Niño that developed in the California Current system last winter were short-lived and modest by most standards. The event was marked by increased SSTs throughout the region in late winter, but these rapidly cooled in the spring. The influence of El Niño was most clearly seen in the biological characteristics. Chlorophyll concentrations were reduced in February 2003 in the CalCOFI region (fig. 22). Macrozooplankton volumes were low in February 2003 in both CalCOFI and IMECOCAL regions (fig. 25).

The most apparent response to this El Niño event in our biological data appeared in seabird communities at sea. The avifauna has shifted from year to year in response to transient warming and cooling periods since the spring of 1998, with a series of short-term incursions of subarctic taxa and subtropical species (fig. 27). Starting in the second half of 2002, we observed changes in seabird communities that were consistent with the onset of El Niño conditions. By the fall of that year, the avifauna was dominated by warm-water indicators, like the black-vented shearwater (fig. 27c). The northward incursions of subtropical species were particularly apparent during the spring of 2003, when brown boobies (*Sula leucogaster*), black storm-petrels (*Oceanodroma melania*), and least storm-petrels (*O. microsoma*) were recorded off southern California. Large numbers of these species have not been observed within the CalCOFI study area since the 1997–98 El Niño event (Hyrenbach and Veit 2003).

This was the first winter in five years with warm surface waters in the California Current system (fig. 4). The rapid breakdown of El Niño conditions in our waters and the evidence for a La Niña to develop next year strengthen the possibility that an interdecadal climate shift took place in 1998–99. Of the biological data under consideration in this report, the avifauna provide the strongest evidence for a corresponding "regime shift." Because seabird populations integrate the variability in oceanographic conditions during the breeding season, productivity metrics respond strongly to interannual changes in ocean conditions and prey availability (Ainley et al. 1995; Sydeman et al. 2001). The productivity data from the Farallon Islands indicate that locally breeding seabird populations have undergone four consecutive years of elevated reproductive success across the board (fig. 28). This change in seabird productivity suggests that breeding populations have benefited from enhanced upwelling and ocean productivity after the 1998–99 regime shift (tab. 2). Nevertheless, we have yet to observe the recovery of the sooty shearwater, a transequatorial migrant that dominated the avifauna in the late 1980s, in response to the switch to a cold-water period. Modeling studies of prey consumption and energetic requirements may provide insights into the shearwater numerical response to changing ocean climate and prey availability in the California Current system.

Additional at-sea and colony-based observations are needed to fully characterize and understand the response of marine bird populations to ocean climate variability in the California Current system. As with all ecosystem components, we are faced with the challenge of reconciling range shifts with local population changes in productivity and mortality.

The evolution of the La Niña conditions currently developing in the tropical Pacific Ocean (NOAA Climate Prediction Center, ENSO Diagnostic Discussion, http://www.cpc.ncep.noaa.gov) will set the stage for 2004. Understanding the coupling of high-frequency (i.e., ENSO) and low-frequency (i.e., PDO) environmental variability will require continued time series of physical and biological properties. Once more, the dynamic nature of the California Current system underscores the value of prolonged time series when interpreting short-term and long-term changes in marine ecosystems (McGowan 1990).

ACKNOWLEDGMENTS

Nearly all of the data discussed here was collected the hard way and would not have been collected at all without the seagoing scientists and technicians who spent long, cold, wet hours doing so, or the ships' captains and crews who took us where we needed to go and kept us safe. We are indebted to them all. Christine Abraham and Peggy Yen (PRBO) compiled the seabird productivity and at-sea data, respectively. Pete Warzybok and Russell Bradley (PRBO) supervised collection of Farallon seabird data in 2002. Phaedra Green-Jessen and Mark Pickett assisted PFEL in preparing figures.

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APPENDIX

This appendix contains a selection of e-mail correspondence concerning an anomolous intrusion of subarctic waters. Correspondence is among Jane Huyer (Oregon State University), Curtis Collins (Navy Postgraduate School), Ronald Lynn (Southwest Fisheries Science Center/National Marine Fisheries Service), Howard Freeland, Frank Whitney (Institute of Ocean Sciences), Steven Bograd (Pacific Fisheries Environmental Laboratory/NMFS), and Arnold Mantyla (SIO). Correspondence was edited lightly for brevity and clarity.

——-Original Message——-
From: Jane Huyer
Sent: Monday, 05 Aug, 2002 11:55 AM
Subject: cold halocline off Oregon
Colleagues,

Attached is a postscript file containing a set of three T-S diagrams for our standard station NH-25 that is 25 nm west of Newport, Oregon. The remarkable conclusion is that the halocline (S between 32.4 and 33.8) observed off central Oregon on 9–10 July 2002 is nearly one degree Celsius lower this year than it has been in the three previous summers. It is at the lower limit of halocline temperatures in all of our previous observations including the cold years (1972 and 1973) of the Coastal Upwelling Experiments CUE-1 and CUE-2. In the salinity range of 33.0 to 33.6, the halocline is colder than we have ever observed at this location.

This permanent halocline provides most or all of the water that upwells along the coast of central Oregon. The cold halocline extends offshore at least to NH-85, the most offshore of our standard stations, 85 nm west of Newport. Since this water is both fresher and colder than normal, we do not (and would not expect to) see anomalous values of steric height. These T-S diagrams indicate stronger subarctic influence than normal, suggesting either increased advection from the north, or that the subarctic source was colder than normal.

We are wondering if any of you have seen similar anomalies elsewhere off the west coast of North America.

From: Curtis Collins
Sent: Wed, 07 Aug, 2002 10:48 AM
Jane,

I don't think that we have seen these kinds of changes in the coastal area yet. The change that we have seen that is probably related to what you are seeing is offshore in the "California Current" area. Beginning last December, the subducted surface waters showed a pronounced salinity minimum, with values as low as 31.8 or so. The subduction might be related to the low temperatures that you are seeing.

From: Frank Whitney
Date: Wed, 7 Aug 2002 15:37:16
Jane:

I see colder halocline temperatures also off the southern BC coast. I quickly checked back to 1989 and find this is the coolest water we have seen in spring over the past decade. Line P data for these years is on our web site,

http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/linepdata/default.htm

but not quite yet for July 2002. Also, nitrate levels (vs. salinity) are higher in this water, a distinct marker of subarctic rather than subtropical waters.

Just preparing to head out on Line P again. I'll be looking for this feature as we head offshore.

To: Ron Lynn
Date: Thu, 08 Aug 2002 15:52:59 -0700
From: Arnold Mantyla

That's a neat plot from Adriana, it looks like the type of T/S curve that you see much further north, so it looks like a stronger influx from the subarctic.

On our last CalCOFI [cruise], we had 2 stations on line 80 (90 and 80) that had a lower than usual salinity minimum, about 32.75 at about 12 degrees or a little less.

neat!

Date: Wed, 07 Aug 2002 13:47:34
From: Ron Lynn
Jane,

The crew on the July CalCOFI survey say that temperatures were, for the most part, a quarter to a half degree C below the ltm over a broad area. Some response was expected from the unusually strong upwelling off central CA. See the El Niño Watch, http://cwatchwc.ucsd.edu/cgi-bin/elnino.cgi.

From: Howard Freeland
Date: Wed, 07 Aug 2002 19:05:03

I pulled all of the files in the Institute of Ocean Sciences data library from station MP3 observed in June or July [deleting duplicates close in time]. The attached TS plot on a gif file shows the result. Clearly the observations this year are outside of all previous experience.

From: "Collins, Curtis"
Date: 13 Aug 2002 21:09:39. 0329 (UTC)

Here is a T/S plot for a station at the entrance to Monterey Bay. There are no effects yet at this inshore station from the cooling of the halocline off Oregon. Regards.

Date: Thu, 15 Aug 2002 17:23:13
From: Steven Bograd
Hi Jane et al.,

Following up on Ron Lynn's plot, I am attaching a PDF showing a T-S scatter for CalCOFI station 80.90, all summer (Jul-Sep) profiles for 1984–99 (bottles), and July 2002 marked green. This is clearly a well-confined feature (seen only at stations 80 and 90 on line 80, and between 60–90 m), although it's remarkable that it shows up clear to Line P.

We know 80.90 also had an anomalously high O2 content at this depth as well. Perhaps we should check with Reggie Durazo and the IMECOCAL lines?

From: Howard Freeland
Date: Fri, 16 Aug 2002 13:57:54

I think the pictures from Steven Bograd and Ron Lynn are remarkable. They are very similar to what we have seen on line P and Jane is seeing off Newport. The big question in my mind is, why is it not being seen in the MBARI data?

Date: Fri, 16 Aug 2002 11:07:11
From: Jane Huyer

Howard et al.,

I'm pretty sure that Curt's data from the Monterey area is too close to the coast for the phenomenon to be manifest there. Steve Bograd's CalCOFI station 80.90 lies about 300 km offshore. This fits my conceptual image of the California Current lying near shore off Washington and Oregon, migrating offshore between Cape Blanco (at 43°N) and Point Reyes (at 38°N), and lying offshore off central and southern California.

For a "typical best example" of shape of California Current, you might want to take a look at 15-m drogued drifter trajectories at:

http://diana.coas.oregonstate.edu/drift/recent/fixes-2001-07.html

Further examples can be found at http://ltop.coas.oregonstate.edu

Date: Mon, 19 Aug 2002 07:58:13
From: Ron Lynn

Not mentioned before are the two CalCOFI stations (80.70 & 80.100) that lie either side of the low-salinity plug. They have a definite high salinity bias from 75 to 150 or 200 m. Does that show up elsewhere?

From: Howard Freeland
Date: Mon, 19 Aug 2002 11:12:09

Along Line-P there seemed to be a low-salinity anomaly associated with the low-temperature anomaly. I think it is evident in these two anomaly plots.

From: Frank Whitney
Date: Tue, 20 Aug 2002 11:26:08

Marie Robert has plotted July line-P data (Howard previously plotted T anomaly) for T, S, and sigma-t anomalies. Results show that waters underlying the mixed layer (salinity 32.6–33.9) in the southern Gulf of Alaska are distinctly cold, fresh, and light. As I pointed out earlier, these waters are relatively LOW in oxygen (not high as might be expected for cold waters) and high in nutrient at our shelf station (P4) compared with data collected in the past decade. This indicates that we are seeing waters of stronger subarctic character off the BC coast.

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Part II

SCIENTIFIC CONTRIBUTIONS

INFLUENCE OF WATER COLUMN STRATIFICATION ON THE DEPTH DISTRIBUTIONS OF PELAGIC JUVENILE ROCKFISHES OFF CENTRAL CALIFORNIA

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ABSTRACT

We examined the vertical distribution of pelagic juveniles in 15 species of rockfishes off central California. In depth-stratified midwater trawls made at night, pelagic juveniles of most species were equally distributed throughout the water column. Notable exceptions were *Sebastes paucispinis*, which was significantly more abundant in 10 m and 30 m tows, and *S. melanops*, *S. entomelas*, and *S. mystinus*, which were common in 100 m tows though not significantly so. All species were collected mainly below the thermocline, but thermocline depth was a poor predictor of the vertical distribution of pelagic juveniles. Increased stratification of the water column, however, led to a tendency for deeper centers of density for most species (13 of 15), and smaller rockfishes (≤25 mm standard length) occurred primarily below the thermocline. In the presence of weak or gradual thermoclines, Simpson's (1981) parameter of water column stratification may be a better measure of overall water column characteristics than thermocline depth alone, and it may be a better indicator of the effects of water column characteristics on the distribution of pelagic juvenile rockfishes. The patterns indicated by our data suggest that it would be worthwhile to further examine the effects of ontogeny and hydrography on the vertical distributions of pelagic juvenile rockfishes.

INTRODUCTION

While the effects of coastal oceanographic features and the horizontal distributions of the early life stages of fishes have been studied extensively (Kingsford and Choat 1986; Grimes and Finucane 1991; Cowen et al. 1993; Sabatés and Olivar 1996), comparatively little attention has focused on their influence on vertical distributions. Knowledge of vertical distribution of early life stages, however, is essential to understanding the interactions between oceanographic and biological processes. For example, pelagic early life stages of fishes may exhibit behavioral strategies that help them either to remain in, or to be transported to, favorable areas. A combination of vertical migration and vertically structured ocean processes may provide a mechanism for avoidance of passive larval drift, resulting in increased larval retention, survival, and recruitment (Sinclair 1988; Bakun 1996).

Interactions between active vertical migration (Parrish et al. 1981; Moser and Boehlert 1991), stage of development (Larson et al. 1994; Sakuma and Larson 1995), and physical transport mechanisms may affect the onshore/offshore distributions of the pelagic early life stages of fishes in the upwelling regions of the California Current system. Studies of vertical distribution in these upwelling areas suggest that the depth distributions of rockfish larvae in particular are directly related to water column stratification, with the lower depth limit of larvae being bound by either the depth of the thermocline (Ahlstrom 1959; Moser and Boehlert 1991) or the pycnocline (Sakuma et al. 1999). Lenarz et al. (1991) found no evidence of a relationship between thermocline depth and the vertical distributions of pelagic juvenile rockfishes off central California. However, the data of Shenker (1988) and Doyle (1992) indicate that pelagic juvenile stages may occur shallower in the water column than larvae, suggesting that responses to depth and to the thermocline may vary with ontogeny.

This article employs a long-term data set collected by the National Marine Fisheries Service, during May-June cruises from 1987 to 1998 to investigate the depth distributions of pelagic juvenile rockfishes in relation to hydrography. Specifically, we describe the vertical distributions of pelagic juvenile stages of fifteen *Sebastes* species relative to the stratification of the water column.

METHODS

The California Current system off central California is strongly influenced by seasonal, wind-driven upwelling (Hickey 1979) and associated filaments and eddies (Mooers and Robinson 1984). A strong upwelling center occurs at Point Reyes and a weaker one at Davenport, north of Monterey Bay (Schwing et al. 1991). Filaments from these centers carry upwelled water far offshore and to the south, forming frontal boundaries with warmer, less saline water masses (Mooers and Robinson 1984;

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Schwing et al. 1991). Filaments intermingled with synoptic mesoscale eddies may provide significant cross-shelf transport of heat, nutrients, and biota (Mooers and Robinson 1984).

Data Collection

The National Marine Fisheries Service conducts annual May-June midwater-trawl surveys of pelagic juvenile fishes between Cypress Point (36°35'N) and Point Reyes (38°10'N). A set of stations is sampled during ten-night sweeps of the survey area using a modified Cobb midwater trawl with a nominally square 14 m by 14 m mouth and a 9.5 mm stretched mesh cod-end liner (Wyllie Echeverria et al. 1990). Three replicate sweeps are typically completed from mid-May to mid-June of each year. We used data from trawls at the four most consistently sampled depth-stratified stations to investigate species' depth preferences (see fig. 1). Because target depths varied over the years, catches were divided into three depth categories, 10 m (6 and 8 m target depth tows), 30 m (30 and 32 m target depth tows), and 100 m (80 and 110 m target depth tows). Since 1993, a Vemco TDR (time-depth recorder) was attached to the upper bridle of the net and recorded the depth of each tow. The net was lowered to the target depth and towed at a ship speed of approximately 5 km/hr for 15 min, as described by Lenarz et al. (1991).

Conductivity-temperature-depth (CTD) casts were made using a Sea-Bird Electronics SEA-CAT-SBE-19 profiler at each trawl station to obtain temperature, salinity, and density information at depth.

Pelagic juvenile *Sebastes* were collected, identified, counted, and frozen at −80°C aboard the research vessel. In the laboratory, standard length (SL) was measured to the nearest mm for either all individuals of each species or a subsample of 100 fish per tow of each species.

Data Analysis

Acoustic measurements indicate that the mouth width of the Cobb midwater trawl changes with depth. Width varies from 8 m at a depth of 10 m, to 11 m at 30 m depth, and 13.5 m at 100 m depth (Lenarz at al. 1991). We adjusted catch abundances for mouth width prior to analysis by multiplying the 10 m depth trawls by 1.375 (11/8) and 100 m depth trawls by 0.8148 (11/13.5); we did not adjust 30 m depth trawls. We log transformed adjusted species abundances (abundance +1) to normalize the data and equalize variances. Because of high variability of towed net sampling, we present data results at both the 0.05 and 0.10 significance levels.

We examined within-station differences in species' abundances due to year, depth, and year*depth interactions using a two-factor, repeated-measures analysis of variance (ANOVA). For this analysis, catches for each species were averaged within depth categories for each station and year because not all depths at a station were sampled in each sweep and we needed a complete data matrix to perform the statistical analysis. As a result, the average catch at each station and depth, while typically based on three data points, was sometimes based on one or two data points. We considered year and depth as experimental treatments. We performed all *F*-tests under the assumption of multivariate normality and adjusted probability values for violations of the assumption of compound symmetry using the Huynh-Feldt epsilon (O'Brien and Kaiser 1985; Athey and Connor 1989).

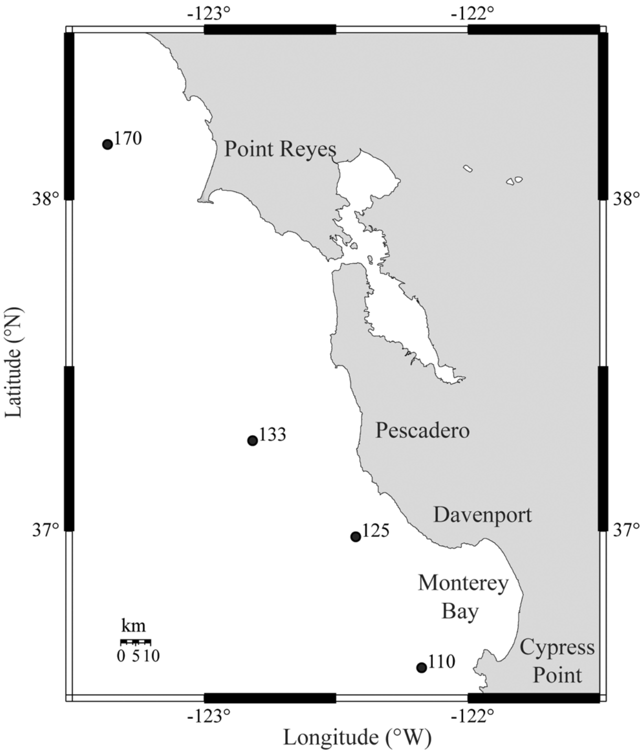


Figure 1. Location of four stations with depth-stratified tows sampled during May–June cruises, 1987–98, and included in the repeated measures analysis of variance.

We compared the vertical distribution of each species to the depth of the thermocline by subtracting the mean depth of catch from the depth of the thermocline at each of the four stations (Sakuma et al. 1999). We refer to this as the *depth of catch relative to the thermocline* (DCRT). We carried out this analysis for stations at which all three depth strata were sampled and at which the species was captured in at least one depth stratum. We calculated the mean depth of each species as the center of density:

$$Z = \sum_{i=1}^{n} P_i Z_i,$$

where Z_i is the depth of the *i*th sample, and P_i is the proportion of pelagic juveniles at depth *i* (Fortier and Leggett 1983).

TABLE 1
Standardized Catches and Lengths (mm SL) of Pelagic Juvenile Rockfishes Collected at Depth-Stratified Stations off Central California During May–June Cruises, 1987–98

	10 m tows			30 m tows			100 m tows		
Species	Catch	Length range	Length mode	Catch	Length range	Length mode	Catch	Length range	Length mode
Sebastes auriculatus	369	12–34	16	89	16–39	17	10	14–32	19
S. crameri	38	12–53	ND	15	18–52	ND	3	19–41	41
S. entomelas	356	27–81	62	529	20–73	34	320	25–66	53
S. flavidus	96	16–52	15–83	60	26–50	ND	36	31–50	ND
S. goodei	3,280	15–83	60	2,526	10–80	57	56	14–69	50
S. hopkinsi	707	17–64	50	1,076	16–62	53	87	19–59	48
S. jordani	46,925	8–81	73	111,251	9–82	67	2,831	9–83	68
S. levis	17	22–57	50	7	15–62	ND	1		48
S. melanops	10	31–46	ND	23	23–44	41	12	21–44	38
S. mystinus	239	39–63	48	196	23–55	43	239	29–60	49
S. paucispinis	352	13–110	48	134	14–107	47	19	23–83	24
S. pinniger	202	16–38	34	200	15–39	33	178	14–39	33
S. rufus	105	34–56	51	10	39–60	52, 54	3	46–53	51
S. saxicola	293	21–45	35	191	23–52	34	23	22–44	34, 37
S. wilsoni	59	27–36	32	44	14–38	30	14	28–36	34
Overall	53,048	8–110	73	116,358	9–107	67	3,832	9–83	68

Note: Catches adjusted for net width at depth. ND denotes no discernable mode.

We defined station thermocline depth as the depth of maximum change in temperature (ΔT). We addressed the question of whether this represented a "true" thermocline by comparing a measure of water column stratification, ϕ (Simpson 1981), to our estimated thermocline depths. A highly significant Spearman rank correlation between ΔT and ϕ supports our definition ($r_s = 0.513$, $p = 0.000$, $n = 120$). We calculated the stratification parameter, ϕ, the amount of work per unit volume (J/m^3) required to bring about vertical redistribution of the mass in complete mixing, as

$$\phi = 1/h \int_{-h}^{0} (\overline{\rho} - \rho) gz dz,$$

where

$$\overline{\rho} = 1/h \int_{-h}^{0} \rho z dz,$$

h = depth of CTD cast (m),

ρ = density (kg/m^3),

$g = -9.8$ (m/s^2), and

z = depth (m),

using the density data over the depth of the CTD cast or 150 m, whichever was the least.

To determine if the depth of the thermocline had a direct influence on vertical distribution, we calculated the mean depth of catch relative to a fixed depth of 20 m (DCR20) and compared the variances with those of the DCRT (Sakuma et al. 1999).

We investigated the role of thermocline strength in determining species' depth distributions by regressing the mean depth of catch against water column stratification, ϕ, at the same station. We assume that the stratification parameter is a good proxy for the strength of the thermocline (pycnocline and thermocline depths were highly correlated, $r_s = 0.816$, $p = 0.000$, $n = 120$).

RESULTS

Over 173,000 pelagic juvenile rockfishes were collected in the midwater trawls, and catches were dominated by *Sebastes jordani* (tab. 1). Specimens ranged in size from 8 to 110 mm SL, with a mode of 73 mm SL in shallow tows, 67 mm SL in mid-depth tows, and 68 mm SL in deep tows. A small proportion of the individuals were either late larval or early juvenile stages 10–20 mm in SL, but most were larger juveniles of a size believed competent to settle (30–90 mm SL, depending on species) (Anderson 1983; Ralston and Howard 1995). Fish smaller than 25 mm SL, however, are not fully vulnerable to the midwater trawl gear, so they are underestimated in the catches (D. Woodbury, National Marine Fisheries Service, Southwest Region Field Office, pers. comm.).

A wide range of water column conditions was observed during the 12 years of the study (fig. 2). As these examples illustrate, the thermocline was relatively sharp at some stations, stepped at others, and quite gradual at others. Mean thermocline depth, computed from all CTD profiles, was 24.5 m (standard error = 1.3, $n = 120$) with a minimum depth of 4 m and a maximum depth of 89 m. Water column stratification ranged from 36 to 308 J/m^3, with a mean of 141.1 J/m^3 (SE = 5.7, $n = 120$).

Pelagic juvenile rockfishes of most species were more or less evenly distributed among the three depth cate-

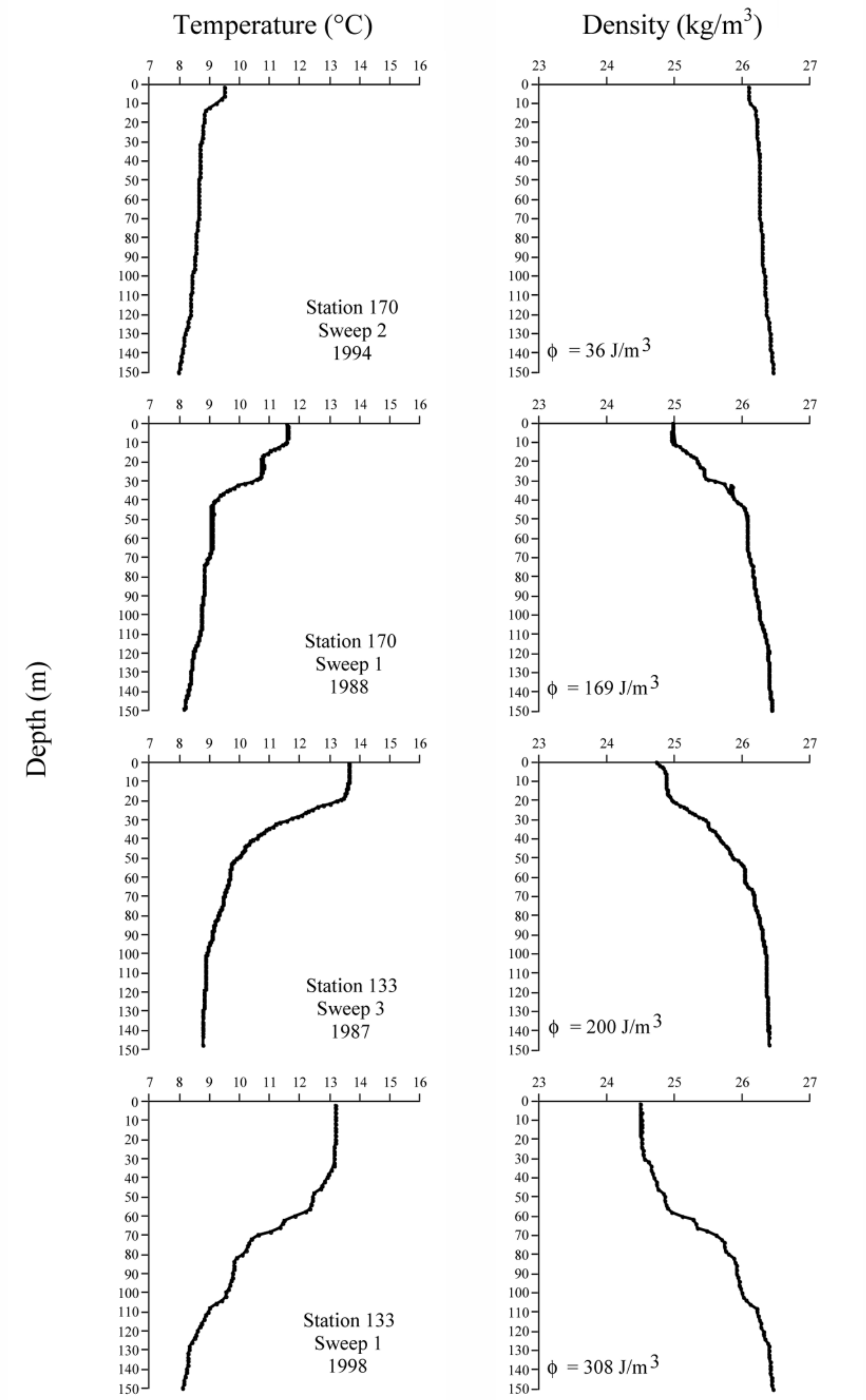
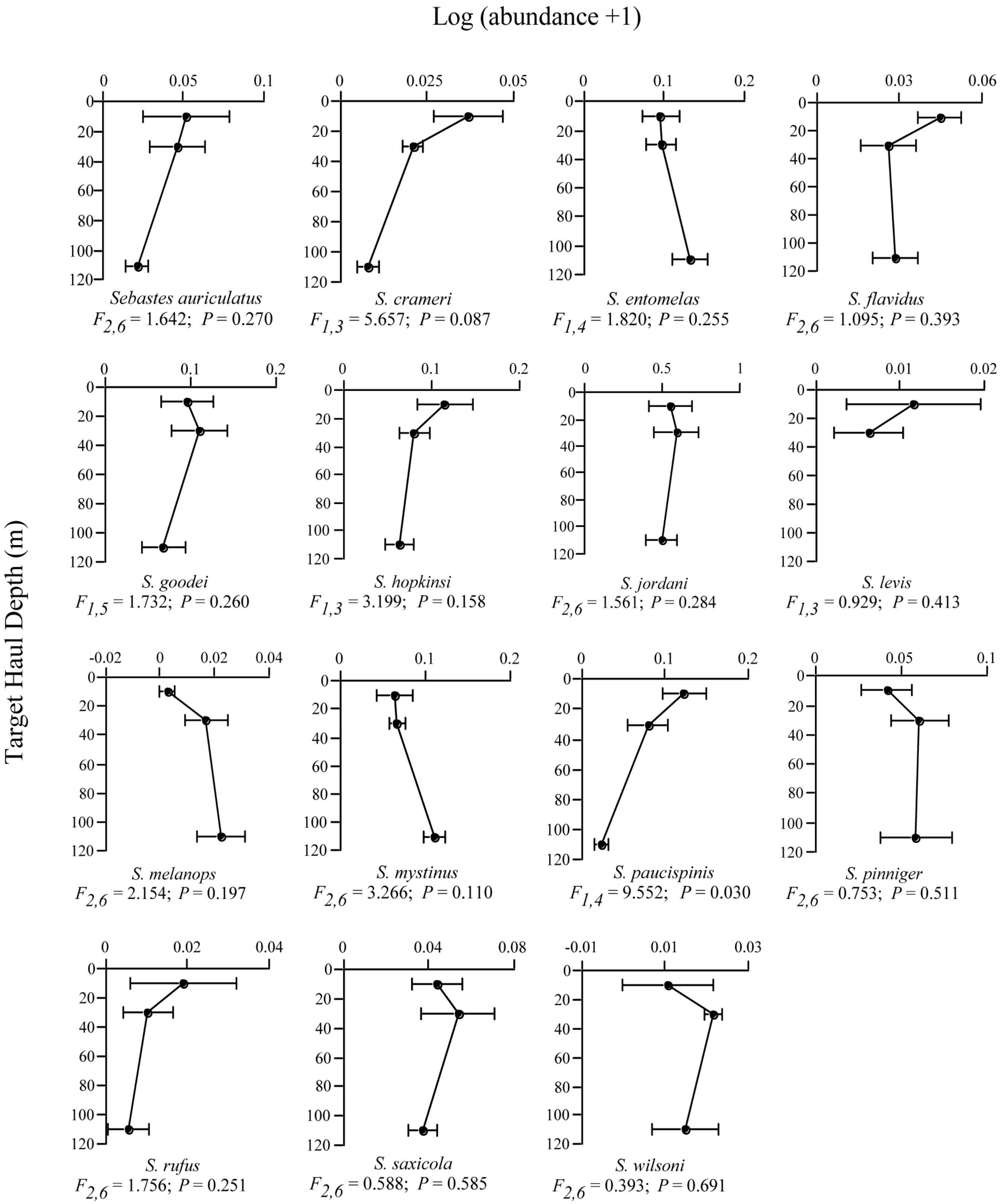


Figure 2. Examples of individual CTD cast profiles with strength of water column stratification, ϕ, shown in density plot. For station locations, see fig. 1.



Sebastes auriculatus
$F_{2,6} = 1.642$; $P = 0.270$

S. crameri
$F_{1,3} = 5.657$; $P = 0.087$

S. entomelas
$F_{1,4} = 1.820$; $P = 0.255$

S. flavidus
$F_{2,6} = 1.095$; $P = 0.393$

S. goodei
$F_{1,5} = 1.732$; $P = 0.260$

S. hopkinsi
$F_{1,3} = 3.199$; $P = 0.158$

S. jordani
$F_{2,6} = 1.561$; $P = 0.284$

S. levis
$F_{1,3} = 0.929$; $P = 0.413$

S. melanops
$F_{2,6} = 2.154$; $P = 0.197$

S. mystinus
$F_{2,6} = 3.266$; $P = 0.110$

S. paucispinis
$F_{1,4} = 9.552$; $P = 0.030$

S. pinniger
$F_{2,6} = 0.753$; $P = 0.511$

S. rufus
$F_{2,6} = 1.756$; $P = 0.251$

S. saxicola
$F_{2,6} = 0.588$; $P = 0.585$

S. wilsoni
$F_{2,6} = 0.393$; $P = 0.691$

Figure 3. Estimated mean abundances and standard errors showing the vertical distributions of pelagic juvenile rockfishes off central California during May–June cruises, 1987–98. *F*-test degrees of freedom adjusted and rounded to the next lowest integer using the Huynh-Feldt epsilon (O'Brien and Kaiser 1985). *X*-axis scales vary with species.

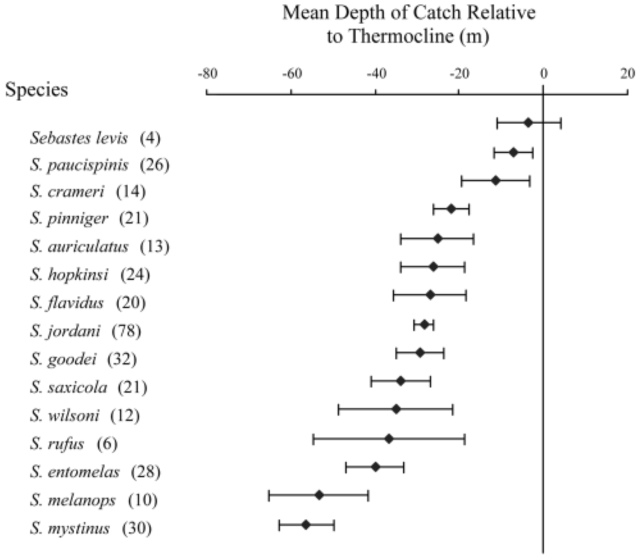


Figure 4. Mean depth of catch relative to the thermocline (DCRT) for pelagic juvenile rockfishes off central California during May–June cruises, 1987–98. Diamonds denote depth of thermocline minus mean depth of catch, horizontal lines denote standard error, and numbers in parentheses are number of positive stations.

TABLE 2
Variance of Mean Depth of Catch Relative to the Thermocline (DCRT) and the Depth of Catch Relative to a Fixed Depth of 20 m (DCR20) for Pelagic Juvenile Rockfishes off Central California, May-June Cruises, 1987–98

	Variance	
Species	DCRT	DCR20
Sebastes levis (cowcod)	227.7	209.0
S. paucispinis (bocaccio)	543.2	233.7
S. crameri (darkblotched rockfish)	939.1	669.2
S. pinniger (canary rockfish)	372.2	591.7
S. auriculatus (brown rockfish)	967.0	1,117.3
S. hopkinsi (squarespot rockfish)	1,416.8	1,336.6
S. flavidus (yellowtail rockfish)	1,476.1	1,544.3
S. jordani (shortbelly rockfish)	465.2	405.5
S. goodei (chilipepper)	1,050.2	984.6
S. saxicola (stripetail rockfish)	1,019.5	1,215.6
S. wilsoni (pygmy rockfish)	2,217.7	1,837.7
S. rufus (bank rockfish)	1,972.7	2,253.5
S. entomelas (widow rockfish)	1,353.3	1,489.0
S. melanops (black rockfish)	1,402.4	1,272.9
S. mystinus (blue rockfish)	1,281.3	1,328.6

gories (fig. 3). Juvenile *S. paucispinis* and *S. crameri* were most abundant in 10 m and 30 m tows, significantly so for *S. paucispinis* at the 0.05 level ($F_{1,4} = 9.552$, $p = 0.030$), and for *S. crameri* at the 0.10 level ($F_{1,3} = 5.657$, $p = 0.087$) (fig. 3). In contrast, juvenile *S. melanops*, *S. entomelas*, and *S. mystinus* were more commonly taken in the 100 m tows, but not significantly so (fig. 3). We found no significant interactions between year and depth for any species.

The mean nighttime center of density for pelagic juvenile rockfishes occurred either in or below the thermocline in all species examined (fig. 4). Vertical distributions of shallow species—*S. levis*, *S. paucispinis*, and *S. crameri*—were centered closer to the thermocline than those of deep species—*S. entomelas*, *S. melanops*, and *S. mystinus*. Some individuals of each species, however, were found above the thermocline in these nighttime samples.

Variances of the DCR20 were lower than those of the DCRT for just over half the species (8 of 15; see tab. 2). This suggests that these species orient to depth per se rather than to the thermocline. This is further suggested in a plot of mean depth of catch versus thermocline depth, which shows that pelagic juveniles of most species are widely scattered in the water column, leading to the observed high variances (fig. 5). However, linear regression analysis indicates that most species (11 of 15) tended to have deeper mean centers of density as a result of increasing thermocline depth, significantly so for *S. pinniger* ($p = 0.002$) and *S. jordani* ($p = 0.034$) at a level of 0.05, and for *S. rufus* at a level of 0.10 ($p = 0.054$) (fig. 5).

Mean depth of catch for rockfishes ≤25 mm SL occurred primarily beneath the thermocline (fig. 6). Mean depth of catch occurred below the thermocline slightly more frequently (80 of 88 stations, 91%) at stations with an overall species' mean SL of ≤25 mm than at stations with a mean species' SL of >25 mm (207 of 250, 83%) (chi-square = 3.341, df = 1, $p = 0.068$), suggesting that ontogeny may have influenced the depth distributions relative to the thermocline.

To further evaluate the effects of water column stratification on the depth distributions of pelagic juvenile rockfishes, we regressed mean depth of catch against the water column stratification coefficient (fig. 7). Most species (13 of 15) exhibited a deeper mean depth of catch with increasing stratification of the water column (as indicated by a negative slope), although the slope was significantly different from zero at the 0.05 level only for *S. saxicola* ($p = 0.004$, n = 21), and for *S. entomelas* and *S. flavidus* at the 0.10 level (fig. 7). Those species with greater mean depth of catch were affected by water column stratification more than shallow species, suggesting that the response to stratification depended on mean depth (fig. 8). We found a stronger relationship when we excluded *S. levis* and *S. rufus*, species with less than ten estimates of mean depth, from the regression analysis ($Adj.\ r^2 = 0.151$, $p = 0.104$, $n = 13$).

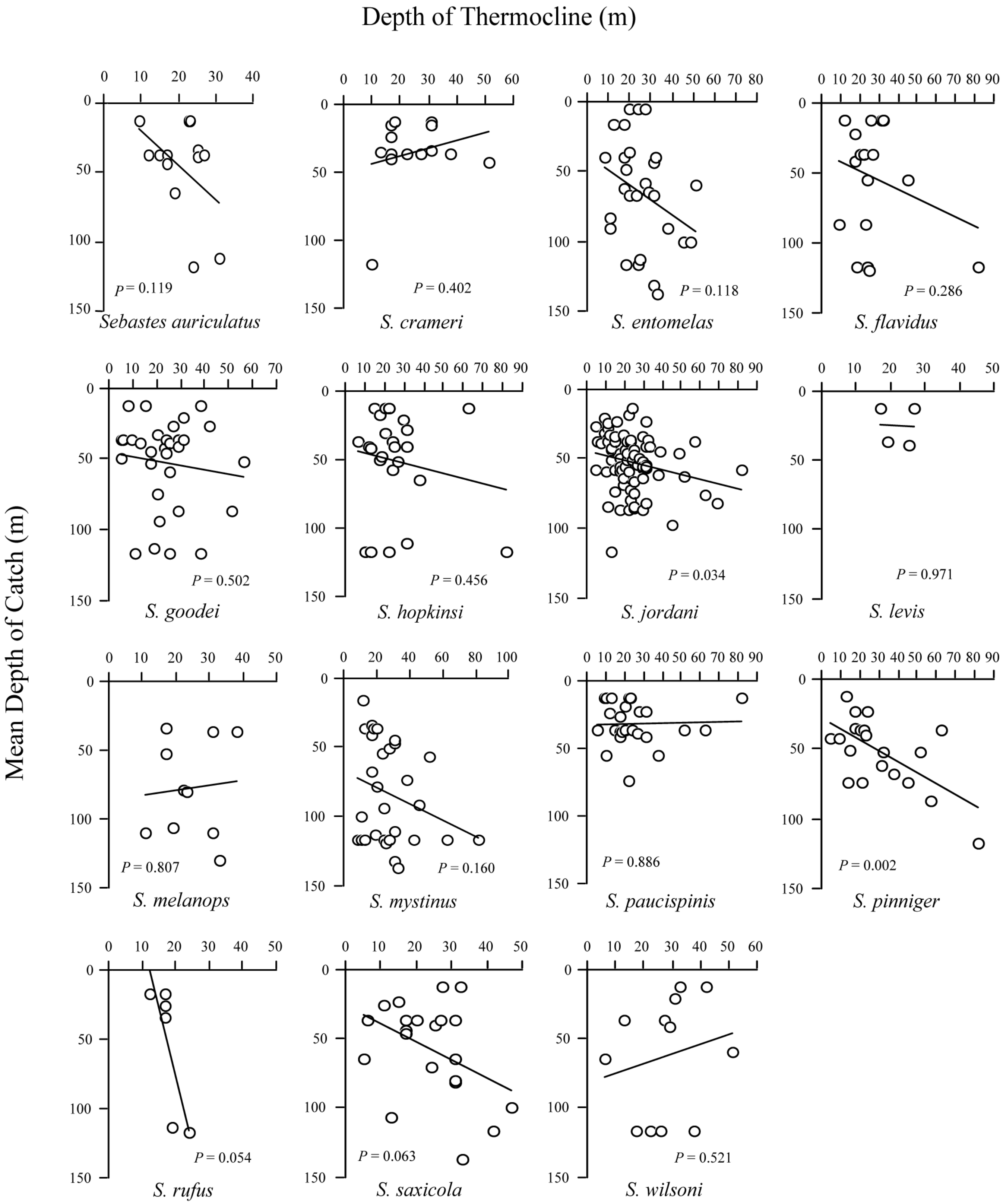


Figure 5. Influence of nighttime thermocline depth on mean depth of catch for pelagic juvenile rockfishes at positive depth-stratified stations off central California during May–June cruises, 1987–98. *X*-axis scales vary with species.

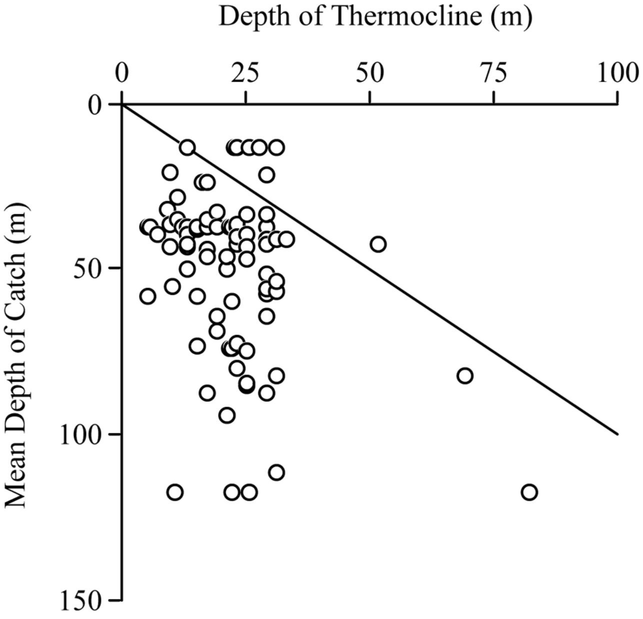


Figure 6. Depth distribution of rockfishes ≤25 mm standard length at night off central California during May–June cruises, 1987–98. Diagonal line indicates that mean depth of catch and depth of thermocline are equal.

DISCUSSION

We attempted through this study to expand on the work of Lenarz et al. (1991), employing an additional eight years of sampling information. Despite the additional data, however, many of the relationships we present are not statistically significant. Perhaps the true patterns in nature are no stronger than those we report here, but much of the additional data came from years in which recruitment of rockfishes, and their abundance in midwater tows, was low, particularly 1992–98 (Ross 2001; S. Ralston, National Marine Fisheries Service, Southwest Fisheries Science Center, pers. comm.). The low catches in midwater tows reduced the opportunity for comparisons of depth distributions. We discuss our results fully recognizing the exploratory nature of the study but in the belief that trends and patterns documented are of enough interest to warrant future investigation.

The nighttime vertical distributions of pelagic juvenile rockfishes we observed in the coastal waters off central California were similar to those described by Lenarz et al. (1991). Our results agree qualitatively with those of Lenarz et al. (1991), who, based on fewer years of data, also found that *S. paucispinis* occurred at shallower depths and that *S. entomelas* and *S. mystinus* were most abundant at the deeper depths.

We found conflicting results on the influence of water column characteristics on the vertical distribution of pelagic juvenile rockfishes. Our data suggest that station thermocline depth is a poor predictor of the vertical distribution of pelagic juveniles. Gray (1996) and Sakuma et al. (1999) also found that thermocline depth poorly predicts vertical distributions. However, Gray (1996) suggested that the occurrence of weak, gradual thermoclines (extending over 20–30 meters of depth) might have made it difficult to find such an association in the coastal waters off Australia. Weak or gradual thermoclines were also common in our data. Although we made no attempt at classification, we observed a wide range of water column conditions during the 12 years of sampling. Because of this variability in the nature of the thermocline, the water column stratification parameter might better indicate the effects of water column characteristics on the distributions of juvenile fishes. In addition, it appears that the response of species to water column stratification may depend on their mean depth in the water column, with deeper-living species showing a slightly greater response to stratification than shallow species.

The thermocline (Ahlstrom 1959; Boehlert et al. 1985; Moser and Boehlert 1991; Larson et al. 1994) and the pycnocline (Sakuma et al. 1999) have been reported as representing lower boundaries to the vertical distribution of larval rockfishes, but this does not appear to be the case for pelagic juvenile rockfishes. Our finding that juvenile rockfishes occur primarily below the thermocline, in contrast to the documented occurrence of larval stages above the thermocline or pycnocline (Ahlstrom 1959; Boehlert et al. 1985; Moser and Boehlert 1991; Larson et al. 1994; Sakuma et al. 1999), suggests a change in rockfish depth distributions with ontogeny. Larval and transforming prejuvenile fishes may need to undergo varying periods of acclimation to decreasing temperatures while descending through the thermocline (Steiner and Olla 1985). Micronektonic *S. diploproa*, splitnose rockfish, have a physiological predisposition for colder conditions (Boehlert 1978, 1981) but do not migrate directly from surface waters to the deeper adult habitat. Instead they have a midwater transition period lasting as long as several months (Boehlert 1977). Similarly, prejuvenile red hake (*Urophycis chuss*) do not descend immediately below the thermocline at transformation but remain above it in warmer waters (Steiner and Olla 1985). Juvenile walleye pollock (*Theragra chalcogramma*) in the laboratory have been observed to alter their vertical position in the water column in response to a thermocline, moving above it but making brief exploratory movements down into or along it (Olla and Davis 1990).

Our results also suggest that the depth distributions of pelagic juvenile rockfishes might be related to ontogeny, in that smaller fish (≤25 mm SL) occurred below the thermocline slightly more consistently than larger fish. The presence of smaller pelagic juvenile rockfishes (≤25 mm SL) beneath the thermocline is consistent with the hypothesis of Lenarz et al. (1991); they found that

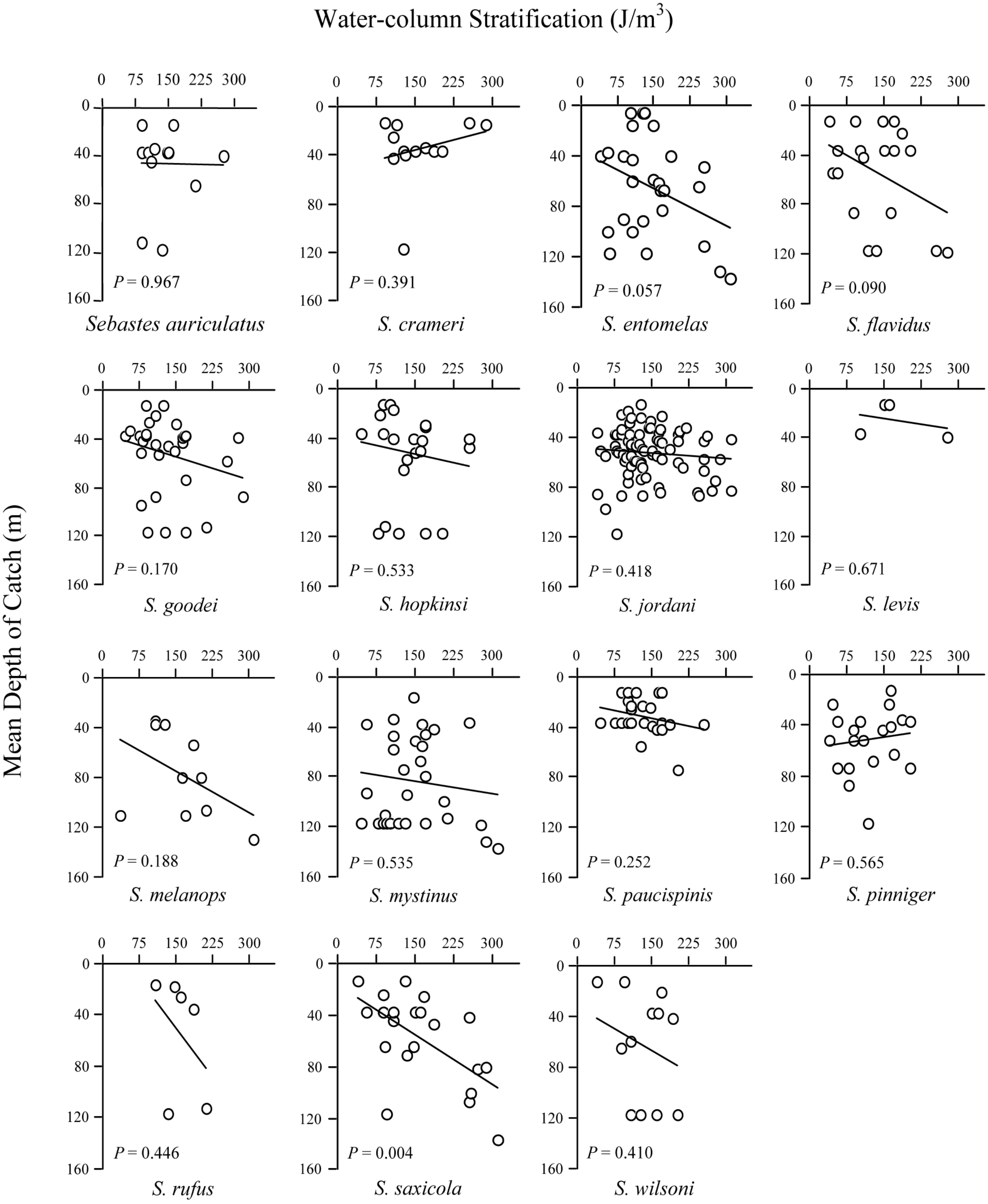


Figure 7. Mean depth of catch as a function of water column stratification at night for pelagic juvenile rockfishes at positive depth-stratified stations off central California during May–June cruises, 1987–98.

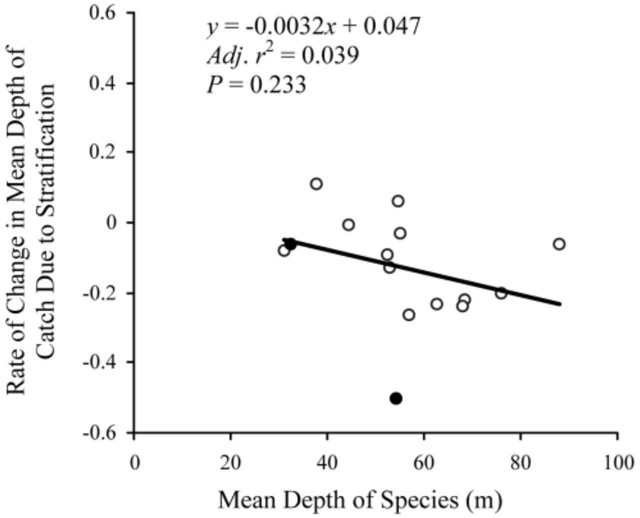


Figure 8. Relationship between the rate of change in mean depth of catch due to water column stratification (see fig. 7) and the mean depth of the species in the water column. Solid dots are data points for *Sebastes levis* and *S. rufus*.

smaller pelagic juveniles of *S. jordani* (which they regarded as those less than 50 mm in SL, because they are small for fully transformed juveniles in this species) might be adapted to avoid shallower waters, in order to reduce the possibility of offshore advection during the May–June period of intense upwelling activity off central California. If the sensory and locomotory abilities of pelagic juvenile rockfishes ≤25 mm SL allow them to make similar adjustments in their depth distributions, this may represent a behavioral response to reduce the impact of upwelling on onshore/offshore distributions and possibly increase recruitment success (Parrish et al. 1981; Larson et al. 1994; Sakuma et al. 1999).

A suite of behavioral responses involving interactions between water temperature, prey availability, ontogenetic stage, and thermoclines, however, may influence the vertical distributions of early life stages of fish (Steiner and Olla 1985; Olla and Davis 1990; Sogard and Olla 1996). Experimental studies indicate that when food is present below a thermocline, prejuvenile walleye pollock (will migrate transiently beneath it, thereby altering their vertical distributions, at least temporarily (Olla and Davis 1990). Food-deprived juveniles may use an energy-conserving behavioral response, descending beneath the thermocline to lower metabolic costs, whereas under conditions of increased food availability they tend to stay above the thermocline (Sogard and Olla 1996).

Lenarz et al. (1991) suggested that larger pelagic juvenile rockfish may be adapted to searching the water column for optimal feeding conditions. The lack of statistical significance in the vertical distributions of 14 of 15 species of pelagic juvenile rockfishes may reflect this feeding behavior. Pelagic juvenile rockfishes appear to be opportunistic feeders, specializing on intermittently abundant single prey items (Reilly et al. 1992). Major prey items are the various life stages of calanoid copepods and subadult euphausiids, including eggs, but diet is apparently unrelated to predator size (Reilly et al. 1992). Synoptic vertical sampling of pelagic juvenile rockfishes, zooplankton, and hydrography is required to determine the relationships, if any, among the depth distributions of predator, prey, and oceanographic features.

Onshore vertical distributions may differ from the offshore vertical distributions presented in the present study, particularly for nearshore species of pelagic juvenile rockfishes as they move onshore into adult habitats later in the season. Moser and Boehlert (1991) reported that larval abundances of rockfish at an onshore and offshore station varied markedly for the 20–30 m depth interval. Almost no larvae were found within this depth interval at the offshore station, whereas a large proportion of the total larvae were found within this depth interval at the onshore station. The difference between the two stations corresponded to the associated depth of the thermocline, which was 20–40 m at the shelf station and 30–50 m at the offshore station. Larson et al. (1994) noted evidence of juvenile rockfishes with an unusually shallow bathymetric distribution in southern Monterey Bay, during the period 2–12 June 1987. This vertical distribution coincided with the development of a sharp, shallow thermocline (approximate depth 15 m) during an upwelling relaxation event and the apparent onshore movement of several species of *Sebastes*. In contrast, during the same relaxation event smaller pelagic juvenile rockfishes remained offshore and deeper (Larson et al. 1994). These results, in combination with the potentially deeper distribution of smaller pelagic juvenile rockfishes seen in this study, and the observations by Shenker (1988) and Doyle (1992) of pelagic juvenile rockfishes in the neuston, suggest that depth distributions may change ontogenetically.

In conclusion, our results suggest that pelagic juveniles of different rockfish species tend to be most abundant at different depths in the water column, in agreement with previous studies. We found conflicting results regarding the effects of water column stratification on vertical distributions. Mean depth of catch was statistically unrelated to thermocline depth, but in most species mean depth of catch tended to be deeper when the water column stratification parameter was greater, and this effect may have been larger for deeper occurring species. Finally, we had indications that depth distributions may change ontogenetically. Despite 12 years of sampling, usually with three replicate sample sets per year, the effects of water column characteristics and ontogeny were poorly resolved in our data set. This may, in part, be the consequence of low abundances of most pelagic juvenile species for most years from 1987 to 1998. We believe that it remains worthwhile to pursue questions about the relationships of ontogeny and hydrography with the vertical distributions of pelagic juvenile rockfishes. Sampling programs more strongly focused on depth distributions per se will be required to evaluate trends suggested by our results.

ACKNOWLEDGMENTS

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SCALES OF INTERANNUAL VARIABILITY IN THE CALIFORNIA CURRENT SYSTEM: ASSOCIATED PHYSICAL MECHANISMS AND LIKELY ECOLOGICAL IMPACTS

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ABSTRACT

We examined interannual change in several physical environmental indexes to isolate the main scales of variation previously reported—the high (~5–7 years), decadal-bidecadal (~20–30 years), and very low frequency (~50–75 years)—in the California Current system. We employed smoothing filters for the purpose of isolating the scales, using their spectral frequencies to analyze their adequacy. In the case of the decadal-bidecadal scale, we tested the coherence between the series against that of random number series. Later, we extracted the first principal component from all series at each scale of variation and compared this to published information, to the physical mechanisms, and to their effects on biological indexes associated with each. We suggest that all the examined frequencies of interannual variation are related to two opposing states of the system, one state associated with relaxed flow of the California Current; intensification of the Aleutian Low, the Alaska Current, and the California countercurrent; increased coastal sea-surface temperature and sea level; frequent mesoscale eddies formation and persistence; and northward advection of southern fauna; the other state associated with the contrary.

INTRODUCTION

Scales of interannual change in the California Current system (CCS) have been the subject of a considerable number of studies in recent years (e.g., Roemmich and McGowan 1995; Brodeur et al. 1996; McGowan et al. 1996). As part of a retrospective experiment of the Living Marine Resources Panel of the Global Ocean Observing System (GOOS) we have been integrating a number of studies dealing with the scales of interannual change and the possibilities of forecasting them, one of which has already been published (Lluch-Belda et al. 2001).

Interannual variability has been reported on a considerable array of frequencies, some of them often mixed; however, Ware (1995) analyzed the interannual variability in the eastern North Pacific Ocean and found four dominant scales: the quasi-biennial oscillation (2–3 years), the El Niño-Southern Oscillation (ENSO) scale (5–7 years), the bidecadal oscillation (20–25 years), and a very low frequency scale (50–75 years). We will be dealing with the last three.

Perception of interannual change in the northeast Pacific has been dominated by ENSO. This recurrent, often intense phenomenon has very obvious physical and biological consequences every few years, so most analysts have been able to follow several of them. Its mechanism is for the most part well understood, and short- to mid-term forecasts are in the process of being developed. Detailed descriptions of recent events include those by Lynn and Bograd (2002) and Schwing et al. (2002b), and Miller et al. (2000) have presented modeling advances.

At the other extreme of the shorter-than-centennial time scale, very low frequency or regime variation has become evident through the quasi-cyclic fluctuations in the abundance of some species, particularly the small pelagic fishes. Their explosive population growth and even more rapid collapse, together with the very high biomass that their populations can attain, result in major changes in their availability to fisheries and are therefore very noticeable. Their characteristic of leaving scales in the laminated sediments allows us to know that such enormous variations are not an exclusive consequence of harvesting but rather are naturally induced fluctuations. Finally, the synchronic behavior of their population abundance in widely separated ocean areas strongly suggests that global environmental variations may be in the root of such changes. Benson and Trites (2002) reviewed many of the published studies on the subject; Chavez et al. (2003) updated and amplified the information on regime changes.

Between those two scales of variation, a number of researchers have reported decadal to bidecadal periods of variation in the eastern North Pacific Ocean (Wooster

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and Hollowed 1995; Ware 1995). Schwing et al. (2002a) found alternating decadal-scale periods on a roughly 14-year cycle. Minobe (2000) pointed out that the pentadecadal (very low frequency) and bidecadal signals arise from different physical mechanisms and likely have different origins. In essence, alternating multi-year warm/cool periods have been identified in temperature (both sea and air, instrumental and reconstructed), location, and intensity of atmospheric pressure cells (particularly the Aleutian Low) and associated wind fields, sea level, upwelling intensity, mixed layer depth, and some biological indexes mostly associated with recruitment level in some populations. Schwing et al. (2002a) updated the description of the cool/warm periods described by Wooster and Hollowed (1995) after the early 1980s.

A number of physical variables have been associated with each of these scales, often with reference to an environmental index. These include, among others, the intensity and east-west position of the Aleutian Low (Emery and Hamilton 1985; Miller and Schneider 2000), intensification/relaxation of the Alaska and California Currents (Wooster and Hollowed 1995; Brodeur et al. 1996), tropic to extratropic teleconnections (Schwing et al. 2002a), winds (Parrish et al. 2000), sea-level height and mixed-layer depth anomalies (Bernal 1979; 1981; Bernal and Chelton 1984; Chelton et al. 1982; Polovina et al. 1995; Parrish et al. 2000), intensified northward advection of the California countercurrent (McLain and Thomas 1983), mesoscale eddies formation and persistence (Longhurst 1966; MacCall 2002), and upwelling intensity (Wooster and Hollowed 1995; Polovina et al. 1995; Schwing and Mendelssohn 1997; Bograd et al. 2001). Some of them may reveal mechanisms of change, based on their correspondence with other variables.

Detected ecological effects of interannual variability include changes in primary and secondary productivity (Polovina et al. 1995; Rebstock 2002), distribution of fauna (Hubbs and Schultz 1929; Hubbs 1948; Radovich 1961; Schoener and Fluharty 1985; Smith 1985; Karinen et al. 1985; Ainley et al. 1995; Dorn 1995; Hamman et al. 1995; Lenarz et al. 1995; Smith 1995; etc.), and recruitment in several fish stocks (Lluch-Belda et al. 1989; Hollowed and Wooster 1992; Bakun 1996; Mantua et al. 1997; Klyashtorin 1998; Norton 1999; Hare and Mantua 2000; Botsford 2001; Botsford and Lawrence 2002; Chavez et al. 2003).

In this study we use several century-long physical/environmental series, attempt to isolate and characterize the reported scales of variation, and seek to relate the variations to reported ecological fluctuations.

DATA AND METHODOLOGY

Monthly average sea-surface temperature (SST) series were extracted from the Comprehensive Ocean-Atmosphere Data Set (COADS) (Mendelssohn and Roy 1996) for 76 quadrants (2° × 2°) (fig. 1), in an effort to cover most of the CCS. The climatology for each quadrant was estimated as the average SST for each month for all the existing data between 1900 and 1990. Monthly anomalies were computed (monthly value minus monthly climatology) and then averaged for the year. Finally, a global index reflecting the SST anomalies of the CCS (hereinafter referred to as CST) was obtained by annually averaging the individual yearly anomalies at all 76 quadrants. The representativeness of these data was analyzed in a previous paper (Lluch-Belda et al. 2001), including averaging procedures, amount, and completeness of the original data and their similarity to other large-scale indexes, particularly given the reservations that have been expressed regarding their validity prior to the 1950s (for instance, MacCall 1996). Similarly, an index of the yearly coastal SST anomalies (COT) was derived from data at coastal stations obtained from the PACLIM database (Cayan et al. 1991), including those at Point Hueneme, Crescent City, Pacific Grove, Los Angeles, San Francisco, and San Diego.

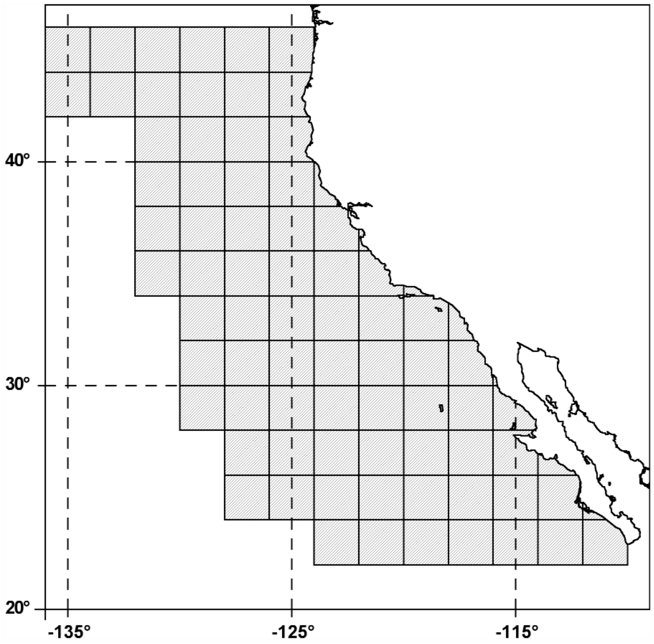

Figure 1. The COADS quadrants used to obtain the annually averaged sea-surface temperature anomalies for the California Current system.

The same procedure was applied to build an index of sea-level height yearly anomalies (SLH), using monthly values obtained from the University of Hawaii Sea Level Center (Kilonski 1998) for San Francisco and San Diego, California. The series were detrended and yearly averaged, further standardized (standard score = [raw score − mean] / standard deviation) and averaged between the two.

TABLE 1
Sources of Data Series Considered in the Analyses

Series	Brief description	Source
Aleutian Low Pressure index (ALP)	Relative intensity of the Aleutian Low pressure system of the North Pacific	Beamish et al.(1997)
Pacific Decadal Oscillation index (PDO)	Leading principal component of monthly SST anomalies in the North Pacific Ocean, poleward of 20°N	Mantua et al.(1997)
Atmospheric Forcing index (AFI)	First principal component from an analysis of the ALP, PDO, and the northwesterly atmospheric circulation anomalies for the North Pacific	McFarlane et al.(2000)
OSCURS index (OSC)	Annually averaged latitudes at each trajectory end point	AFSC-NMFS Web site, http://www.afsc.noaa.gov

We used the Aleutian Low Pressure index (ALP), the Pacific Decadal Oscillation index (PDO), the Atmospheric Forcing index (AFI) and the Ocean Surface Current Simulations (OSCURS) index (hereinafter OSC) as large-scale indexes of the environmental condition of the northeastern Pacific Ocean. (For information on the indexes used, see tab. 1.)

All series (shown in fig. 2) were standardized (standard score = [raw score − mean] / standard deviation) prior to computing their correlation coefficients. Each series was then filtered by means of Hamming windows of 10 and 30 years. This is a weighted moving average transformation computed as

$$w_j = 0.54 + 0.46 * \text{cosine}(\pi * j/p) \text{ (for } j = 0 \text{ to } p)$$

$$w_{-j} = w_j \text{ (for } j \neq 0)$$

$$\text{where } p = (m - 1)/2$$

This weight function will assign the greatest weight to the observation being smoothed in the center of the window and increasingly smaller weights to values that are further away from the center, standardizing the weights so that they sum to 1 (Blackman and Tukey 1958).

The two filtered series that resulted from each (untransformed) series were used to decompose its variability into three main time-scales as follows:

1. The difference between the raw series minus the 10-year Hamming filtered series, assumed to represent the high-frequency (<10 years) component; referred to as the HF series.
2. The difference between the 10-year Hamming filtered series minus the 30-year Hamming filtered series, as containing the decadal-bidecadal (10–30 years) component; referred to as the DB series.
3. The 30-year Hamming filtered series, representing the very low frequency (>30 years) component; referred to as the LF series.

Summarizing, the procedure resulted in three series (HF, DB, and LF) for each of the series shown in Figure 2.

While the HF and LF series result from a single filtering procedure, the same does not occur with the DB series, which results from a double-filtering process. Since filtering itself may induce a certain pattern, ten series of random numbers were processed by the same procedure, and simple linear correlation was performed between the resulting series. The DB series were also correlated among them for comparison. This process was only used for testing the effect of double-filtering at artificially increasing the correlation coefficient, thus the random number series were not utilized further. Later, spectrum analysis (Fourier transform), with 15% tapering and padding the series to a power of 2, was performed for each unfiltered series and the corresponding HF, DB, and LF series. Finally, we obtained the first

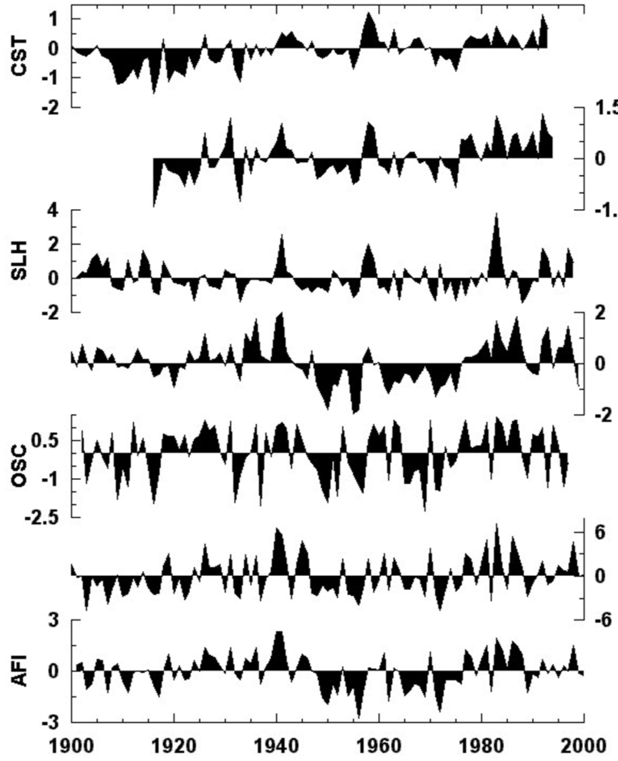

Figure 2. The raw data series. Global index of the California Current system SST anomalies (CST), index of yearly coastal SST anomalies (COT), index of yearly sea-level height anomalies (SLH), Pacific Decadal Oscillation index (PDO), OSCURS index (OSC), Aleutian Low Pressure index (ALP), and Atmospheric Forcing index (AFI).

TABLE 2

Correlation Coefficients between Raw Data Series (*Below* and *Left*) and *N* Pairs of Values (*Above* and *Right*)

	CST	COT	SLH	PDO	OSC	AFI	ALP
CST		78	93	94	92	93	94
COT	**0.84**		79	79	79	79	79
SLH	**0.58**	**0.67**		98	96	98	98
PDO	**0.47**	**0.66**	**0.52**		96	99	100
OSC	**0.35**	**0.42**	0.18	**0.48**		96	96
AFI	**0.31**	**0.48**	**0.25**	**0.73**	**0.78**		100
ALP	**0.40**	**0.50**	**0.31**	**0.60**	**0.72**	**0.86**	

Note: Boldfacing indicates $p < 0.05$.

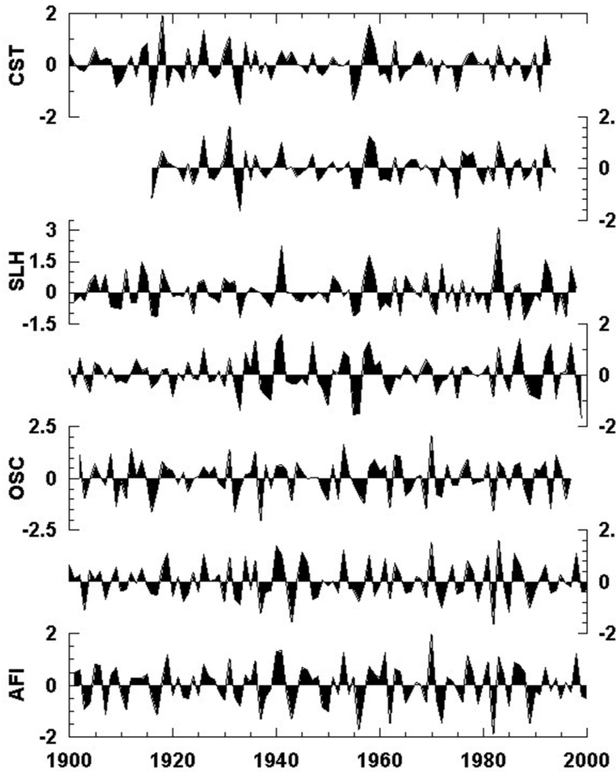

Figure 3. The high-frequency filtered series (residuals of raw data minus 10-year Hamming filter).

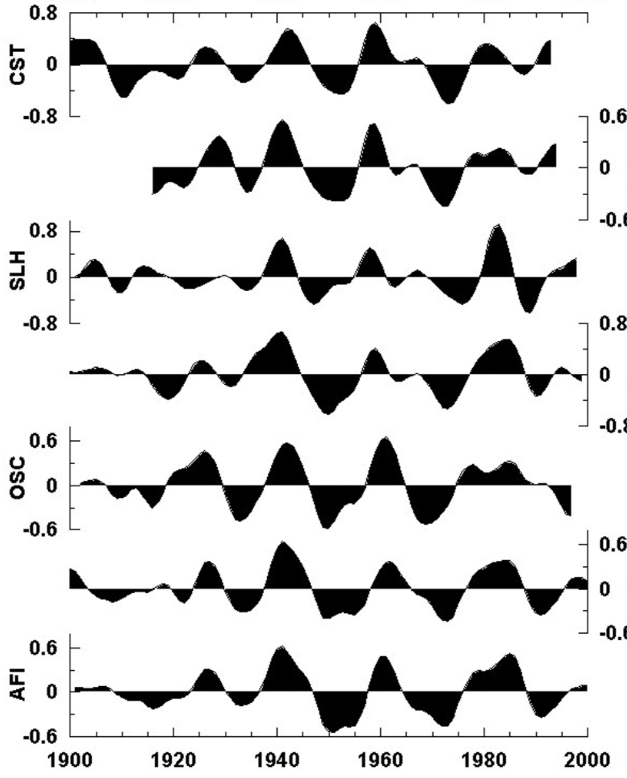

Figure 4. Decadal-bidecadal series (residuals of 10-year Hamming filter minus 30-year Hamming filtered series).

principal component (PC) of the HF, DB, and LF series (i.e., one analysis per time scale) substituting the lacking data by means, to obtain a series representing the main variation pattern for each temporal scale. We compared these principal components with those in published sources. We searched for published reports of latitudinal displacement of fauna, trying to discriminate between large-scale movements and single-species extensions of range.

RESULTS

The correlation coefficients between the raw data series are shown in Table 2. Except for the OSC-SLH case, all are significant at the 5% level.

The HF series that resulted from the filtering of the seven environmental indexes are shown in Figure 3. In spite of the noisy variation, with the lower frequencies removed El Niño events become more evident (e.g., 1940, late 1950s, 1982).

Regarding the DB series (fig. 4), the results show strikingly coherent signals in all of the series, with clear peaks during the late 1920s, early 1940s, late 1950s, and early 1980s. The analysis of random number series indicates that DB filtering will not produce the correlated cycles observed in this figure. This is due to the fact that, although the bidecadal filtering procedure does generate oscillating patterns of about 20 terms in the random number series, the shape of the double filtered series is

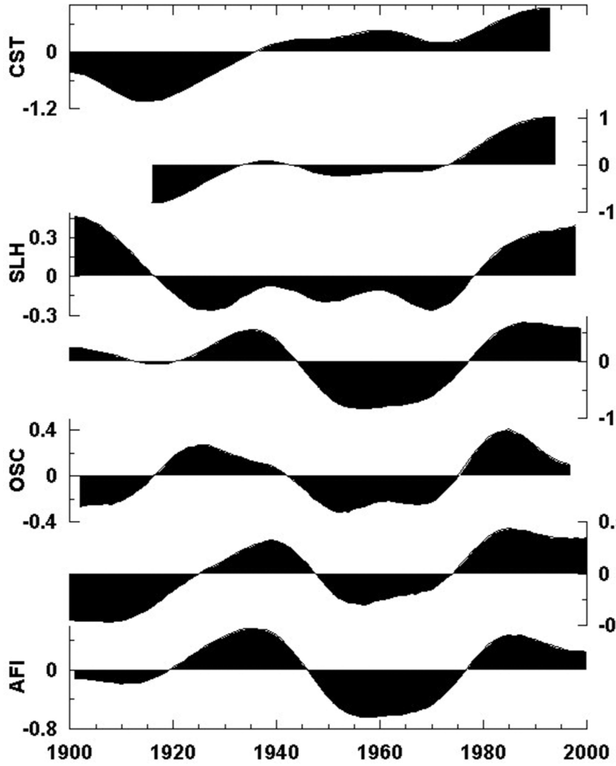

Figure 5. Low-frequency filtered series (Hamming filter of 30 terms).

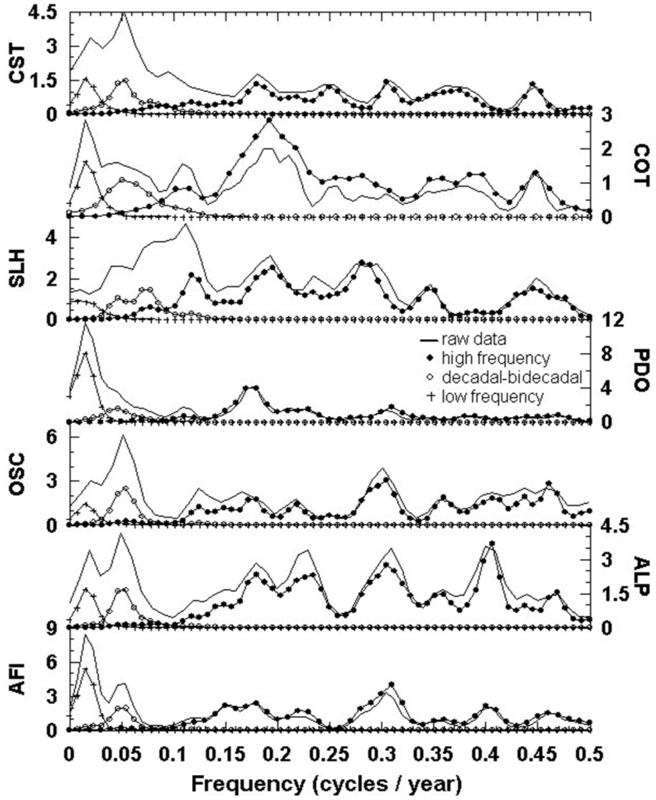

Figure 6. Spectral densities of CST, COT, SLH, PDO, OSC, ALP, and AFI (see fig. 2 for definitions).

different in each case—that is, peaks and troughs occur randomly in time.

As for the LF component (fig. 5), the series of basin scale indexes (ALP, AFI, PDO, and OSC) are quite similar, whereas the others (CST, COT, and SLH, all of them CC-scale indexes) show some differences. This may well indicate, as one of the anonymous reviewers noted, that the basin has a much stronger LF signal than the CC region does. Peaks are more or less evident right before 1940 and after 1980.

Spectral densities for the unfiltered, HF, DB, and LF series are shown in Figure 6. For each case, the solid line shows the spectral density of the unfiltered series; the spectral densities of the HF, DB, and LF series are also shown. In general, the filter works adequately, isolating each spectral window such that the shape of the HF, DB, and LF spectra is always very similar to the spectra of the unfiltered series at the corresponding frequency region.

The HF spectra are noisy, but three main peaks are evident in most of them, one at 0.45 (about a 2-year period), and two ENSO-related (0.3, about 3, and 0.19, about 5-year periods). These frequencies correspond to the tropospheric quasi-biennial (about 18–35 months) and lower frequencies (about 32–88 months) shown by the spectra of most ENSO-related variables (Barnett et al. 1995). The DB and LF spectra each show a characteristic peak (DB 0.05, about 20 years; LF 0.02, about 50 years) in all but the SLH.

The extraction of the first principal component seems to result in reasonable representation of the main variation patterns in each group of the frequency-isolated series. The extraction-utilizing means to substitute missing values is based on the significant correlation coefficients between the raw series (tab. 2) and the convenience of having full-century series for comparison.

The first principal component series for each scale of variation (HF, DB, and LF) are shown in Figure 7. The factor loadings are shown in Table 3. The table also shows that the percentage of variance each PC1 accounts for is greater than 50% for all three scales.

In Figure 7 the high-frequency principal component (HF-PC) is compared to El Niño events as described by Quinn (1992) and to northward displacement of southern fauna reports as shown in Table 4. This is the noisiest frequency, as would be expected. However, the main peaks do correspond to El Niño events and to northward faunal dispersal. In fact, two major events per decade (or two very closely related minor events instead of a major one in some cases) result in a frequency of about 5 years per event, as noticed by Lluch-Cota et al. (2001) for the northeast Pacific north of the mouth of the Gulf of California.

For the DB signal, its PC1 is compared to warm and cool periods described by Wooster and Hollowed (1995)

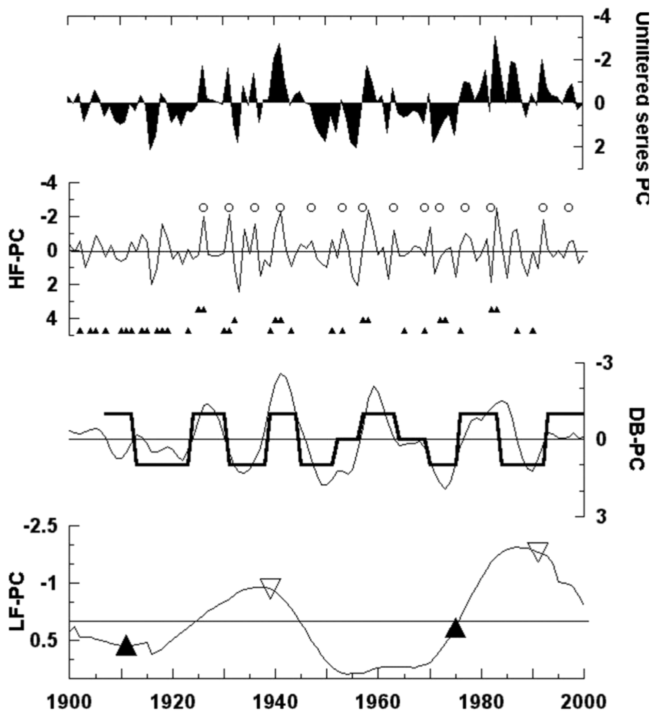

Figure 7. The first principal component (PC1) of the series at each analyzed scale, compared to other indexes. High-frequency (HF-PC): ▲ represents El Niño events (after Quinn 1992), with relative vertical position indicating event strength; ○, northward dispersal of fauna (tab. 4). Decadal-bidecadal (DB-PC): thick line represents cool and warm periods, after Wooster and Hollowed (1995) and Schwing et al. (2002). Low-frequency (LF-PC): ▲ represents cool-to-warm regime shifts; and ▼, warm-to-cool regime shifts.

and updated based on Schwing et al. (2002a). The DB series result in the largest explained variation by the extraction of the first principal component, as would be expected from their remarkable coherence.

Finally, the LF signal is compared to described regime shifts; the main trends are coherent with the cooling and warming periods as described by Lluch-Belda et al. (2001).

DISCUSSION

Coherency between the original series is obscured by the noisy variation, decadal changes, and short-term events, even though some particularly strong signals (as the strongest ENSO events and the mid-1970s regime shift) are suggested in most (fig. 2). Filtering proved useful for substantiating the specific variation at the three scales considered, particularly the DB and LF (figs. 3–5). The coherency is further shown by spectral analysis at all scales, with particularly coherent peaks for DB and LF in most series but SLH (fig. 6).

PC1 extraction from the series proved appropriate for the purpose of obtaining one single series for each scale containing most of the common variability. Each of the principal components agrees with the main features of previously published information: ENSO events, northward faunal movements, cool/warm periods, and regime shifts (fig. 7).

TABLE 3
Factor Loadings of the First Principal Component Extracted for the Series

	Raw data	High frequency	Decadal-bidecadal	Low frequency
CST	−0.68	**−0.78**	**−0.84**	−0.34
COT	**−0.81**	**−0.81**	**−0.88**	**−0.73**
SLH	−0.57	−0.60	−0.67	−0.45
PDO	**−0.80**	**−0.78**	**−0.88**	**−0.90**
OSC	**−0.72**	−0.68	**−0.81**	**−0.85**
AFI	**−0.83**	**−0.75**	**−0.93**	**−0.90**
ALP	**−0.81**	**−0.77**	**−0.90**	**−0.86**
Variance	3.94	3.85	5.01	3.94
Explained variance, %	56	55	72	56

Note: Boldfacing indicates $p > 0.7$.

TABLE 4
Short Period Reports of Southern Fauna Intruding Northward

Year	Fauna	Author(s)
1859	Pelagic red crab stranding in Monterey Bay, California	Hubbs and Schultz (1929)
1880	Considerable number of southern species	Jordan and Gilbert (1881)
1926	*Vellela* and several fish species	Hubbs (1948)
1931	Southern fish strays off California	Hubbs (1948)
1936	Intrusion of southern forms in British Columbia	Hubbs (1948)
1941	Pelagic red crabs off California	Hubbs (1948)
1947	Southern species of fish in Oregon, Washington, and British Columbia	Hubbs (1948)
1953	Northward shift of sardine population center	Radovich (1959)
1957	Intrusion of many southern species	Radovich (1961)
	Doliolum denticulatum off California	McLain and Thomas (1983)
1958	Pelagic red crabs off California	Longhurst (1966)
1959	Pelagic red crabs in Monterey	Longhurst (1966)
1963	Salps of likely southern origin off Oregon	Hubbard and Pearcy (1971)
1969	Pelagic red crabs in Monterey Bay	Hardwick and Spratt (1979)
	Several species of invertebrates	McLain and Thomas (1983)
1972	Pelagic red crab off California	Alvariño (1976)
	Pelagic red crab	Hardwick and Spratt (1979)
1977	Southern fauna	Karinen et al. (1985)
	Subtropical zooplankton	McLain and Thomas (1983)
1978	Salps off British Columbia and southeastern Alaska	McLain and Thomas (1983)
	Pelagic red crab off Ensenada, Baja California	McLain and Thomas (1983)
1982	Pelagic red crab off California	P. Smith, pers. comm.
1983	Southern fauna off Washington	Schoener and Fluharty (1985)
	Southern fauna off Canada	Mysak (1986)
1992	Southern fauna off Canada	Hargreaves et al. (1994)
1997	Pelagic red crab off California	P. Smith, pers. comm.
2002	Pelagic red crab off California	R. Schwartzlose, pers. comm.

The principal component extraction also provides insight on the relation between local and basin-wide index series at each time scale: in all cases relationships are direct and mostly strong as indicated by the factor scores showing the same sign and relatively high absolute values (tab. 3). This indicates that local conditions of the California Current are fluctuating in agreement with the basin-scale indexes and, thus, are likely affected by the same mechanisms that have been related to each of the basin-scale indexes at all analyzed time scales. Therefore, we suggest that the variability at all analyzed scales may conform to two alternative states of the system.

From the local analyzed series (CST, COT, and SLH) the first state would correspond to periods during which the CCS warms up and coastal SST and sea level height tend to be anomalously high. The direct relationship of these local indexes to OSC indicates that these periods would correspond to intensified flow of the Alaska Current and a relaxation of the California Current (Ingraham et al. 1998). Such changes are likely driven by an anomalously strong Aleutian Low, as revealed by their relationship to ALP (Beamish et al. 1997). Further, directly variating values of AFI represent above-average frequency of westerly and southwesterly winds (McFarlane et al. 2000). Finally, cooling of SSTs in the central North Pacific is suggested by the covariance of the CCS indexes with PDO (Mantua and Hare 2002).

The alternative state would be essentially the reverse: cooling of the California Current and anomalously low coastal SST and sea-level height corresponding to an intensified California Current, a relaxed Alaska Current, and a weakened Aleutian Low. Westerly and southwesterly winds would be relatively infrequent, and possibly a warming of SSTs in the central North Pacific would take place during those periods.

These and other related changes have been well-described by many others, though usually in reference to a particular time scale. At the higher frequency, usually associated with ENSO events, various authors have described the relaxation of the California Current (Alvariño 1976; Bernal 1979, 1981; Chelton et al. 1982), intensified northward advection of the California countercurrent (McLain and Thomas 1983), and the Alaska Current (Emery and Hamilton 1985; Brodeur et al. 1996) and mesoscale eddies formation (Longhurst 1966). La Niña corresponds to the second state at this time scale.

At the decadal scale, Hollowed and Wooster (1992) described two environmental states related to weak/strong circulation of the Alaska Gyre and to cool/warm coastal SST, while later Wooster and Hollowed (1995) estimated the average duration of such eras as about 17 years. The Alaska Gyre was shown to be related to the relative position and intensity of the Aleutian Low by Emery and Hamilton (1985), who found that an intensified/weak and eastward/westward-displaced Aleutian Low is associated to strong/weak circulation pattern. During periods of strong circulation, the Alaska Gyre is stronger while the California Current relaxes, concomitant with increased northward flow of the west wind drift bifurcation (Wooster and Hollowed 1995; Brodeur et al. 1996), similar to Chelton and Davis's (1982) description that the Alaska and California Currents fluctuate out of phase. Strong circulation also corresponds to high temperature at 100 m, high coastal sea level, high atmospheric pressure, and low upwelling during January–February; offshore (beyond ~140°W), opposite conditions to those of the coastal area occur (Hollowed and Wooster 1992).

The low-frequency scale has often been regarded as equivalent to the regime variation; it also likely corresponds to the pentadecadal variation described by Minobe (2000). Regarding this scale, Parrish et al. (2000) made a review of previous information together with an analysis of wind data and suggested that surface water entering the California Current was of more subtropical origin after 1976. After this year, the surface of the central North Pacific cooled by 1°C or more, whereas along the North American coast and in the Gulf of Alaska it warmed by a similar amount. Furthermore, there was ~20 m shoaling of the mixed layer depth in the subarctic gyre after 1976 and deepening by a similar amount in the subtropical gyre. Dynamic heights and SST increased at the Gulf of Alaska after 1976, and transport into it increased while weaker transport occurred in the California Current.

Brodeur et al. (1996) and more recently Ingraham et al. (1998) report on a surface-drift simulation model (OSCURS, included in this study) that showed that winter trajectories begun at Ocean Station P drifted more toward the California Current before 1976 and more into the Alaska Current after 1976. Polovina et al. (1995) found that from 1976 to 1988 there was a period of intensified Aleutian Low, with deepening of the mixed layer at the eastern subtropical Pacific and shoaling at the Gulf of Alaska, as compared to the 1960–1976 period.

In summary, among the analyzed time scales many of the physical signals of variability seem qualitatively similar, thus suggesting similar large-scale changes in ocean current patterns and associated atmospheric states. If so, it would be difficult to discriminate among short- and long-term variability (e.g., a strong El Niño and the onset of a regime shift) solely from the examination of physical information. However, biological indexes may reflect changes at each scale in a different manner.

For example, the warming phase of short-term events (essentially those connected to ENSOs) are often associated with reports of some tropical species at locations poleward of their usual distribution limit. This is the case with the northward advection of pelagic red crabs (*Pleuroncodes planipes*), usually restricted to the Sebastián Vizcaíno Bay and south of it. Longhurst (1966) discussed the likely mechanisms responsible for their northward advection during the 1957–59 El Niño, including the intensification of the California countercurrent and the Davidson Current, the development of semi-permanent eddies, and the offshore displacement of the main current. Other passive fauna advected northward during these events include *Vellela* and *Doliolum lenticulatum*. Northward advection of passive fauna mostly results in a part of the population lost to nonsuitable areas where reproduction does not occur.

However, not only passively transported fauna move northward during warming events. Many pelagic, nectonic, and benthic strong-swimming fishes, particularly tunas, would hardly be passively transported. If they move north, it must be because the general conditions of the otherwise unsuitable area are appropriate at the time. Johnson (1962) related sea temperatures and albacore availability off Oregon and Washington, and Clark et al. (1975) showed interannual variations in the percentage of albacore tuna fished north or south of San Francisco related to climatic fluctuations. As one of the anonymous reviewers noticed, ENSO events are quite different among them (Schwing et al. 2002b), thus some species such as albacore may become more vulnerable when they access the California Current from the west as warm water expands to the east (Pearcy 2002). In any event, biological responses of other local populations, such as increased recruitment of the southeastern Alaska herring (Mysak 1986) or survival index of Pacific mackerel (Sinclair et al. 1985), do point toward large-scale conditioning of the area during ENSO years.

Biological effects of decadal-scale warm periods in the northeast Pacific include an increase of primary and secondary productivity (Polovina et al. 1995), together with strong recruitment in several groundfish stocks (Hollowed and Wooster 1992). Salmon stocks in Alaska show enhanced productivity, contrary to those in the U.S. Pacific Northwest (Mantua et al. 1997). Parker et al. (1995) discussed climate's forcing biological changes in Pacific halibut recruitment and affecting the productivity of a number of salmon species. Wooster and Hollowed (1995) suggest that changes in the intensity and direction of flow are required to account for the large time and space scales of the variations observed.

The regime variation has been linked to sardine and anchovy population abundance in several areas of the world's oceans (Lluch-Belda et al. 1989; Schwartzlose et al. 1999). In the Pacific, there have been reports of a number of other species' being affected, including albacore and several groundfishes, such as pollock (Bakun 1996), salmon, and jack mackerel (Klyashtorin 2001). In general terms, the warming regimes (~1910–40 and ~1975–90) have coincided with growth of the sardine, jack mackerel, salmon, and Alaska pollock populations; whereas increased abundance of herring and anchovies has occurred during the cooling regime (~1940–75). These changes in the abundance of fisheries populations seem to be synchronic, but not a consequence, of temperature; rather, they seem to be caused by large-scale modifications of ocean currents and associated atmospheric states (Lluch-Belda et al. 2001).

Finally, a relevant question brought up by one of the reviewers is the characterization of climate variability. Two extreme shapes would consist of a saw-tooth warming/cooling pattern, on the one hand, and a boxcar pattern of warm and cool periods with rapid transitions, on the other. At least at the low-frequency scale of variation, the pattern appears to be the former. For example, consider that the growth of sardine populations begins while the area is still cool (at the end of the cooling trend), and the onset of collapse occurs while it is warm, at the peak of the warming period; it is the change itself that makes the difference (Lluch-Belda et al. 2001). This would seem to be the case as well with the decadal-bidecadal variation (fig. 7); high-frequency ENSO events are too short to permit characterizing the type of change occurring and they might be different, particularly since they are not equal among themselves. A boxcar shape should be expected, however, when measuring certain variables. For instance, if we measured the direction of change around a long-term average, then we would have a negative period along a cooling trend, a rapid reversal, and a positive interval afterward during a warming trend. The change would occur during the regime shift, when the direction of change is reversed.

CONCLUSIONS

Climate variability in the CCS shows qualitatively similar physical signals at the three analyzed time scales: increased sea level and coastal temperatures, relaxation of the California Current, and intensification of the Alaska Current occur during warm episodes, while the contrary takes place during cool ones.

These alternative states appear to be consequences of similar large-scale changes in ocean current patterns and associated atmospheric states, thus making it difficult to discriminate between short- and long-term physical variability. Some biological indexes, however, respond differently to each scale of variability and thus may be useful for discriminating among their signals. Interannual variation in the CCS is better described as alternating periods of continuous change at the time scales considered, rather than as sustained warm and cold periods.

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AN ECONOMIC OVERVIEW OF DUNGENESS CRAB (*CANCER MAGISTER*) PROCESSING IN CALIFORNIA

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ABSTRACT

Dungeness crab (*Cancer magister*) was among the three most valuable commercial fisheries in California in seven of the last ten years. The "sex-size-season" regulatory system in California induces an annual derby fishery that results in a temporally compressed pulse of landings. The fishery relies on a few large receiver/processors capable of freezing and storing large quantities of crab. Research on former derby fisheries indicates that improved economic conditions (more valuable fresh product forms and more competitive processing) can be obtained if landings are temporally distributed. Consequently, questions have been raised about the current status of the Dungeness crab processing industry and whether economic conditions could be improved by eliminating the derby fishery. This article addresses part of the question by providing baseline economic information for this industry, including the mix of product forms and prices, value added, capital stock, and employment.

INTRODUCTION

Dungeness crab (*Cancer magister*), traditionally an important fishery in central and northern California, was among the three most valuable fisheries in California in seven of the last ten years. Since the mid-1970s the California/Oregon/Washington Dungeness crab fishery has experienced a sharp increase in number of traps fished. According to Didier (2002), there were an estimated 130,130 traps fished in the California/Oregon/Washington fishery in the 1975–76 season. In the 2000–2001 season Oregon and Washington combined had over 200,000 traps being fished (Didier 2002). From a recently completed survey of California Dungeness crab permit holders, we estimate that at least 172,000 traps were being fished in California in the 2001–2002 season.[1] In contrast, an economic analysis of the Dungeness crab fishery in the 1970s concluded that net economic benefits from the California/Oregon/Washington fishery would be maximized with a combined average effort level of around 60,000 traps across all three states (Pacific Marine Fisheries Commission 1978). Therefore, it is possible that combined current trap levels (about 375,000 traps) are more than six times the optimal number of traps.

This increase in effort combined with the "sex-size-season" regulatory system in California, Oregon, and Washington induces an annual "race for crab" or derby fishery that results in a temporally compressed pulse of landings. The commercial fishing season in California for Dungeness crab starts on 15 November (central coast) or 1 December (north coast), subject to meat yield testing and price negotiations between fishers and receiver/processors, and lasts until 30 June (central coast) or 15 July (north coast). (The season is of similar duration in Oregon and Washington.) Despite this long season, in recent years more than 70% of annual landings have occurred from 15 November to 31 December.[2] Due to this pulse of landings, the fishery relies on a few large receiver/processors capable of freezing and storing large quantities of crab. Research on former derby fisheries indicates that improved economic conditions (more valuable fresh product forms and more competitive processing) can be obtained if landings are temporally distributed. Consequently, questions have been raised about the current status of the Dungeness crab processing industry and whether eliminating derby conditions would improve economic conditions in the fishery. We address part of the question by providing baseline economic information for this industry, including the mix of product forms and prices, value added, capital investment, and employment.[3]

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[1] For a copy of the survey questionnaire, contact the authors.

[2] This pattern of temporal compression of Dungeness crab landings in California can be observed as far back as the early 1980s and also occurs in Oregon (Kaiser et al. 2001) and to some extent in Washington (PSMFC 1993). In contrast, between the 1950s and the mid-1970s only 30% to 40% of statewide landings occurred between 15 November and 31 December, and approximately 10% of annual landings were made in each of the months of February, March, and April.

[3] To more fully answer this question one would need to engage in market research to analyze the potential and the profitability associated with increasing the demand for live and fresh Dungeness crab outside of the traditional holiday season.

BACKGROUND

Fisheries management affects the structure of the fish-processing industry, the types of fish products sold by processors, and the marketing channels through which these fish products flow. Derby fisheries tend to promote overcapitalization by fishers, hazardous fishing conditions, and larger, more capital-intensive processors with freezing capacity adapted to the large pulse of landings. Prominent among the various proposed remedies for derby fisheries are individual quotas (IQs).[4] There is some evidence, summarized below, that IQs have resulted in higher ex-vessel prices, an increase in the processing of more valuable fresh product forms relative to frozen product forms, and structural changes in the fish-processing sector.

The potentially beneficial impacts of an IQ system on product forms, prices, and the structure of the fish-processing industry are illustrated by the British Columbian Pacific halibut (*Hippoglossus stenolepis*) fishery. As Casey et al. (1995) observe, attempts at managing this fishery by way of limited season openings resulted in overcapitalization, which in turn necessitated progressively abbreviated openings. By 1990 the annual fishing season had been compressed to a few days, and the resulting pulse of landings was largely processed into frozen product forms. In 1993, two years after an individual vessel quota (IVQ) system was implemented, landings were spread over eight months. This extended season led to an increase in fresh product forms and ex-vessel prices. While in 1989 the share of British Columbian halibut sold as a fresh product form was 42%, by 1993 this figure had increased to 94%. Moreover, the IVQ system encouraged the proliferation of smaller processors exploiting new niche markets for fresh fish.[5] More processors competing for fish bid up ex-vessel prices, creating financial benefits for fishers. Herrmann (1996) estimates that the IVQ system generated $23.22 million in additional revenue to fishers over the first four years of the program due to improved ex-vessel price. An IQ system for Alaskan halibut and sablefish was implemented in 1995.[6]

In 1986 New Zealand implemented an individual transferable quota (ITQ) system on some select fisheries in an attempt to conserve fish stocks. A 1987 survey by Dewees (1989) found that 77% of the fishers and processors had already significantly changed their operations, and notable among these was that fishers had placed more emphasis on new handling techniques to add value to their catch.[7] Export of live rock lobster (*Jasus edwardsii*) increased from 1,947 metric tons in 1990 to 2,722 metric tons in 1993. Australia and Tasmania have since also implemented ITQs. The South Australian rock lobster fishery has shown a 67% increase in real ex-vessel revenue between 1991 and 1998 in the northern zone, due to a 7% increase in landings and a 77% increase in nominal price (Donohue and Barker 2000). The southern zone showed a 33% increase in real ex-vessel value over the same period.

While trap limits (or trap certificates) have been a popular management tool for controlling effort in crustacean fisheries, there is little evidence to date indicating that they have had a significant impact in either reducing effort or increasing the proportion of more valuable product forms. For example, participants in the Maine lobster (*Homarus americanus*) fishery agreed to a trap quota system to address concerns over escalating trap numbers (Acheson 2001, 1998). The Maine trap-reduction program was widely seen as a failure in spite of initial participant support.[8] Between 1995 and 1998, 25% of the Maine lobster fleet increased their trap counts by over 200 traps, while only 17% of the fleet experienced any level of reduction in traps fished. Florida's spiny lobster (*Panulirus argus*) fishery faced similar overcapitalization problems and implemented a tradable trap certificate program in 1992. Although this program has reduced the total number of traps fished, Milon and Larkin (2000) estimate that the current number of traps is still roughly twice the optimal level, and they are skeptical that this program will achieve the optimal level of effort.[9]

METHODS

We focus our analysis on the firms that receive and process Dungeness crab landed in California and on the

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[4] IQs assign a share of a total allowable catch (TAC) to individual fishers (IFQs), vessels (IVQs), or communities (CFQs), and may be transferable (ITQs). Fishers can fill their quota at any time during the open season, thereby eliminating derby effects in a fishery.

[5] Note, however, that the transition likely imposed costs on the large capital-intensive processors with freezer capacity adapted to the former pulse of landings.

[6] The National Research Council (1999) cites anecdotal evidence that increasing numbers of Alaskan halibut fishers are bypassing traditional processing market channels and marketing directly to wholesalers and retailers. The same report cited testimony from processors indicating that the shift from large pulses of landings to a more even flow of landings had disadvantaged some of their operations, noting that "it is reasonable to assume that processing operations that had relied on large pulses of product for processing for the frozen market and had failed to modify their operations to accommodate the longer IFQ season would be less profitable as season lengthened" (p. 390).

[7] Similarly, following a change to an IQ system, the processing sector in Iceland has experienced a reduction in freezing capacity and in the number of large onshore processors, due in part to an increase in higher valued fresh product forms and at-sea processing.

[8] Equal trap limits set on all vessels allowed smaller vessels to increase the number of traps fished over the term of the program (Acheson 2001).

[9] Trap limits are finding their way into West Coast Dungeness crab fisheries. Washington's Fish and Wildlife Commission recently adopted a three-tiered Dungeness crab trap-limit system that has resulted in a 6.6% reduction in the total number of traps in the fishery. Moreover, a 2001 survey indicated that 86.5% of Oregon's Dungeness crab fishers favored trap limits (Kaiser et al. 2001). Fisher groups have discussed trap limits in California, but to date they have been unable to agree on any management measures to address economic conditions in the fishery.

product forms they sell. Our interviews included six processing firms in California and southern Oregon that purchased 60% of the crab landed in California in 2000. While economic conditions in the fishery and the processing industry are similar in Oregon and Washington, analysis of the combined California/Oregon/Washington Dungeness crab fishery is beyond the scope of the present analysis.

Value Added

At any given market-mediated stage of production, value added is measured as total revenue generated from sales of the product at that stage of production minus the value added at the previous stages of production (if any). Thus value added at the harvesting stage of production in a capture fishery is simply total revenue to the fishers. In contrast, value added at the receiving/processing stage of production (including any integrated wholesale distribution functions) is total revenue from sales of processed fish products minus the value of the fish received from the fishers. Value added represents income that flows to those who supply the capital, labor, entrepreneurship, and intermediate good and service inputs that are assembled together in production. Value added also includes tax income provided to federal, state, and local government (Hackett 2002).[10]

The term *percent value added* will be used here to describe processor value added as a percentage of the cost of purchased crab. Processor product mix ratios will also be crucial for the analysis. These ratios will aid in understanding the current flow of crab products through markets. The product mix will be important in analyzing the current production status as well as potential changes due to temporal distribution of product flow.

Data

The data used in this report come from both primary and secondary sources. In all cases these data are confidential and/or proprietary in nature. Data on vessel landings are derived from existing fish ticket data gathered by the California Department of Fish and Game (CDFG) and archived by the Pacific States Marine Fisheries Commission (PSMFC) in their PacFIN database. Each ticket contains information on quantity and revenue of crab landed and sold. Fish tickets also identify the receiver/processors who buy the crab, which is essential to the estimation of processor value added employed here. Product form, price, and product mix information were collected from the processors through on-site interviews and completion of a questionnaire.[11] The survey instrument also gathered information on capital investment and employment. Price per pound for various product forms can vary substantially over a given season, and so we asked processors to report average or typical price per pound for various product forms. The mix of various crab products made by processors was generally reported in two forms, either total pounds of each product form produced, or the percentage of purchased crab going into each product form.

In order to determine value added by processors we acquired authorization to access confidential data on purchases of crab by various processors in 2000 from fish ticket data archived by the PSMFC in the PacFIN database. The data covered purchases of crab landed at the four north coast ports in California (Fort Bragg, Eureka, Trinidad, and Crescent City). The original scope of this study was focused on the north coast ports of California, but later the scope was expanded to include the central coast Dungeness crab fishery. Unfortunately a subsequent supplemental request for 2001 central coast data, and for season rather than annual year data, was rejected by CDFG due to a dramatic change in data access policy that currently eliminates all independent researcher access to any confidential fish ticket data.

Due to the incomplete data set from CDFG a number of adjustments and estimates had to be made in our analysis. While the data we initially received from PacFIN was annual year data, we later learned that processors generally track their data based on fishing seasons (November/December through July). Because we could not go back and get processor purchase data from PacFIN based on fishing season, we were forced to assume that a processor's purchase share of statewide landings based on annual year data is equivalent to what it would be based on fishing season data. Consequently, the estimates reported as "2000" in this article refer to the 1999–2000 fishing season, while estimates reported as "2001" refer to the 2000–2001 season.

Moreover, since the PacFIN dataset provided to us only included purchases of crab landed at the four north coast ports, we had to estimate processor purchases of crab statewide based on the known proportion of north coast landings purchased by each processor. Specifically, we first computed the share of north coast landings purchased by each processor and then assumed that the same proportion applied to their statewide landings. Thus, if a processor received 20% of all north coast landings, we assumed that the processor had likewise received 20% of statewide landings. Since the four north coast ports generally include most of the state's overall landings (between approximately 70% and 90% of statewide landings

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[10] Note that value added does not necessarily include all of the possible positive and negative economic impacts of commercial fishing; for example, the income to employees of a processing facility is included in value added, but the additional community income generated by workers spending their paychecks at local grocery stores is not.

[11] For interview questions and methods, contact the authors.

over the last ten years), our projection of central coast purchases covers less than 30% of statewide landings.

Due to the natural fluctuation in Dungeness crab landings it is desirable to generate analysis for more than one year, and consequently we sought out data for 2000 and 2001. Unfortunately, the change in data-management policy at CDFG prevented us from acquiring 2001 fish ticket data indicating the quantity and price of crab received by individual processors, a situation that resulted in our having to estimate those purchases.[12] We used the statewide weighted average ex-vessel price per pound for 2001 to reflect the cost per pound of purchased crab for each processor. We developed two scenarios for estimating 2001 processor purchases to indicate the sensitivity of our results to different estimation approaches. Scenarios with the suffix "00" in Table 1 involved estimating 2001 processor purchases by assuming that a processor's share of total statewide landings in 2001 was the same as its known share of total statewide purchases in 2000. Since year-to-year landings and processor volumes fluctuate, a second scenario was developed (designated by the suffix "9800" in Table 1) by assuming that a processor's known share of total statewide landings in 2001 is equal to the average share of its known total statewide landings purchased over 1998–2000.

A final data issue concerns the extent to which the sample of processors interviewed for this study is representative of all processors that purchase Dungeness crab landed in California. We succeeded in surveying six processors in California and southern Oregon that together purchased 60% of all crab landed in California in 2000. We use these data to develop estimates for all processors that purchased Dungeness crab landed in California. The processors we surveyed tended (with one exception) to be the larger operators; this resulted in a sample bias in our processor data. The bias exists because small processors frequently lack fixed facilities and may only operate for a number of weeks each year, making them difficult to locate and interview. For example, some small processors purchase crab at the dock and drive the live crab to urban seafood markets. Small processors tend to specialize in live and fresh crab and lack the facilities to process frozen product forms (some of which later undergoes secondary processing into a picked meat product). Thus the "in-sample" data are biased toward frozen product forms.

Consequently, we created two additional scenarios based on different methods for extrapolating industry-wide product forms, prices, and value added from our survey data. One of these, designated with the letters "EX" in Table 1, is based on a simple extrapolation of the data from our overall survey data to processors outside of our sample. The other, designated with the letters "SM" in Table 1, is based on an extrapolation of the data from the small processor in our sample to processors outside of our sample.[13]

TABLE 1
Estimate Scenarios

Scenario	Description
2000EX	2000 processor estimates, extrapolating in-sample processor data to out-of-sample processors
2000SM	2000 processor estimates, extrapolating small-processor in-sample data to out-of-sample processors
2001EX00	2001 processor estimates, extrapolating in-sample processor data to out-of-sample processors, based on processor purchases in 2000
2001SM00	2001 processor estimates, extrapolating small-processor in-sample data to out-of-sample processors, based on processor purchases in 2000
2001EX9800	2001 processor estimates, extrapolating in-sample processor data to out-of-sample processors, based on average processor purchases in 1998–2000
2001SM9800	2001 processor estimates, extrapolating small-processor in-sample data to out-of-sample processors, based on average processor purchases in 1998–2000

Thus, we have four scenarios for estimating product mix, product form prices, and value added for processors purchasing all California Dungeness crab landings in 2001 and two scenarios for estimating landings for 2000, as shown in Table 1.

ANALYSIS AND RESULTS

Analytical Approaches

In order to perform value added analysis we had to yield-adjust product form quantities and prices to place them on a common basis with the original whole purchased crab ("round").[14] Yield adjustment is used to determine the percentage of the original whole crab by weight that remains in the product form after processing. For example, from Table 2 we can see that the "whole cooked" product form represents 87.5% of a whole crab by weight (due to loss of fluids), whereas the "picked meat" product form represents 25% of a whole crab by weight (due to fluids, viscera, and shell). Yield-adjusted price per pound for each product form was similarly calculated by multiplying the product form price per pound by the yield figures in Table 2. We then calculated the percentage of total yield-adjusted production going to each product form for each processor in our survey.

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[12] The CDFG policy change occurred in November 2001, before 2001 fish ticket data were fully tabulated and archived in the PacFIN database.

[13] The small processor scenarios rely on data from one small processor, which lends a degree of uncertainty to the conclusions that follow.

[14] We also had to convert any specific product form quantities reported by processors into percentages of total purchases allocated to each product form.

TABLE 2

Dungeness Crab Product Forms and Yield

Product form	Yield	Description
Whole cooked	87.5%	Frozen or fresh, cooked in brine; frozen product glazed to prevent freezer burn
Clean and cracked	87.5%	Same as whole cooked product, except legs are scored, often with band saw, for easier access to meat
Frozen section	~58%	Crab split into legs and sections, glazed
Live	~100%	
Picked meat	25%	Whole crab is blanched, hand picked with the picked meat sold fresh, frozen, or canned

Source: Processor interviews.

The next step involved calculating each processor's weighted average price (WAP), which is the weighted average yield-adjusted price charged for final product forms sold by each processor.[15] Industry-wide weighted average price was estimated by multiplying each processor's WAP in our sample by their estimated share of statewide crab landings purchased. We then extrapolated the sample WAP (scenarios denoted by "EX"), or extrapolated the WAP for our small firm (scenarios denoted by "SM"), to get an industry-wide WAP.

Once the industry-wide WAP was estimated, value added for the crab-processing industry could then be estimated. The percent value added was calculated as (WAP—weighted average ex-vessel purchase price) divided by average ex-vessel purchase price provided in Didier (2002). The percent value added simply expresses processor value added per dollar of purchased crab. Industry-wide value added was then calculated by multiplying percent value added by the total cost of purchased crab landed in California (ex-vessel revenue).

The scenarios were also used in an equivalent manner to estimate the industry-wide mix of Dungeness crab product forms, their weighted average prices, and their percent value added for 2000 and 2001.

Estimates

For purposes of comparison, information on ex-vessel landings, revenue (value added), and price per pound is provided in Table 3. Crab fishers added nearly $18 million in value in the 1999–2000 season. In contrast, higher prices in 2000–2001 were not enough to compensate for reduced landings, and value added by crab fishers declined to a bit more than $12 million.

Estimates for WAP, value added, and percent value added for processors that purchased Dungeness crab landed in California in 2000 and 2001 are provided in Table 4.

TABLE 3

California Dungeness Crab Landings, Value Added, and Price

Season	Quantity landed, in lb (kg)	Ex-vessel value added	Price per lb (kg)
1999-2000	8,769,512 (3,977,013)	$17,799,767	$2.03 ($4.48)
2000-2001	5,646,772 (2,560,894)	$12,616,251	$2.23 ($4.92)

Source: Processor interviews and PacFIN database.

TABLE 4

Industry-wide Estimates for Weighted Average Price (WAP), Value Added, and Percent Value Added for California Dungeness Crab

Scenario	WAP per lb (kg)	Value added	Percent value added
2000EX	$3.04 ($6.70)	$8,831,287	49.6
2000SM	$2.99 ($6.59)	$8,448,237	47.5
2001EX00	$2.89 ($6.37)	$3,676,024	29.1
2001EX9800	$2.88 ($6.35)	$3,651,140	29.0
2001SM00	$2.86 ($6.31)	$3,534,661	28.0
2001SM9800	$2.85 ($6.28)	$3,487,451	27.6

Source: Processor interviews and PacFIN database.

In terms of value added, there was little difference in the two scenarios ("EX" and "SM") used to estimate WAP, value added, and percent value added for 2000. In both cases the weighted average price per pound of the product forms was approximately $3 (or $6.62 per kilogram), industry-wide value added ranged from $8.45 to $8.83 million, and value added by processors is estimated to be 47.5% to nearly 50% of that added by crab fishers. It is interesting to note that prices, value added, and percent value added were all slightly lower in the "2000SM" scenario, which extrapolates information from the small processor in our sample to the out-of-sample processors, relative to the "2000EX" scenario. As will be described in greater detail below, this is because the fresh and live product forms add less value per pound than the frozen and picked-meat product forms.

The 2001 estimates for industry-wide value added were also relatively insensitive to scenario. In particular, industry-wide value added ranged from $3.49 million (scenario 2001SM9800) to $3.68 million (scenario 2001EX00), a difference of only 5.4%. As with the 2000 estimates, value added was lower in the "SM" scenarios relative to the "EX" scenarios in 2001. Value added by processors ranged from 27% to 29% of that added by crab fishers, which is substantially lower than the comparable estimates for 2000.

Several factors resulted in the decrease in total value added and percent value added in 2001 relative to 2000. First, note from Table 3 that weighted average ex-vessel price per pound was higher in 2001 ($2.02 in 2000 com-

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[15] The weighting factor is simply the yield-adjusted share of the particular product form in the processor's overall product mix. Note that WAP multiplied by the pounds purchased by processors is equal to total gross processor revenue.

TABLE 5
Industry-wide Percent Value Added by Dungeness Crab Product Form

	Percent Value Added				
Scenario	Frozen whole cooked	Frozen sections	Frozen picked meat	Fresh whole cooked	Live
2000EX	39.6	53.6	73.5	28.5	38.6
2000SM	39.6	60.6	76.4	32.4	38.6
2001EX00	25.8	42.3	32.0	21.4	26.3
2001EX9800	26.1	43.3	31.8	20.8	26.2
2001SM00	35.6	51.9	32.1	18.9	26.3
2001SM9800	37.1	55.2	32.1	18.5	26.2

Source: Processor interviews and PacFIN database.

pared to $2.23 in 2001), likely because of the substantially lower landings in 2001 (in kilograms the respective numbers are $4.45 and $4.92). Second, note that the estimated industry-wide WAP of crab product forms was lower in 2001 across all scenarios. From Table 5 we can see that the percent value added declined for each product form in 2001 relative to 2000 across nearly all the scenarios. One possible explanation for this decline could be the worsening economy in the United States and the 9/11 tragedy in 2001, which reduced consumer confidence and vacation travel.[16]

In terms of the primary questions this study addresses, note that the percent value added by fresh and live product forms was generally less than that of the frozen and picked meat product forms. If consumers perceive fresh and live product forms as possessing superior quality to the frozen product forms (much of the picked meat product form originates from the secondary processing of previously frozen crab), then presumably this would be manifested in higher prices per pound for the fresh and live product forms, especially if the pulse of landings suppresses this product form.[17] In fact, our analysis suggests that this is not the case. Since estimated percent value added by product forms in Table 5 relates the yield-adjusted sales price to a given dollar of purchase cost, it is evident that the frozen (and picked meat) product forms featured higher yield-adjusted prices per pound. From Table 6 we can see that under most scenarios only about half of the Dungeness crab landed in California is processed into fresh or live product forms.[18]

The superior yield-adjusted price for picked meat products might be explained by the notion that many final consumers (e.g., diners at restaurants and on cruise ships) value convenience over freshness, since picking meat from a Dungeness crab is a somewhat laborious task.[19] In fact, our estimates for percent value added in 2000 are consistent with the picked meat product having the highest yield-adjusted value in the marketplace (though this was less evident in the 2001 estimates). Processors in our interviews noted the importance of maintaining restaurant, cruise ship, and other food service accounts that serve as key market channels for picked meat. The importance of maintaining these picked meat market channels is indicated by trends in the estimated share of total statewide Dungeness crab landings going into the picked meat product form. Note that the percentage of crab processed into a picked meat product generally increased in 2001, when landings had decreased, indicating the importance of protecting market channels for picked meat.

Recall that the literature cited earlier suggests that derby fisheries result in substantial unmet consumer demand for fresh finfish. The superior market value of fresh finfish product forms over frozen product forms served as the foundation for improved economic conditions in the relevant fisheries when IQ management systems were utilized. While our analysis can only conjecture about the changes in product forms that might occur as a result of temporally distributing the current pulse of Dungeness crab landings, the higher yield-adjusted market value of frozen and picked meat product forms suggests that the economic benefits may be smaller for crab than have been observed for finfish.

Comparing the scenarios that emphasize the characteristics of small processors (scenarios designated by “SM”) with those based on an extrapolation of the overall sample (scenarios designated by “EX”) in Table 6 sheds light on the different product form strategies pursued by small and large processors. Our small processor scenarios indicate a focus on fresh “whole cooked” crabs, though, interestingly, large processors appear to produce the larger proportion of the live crab product form.[20]

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[16] San Francisco, for example, experienced a significant loss of tourist visitation following 9/11, and news reports at the time indicated proportionately lower sales of Dungeness crab and other seafood.

[17] Connoisseurs of Dungeness crab who advocate for superiority of fresh and live crab might argue that this is a consumer education issue and a shortcoming of current marketing efforts.

[18] By way of comparison, Radtke and Davis (2000) estimated that roughly 25% of Dungeness crab in 1996 was processed into a “fresh whole cooked” product form, with the remainder processed into picked meat or frozen sections. Evidently the live crab market is relatively recent.

[19] Given the regional nature of the market for fresh crab and the perishability of this product, lower prices may also be required in order to sell fresh crab quickly.

[20] Several of the large processors in our survey noted that they had made efforts to penetrate the live crab market in recent years.

TABLE 6
Industry-wide Estimated Dungeness Crab Product Mix (percentages)

Estimate scenario	Frozen whole cooked	Frozen sections	Picked meat	Fresh whole cooked	Live
2000EX	3.8	12.3	30.4	21.9	27.2
2000SM	2.6	11.7	22.2	42.1	18.6
2001EX00	4.6	6.6	48.3	19.2	21.4
2001EX9800	4.9	5.9	50.5	20.4	18.3
2001SM00	5.9	7.2	35.4	37	14.6
2001SM9800	6.3	6.9	33.8	41.8	11.2

Source: Processor interviews and PacFIN database.

TABLE 7
2001 California Dungeness Crab Processing Employment and Capital Stock Estimates

Scenario	Peak employment	Off-peak annual employment	Capital stock
2001EX00	485	142	$6,070,475
2001EX9800	506	146	$6,246,654
2001SM00	530	97	$4,291,782
2001SM9800	552	89	$3,995,356

Source: Processor interviews and PacFIN database.

We were only able to get sufficient information on employment and capital stock from our survey to develop industry-wide estimates for 2001, as illustrated in Table 7. As before, industry-wide estimates were found by extrapolating in-sample employment and capital stock to out-of-sample processors. Note that in 2001 the peak employment estimate ranges from 485 to 552 (during the weeks when the pulse of landings is being processed), depending on scenario, whereas the off-peak "year-round" industry-wide employment (mostly picking lines) estimate ranges from 88 to 142. Note the distinctive employment signatures of small and large processors. Large processors cause the "EX" scenarios to estimate a larger off-peak level of employment than the "SM" scenarios. In contrast, the greater emphasis on small processors in the "SM" scenarios results in a higher estimate for peak season employment. A likely explanation is that large processors, which produce proportionately more picked meat, operate picking lines throughout the year, whereas small processors produce proportionately more fresh "whole cooked" crab sold during the holiday season.

Capital stock is also clearly a marker of large processors.[21] The "SM" scenarios lead to capital stock estimates of around $4 million, whereas the "EX" scenarios lead to capital stock estimates of around $6 million. Clearly this difference reflects the added expense of large freezer capacity held by large processors.

CONCLUSION

Our analysis estimates that picked meat and frozen crab product forms elicit the highest yield-adjusted market prices and value added under the current fishery management system. By freezing crab sections for picking later, the larger processors are able to manage the flow of product into the market, in sharp contrast to the large pulse of fresh crab landed in the season's first weeks. The share of landed crab being processed into picked meat increased when overall landings decreased, which supports the importance asserted by processors we interviewed of protecting market channels for picked meat during years with poor landings. Our findings were somewhat surprising because analysis from finfish fisheries indicates that fresh product forms tend to carry a higher consumer valuation than frozen product forms. We conjecture that many final consumers value the convenience of picked crab over fresh or live crab. These findings suggest that the shift to higher-value product forms resulting from the temporal distribution of landings in finfish fisheries may not necessarily occur if the current derby fishery for Dungeness crab were eliminated.

We hasten to observe that these findings are only suggestive, and that fishery management that expands the temporal distribution of landings significantly (such as through IQs) could generate a variety of benefits. These benefits may include improved safety, less incentive to overcapitalize, and stronger incentives for product innovation and marketing efforts. Over time the latter could very well change relative consumer preferences for different Dungeness crab product forms.

Most of the processors interviewed for this report consider Dungeness crab to be a seasonal or luxury food item associated with various celebratory events, with peak consumption of fresh crab products occurring between Thanksgiving and New Year's Day. Processors noted difficulty in moving fresh crab after late January (Super Bowl weekend). The fact that peak consumption of fresh Dungeness crab occurs during the holiday season, which corresponds to the only time in recent years that fresh product is available, suggests that consumer demand may be adaptable to seasonable availability.

The large processors in our survey mentioned that target frozen inventory levels are usually set prior to the season based on existing inventory and projected consumer demand. Processors base their estimate of future

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[21] Note that "capital stock" refers to processing facilities, equipment, and inventory, and is not specific to crab.

consumer demand on overall economic indicators (economic growth, consumer confidence) and the price and availability of substitutes. Key substitutes were reported to be Dungeness crab products out of Washington, Oregon, and British Columbia, snow crab products, and more generally other seafood and meat products. As the season begins and it becomes clear that their target inventory level will be reached, then production shifts to include fresh and live product forms. Processors noted that fresh product is easier to unload quickly. In years with low landings, large processors focus most of their production on frozen products, leaving more of the fresh and live market to smaller processors.

The processors interviewed for this study report considerable difficulty in moving large quantities of fresh crab product forms outside of the region due to the cyclical nature of the fishery. In years with large landings, the industry is able to develop new markets, such as East Coast restaurant accounts. These processors report high product satisfaction in these new markets. But then when years with very small landings come along, processors report that rising ex-vessel prices put upward pressure on fresh product form prices, and out-of-region markets are more price sensitive than those within the region due to reduced product identity. Processors claim that this price sensitivity effectively eliminates fresh Dungeness crab products from being regular restaurant menu items outside of the region.

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TRENDS IN THE SOUTHERN CALIFORNIA SPORT FISHERY

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ABSTRACT

We constructed a database for the Southern California commercial passenger fishing vessel (CPFV) fleet for the years 1959–1998 using the daily fish reports from the *Los Angeles Times*. This database includes information on number of fish caught by species, landing port, landing date, and number of anglers. Comparison of this database to the logbook database maintained by the California Department of Fish and Game shows high correlation.

Angler effort has been consistent throughout the time series at about 620,000 passengers per year. The annual fish catch averaged 4.25 million fish from 1963 to 1991 but has declined since 1992 to 2.5 million fish in 1998. The data show a decided decline in the CPFV catch of rockfish species since the early 1980s; a possible consequence of this decline appears to be a shift in effort toward less utilized species over the past decade, most notably ocean whitefish, California scorpionfish, cabezon, and more recently sanddabs.

The CPFV fishery not only provides a recreational opportunity to residents and visitors to southern California but also contributes to local economies. This fleet's catches, combined with those of private recreational anglers, are substantial enough to impact fish populations, particularly in regional areas. The database, which will be available on the NOAA-NMFS Southwest Fisheries Science Center Web site and updated regularly, provides a means of monitoring fisheries trends in real time.

INTRODUCTION

One of the difficulties in assessing fish stocks is obtaining time series spanning enough time to recognize long-term trends in abundance and to measure the effects of fishery regulations. The *Los Angeles Times* has carried a daily report of marine fish landings by commercial passenger fishing vessels (CPFVs) in Southern California for over 50 years. Although the central function of these reports is to encourage anglers to fish aboard CPFVs, the reports, if compiled into a database, could also provide a valuable tool for monitoring the fishery and the stocks on which it depends. The *Los Angeles Times* usually reports each day's landings for most fishing ports, the number of CPFVs reporting landings on that day, the total catch numbers by species or species group, and the total number of fishing passengers. In 1997 Charles Mitchell (of MBC Applied Environmental Sciences) was awarded a Saltonstall-Kennedy Grant (NA76FD0050) to enter 40 years of the *Los Angeles Times*' marine fish reports into a database to make this information available for fishery researchers in California. The Southwest Fisheries Science Center, National Marine Fisheries Service, assumed responsibility for updating and maintaining the database after Mitchell completed his grant project. Data are currently available for 1959 to the present. The database provides a data set for tracking trends in the abundance of fishes taken by the CPFV fishery in southern and central California and for following interannual and seasonal trends in recreational fishing effort. The California Department of Fish and Game (CDFG) maintains a similar database derived from logbook records begun in 1935 that also reports the catches of the CPFV fleet (Hill and Schneider 1999). A comparison of CDFG's logbook data with *Los Angeles Times'* reports over 6 years showed strong correlations between the two data sets for many of the more popular species within ports and years (Hill and Barnes 1998).

Our objective in this article is twofold: to describe major trends in recreational fishing in southern California as revealed by the *Los Angeles Times'* data set, and to describe the data set, identifying its strengths and limitations, so that fishery researchers and the public can use the data to better understand the dynamics of the resources and recreational fishing patterns in California waters. This database, which will be available on the NOAA-NMFS Southwest Fisheries Science Center Web site and updated regularly, provides a means of monitoring fisheries trends in real time.

Trends in the CPFV fishery are of consequence. Recreational fishing in California is a substantial business contributing over $173 million to the economy annually (Gautam 1996). A major segment of that industry is the CPFV fleet, which provides fishing experiences to millions of anglers in southern California

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(Young 1969; Gruen, Gruen, and Associates 1979). In 2001 the fleet consisted of 200 vessels licensed to operate in southern California.

METHODS

Properties of the Data Set

The database was generated by MBC Applied Environmental; microfiche records of the *Los Angeles Times'* fishing reports from the newspaper's archives were copied and the data was subsequently entered into the database. The daily information includes the date, landing code, local landing name, number of anglers, species code, number of fish caught for each species, and number of fish released for each species; there is also an appendix of species codes, *Los Angeles Times* names, common names, scientific names, and family groups. Presently, the data are for 1959–1998, except for a gap between June 1961 and April 1962 when the *Los Angeles Times* did not publish a fish report. The present database has been extensively edited since its initial production; numerous data entry and coding errors have been eliminated, species codes altered, and changes verified by returning to the original microfiche records. The edited data set was converted into Microsoft Access format.

The data set includes 1.23 million records, 147 species or species groups (e.g., rock cod or bass), with 27 ports represented from Ensenada, Baja California, in the south to San Simeon, California, in the north. The *Los Angeles Times* published its reports daily, with occasional minor gaps, including the one mentioned above.

The reports sometimes distinguished between half-day and full-day trips, but this distinction was not included in the database. Multiday or long-range trips are not included in the fish reports. Therefore, effort calculations derived from number of anglers fishing are expressed as an angler trip, irrespective of trip length.

Common Names

The species names reported in the newspaper are common names and many species may have more than one common name, or a single common name may refer to more than one species and usages have changed over the years. For example, many large catches were recorded as "grouper." Three species of grouper—*Mycteroperca jordani*, M. *xenarcha*, and *Epinephelus niveatus*—are occasionally caught in southern California waters; however, each is considered rare (Miller and Lea 1972), and catches are usually of a single specimen. Fishers commonly refer to the rockfish bocaccio (*Sebastes paucispinis*) as salmon grouper, with the name frequently being shortened to grouper in the report. Thus, reports of "grouper" were assigned to bocaccio unless a specific type of grouper was actually named. Similarly, Hill and Barnes (1998) noted that yellowtail (*Seriola lalandi*) were reported by the *Los Angeles Times* but this species does not appear in logbook records for the ports of Avila, Morro Bay, and San Simeon. Yellowtail rockfish (*Sebastes flavidus)* are commonly caught in these ports, and the name is frequently shortened to "yellowtail" (and likely reported this way to the *Los Angeles Times*). Because *Seriola lalandi* seldom occurs north of Point Conception except occasionally during strong El Niño years, references to "yellowtail" from these ports were assigned to *Sebastes flavidus*. Many other instances of assigning common names to specific species exist in the data. In some instances we had to use group names like rockfish, rock cod, bottom fish, or bass because this was how the catch was reported.

We have assigned all of the common names to single species where possible, including multiple common names. This effort has included correcting obvious typos in the newspaper records. Many species are listed individually, for instance, albacore tuna (*Thunnus alalunga*), yellowfin tuna (*Thunnus albacares*), yellowtail (*Seriola lalandi*), bonito (*Sarda chiliensis*), and Pacific barracuda (*Sphyraena argentea*). Other species may be listed individually or included in a "group" classification; some examples would be kelp bass (*Paralabrax clathratus*), barred sand bass (*P. nebulifer*), and spotted sand bass (*P. maculatofasciatus*), which are sometimes lumped together as "bass," or individual *Sebastes* species, which may be reported individually as bocaccio, chilipepper, or widow rockfish or be lumped in group designations ("rockfish," "rock cod," "red rock cod," or "red snapper"). Group designations such as "rockfish," "rock cod," "red snapper," "red rock cod," "bottom fish," and "flatfish" are included as reported. We list "rock cod" and "rockfish" as they may represent primarily deep and shallow *Sebastes* spp., respectively, but it is by no means a hard and fast line that separates the two designations. "Rockfish" could quite possibly include other non-*Sebastes* species such as cabezon, ling cod, and ocean whitefish in some instances. "Bottom fish" should be considered a catch-all group of varied, less valued, but unknown species. Since the reports are an advertisement, the most desirable species are consistently reported by species rather than as a group. This makes tracking of the more desirable species an easier task and enhances the overall value of the database to researchers. In a database of this size the value is in the historical trends reflected in the catches, and the small errors in daily reports are assumed to be of minor import.

Geographical Distribution of Landings

The *Los Angeles Times* reported landings from 27 ports from 1959 to 1998 (fig. 1). In the early years, many of the northern recreational fishing ports either did not

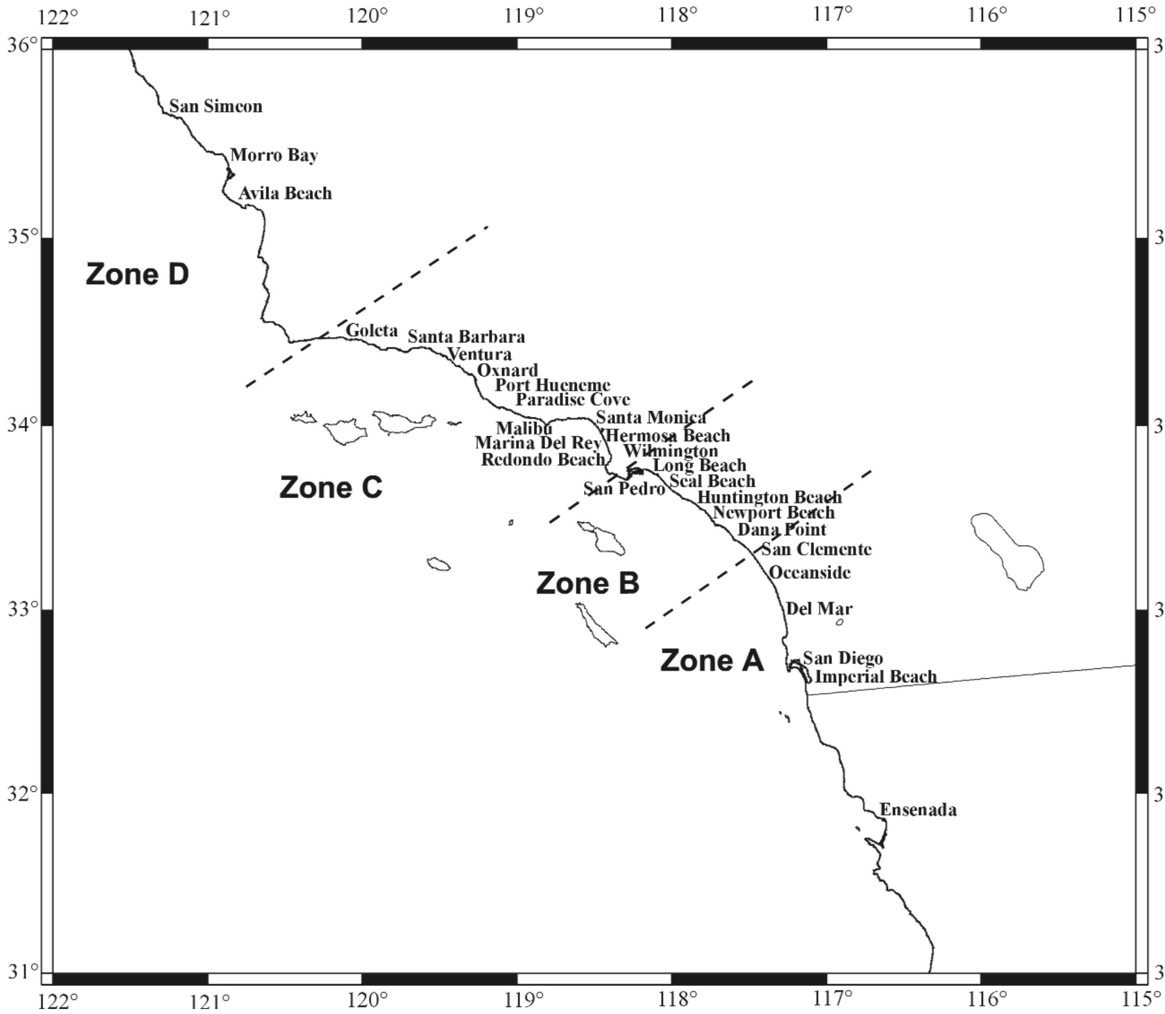

Figure 1. Area covered by the *Los Angeles Times'* marine fish report during 1959–98 showing the 27 ports from which reports are taken and the four geographical zones.

exist, did not report, or reported only intermittently. In addition, the consistency of landings reporting the catch varied among ports. In this article we group the data by four geographic zones (fig. 1). Zone A includes 5 ports from Ensenada to Oceanside, with fishing areas including the waters off northern Baja California, Mexico, and San Diego north to Oceanside, the southern region of the Southern California Bight. Zone B includes 7 ports from San Clemente to San Pedro, with fishing areas including the coastal waters off San Clemente, the flats off Huntington Beach and Newport Beach, waters off Long Beach, around the islands of San Clemente, San Nicolas, and Santa Catalina, and the central region of the Southern California Bight with occasional tuna trips into Mexican waters. Zone C includes 12 ports from Wilmington to Goleta, with fishing areas including the regions of Santa Monica Bay and Ventura flats, islands of Santa Barbara, Anacapa, Santa Cruz, Santa Rosa, and San Miguel, and the northern portion of the Southern California Bight. Zone D includes 3 ports north of Point Conception, from Avila to San Simeon, with fishing areas north of Point Conception in coastal waters and on Santa Lucia Bank, and offshore.

Landings from zone D were not reported until 1964, and they became consistent by 1972 when they averaged about 600 reports annually, increasing to 1,000 annual reports for this zone from 1991 until the present. Zone A averaged 550 reports a year from 1959 to 1984, increasing to 1,200 a year from 1985 to 1998. Zones B and C, having the greatest number of ports and the highest population density, have averaged around 2,300 reports a year since the peak reporting years of 1967–68 when they averaged more than 3,000 reports a year. Pier and barge reports were included occasionally, until removal of the barges in the late 1960s. Between 27 September 1965 and 23 May 1985 the report did not include the total number of boats fishing but did include the total number of anglers.

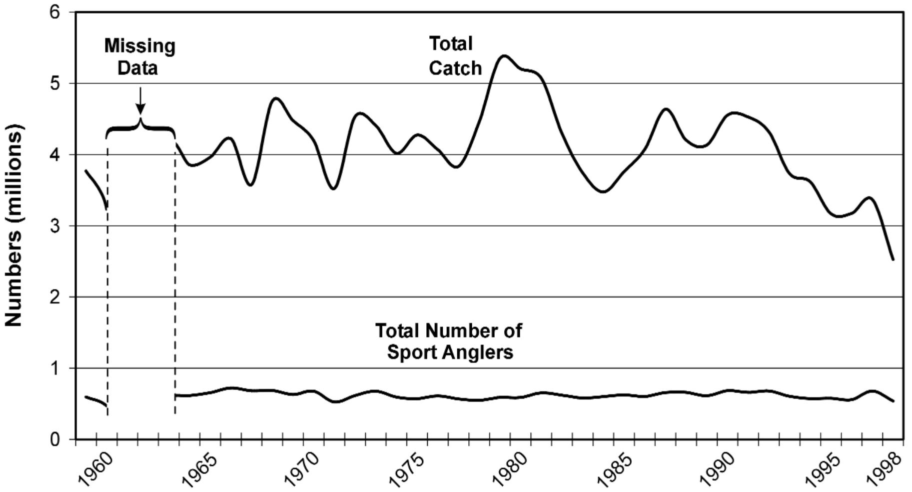

Figure 2. The total annual effort (angler numbers) and catch of all fish species reported in the *Los Angeles Times'* marine fish report for 1959–98.

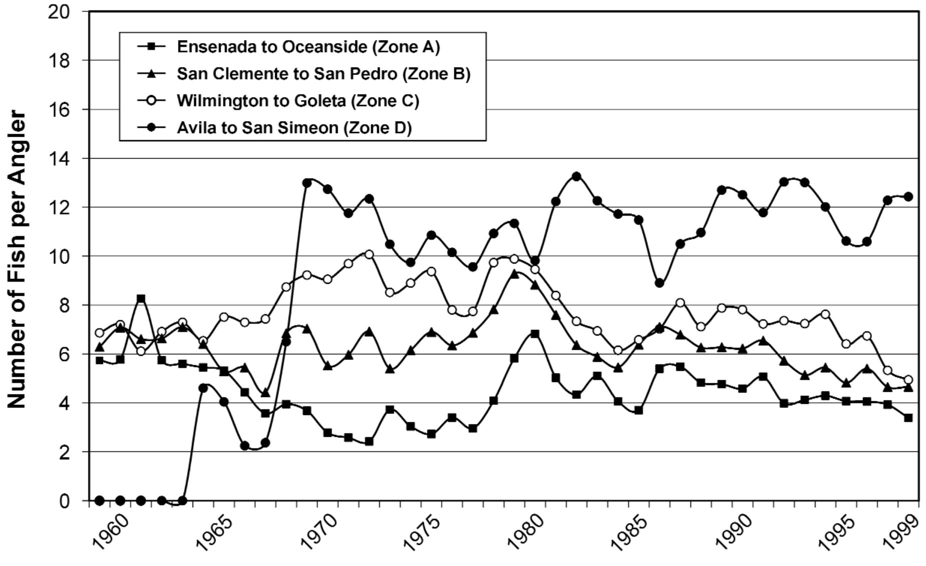

Figure 3. Annual CPFV catch per angler by geographical zone, 1959–98.

TRENDS IN THE CPFV FISHERY, 1959–98

Annual Number of Fishing Trips and Catch

A surprising feature of the CPFV fishery is that the total number of angler trips has remained relatively constant at about 620,000 angler trips per year over the 40-year time series (fig. 2). This is remarkable given the large increase in the coastal population of California over the same period. A partial explanation for the lack of growth in the average number of angler trips is that the percentage of the population that participates in recreational fishing is declining. It dropped from 6.5% to less than 5% from 1993 to 1998 (Milton 2000). The increasing popularity and availability of private boats may be the major area of growth in coastal fishing. In southern California, private boats in 1998 accounted for 45% of the recreational fishing effort as opposed to 23% for the CPFV fleet (NMFS 2000).

While the number of angler trips has remained relatively constant over the last 40 years, the number of fish caught is declining (fig. 2). The reported total annual catch varied around a mean of 4.25 million fish for the period 1963–91, but since 1992 the catch has been decreasing. In 1998 the annual catch was about 2.5 million fish, which is a 41% reduction from the long-term mean 1963–91 and the lowest value in the time series thus far. Considerably more fish are captured per angler trip in the northern ports (zone D) than in the more southern ports (fig. 3). Zone D anglers averaged 11.5 fish per angler trip during 1969–98 (earlier years were

TABLE 1
Top Ten Species Caught by CPFVs in Each Zone and Percentage of Total Catch for That Zone

Rank	Zone A	Zone B	Zone C	Zone D
1	Calico and sand bass (21%)	Calico and sand bass (29%)	All rockfish species (52%)	All rockfish species (80%)
2	Bonito (16%)	All rockfish species (22%)	Calico and sand bass (19%)	Calico and sand bass (14%)
3	All rockfish species (15%)	Bonito (17%)	Pacific mackerel (11%)	Lingcod (3%)
4	Pacific mackerel (12%)	Pacific mackerel (13%)	Bonito (9%)	Albacore (2%)
5	Pacific barracuda (11%)	Pacific barracuda (10%)	Pacific barracuda (3%)	Pacific mackerel (<1%)
6	Albacore (8%)	Yellowtail (2%)	Ocean whitefish (1%)	All salmon (<1%)
7	Yellowtail (8%)	Pacific halibut (1%)	Sculpin (1%)	Miscellaneous (<1%)
8	Yellowfin tuna (2%)	Sculpin (1%)	Pacific halibut (1%)	Pacific barracuda (<1%)
9	Sculpin (2%)	Ocean whitefish (1%)	Lingcod (<1%)	Bonito (<1%)
10	Skipjack tuna (2%)	Albacore (1%)	Bottom fish (<1%)	Pacific halibut (<1%)
	All others (3%)	All others (3%)	All others (2%)	All others (<1%)

not used because of reporting vagaries); zones C and B averaged 7.7 and 6.3 fish per angler trip, respectively, during 1959–98; and zone A anglers caught an average of 4.4 fish during 1959–98. These regional differences are due to differences in the target species (tab. 1). The farther north a port is, the greater the focus on rockfish species with large bag limits and high catch rates during much of the year. Rockfish species constitute 80% of the catch for ports in zone D. CPFVs in the two central zones, B and C, also depend heavily on rockfish, which rank second and first in their contribution to the total catch, respectively. However, they also target an assortment of coastal species such as bass, barracuda, bonito, mackerel, California halibut (*Paralichthys californicus*), and yellowtail, which even with liberal bag limits tend to have lower catch rates than rockfish. CPFVs in the most southern ports in zone A frequently expend a large fraction of their fishing effort on the highly desirable but more elusive tunas and yellowtail and have consequently lower catch rates compared to coastal species or rockfish throughout much of the season. In addition, vessels from southern ports often fish in Mexican waters, where the bag limits are less restrictive than California's for large pelagic species.

Seasonal Variability in Catch Rates of Common Species

Catches of various species fluctuate because species vary not only in their availability and abundance but also in their desirability to anglers. Boat captains plan trips to maximize catches of the most desirable of the available species, shifting their effort from one target species to another and creating seasonal patterns in the fishery unrelated to abundance. For example, in winter and spring, catches are resident cold-water species such as rockfish, but as the waters warm in the spring or summer, fishing effort shifts to summer migrants, as shown in Figure 4.

Environmental conditions play a role in the appearance of migratory species in the southern California sport fishery. The most noted influence has been El Niño or La Niña events with their resultant anomalously warm or cool sea-surface temperatures off southern California. There were 13 El Niño and 7 La Niña events during

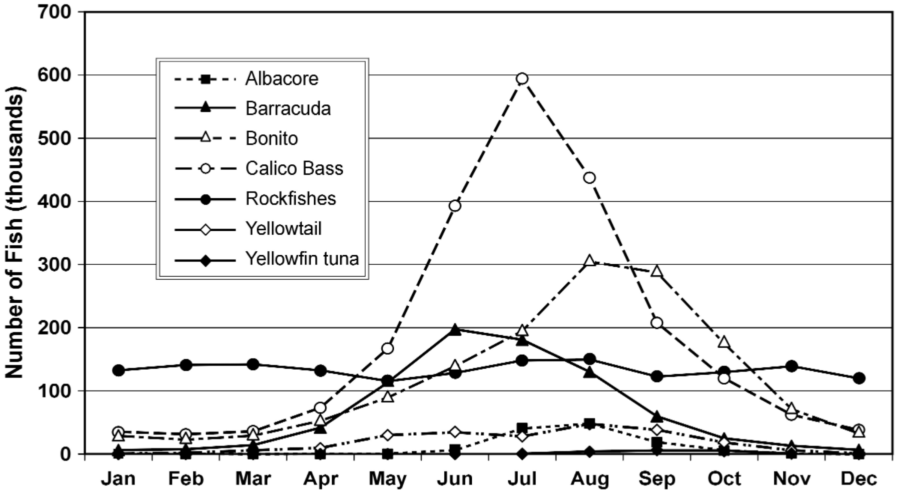

Figure 4. Average monthly CPFV catch, 1959–98, for several popular sport fish species or species groups.

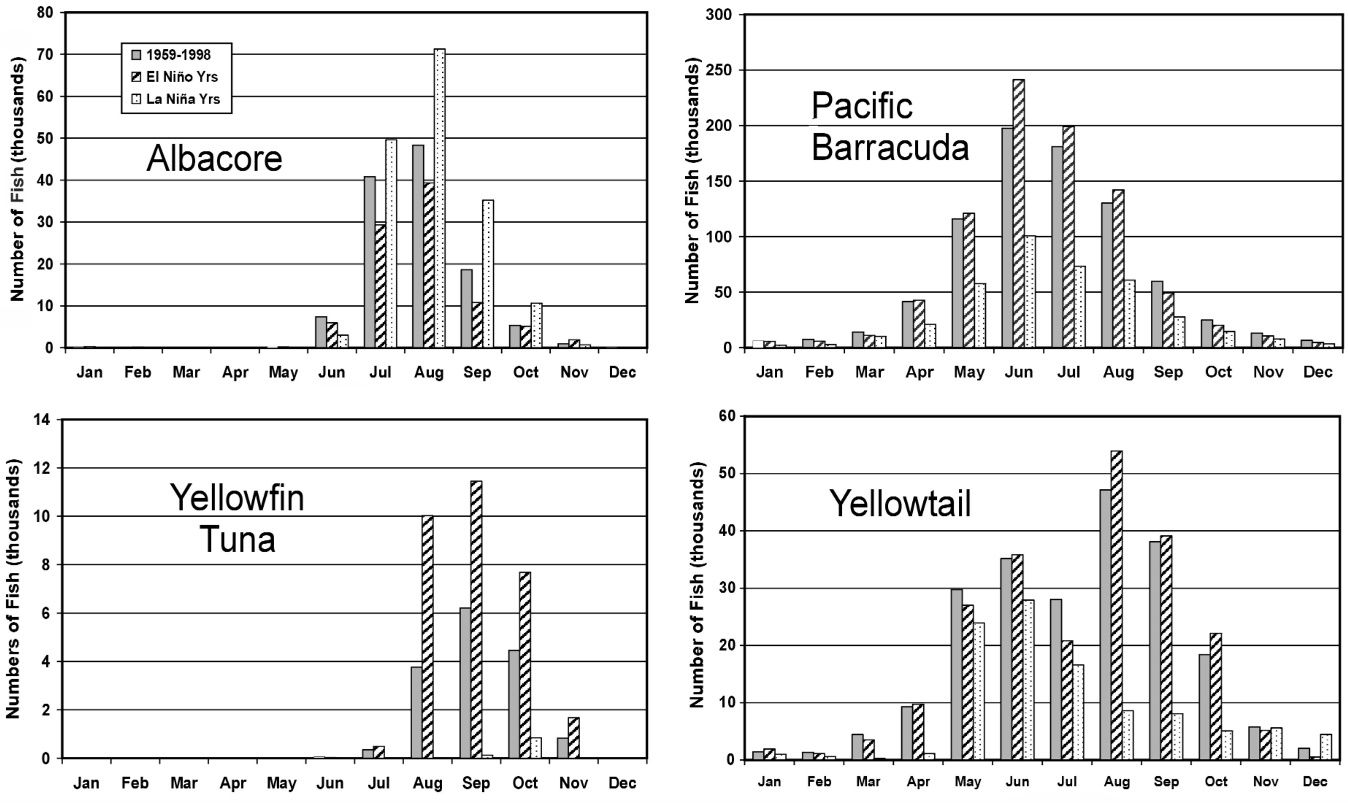

Figure 5. Average monthly CPFV catches of some migratory species, during 1959–98 and following El Niño and La Niña years.

1959–98. Figure 5 shows the average monthly catches of some migratory species as well as the averages for years following an El Niño or La Niña winter. For yellowtail, monthly catches during El Niño years do not appear to differ significantly from the 40-year average but appear significantly lower during La Niña years. Pacific barracuda show much the same trend as yellowtail. Albacore catches are affected by both events, with lower catches during El Niño events and higher catches during La Niña events. Yellowfin tuna, a tropical species, appear primarily in El Niño years and late in the season when waters have warmed to their maximum.

Angler Response to Reported Catch

The demand for fishing trips is tied to anglers' expectations of what will be caught on the trip (Center for Natural Areas 1980), and, of course, it is precisely for this reason that the *Los Angeles Times* publishes the daily catch. In order to see the effect of catch reports on passenger numbers or effort, we grouped the change in reported catch from one day to the next for albacore and yellowtail in zone A and plotted that against the change in passenger count for 1–3 days following the report (fig. 6). The change in catch was grouped as −100–100 fish, ±100–500 fish, ±500–1,000 fish, and ≥1,000 fish.

When changes in yellowtail catches in zone A are slight (±100 fish), passenger counts remain static, but as reported catches increase or decrease from this level, passenger counts also increase or decrease (fig. 6a). The angler response to increasing catches was strongest on the day following the report's appearance in the newspaper, with the effect diminishing 2–3 days later. When yellowtail counts increased by over 1,000 fish from the previous day's catch, the average increase exceeded 400 anglers. When counts decreased, passenger counts also decreased, and, again, the response was greatest on the first day following the report. Thus, anglers are quick to respond to both increasing and decreasing catches of yellowtail. The angler response to changes in albacore catches in zone A is similar to that of yellowtail: increasing catches resulted in increased passenger count, and decreasing catches resulted in decreasing passenger counts (fig. 6b). However, unlike yellowtail, the angler response on the second and third days after a report was about the same as the first day after the report. Albacore trips are generally overnight trips, requiring two days to complete, whereas yellowtail trips require only one day. Thus, the difference in response between albacore and yellowtail trips may be due to differences in the extent of planning required. The magnitude of passenger change in albacore trips was only about 75% of that reported for yellowtail.

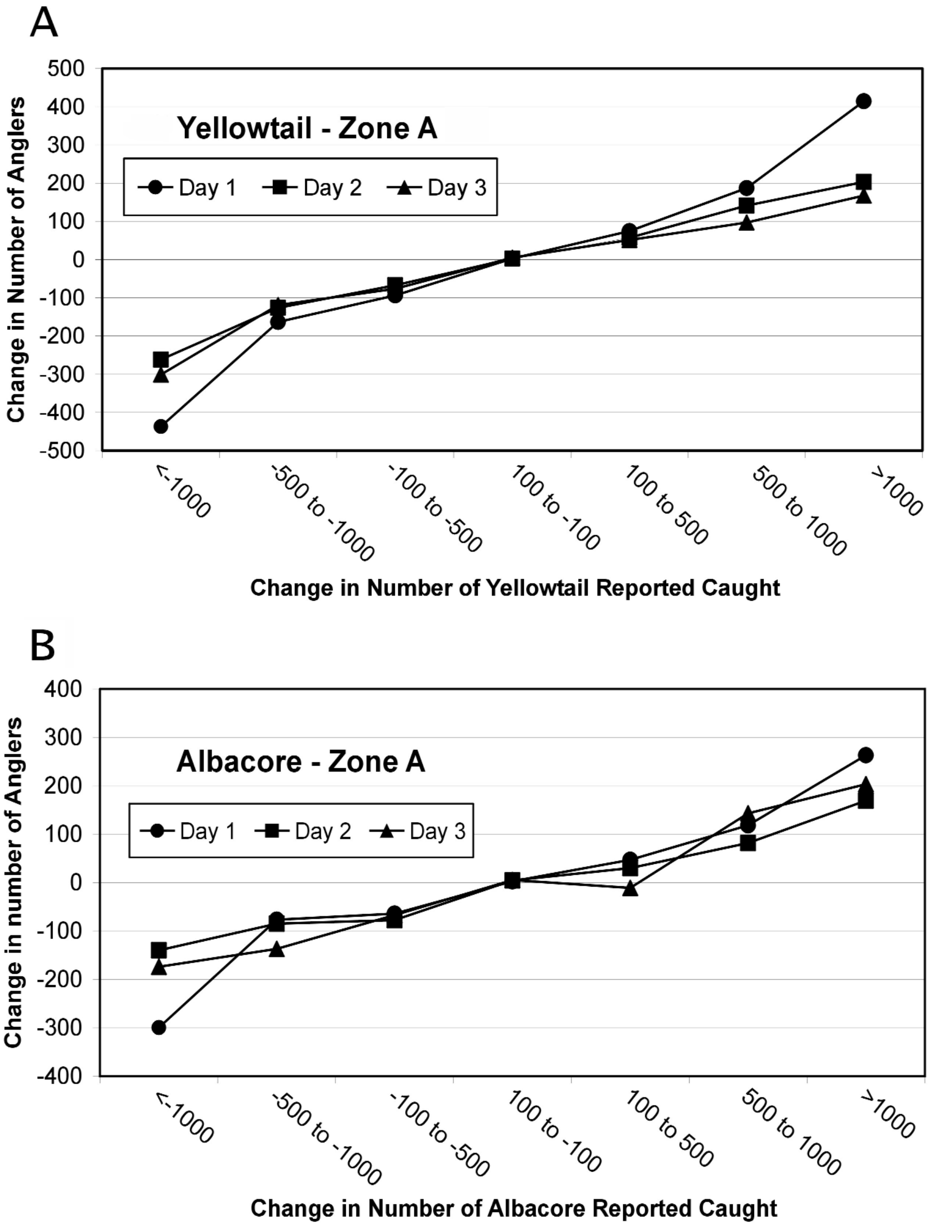

Figure 6. Angler response to reported changes in catch in zone A of (*a*) yellowtail (*Seriola lalandi*) and (*b*) albacore (*Thunnus alalunga*).

Long-Term Trends in Abundance or Availability of Key Species

Total annual catches of four popular coastal species are shown in Figure 7. Large intra-annual fluctuations appeared in catches of both kelp/barred sand bass and Pacific bonito, and Pacific barracuda has been showing a steady increase since the early 1980s, following a large drop in the late 1960s; yellowtail remained fairly constant throughout the 40-year series until jumping in 1997 from around 50,000 fish to over 400,000 fish. Since kelp and barred sand bass are resident species, catch fluctuations probably reflect relative abundance, although susceptibility to capture of kelp bass may be influenced by the density of kelp forests that varies intra-annually. Bonito, barracuda, and yellowtail are all seasonal migrants into southern California waters, so their catches may reflect not only population size but also the extent and timing of their annual migration into southern California waters. However, the steep and persistent decline of bonito catches suggests that a major decline in abundance has occurred.

In the past several years many species within the rockfish complex (*Sebastes* spp.) have been classified as overfished (MacCall et al. 1999; Ralston 1999). The total

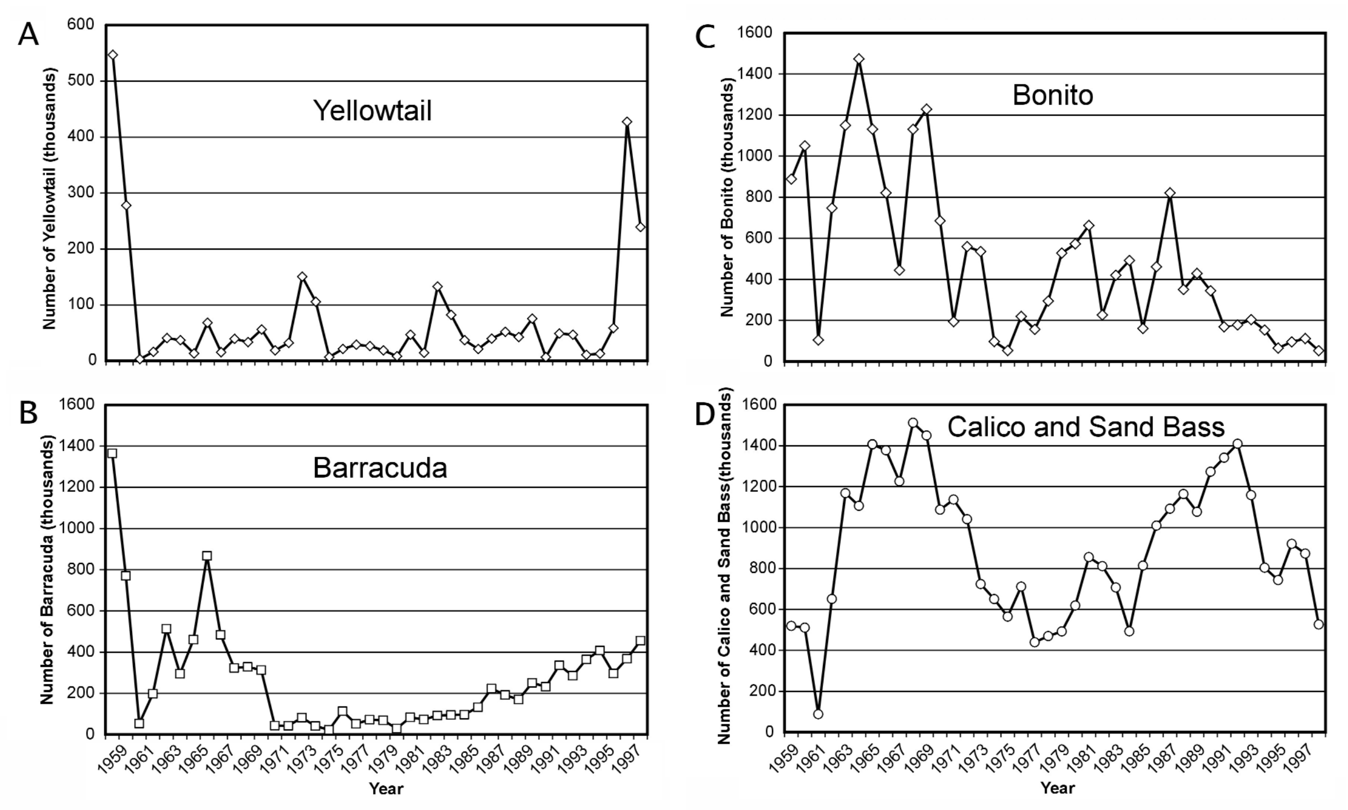

Figure 7. Annual catches of some popular coastal species targeted by CPFVs during 1959–98.

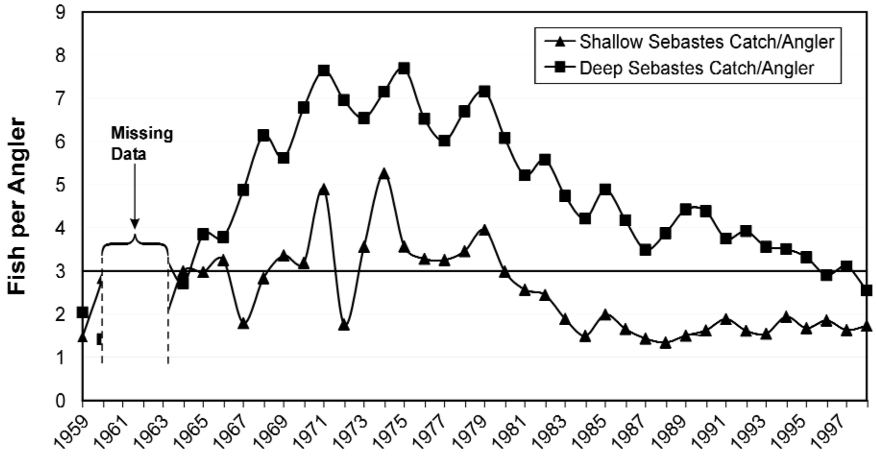

Figure 8. Annual catches of shallow and deep-water *Sebastes* species by CPFVs, 1959–98.

annual CPFV catch of rockfish peaked in 1975 at 3.3 million fish, decreasing by 80% since then to 648,000 fish in 1998. A plot of the number of fish per angler of the deep-water and shallow-water rockfish (fig. 8) shows that after peaking in the mid-1970s at 7.5 and 5 fish per angler, respectively, catches of both groups began to decline. The shallow-water catches leveled out at around 1.7 fish per angler in the late 1980s, but the deep-water catches continued to decline to the end of the series. This severe decline in CPFV rockfish catches has also been noted by Love et. al. 1998. Following the decline in the *Sebastes* catches that occurred in the early 1980s, CPFVs appear to have begun targeting other species to supplement their catches. Sculpin, cabezon, and ocean whitefish are three bottom species that are commonly caught together in the winter/spring months when alternatives such as yellowtail, bass, bonito, and barracuda may not be available. A plot of monthly *Sebastes* spp.

catches along with the combined catches of California scorpionfish (sculpin) (*Scorpaena guttata*), cabezon (*Scorpaenichthys marmoratus*), ocean whitefish (*Caulolatilus princeps*), and sanddabs (*Citharicthys* spp.) (fig. 9) shows that fishery effort may have switched from rockfish to these alternative species. However, as mentioned by Hill and Barnes (1998), the decline in catches of rockfish species may have resulted in increased reporting of these more marginal species to the *Los Angeles Times* as a means of drawing more customers.

Cowcod (*Sebastes levis*), a rockfish long prized by anglers because of its flavor and size, has experienced a severe decline in numbers. The Pacific Fishery Management Council has classed it as overfished, and it is currently being managed under a rebuilding plan (Butler 2003).

Catches reported in the *Los Angeles Times* peaked at over 25,000 fish per year in the early 1970s, declining 72% through the late 1970s to 7,000 fish by 1983, and declining further to a catch of 1,100 fish in 1998 (fig. 10a). These figures represent a decline of 96% in cowcod catches in the past two decades. Viewing the catches by zone (fig. 10b), one can see that zones B and C account for most of the CPFV catch of cowcod. Cowcod catches in zone B peaked in 1967 at 16,000 fish, then began declining in the late 1960s, with large annual fluctuations until the late 1970s. Zone C cowcod catches peaked at 18,000 fish in 1973, remaining at fairly high levels until beginning a rapid decline around 1982. These two zones also coincide with the majority of the larval catch on CalCOFI cruises off southern California (Moser et al. 1994). In 2001, a 4,300 mi^2 Cowcod Conservation Area that was closed to deep-water bottom fishing was established around offshore banks 43–120 miles offshore of zones B and C, coinciding with the region of highest historical cowcod catches and incidence of larval fish.

Effects of Regulations

The *Los Angeles Times'* data set may also be useful for measuring the effects of fishing regulations on the recreational fishery. The California halibut and white sea bass (*Atractoscion nobilis*), species popular among California anglers, were caught in large numbers by anglers in the early 1960s and then declined rapidly, prompting size and catch regulations on the recreational catch (fig. 11). White sea bass sport catches peaked at around 19,000 fish in 1963, and catches declined to less than 2,000 fish in 1967 (fig 11a). Prior to 1972, the legal take per angler was ten fish with two fish under 28 inches allowed, but after 1972 no fish under 28 inches could be taken; this policy was modified in 1974 to allow the take of one fish under 28 inches. In 1981, the limit was changed to zero fish for part of the season and three fish thereafter, with none under 28 inches allowed; this was changed again in 1985 to one fish and then three fish during the season with the same size restrictions. These changes in regulations seemed to have had little effect on the white sea bass catches until the late 1980s and, notably, in 2000, when the sport catch again reached 18,000 fish.

Historically, high halibut catches over 100,000 fish annually were reported in the CPFV fishery in the mid- to late 1940s, declining to 11,000 fish in 1957 (Oliphant 1990). In our data time series, annual California halibut sport catches were over 100,000 fish from 1962 to 1966, peaking at 176,000 fish in 1963, then declining rapidly to 19,000 by 1971 (fig. 11b). Regulations for the recreational fishery changed from two fish and no size limit in the late 1950s, to five fish and no size limit in 1962, and then five fish and 22 in. minimum length in 1971. In the two decades from 1978 to 1998, annual CPFV catches of California halibut have averaged 7,660 fish, a drop of 96% from the high catches in 1963.

A legislative ban on coastal gillnetting in southern California waters was passed in 1990 (Proposition 132) and went into effect in January of 1994, creating a "Marine Resources Protection Zone" roughly 3 miles offshore in coastal waters and 1 mile offshore channel islands south of Point Arguello. Planting of hatchery-reared juvenile white sea bass began in 1986 and continues, with 502,885 released in southern California waters, of which 42,900 are expected to have reached adulthood of 2–3 years based on mortality estimates.[1] These factors may have contributed to the resurgence in the sport catch of white sea bass. A survey of 2–3-year-old white sea bass caught in 2000 indicates that 7% contained the coded wire tags implanted in the released juveniles. Much of the resurgence in the fishery may also be due to a strong recruitment in 1997.[2] As for the California halibut fishery, no effect of the gillnet closure nor other regulations has resulted in a return to 1960s levels in the recreational catch of halibut.

Management decisions may sometimes have unforeseen consequences. Reports began surfacing in 1998 of extremely large winter catches of sanddab, a small but delicately flavored flatfish with no bag limit. Poor rockfish catches in 1998, perhaps due to the El Niño event, may have resulted in increased fishing on sanddabs. In 2000, a 2-month rockfish closure in southern California waters was instituted with additional restrictions and areal closures in 2001. Regulations restricting winter fishing for rockfish were a strong incentive for the CPFV fleet to target other species. Looking at annual catches of sanddab (fig. 9), one can see that beginning in 1998, catches skyrocketed from incidental levels, generally below 2000 fish annually, to 80,000 fish in 1998, 128,000 in 2000, and 244,000 in 2001 (1999 data is not

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[1] S. Crooke, CDFG, pers. comm.

[2] S. Crooke, CDFG, pers. comm.

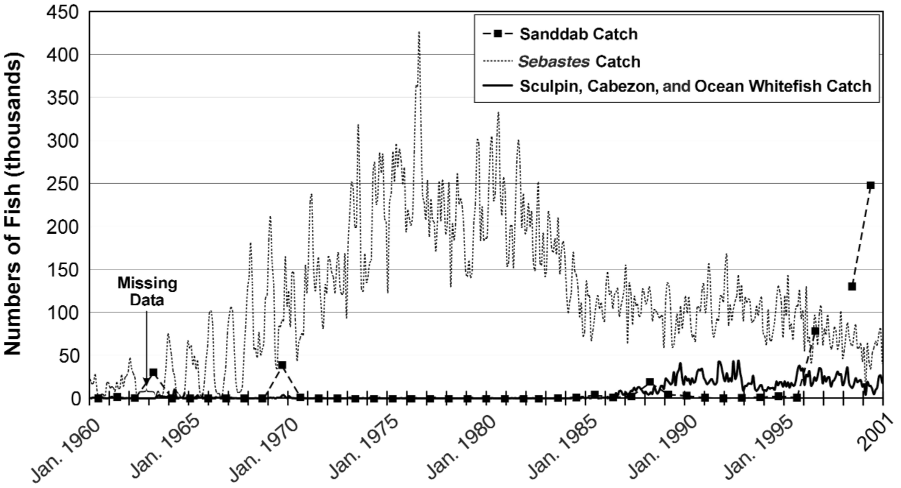

Figure 9. Monthly CPFV catches of *Sebastes* spp., sanddabs, and the combined grouping of sculpin, cabezon, and ocean whitefish, 1959–98.

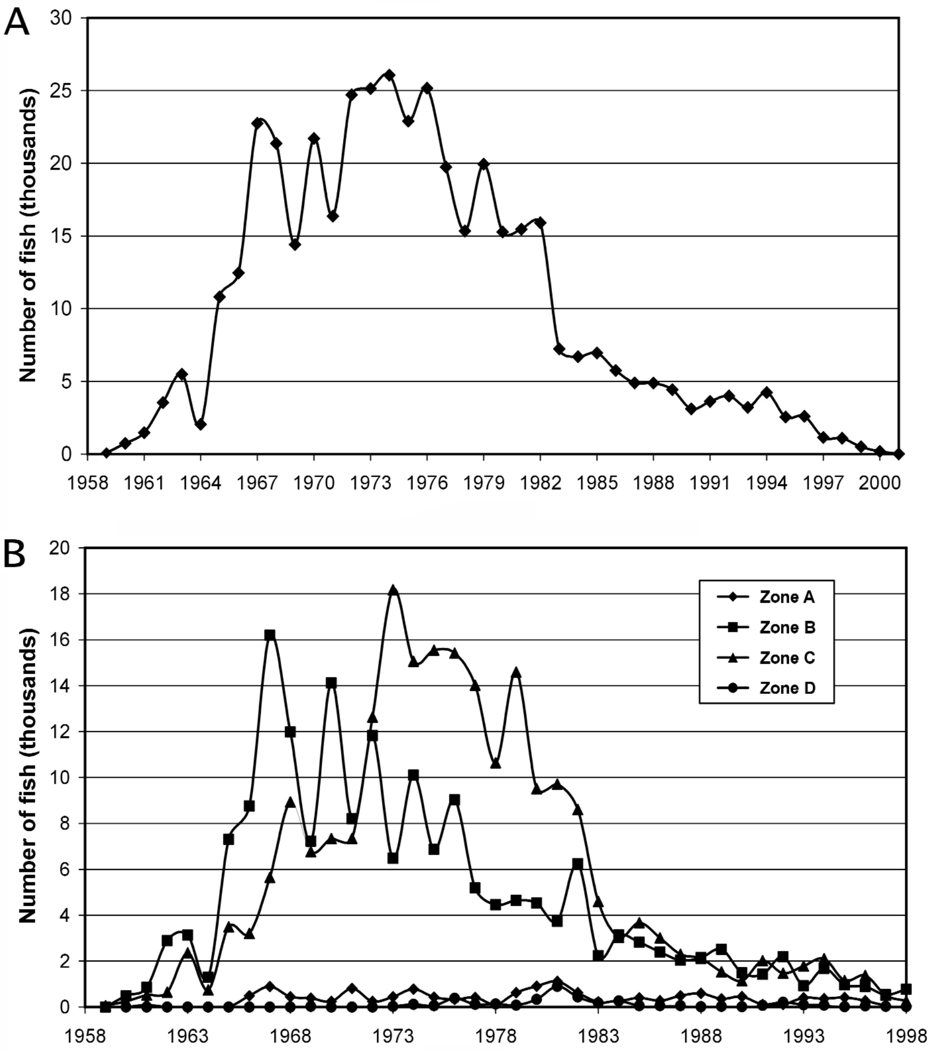

Figure 10. Annual CPFV catches of cowcod (*Sebastes levis*), 1959–98. *A*, overall catch; *B*, catch by zone.

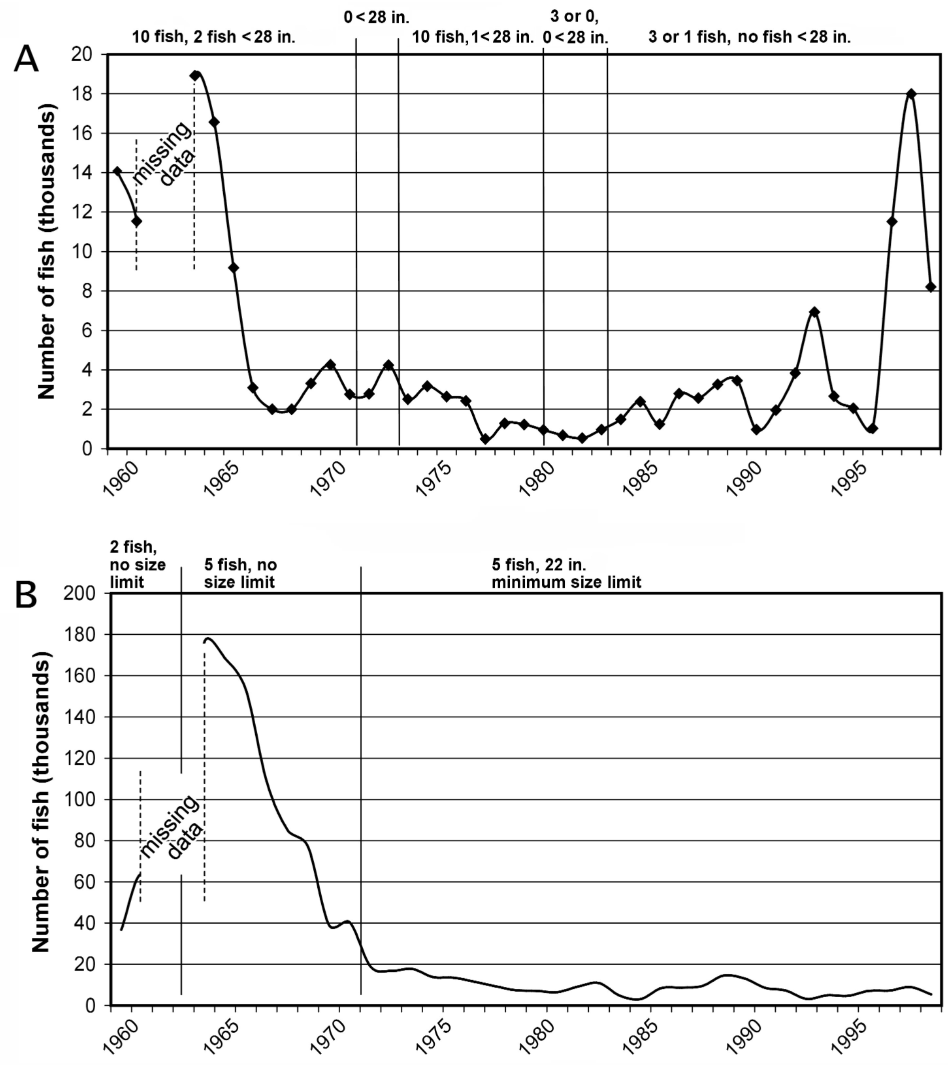

Figure 11. Annual CPFV catches and sport fishery regulations, 1959–2001. *A*, white sea bass (*Atractoscion nobilis*); and *B*, California halibut (*Paralichthys californicus*).

yet complete and is not included). However, when we look at sanddab catches by zone, zone B accounts for virtually all of the additional catch. Zone C historically has landed 2.5 times as many rockfish as zone B yet has not accounted for the large increase in sanddab catches. This raises the question of whether the increase in sanddab landings is actually a response to restrictions in the rockfish fishery restrictions or is caused by a large increase in sanddab numbers or discovery of this fishery by local anglers in zone B.

DISCUSSION

The CPFV fleet is a valuable recreational and economic unit within California, with 200 licensed vessels in southern California in 2001 (Young 1969; Gruen, Gruen, and Associates 1979). The NMFS Marine Recreational Fisheries Statistics Survey (MRFSS) concluded from an economic add-on survey in 1998 that southern California anglers on CPFVs or charter boats spent on average $35 per day on boat fees, bait, and fishing licenses (NMFS 2001). Expenditures for charter boat trips in southern California were estimated by Gautam (1996) as $68–97 and by Hanemann et al. (1989) as $80. Ticket prices of CPFV trips in southern California range from $25 to $30 for half-day boats, $36 to $66 for three-quarter day trips, $40 to $99 for a full day, and $85 to $175 for overnight trips to the islands or for offshore tuna fishing. According to the *Los Angeles Times'* database, 539,478 anglers took CPFV trips in 1998. Assuming a mean cost of $89 a ticket, ticket expenditures would total over $43 million. Huppert and Thomson (1984) estimate that the ticket price accounts for 75% of the trip cost. Travel, gear, and other costs add an additional 126% over the ticket price. Thus, the CPFV fleet may

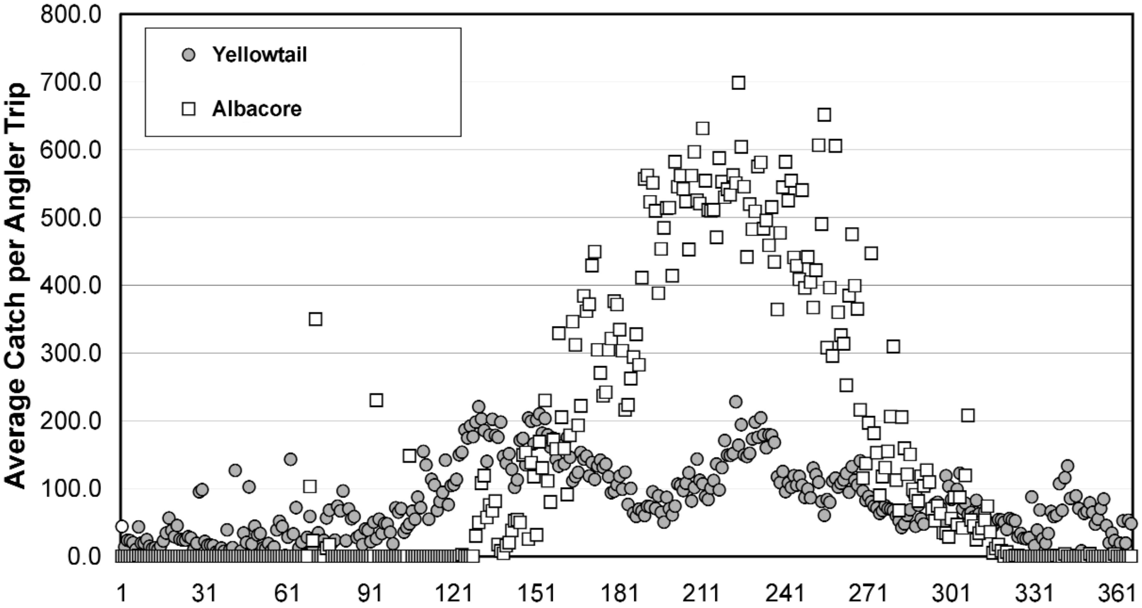

Figure 12. Average daily CPFV catches of yellowtail (*Seriola lalandi*) and albacore (*Thunnus alalunga*) in zone A, 1959–98.

contribute over $97 million to the economy. Thomson and Crook (1991), using MRFSS survey data, calculated the average CPFV cost to be $131 per trip, including ticket, tackle, equipment rental, mileage, food, and lodging. One recent estimate of the total value of southern California recreational fishing, including private boats, was $173 million annually (Gautam 1996).

It is also clear that the catches of this fleet can have a substantial effect on the abundance of some local stocks. While only a few fish are taken per angler per trip, when multiplied by the number of trips, the catch is substantial. In a study of the CPFV rockfish catches from 1980 to 1996, Love et al. (1998) noted not only that some previously abundant species of the *Sebastes* complex were no longer represented in the catch in the 1990s but also that older, larger individuals were particularly absent and smaller species predominated in later catches. The CPFV fleet catch has averaged about 4 million fish a year over the past four decades. The effect of marine recreational angling is substantially greater than the CPFV fleet alone, however. According to the 1998 MRFSS survey, private boaters average about twice as many trips as CPFV anglers per year. Although the effect of recreational fishing on local stocks is significant, the catch of large stocks of migratory species such as albacore tuna seem negligible compared to commercial landings. For example, for 1959–98 the CPFV fleet accounted for only 3.6% of the U.S. catch of North Pacific albacore and 0.7% of the total North Pacific landings for all countries.

The specific diversity of the catch is a salient feature of the CPFV recreational fishery and one of the more vexing properties when the goal is to understand underlying biological characteristics of the stock such as abundance and migration. We show here that the species composition of the catch varies with latitude, season, and, importantly, the species preferences of anglers and vessel operators. Perhaps one of the best examples of changes in seasonal preferences is the bimodal summer peak in yellowtail landings in zone A (fig. 12). No reasonable biological explanation exists for this midseason bimodality, but it is adequately explained by a midseason switch from local yellowtail to the more valued offshore fishing for albacore.

Obviously, the business function of the *Los Angeles Times'* reports is to attract potential clients to a particular landing by reporting the catch. This may lead to inaccurate reporting of catch by some landing operators. A comparison of *Los Angeles Times'* data to CPFV logbook data compiled by CDFG shows that the data sets are strongly correlated, with r^2 ranging from 0.937 to 0.981 for halibut, yellowtail, barracuda, and bonito for the years 1959–98 exclusive of 1961–62, for which there is no *Los Angeles Times'* data. Hill and Barnes (1998) also noted good correlations between the two databases with both over- and underreporting of catches by different ports and different years and a particular tendency to underreport less-valued species. Overreporting of catch in the *Los Angeles Times'* reports is probably no more serious a problem than the underreporting of catch common in commercial fisheries or in logbook records. Clearly, the strength of these data from the biological standpoint is the measurement of trends over decades rather than absolute abundances. In this study, we identify major declines in recreational landings of halibut, rockfish, cowcod, and bonito, stability in yellowtail, and perhaps the onset of a recovery in white sea bass.

The advertisement aspect of the *Los Angeles Times'* data set, far from being a detraction, is in fact one of the more useful and interesting properties of the data set. The data set could be used, for example, to gauge angler responses and species preferences under a variety of fishing and regulatory situations. Our simple and preliminary analysis shows that angler response to the reports (number of anglers purchasing tickets) is positively correlated with reported catch on the previous day, with this effect diminishing over succeeding days. Although a thorough analysis would require a complex modeling approach, it is clear that the *Los Angeles Times*' daily reports provide a daily assay of angler response that could be used to model the response of anglers to a variety of regulatory situations.

The CPFV fishery came under very stringent regulations on 1 July 2002 when fishing was prohibited for rockfish, lingcod, ocean whitefish, and California scorpionfish (sculpin) in waters 20 fathoms and greater in depth by the PFMC. The zone D CPFV fleet faces difficult times because rockfishes dominated its catch (tab. 1). Adjustments will have to be made throughout the fleet since the prohibited species were a mainstay for the winter CPFV fishery regardless of zone, ranking first in catch numbers for two zones and second and third for the other two zones. The resourcefulness of the CPFV vessel and landing operators should not be underestimated, however. The total number of angler trips has remained remarkably constant over the years, despite major shifts in the abundance or availability of target species and an overall decline in the catch of 41% in recent years. Another measure of this resourcefulness was a surprising development of a fishery for sanddabs in 1999, presumably in response to new rockfish regulations. Catches soared to 12,200% of the long-term mean in just 4 years.

As long as the *Los Angeles Times* continues to report the catches of the fleet and the number of anglers, a way exists to track and interpret the responses of the CPFV fleet and their anglers on a daily basis to new regulations and changes in abundance and availability of stocks. We plan to continue compiling our database from the daily reports, and the database shall be made available for all to use at the SWFSC Web site.

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SILICEOUS PHYTOPLANKTON IN THE SANTA BARBARA CHANNEL: A SEVEN-YEAR COMPARISON OF SPECIES IN A NEAR-BOTTOM SEDIMENT TRAP AND IN WATER SAMPLES FROM THE EUPHOTIC LAYER

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ABSTRACT

Biweekly sediment trap samples were collected from the Santa Barbara Basin between August 1993 and April 2000. We compare the siliceous phytoplankton species from these traps with mixed-layer phytoplankton samples from quarterly cruises. We evaluate signals from the two data sets, without regard to their specific compositions. Both data sets indicate strong, regular spring blooms. The trap data allow definition of a fall-winter flora not identified from the water samples. The water samples allow definition of an oceanic warm-water flora, not readily seen in the trap data.

Many of these differences are procedural artifacts. However, significant differences arise from the different scales of the samples. Species' relationships, which are often expressed over relatively short scales of time and space, are better captured by the small-scale water samples. Regional oceanographic and climatic signals are more efficiently captured in trap samples, which integrate over small-scale variability.

INTRODUCTION

Between 1993 and 2000, two sets of phytoplankton samples were collected from the Santa Barbara Basin at the northern end of the Southern California Bight (fig. 1). One set is a series of contiguous sediment trap samples collected from approximately 540 m depth; the second is a series of quarterly water samples from the mixed layer above the trap. Portions of both sets have been the subject of previous studies (Thunell 1998; Lange et al. 1997, 2000; Venrick 1998), and additional analyses of the trap material are underway. Although these two data sets are not well matched in number of samples or in frequency, they are both typical of the data sets commonly collected by discrete samples from the euphotic zone and by sediment traps at greater depth.

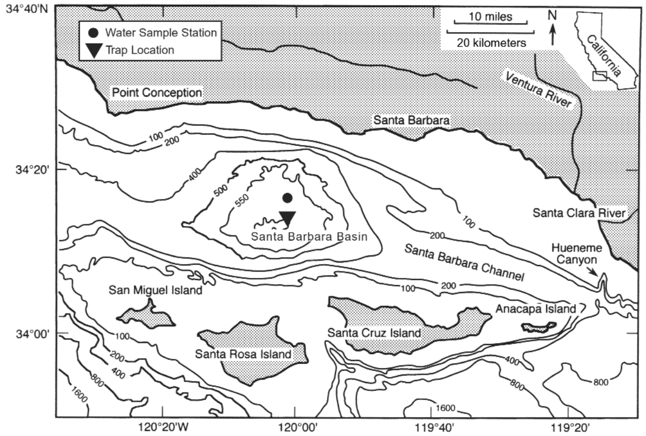

Figure 1. Geographic and topographic map of the Santa Barbara Channel and the Santa Barbara Basin showing the locations of the sediment trap and the water sample station.

Several studies in the past have examined transformation of organic material as it sinks through the water column and settles on the seafloor (e.g., Bishop et al. 1977; Knauer et al. 1979; Deuser and Ross 1980; Honjo et al. 1982; Shipe and Brzezinski 2001). Some of these have considered species composition (Passow 1991; Passow and Peinert 1993; Sancetta 1992; Treppke et al. 1996; Scharek et al. 1999; Romero et al. 2000). We know of no other instance where the data sets include species composition over a range of several years and hence allow comparison of the long-term taxonomic information contained by samples from the euphotic zone and from a sediment trap just above the seafloor.

We first compare estimates of abundance and flux of total siliceous phytoplankton as well as the overall species compositions of the two data sets. We then apply two different grouping procedures in an analogous manner to both sets: the first procedure identifies individual species that tend to be abundant in the same trap samples or the same water samples; the second procedure groups individual trap samples or water samples according to the similarity of their species composition.

The purpose of this article is not a detailed interpretation of either data set but rather a comparison of their primary signals. The ecological mechanisms underlying the patterns will be explored only as needed to make the comparison. The information content of each data set may be modified by several factors: the different total number and frequency of samples in the two data sets, the different temporal/spatial scales represented by a single sample from each data set, and their different species

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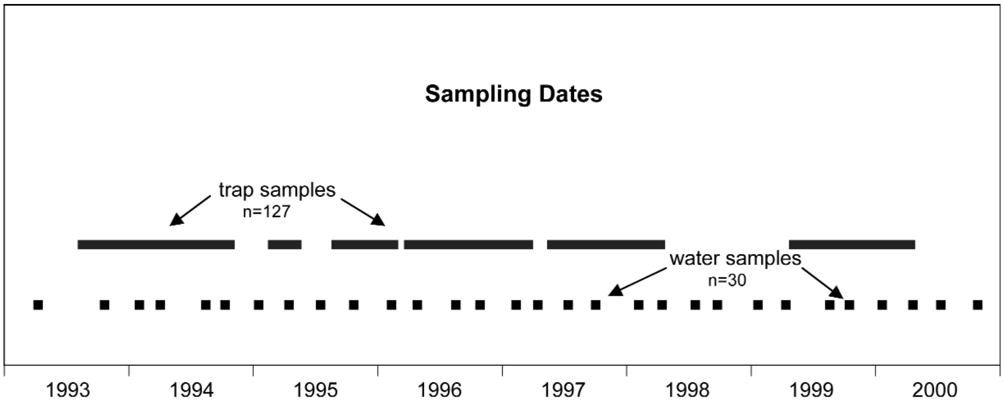

Figure 2. Sampling dates for water samples and range of consecutive dates for trap samples; n = number of samples.

compositions. We will attempt to differentiate between these factors.

METHODS

The sediment trap was a 13-cup trap with a 0.5 m^2 collection area, located near the center of the Santa Barbara Basin (34°14'N, 120°02'W; fig. 1) about 50 m above the bottom (Thunell 1998). One hundred and twenty-seven samples of 2-week (rarely 1-week) duration were collected sequentially between 19 August 1993 and 12 April 2000. In this article, the trap date is the midpoint of the trap collection period. Because of trap malfunctions, there are no samples between 10 April 1998 and 5 May 5 1999, as well as some shorter data gaps (fig. 2).

Trap samples were poisoned in the field with $HgCl_2$. Splits of the original sample (usually, 1/16–1/64) were washed through a 45 µm sieve, acid-cleaned (Wigley 1984), and mounted on permanent slides with Naphrax. Subareas of a slide were counted for siliceous phytoplankton skeletons (diatoms and silicoflagellates) using a phase contrast microscope and a magnification of 250×, or 650× for spores and small valves (for details on methodology, see Lange et al. 1997).

The 30 water samples were collected quarterly from 4 m to 11 m depth at CalCOFI station 82.47 (34°16.5'N, 120°1.5'W; fig. 1). Samples were preserved with neutralized formalin; volumes between 0.225 ml and 24.6 ml were settled and counted under an inverted microscope. Effort was made to identify and count all phytoplankters > 5 µm; larger and rarer taxa were counted at 100×, and smaller taxa at 250×. Some related heterotrophs were included.

We have coordinated taxonomic identification for more than 20 years. We are confident that our identifications are as comparable as possible for different workers. We have based our taxonomic nomenclature on Round et al. (1990) for diatoms and Tomas (1997) for the other groups. Because the genus *Pseudo-nitzschia* is important in both sets of data, we have lumped the species in the trap samples into the two size categories used for the water samples.

There are 19 pairs of simultaneous samples in which a trap was open when a water sample was collected. There are 17 pairs of samples where the trap opened 1 to 14 days after the collection of the water sample (lag one 2-week interval). Likewise, there are 19 pairs with lag = 2 (trap opened 2–4 weeks after collection of the water sample), 19 pairs with lag = 3, 19 pairs with lag = 4, 19 pairs with lag = 5, and 17 pairs with lag = 6. This restricted set of simultaneous samples allows direct comparison of trap and water sample data.

We measure species diversity by means of the entropy index (Legendre and Legendre 1983):

$$H = -\sum_{i=1}^{n} p_i, \log p_i,$$

where p_i is the proportion of species i in a sample of n species.

Species are clustered using the recurrent group procedure (Fager and McGowan 1963), scoring species above and below their median (Venrick 2002). For species present in less than half of the samples, presence and absence are used. Recurrent groups present in less than 10% of the samples are eliminated from further consideration.

The recurrent group procedure is based on an affinity index:

$$\alpha = [J/(N_a N_b)^{1/2}] - (1/2)(N_b)^{1/2},$$

where J is the number of joint occurrences of species a and species b out of a total of N_a occurrence of species a and N_b occurrences of species b, and $N_a > N_b$. Alpha varies from 0 (no co-occurrence) to 1 (perfect co-occurrence).

As α is relaxed, groups typically increase in size and number. At the same time, more cross-group affinities appear. In many situations, the most informative groups are those at the lowest α that produces distinct groups or clusters of groups. In this study, groups are defined at α levels of 0.80, 0.75, 0.70, 0.65, 0.60, 0.55, and 0.50. Results are discussed for groups defined at 0.70 and 0.55.

Alpha is a proportional index, independent of sample size. If the number of occurrences of species *a* and *b* are the same in two sets of samples, and if the number of joint occurrences is the same, then α will be the same, regardless of the total number of samples. If N_a, N_b, and J are scaled up proportionately (as would happen, for instance, if additional samples were collected without error from the same population), then α is affected only by the correction for sample size, which becomes smaller as N_b increases. All else remaining the same, the effect of an increase in sample number is an increase in the value of α. Therefore, in this study we expect α values among species in the trap samples to be somewhat larger than α values among species in the water samples.

Correlations are Spearman's nonparametric correlations (Conover 1999). Cluster analyses of samples use the method of unweighted average linkages (Legendre and Legendre 1983).

Because many of the following analyses involve multiple tests with nonindependent data sets, the assumptions underlying the usual statistical "probability" values are violated. In these cases, we base our conclusions on the patterns of the statistics rather than on the usual tests of significance.

PHYSICAL SETTING

The Santa Barbara Channel is an elongated channel bounded by Southern California on the north and east and by the Channel Islands on the west and south. The Santa Barbara Basin is a bottom depression in the western center of the channel, reaching depths in excess of 500 m (fig. 1). Because of a unique combination of bottom topography, hydrography, and biology, the seasonal patterns of production are well preserved in the sediments, making it an important location for high-resolution studies of paleoecology and paleoceanography (e.g., Soutar and Isaacs 1974; Baumgartner et al. 1992; Kennett and Ingram 1995; Schimmelman and Lange 1996). The present data come from one of two sediment trap studies currently underway in the Santa Barbara Basin (e.g., Thunell et al. 1995; Thunell 1998; Lange et al. 1997, 2000; Shipe and Brzezinski 2001; Shipe et al. 2002).

Since 1993, a number of moorings have been in place in and north of the Santa Barbara Channel. These, together with drifter releases, hydrographic surveys, and anemometer measurements have provided detailed information about the near-surface current patterns (e.g., Hendershott and Winant 1996; Dever et al. 1998; Harms and Winant 1998; Bray et al. 1999; Winant et al. 1999, 2003). At the eastern entrance, annual mean flow into the channel at the surface is poleward. However, this reverses seasonally, being generally equatorward between February and June. At the western mouth, annual mean flow is poleward along the northern shore and equatorward along the southern. Overall, equatorward transport is greatest during the spring and weakest during the winter. There is a tendency for downwind transport during upwelling-favorable winds, with consequent transport of newly upwelled water into the channel from the northwest. The Santa Barbara Channel has a mean tendency for cyclonic rotation of the near-surface currents. This tendency is strongest in summer, weakest in winter. Superimposed on the mean patterns is a complex pattern of near-surface currents and reversals, filaments, and eddies. These have been described as synoptic states (Harms and Winant 1998; Dever et al. 1998; Winant et al. 2003) that have seasonal cycles as well as fluctuations on smaller time scales.

Of 235 drifters released at various locations within the Santa Barbara Channel, the average residence time was 7 days (Winant et al. 1999). This estimate may be biased downward by the proportion of drifters that ran aground before exiting the channel—about one-third. One drifter was caught in a local eddy for 21 days; nevertheless, it is clear that the Santa Barbara Channel cannot be considered a closed system.

There are two primary sources of water in the Santa Barbara Channel. From the north, water is coastal and includes cold, upwelled water from the region between Point Conception and Point Arguello. This source is most pronounced in the spring when upwelling is most consistent and surface flows through the channel are primarily equatorward. However, upwelling along the coast at Point Conception and north can occur throughout the year, and there remains the possibility of sporadic incursions of upwelled water in other seasons. From the south, water is warm saline water from the California Bight. This water has a complex origin that includes the Central Pacific, the East Tropical Pacific, and modified water from the California Current. The core of the California Current rarely penetrates into the Santa Barbara Channel directly.

RESULTS

Total Siliceous Phytoplankton

The time series of total siliceous phytoplankton cells from both data sets show distinct peaks of flux or abundance in the spring, but the relative magnitudes differ (fig. 3). The trap data show occasional peaks in the fall. Both data sets indicate very low values from mid-1997 through early 1998; these have been interpreted as an

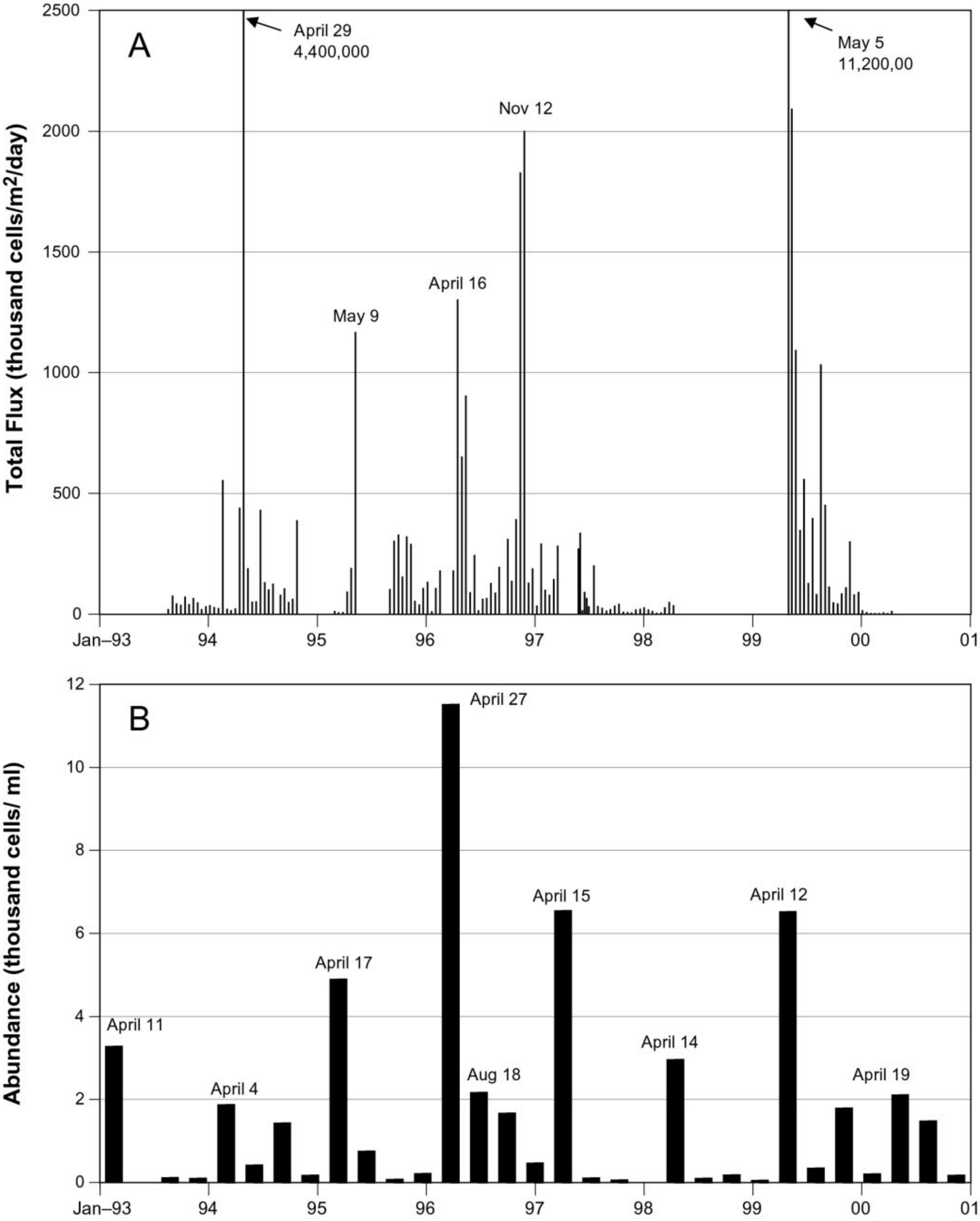

Figure 3. Fluctuations of flux and abundance of total siliceous phytoplankton, 1993–2000: *A*, trap samples; *B*, water samples. Dates of major peaks of flux or abundance are given.

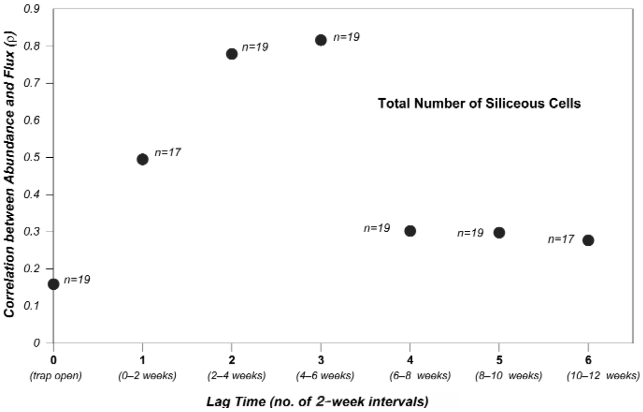

Figure 4. Correlation between abundance and flux of total siliceous phytoplankton at lag times from zero to six 2-week intervals, with abundance leading flux.

effect of the 1997–98 El Niño (Lange et al. 2000). Low flux values at the start of the series have been explained as a consequence of the El Niño conditions just preceding the data collection (Thunell 1998).

Correlation between abundance of total siliceous phytoplankton in the water column and flux into the trap is examined quantitatively by comparing the 19 data pairs where the trap was open when the water sample was collected (fig. 4). Correlation between simultaneous samples is poor. Lagging the trap samples by successive intervals causes the correlation to increase to maximum values at two and three trap intervals ($\rho = 0.78$ and 0.82), that is, intervals of 2–4 and 4–6 weeks between the collection of the water sample and the opening of the trap. The relatively smooth parabolic pattern of ρ versus lag time, as well as the high maximum correlations, gives strength to this interpretation.

Species Composition

Analysis of total particles neglects the rich taxonomic data contained in both data sets. A total of 204 species was identified from the trap samples, 178 from the water samples. The data sets have 112 taxa in common. One obvious source of difference between the two data sets is the removal of smaller and nonsiliceous cells from the trap samples during sample preparation. In the water samples 42% of the taxa are nonsiliceous, and these account for 10% of the cell totals. Another difference is the absence of benthic species from the water samples. In the trap samples, 30% of the species are benthic, but these represent less than 1% of the total number of cells. In addition, the process of acid cleaning and mounting cells before enumeration of the trap material facilitates the identification of several groups of diatoms that are problematic in water samples, such as species in the genera *Coscinodiscus* and *Thalassiosira*. The high frequency of *Chaetoceros* resting spores in the trap material also allows identification of Hyalochaete species that are difficult to identify in vegetative phase and may not have been consistently recognized in the water samples. In addition to the methodologically caused differences, discrepancies are expected to arise from dissolution of cells below the euphotic zone, influx of cells into traps from other areas, and undersampling of the euphotic zone.

The ten dominant species in the two data sets are given in Table 1. In the case of the Hyalochaete species, the dominant forms in the sediment trap are resting spores; these were almost never observed in water samples. *Chaetoceros radicans* is the most abundant species in both data sets. *Ch. debilis* is the third most abundant in both data sets and *Ch. compresses* is ranked eighth. Other taxa agree less well. Many discrepancies can be attributed to the analytical differences (pennate 1 and *F. pseudonana* are too small to be retained by the 45 μm sieve used in preparing the trap samples; "slim" *Pseudo-nitzschia* spp. may be too delicate to reach the trap intact or may pass through the sieve end-first; *Ch. diadema* and *Ch. vanheurckii* are difficult to identify in vegetative form). One unexpected discrepancy is *Coscinodiscus radiatus*, which occurs in every trap sample (ranking sixteenth in abundance) but occurs only twice in the water samples. This is unlikely to be an identification problem. In the water column, this species may be most abundant below the mixed layer and thus be missed by the water samples.

A comparison of sample diversity for the two sets of data (fig. 5) shows that 23% of the trap samples have a diversity of less than $H = 1.38$, the lowest diversity in a water sample. The lowest trap values ($H = 0.35$ and 0.36) are from two trap samples collected during late April–early May 1994 in which *Ch. radicans* resting spores comprised more than 90% of the flux. The previous water sample (5 April 5 1994) was also dominated by *Ch. radicans* (vegetative cells), but these only accounted for 39% of the total cells. Only 2.5% of the remaining cells in that water sample were nonsiliceous, so the broader range of floral types counted in the water samples does not explain the relatively low proportion of *Ch. radicans*.

Of the 29 low-diversity trap samples ($H < 1.38$), 90% are dominated by Hyalochaete resting spores, which are rarely observed in water samples. Resting spores dominate in only 67% of the higher diversity trap samples (χ^2; $p < 0.005$). Thus, the low diversity of some trap samples appears to be due to a very high proportion of Hyalochaete resting spores. The absence of resting spores from the water samples suggests that spores may develop at depths below the mixed layer, and/or over very short time scales, and are not captured by the water samples. Their extreme dominance in some trap samples, compared with the dominance of vegetative cells in the mixed layer, suggests some concentrating mechanism, such as

TABLE 1
Comparison of the Ten Most Abundant Species in Trap and Water Samples

a. Trap Samples

		Abundance in water samples		
Species	Proportion of all species (%)	%	Rank	Notes
Chaetoceros radicans	51.4	18.90	1	Includes *Ch. cinctus*
Chaetoceros vanheurckii	23.6	0.25	32	
Chaetoceros debilis	5.3	14.50	3	
Chaetoceros diadema	3.5	0.25	31	
Chaetoceros concavicornis	2.3	0.25	32	
Chaetoceros affinis	1.6	0.10	43	
Bacteriastrum delicatulum	1.6	0.52	19	Includes *B. furcatum*
Chaetoceros compressus	1.4	4.10	8	
Chaetoceros "peanuts"	1.3	0.00		Unidentified resting spores
Chaetoceros 1	1.0	0.00		Possibly *Ch. lorenzianus* or *diadema*

b. Water Samples

			Abundance in trap samples		
Species	Proportion of all species (%)	Proportion of siliceous species (%)	%	Rank	Notes
Chaetoceros radicans	18.9	19.7	51.40	1	Includes *Ch. cinctus*
slim *Pseudo-nitzschia* spp.	18.2	18.9	0.08	70	Sum of 5 slim species
Chaetoceros debilis	14.5	15.1	5.30	3	
Chaetoceros socialis	8.4	8.7	0.00		Not found in trap samples
Dactyliosolen fragilissimus	5.9	6.2	0.00		Not found in trap samples
Skeletonema costatum	5.0	5.2	0.18	23	
robust *Pseudo-nitzschia* spp.	4.2	4.4	0.57	12	"Sum of 5 species, *P. australis* most abundant"
Chaetoceros compressus	4.1	4.3	1.40	8	
Pennate 1	1.8	1.9	0.00		Unidentified small pennate
Fragilariopsis pseudonana	1.6	1.6	0.00		Too small to be retained during trap sample preparation

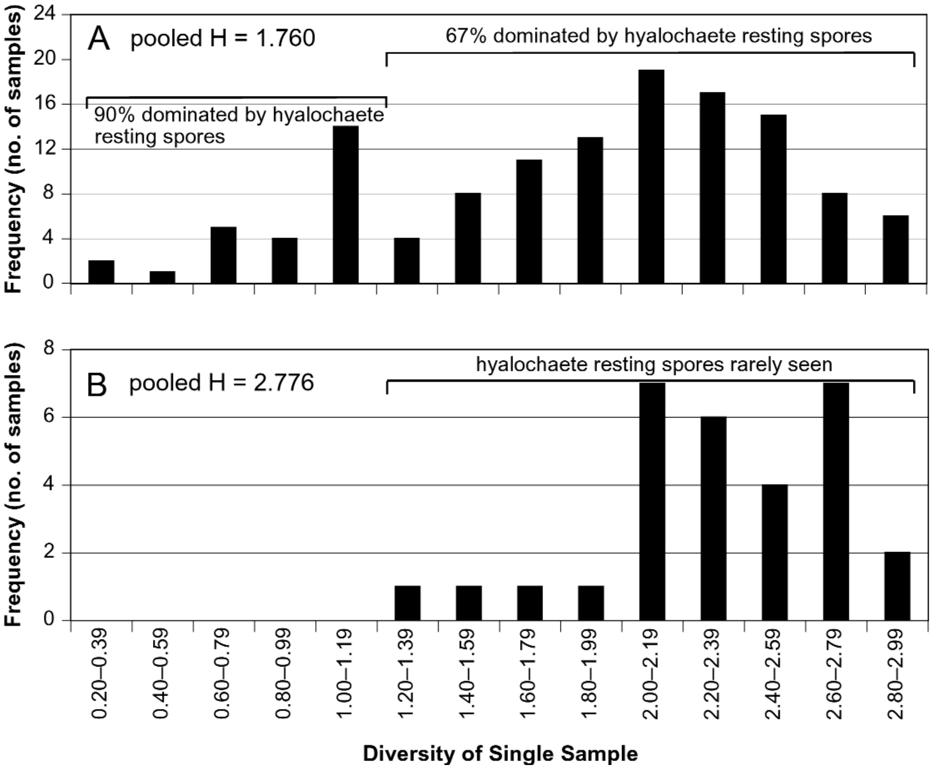

Figure 5. Frequency of diversity (H) of individual trap and water samples: *A*, trap samples; *B*, water samples. Traps with H values < 1.38 are strongly dominated by hyalochaete resting spores.

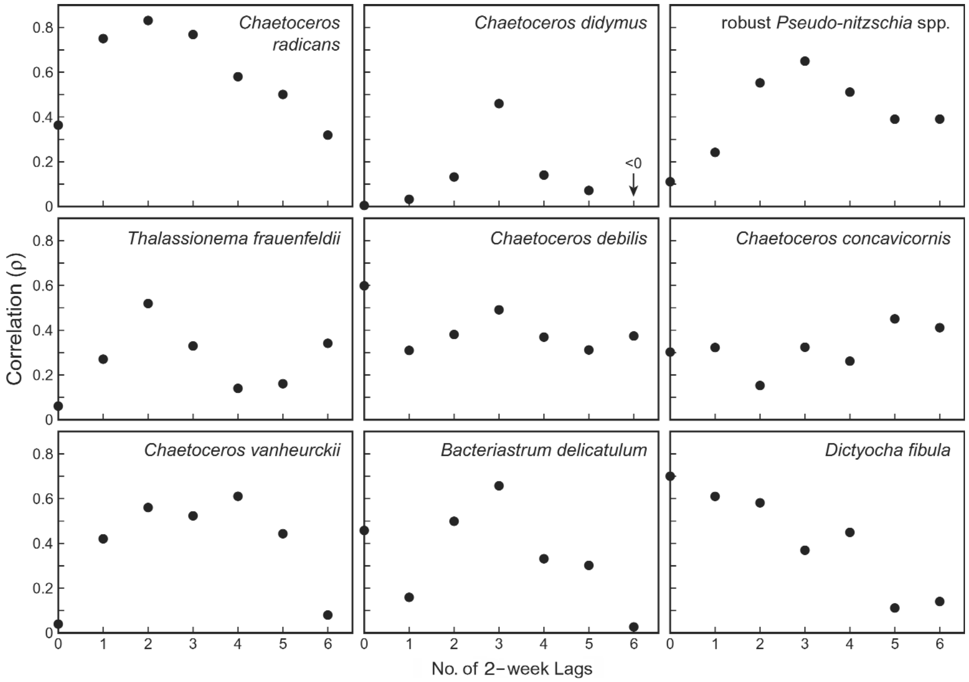

Figure 6. Correlations between abundance and flux of nine species at lag times from zero to six 2-week intervals with abundance leading flux.

an accumulation of cells at some horizon below the mixed layer prior to spore formation or accumulation of spores on the sediment at shallower depth and subsequent advection into the basin (Sancetta 1992).

Although 112 taxa occur in both data sets, only 16 species occur in 20% or more of the samples in each set. The correlations between flux and abundance of these 16 species are compared at various time lags using the reduced set of simultaneous samples, as explained in the Methods section. To maintain the power of the correlation, we require that the species be present in at least 20% of the samples in each reduced data set. Only 9 species are frequent enough to meet this criterion. There is a spectrum of relationships between mixed-layer abundance and flux into the traps (fig. 6). For *Ch. concavicornis*, there is no discernable relationship. For *Dictyocha fibula*, the relationship appears tight; the period of maximum flux includes the time of maximum abundance in the water above. Other species, however, show indications of the parabolic relationship that occurs when there is a lag time between abundance and flux. The overall median and modal lag is three 2-week intervals (4–6 weeks). However, correlations at two 2-week intervals are often high.

With only nine species abundant in both data sets, the challenge of this study is to compare the information content using the species composition drawn from two different pools of species. After some consideration, we have retained *all* species in both data sets, even those with serious methodological biases. This avoids drawing an arbitrary line between "biased" and "unbiased." More importantly, it is the only way to objectively evaluate the loss of information arising from procedural practices.

Groupings of Species

The recurrent group procedure was applied to each set of data to define groups of species that tend to be abundant together. The question in the present study is not whether groups of the same species are formed from each data set but whether analogous groups are formed.

Trap Samples. At the higher affinity level ($\alpha = 0.70$), ten species are grouped into four recurrent groups (fig. 7a). The groups can be distinguished on the basis of their seasonal cycles (fig. 8) and are concordant with respect to their mean annual fluxes (Kendall concordance test, $p < 0.05$). Thus, they are separated primarily on the basis of their seasonal cycles. At the lowest affinity index ($\alpha = 0.55$), 32 species or categories are associated into ten recurrent groups with 10 associated species (fig. 9a, tab. 2). At this affinity there is a large amount of connectivity between all recurrent groups; there are no distinct recurrent groups or clusters of recurrent groups. Two of the original four recurrent groups (groups I and III) have been split into different groups (groups I, III, and IV; fig. 7).

The largest group at $\alpha = 0.55$, group I (fig. 7 and tab. 2), consists of Hyalochaete *Chaetoceros* and *Coscinodiscus*

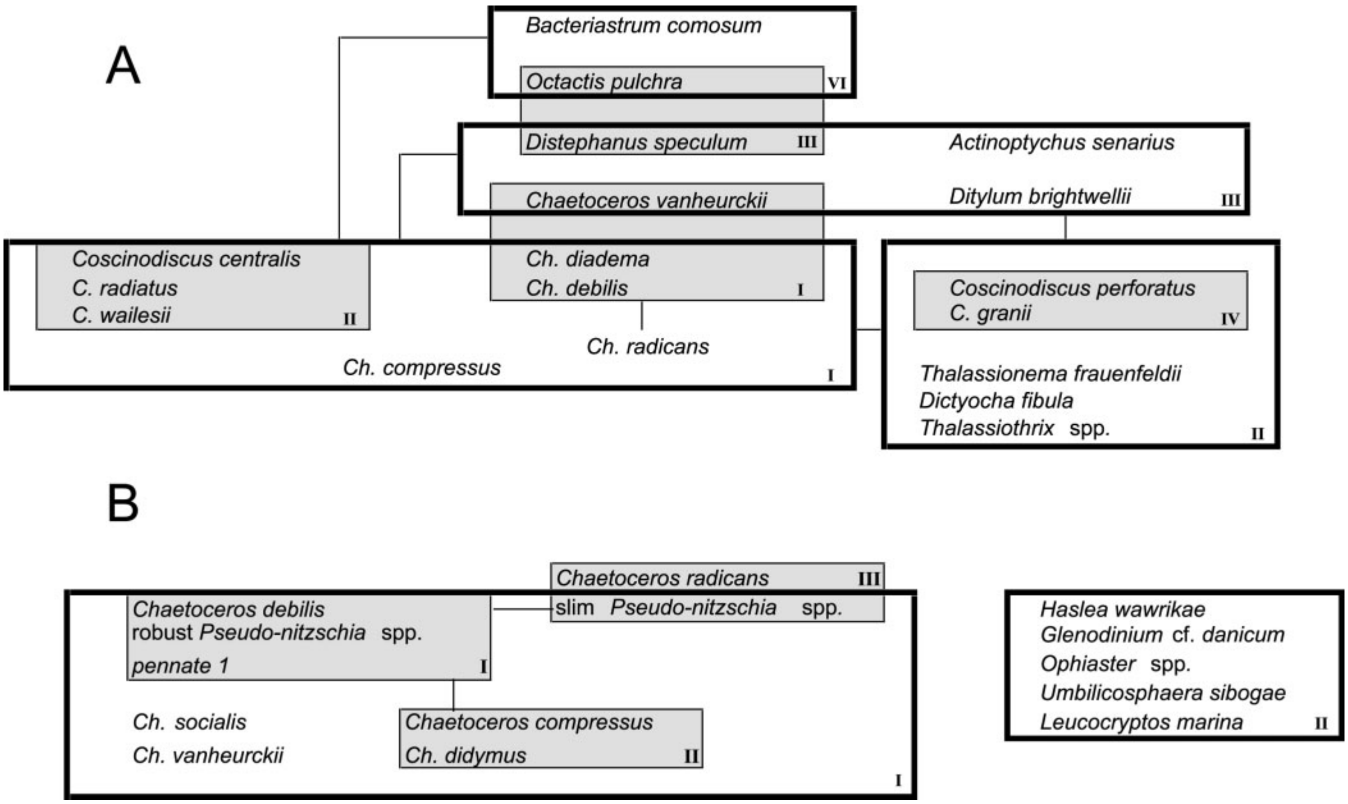

Figure 7. Recurrent groups of species defined at α = 0.70 (*shaded boxes*) and at α = 0.55 (*unshaded boxes*): *A*, trap samples; *B*, water samples. Composition of a recurrent group is indicated within a box. Lines between boxes (or between a species and a box) indicate association between groups or between a species and a group. Thus, in the trap samples, the species of group II and IV at α = 0.70 continue to be associated at α = 0.55. Groups I and III at α = 0.70 are each split into two groups at α = 0.55. Not all groups at α = 0.55 are shown.

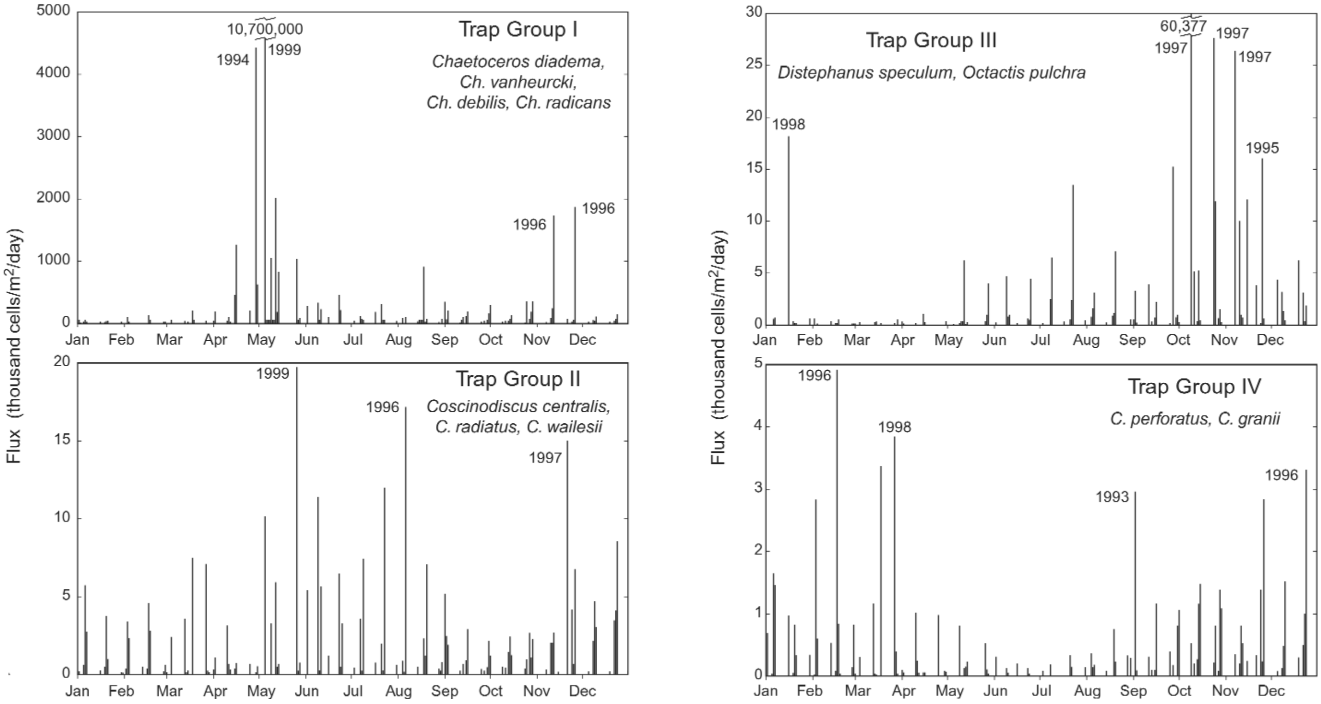

Figure 8. Seasonal cycles of the total flux of recurrent groups and associated species formed from trap samples at α = 0.70. Years of major peaks are given.

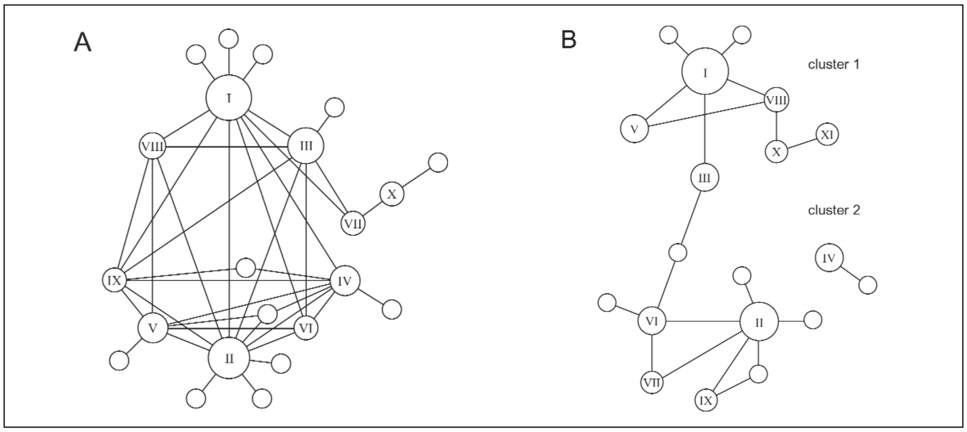

Figure 9. Recurrent groups and associated species formed from trap and water samples at $\alpha = 0.55$: *A*, trap samples; *B*, water samples. Numbers in circles are group numbers; circle size reflects group size; blank circles represent associated species. Lines connecting groups and associated species indicate cross-group affinities, and clusters represent groups of associated recurrent groups.

TABLE 2
Composition of Recurrent Groups at α = 0.55

Trap samples	Water samples
GROUP I *Chaetoceros compressus* *Ch. debilis* *Ch. diadema* *Ch. radicans* *Coscinodiscus centralis* *C. radiatus* *C. wailesii* Associated species: *Ch. decipiens* *Chaetoceros* sp 1 *Pleurosigma normanii*	GROUP I (CLUSTER 1) *Chaetoceros compressus* *Ch. vanheurckii* *Ch. debilis* *Ch. didymus* *Ch. socialis* robust *Pseudo-nitzschia* spp. slim *Pseudo-nitzschia* spp. pennate 1 Associated species: *Thalassiosira aestivalis* *T. rotula*
GROUP II *Coscinodiscus granii* *C. perforatus* *Dictyocha fibula* *Thalassiothrix frauenfeldii* *Thalassiothrix* spp. (fragments) Associated species: *Azpetia nodulifera* *C. cf. concinnus*	GROUP II (CLUSTER 2) *Haslea wawrikae* *Glenodinium danicum* *Ophiaster* spp. *Umbilicosphaera sibogae* *Leucocryptos marina* Associated species: *Mastogloia capitata* *Gephyrocapsa* spp. *Dictyocha fibula*
GROUP III *Actinoptychus senarius* *Chaetoceros vanheurckii* *Distephanus speculum* *Ditylum brightwellii* Associated species: *Thalassiosira eccentrica* (small)	GROUP III (CLUSTER 1) *Dactyliosolen fragilis* *Leptocylindrus danicus/minimus* *Nitzschia* sp. 1 Associated species: *Rhizosolenia setigera*
GROUP IV *Amphitetras antediluviana* *Coscinodiscus marginatus* *Triceratium formosum f. quadrangularis* Associated species: *C. oculis-iridis* *Ch. didymus* *Asterolampra marylandica*	GROUP IV (CLUSTER 2) *Bacteriastrum hyalinum* *Lingulodinium polyedra* *Peridinium cf. steinii* Associated species: *Mesoporos perforatus*
GROUP V *Bacteriastrum elongatum* *B. delicatulum* *Chaetoceros messanensis* Associated species: *Asterolampra marylandica* *Rhabdonema adriaticum*	GROUP V (CLUSTER 1) *Chaetoceros decipiens* *Ch. cf. laciniosus* *Skeletonema costatum*
GROUP VI *Bacteriastrum comosum* *Octactis pulchra*	GROUP VI (CLUSTER 2) *Leptocylindrus mediterraneus* *Proboscia alata* *Nitzschia cf. closterium* Associated species: *Bacteriastrum delicatulum* *Rhizosolenia setigera*
GROUP VII *Chaetoceros concavicornis* *Thalassiosira eccentrica*	GROUP VII (CLUSTER 2) *Chaetoceros anastomosans* *Prorocentrum vaginulum*
GROUP VIII *Chaetoceros affinis* *Rhizosolenia robusta*	GROUP VIII (CLUSTER 1) *Chaetoceros radicans* *Dactyliosolen cf. phuketensis*
GROUP IX *Actinocyclus octonarius* *Biddulphia biddulphiana* Associated species: *Chaetoceros didymus*	GROUP IX (CLUSTER 2) *Glenodinium* spp. *Octactis pulchra* Associated species: *Dictyocha fibula*
GROUP X *Asteromphalus heptactis* robust *Pseudo-nitzschia* spp. Associated species: *Thalassiosira oestrupii*	GROUP X (CLUSTER 1) *Emiliania huxleyi* *Thalassionema nitzschioides*
	GROUP XI (CLUSTER 1) *Asteromphalus sarcophagus* *Thalassionema frauenfeldii*

Note: Cluster memberships, where they exist, are indicated in parentheses. Nomenclature is based on Round (1990) and Tomas et al. (1997).

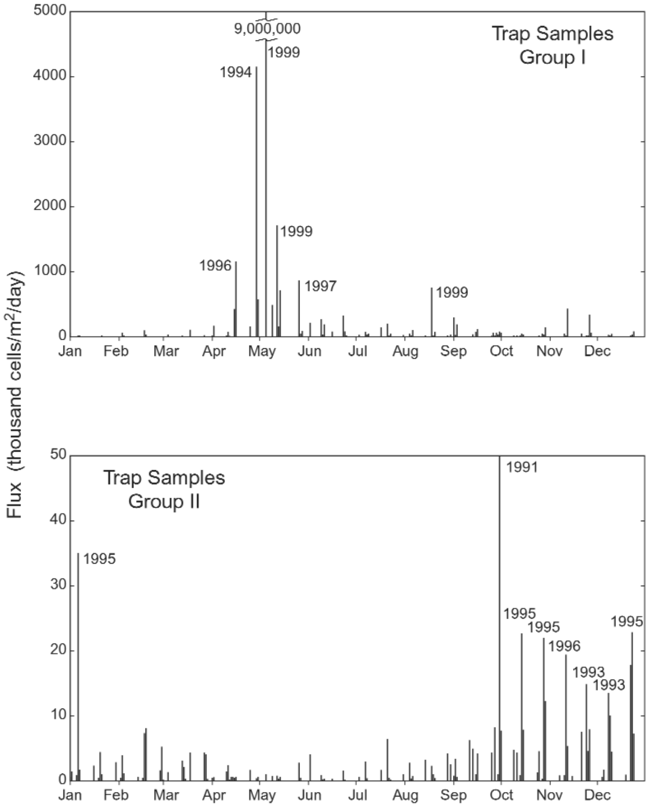

Figure 10. Seasonal cycles of the total flux of the largest two recurrent groups formed from trap samples at α = 0.55. Years of major peaks are indicated.

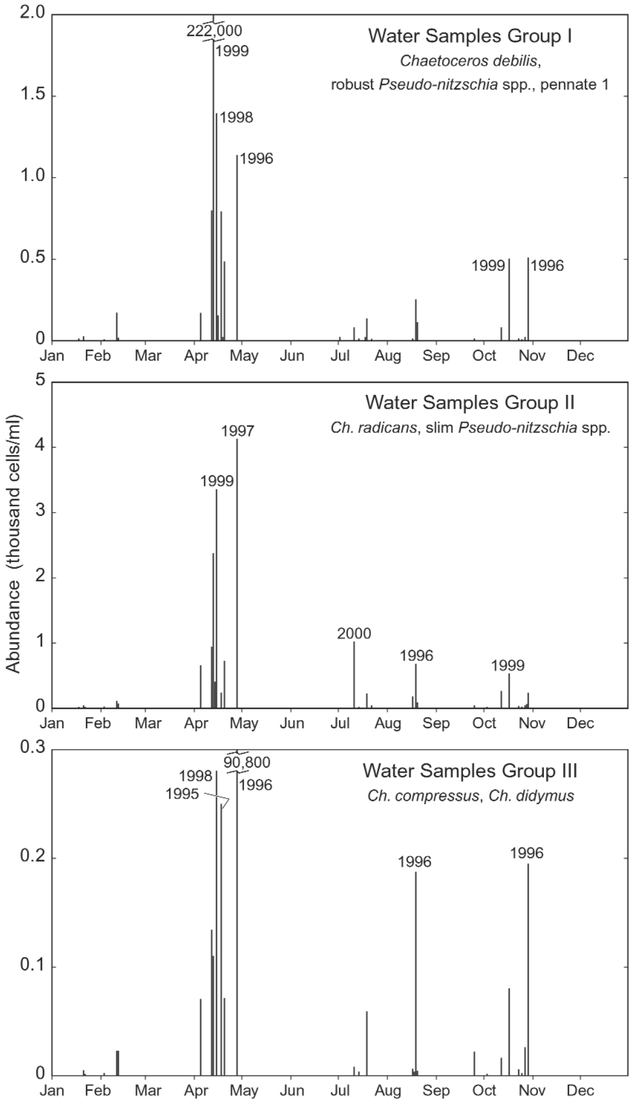

Figure 11. Seasonal cycles of the total abundance of recurrent groups formed from water samples at α = 0.70. Years of major peaks are indicated.

species. The flux of this group peaks in the spring and early summer (fig. 10), echoing the seasonal pattern of group I at α = 0.70 (fig. 8). Maximum fluxes were observed during the recent La Niña event in 1999. The second largest group, group II (fig. 7 and tab. 2) has abundance maxima in fall and winter, showing some of the features of group II at α = 0.70. The fluxes of group II were especially high in 1995. Of the five taxa in group II, *Thalassionema frauenfeldii* is a warm-temperate cosmopolite (Tomas 1997), and *Dictyocha fibula* is a widespread silicoflagellate (Sancetta 1990; Tomas 1997). However, two of the remaining species, *Coscinodiscus perforatus* and *C. granii* (group IV at α = 0.70), are thought to be restricted to coastal environments, and it is possible that the seasonal pattern of this group reflects local conditions.

There are no recurrent groups of benthic species at either level of α. The trio, group IV (α = 0.55, tab. 2), consists of two benthic species and a cold/temperate oceanic species with an associated warm-water species. Other benthic species are associated singly with groups. None can be interpreted as a "benthic" signal.

Water Samples. From the water samples, the highest affinity level (α = 0.70) defines three interrelated groups of seven diatom species (fig. 7). All of these groups have maximum abundances in April (fig. 11), like group I from the trap samples. Since the three recurrent groups are also concordant with respect to interannual abundance, their differentiation into recurrent groups must be due to an interaction between seasonal and interannual signals.

When the affinity index is lowered to α = 0.55, 35 species are grouped into 11 recurrent groups, with 8 associated species (fig. 9 and tab. 2). The initial three groups at α = 0.70 merge completely into the largest recurrent group, group I (fig. 7). Ten of the 11 recurrent groups form two clusters of interrelated recurrent groups of species each centered about one of the two largest recurrent groups. With the sole exception of one associated species, *Rhizosolenia setigera*, that has an affinity with one recurrent group in each cluster, there are no associations between a species in one cluster and one in the other cluster. Thus, at α = 0.55, two distinct signals are clear.

Group I at α = 0.55 (tab. 2) is composed of eight diatoms characteristic of spring blooms. The 22 species of the larger cluster of recurrent groups, cluster I (fig. 9 and tab. 2), are diatoms, with the exception of one coccolithophore (*Emiliania huxleyi*) that is a member of a species pair (group X). The seasonal pattern of the cluster as a whole mirrors the seasonal cycle of the largest group, group I, with maximum abundances in the spring (fig. 12). The second-largest group, group II (fig. 7 and tab. 2) contains only a single diatom. As a whole, the second cluster of recurrent groups and associates is composed of seven diatoms, three coccolithophores, three dinoflagellates, two silicoflagellates, and a heterotrophic chromophyte. A seasonal cycle is not well defined for this group (fig. 12). The most prominent feature of its temporal distribution is the very low abundances during 2000, following a major La Niña event.

Comparison of Trap and Water Samples. The numbers and sizes of recurrent groups from both data sets are quite similar. Both data sets have a strong signal from spring-bloom species. To examine the relationship between the spring groups, we examine the total abundance of the largest recurrent group in each data set at α = 0.55 (fig. 7 and tab. 2) using the reduced set of comparable samples and calculating correlations at lags between group totals between zero and six 2-week intervals. The maximum correlations between the spring recurrent group in the traps samples and in the water samples are high. As expected from previous analyses, the correlation peaks at a lag time of three 2-week intervals (trap opens 4–6 weeks after collection of the water sample). A high correlation also occurs at a lag of two 2-week intervals. The species composition suggests that these groups in both data sets are indicators of nearshore upwelling, which characteristically occurs in the spring in this region (Venrick 1998).

There are three major differences between the complete trap sample and water sample data sets. The first is the difference in compositions of the second largest groups at α = 0.55 (groups II, tab. 2). Neither have a counterpart in the other data set. Clearly this is due to the absence of important species from each data set: the large *Coscinodiscus* species from the water samples and the nonsiliceous species, which were removed from the trap samples during preparation. As discussed previously for *C. radiatus*, the absence of many of the *Coscinodiscus* species from the water samples is surprising. Given that the populations of trap group II are best developed in the fall and winter (fig. 10), when the thermocline is strong and nitrate is low or absent from the mixed layer, we speculate that these species may develop below the mixed layer (i.e., below the sampling depth). We have no direct evidence that this is so. The absence of a warm-water oceanic signal from the trap data appears because much of this signal comes from nonsiliceous species that are removed from the trap material by acidification during sample preparation. In siliceous deposits, advective signals from central or equatorial species are likely to be much weaker than signals from coastal, diatom-dominated environments.

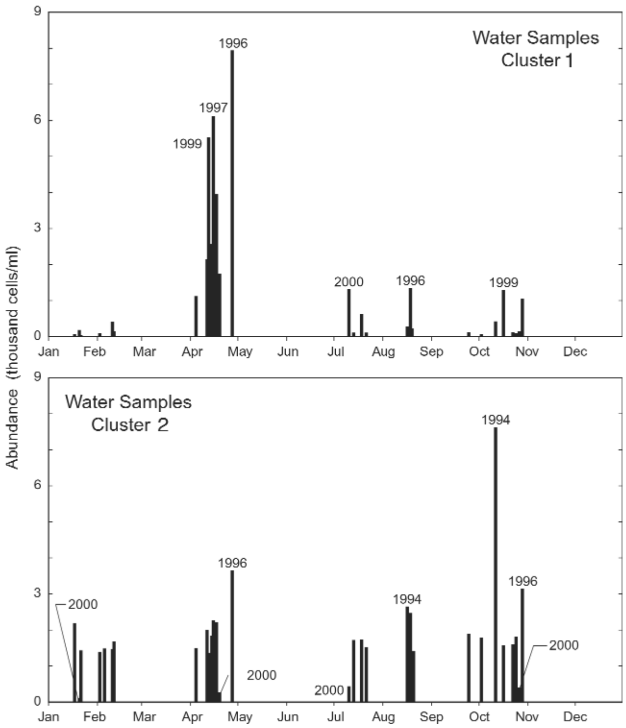

Figure 12. Seasonal cycles of the abundance of the two clusters of recurrent groups formed from water samples at α = 0.55. Years of major peaks are indicated as are the low abundance samples from 2000.

The second difference is the degree to which the spring species are delineated from the rest of the species. In the trap samples, the signal is clear at the higher level of α (0.70; fig. 7) but becomes increasingly diffuse as α is relaxed. At α = 0.55, all groups have cross-group affinities with most of the other groups (fig. 9). In contrast, in the water samples, the initial group of spring species increases in size as α is relaxed. Several smaller spring groups appear, but these, together with group I, form a cluster of recurrent groups. The signal from spring species remains distinct from other groups even at α = 0.55.

The performances of the recurrent group procedure in both sets of samples are characteristic: as the value of α is lowered, groups increase in size and number, and the number of cross-group affinities tends to increase. It is often the case that the most informative groups are

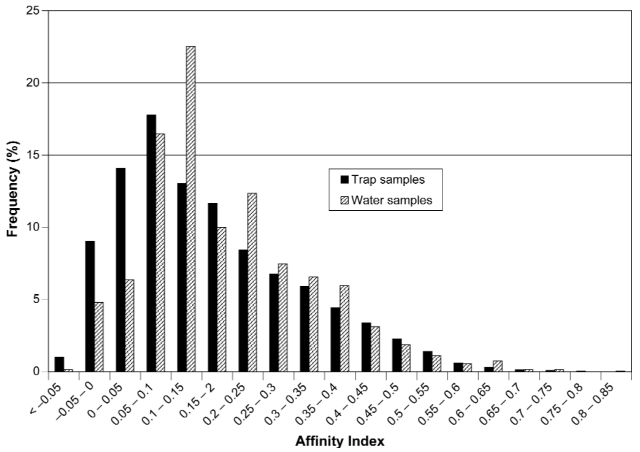

Figure 13. Frequency distribution of affinity indexes (α) between all species pairs in trap samples and in water samples.

the largest recurrent groups or group clusters that retain a level of separation. In the trap samples, the distinction between groups begins to weaken when α is as high as 0.65 (not shown). In the water samples, a distinction is clear at α = 0.55. Thus, the most meaningful recurrent groups from the trap samples are those at α = 0.70, and these are small groups of two and three species. The meaningful groups from the water samples are much larger, both because of the larger recurrent groups at α = 0.55 and because the groups themselves are clearly clustered.

There are 127 trap samples and 30 water samples. We expect the influence of sample numbers on the affinity index to tend to reduce the observed values of α between species in the water samples. Thus, the effect of the smaller numbers of samples should reduce the size and number of groups in the water sample data. This does not appear to be the case. We examine this directly by plotting the frequency distributions of α values for trap samples and water samples (fig. 13). Contrary to prediction, the frequency distribution of α values in the water samples is shifted to higher values relative to the trap samples (χ^2; $p < 0.001$). Thus, the greater number of trap samples in this comparison does not appear to be a factor in explaining the results.

Groupings of Samples

Spearman's rank order correlation coefficient, ρ, is the basis for constructing dendrograms that show the similarity of samples with respect to their species compositions (rank order of abundance).

Trap Samples. A ρ value of 0.23 was subjectively selected as that which defines the most meaningful groups of trap samples. When this value is considered, the traps are clearly grouped by date of collection (fig. 14). Ninety-four percent of the traps are included in a group, and only 6% of the clustered traps are clustered out of sequence. The longest series of traps include 9 months of data: 2 September 1993 through 13 May 1994. However, the median sequence length is less than 2 months—about five traps. Unexpectedly, this analysis does not indicate the annual cycle seen in the fluxes of some recurrent groups. In the dendrogram, spring samples are more similar to other samples in the same year than to spring samples of different years. (In a separate study it will be shown that this is, in part, a function of the use of a nonparametric correlation coefficient as the basis for clusters. Rho weights all species equally, whereas the spring bloom is an increase in a relatively few species.)

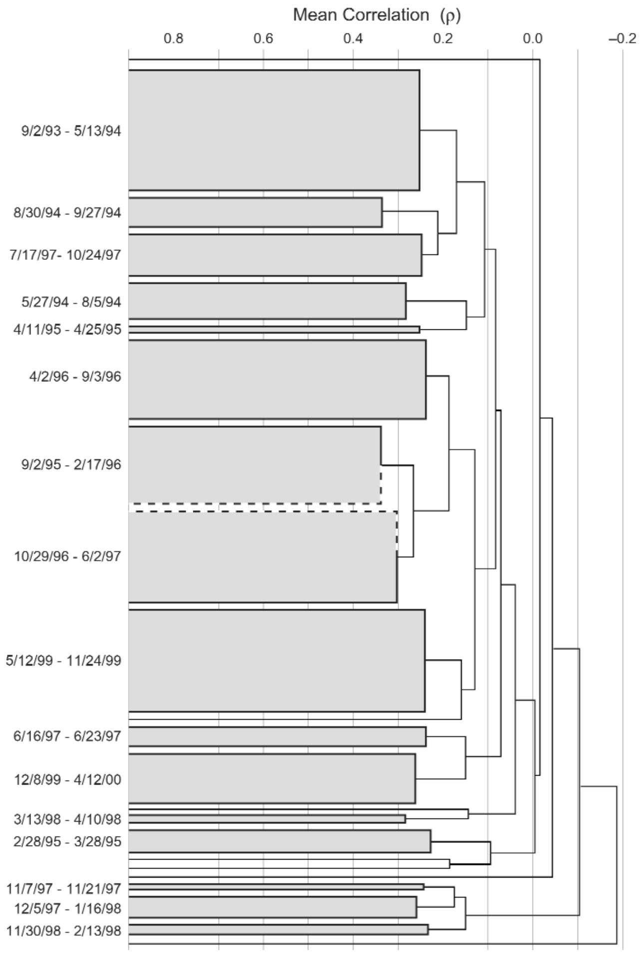

Figure 14. Abbreviated ρ-based dendrogram showing similarity of species structure of trap samples. Shaded areas indicate groups of traps similar at ρ ≥ 0.23, and dates indicate the midpoints of collection dates of the component trap samples. Dashed lines indicate possible subgroups, defined by dates.

Water Samples. In the dendrogram of water samples, no value of ρ produces informative groups of water samples (fig. 15). At ρ = 0.23, only 19 of the 30 water samples are related to other samples. The largest group consists of 7 samples that were collected in different seasons of different years. All other related samples at ρ = 0.23 are sample pairs.

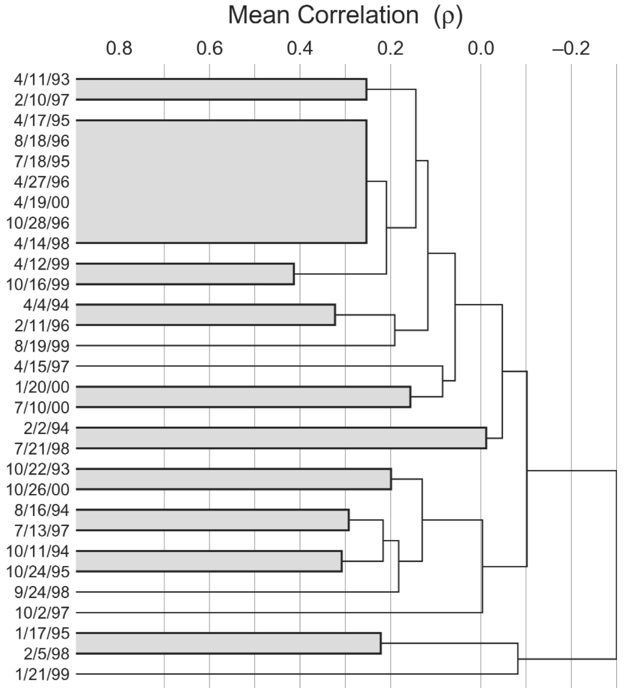

Figure 15. Rho-based dendrogram showing similarity of species structure of water samples. Dates indicate the collection dates of the samples.

Comparison of Trap and Water Samples. No evidence of the trap clusters can be found in the water sample dendrogram. To some extent, this may be a function of sample frequency in that many of the trap series are too short to include more than a single coincident water sample. On the other hand, there are three water samples collected during the 9-month trap series, 2 September 1993–13 May 1994. None of these water samples are related by the dendrogram criterion; nor are the three water samples collected during the 29 October 1996–2 June 1997 trap series.

A more direct approach to this problem considers the restricted sets of coincident water and trap samples to determine whether pairs of similar (or dissimilar) water samples are coincident with pairs of similar (or dissimilar) trap samples. In other words, we ask, If the correlation between a pair of trap samples indicates a similar (or dissimilar) flora, does the correlation between corresponding water samples also indicate similar (or dissimilar) flora? As a measure of similarity, we use Spearman's correlation coefficient, ρ, between the correlations of the trap sample pairs and the water sample pairs. Maximum similarity is seen when trap samples are lagged three 2-week periods behind the water samples (fig. 16), but there remains considerable scatter. The relationship accounts for only 16% of the variability. There is also a clear tendency for trap samples to be more similar than water samples (i.e., more values in the lower-right quadrant than in the upper-left).

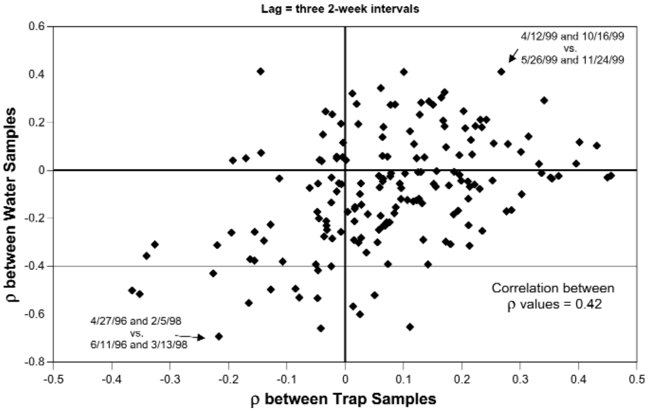

Figure 16. Relationship of the correlation (ρ) between pairs of trap samples to the correlation between the corresponding pairs of water samples, where the trap samples are lagged 4–6 weeks behind the water samples. Thus, water samples collected on 12 April 1999 and 16 October 1999 were similar in their rank order of species abundances. Trap samples collected 4–6 weeks later (mid-dates 26 May 1999 and 24 November 1999) also had similar species composition. Both trap and water samples indicate similar flora in the spring and fall of 1999; they do not necessarily indicate that the species compositions in the trap samples were similar to those in the water samples. In the same way, both trap and water samples indicate that the flora in the spring of 1996 was different from the flora in the winter of 1998.

One explanation for the greater similarity between trap samples, which integrate through time, is that they smooth out small-scale variability in the distributions of the individual species, whereas the water samples, which are point samples in time and space, capture all but the smallest scales. Unless a large proportion of species fluctuations are correlated on a small scale, the variability of individual species among water samples will reduce sample similarity and, hence, lower the mean value of ρ. At the same time, the variability of ρ (about this reduced mean) will be increased. Thus, if the temporal averaging of the trap samples is important, we expect ρ between trap samples to be higher than ρ between water samples, especially at smaller scales. That this is the case can be seen by comparing the distributions of ρ from trap and water sample pairs as the interval between samples increases (fig. 17). Using a 168-day running average, trap samples close in time are similar, and the similarity decreases somewhat asymptotically to zero at about 4.5 years. Only 19% of the values are negative. In contrast, among the water samples, even averaging over 168-day intervals fails to obscure the noise in the data (fig. 17). This may be partly due to the fewer number of water samples and hence the fewer number of samples contributing to each mean value.

Local maxima in the running average at intervals of 1, 2, 3, 4, and even 5 years reveal the annual cycle in both data set. Only the trap samples show maximum similarity (ρ) at the shortest separation intervals. In the water sample data, samples separated by intervals less than 1 year are, on the average, less similar than samples separated by 1 year. At intervals less than about 4 years, trap

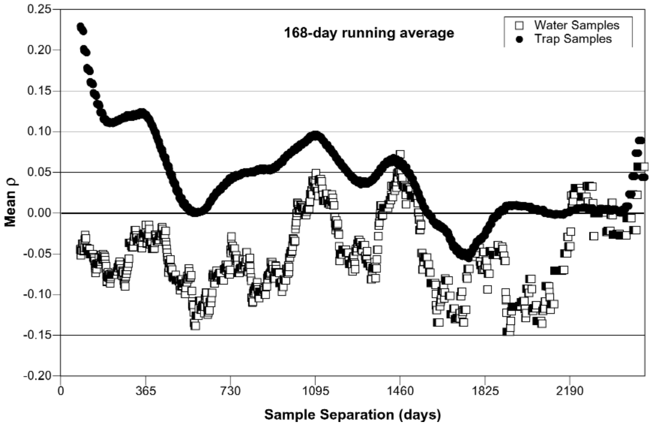

Figure 17. Frequency spectra of the similarity of sample pairs separated by increasing periods of time. Similarity is the correlation (ρ) of the rank order of species abundances in two samples. Running averages (168 days) have been taken to emphasize major trends.

samples are consistently more similar than water samples. Both data sets also show increasing correlations at the longest intervals, but the meaning of this is uncertain.

Both the higher mean ρ and the presence of a maximum at the shortest sampling intervals in the trap samples are evidence that significant small-scale spatial/temporal variability is effectively removed by the trap samples. More frequent sampling of the water column in time would not substantively change this conclusion until the sampling became so frequent that averaging could duplicate the integration of the traps.

DISCUSSION AND CONCLUSIONS

We did not expect that samples from the water column and from near-bottom traps would provide identical representations of the phytoplankton assemblage in the euphotic zone. Nevertheless, we are surprised at the magnitudes of the differences. Out of a combined species list of 260 taxa, only 9 were frequent enough in both sets of samples and were identified with sufficient reliability to provide the basis for direct comparison. If we restrict the original list to siliceous species that are partly or wholly planktonic, the proportion of comparable species improves slightly, from 0.03 to 0.06, but it is still low. Even allowing random chance its fair share, not all discrepancies have an adequate explanation. The seeming disproportionate dominance of Hyalochaete resting spores in the trap samples and the absence of many large *Coscinodiscus* species from the water samples need further study.

Several of our analyses indicate a lag time of three 2-week intervals (4–6 weeks) between water sample and trap sample. Many of these analyses also show correlations at two 2-week intervals (2–4 weeks) that are only slightly less high. The fact that these two values recur suggests an intermediate lag time (on the order of 4 weeks) as the best estimate from our data. However, our analyses are highly interdependent, so the recurrence of the same estimated lag provides little power for generalizing.

A number of studies have used diverse approaches to estimate sinking velocities or lag times between the euphotic zone and the sediment. (e.g., Eppley et al. 1967; Shanks and Trent 1980; Bienfang 1985; Deuser et al. 1990; Passow 1991; Kiørboe 1993). Estimates vary widely, in part due to different environments and different particle morphology and physiology. Species differ in their tendency to form aggregates before settling, and single cells or chains may sink more slowly than aggregates or fecal pellets (Riebesell 1989; Kiørboe 1993). Some of the range in our estimated lag times may reflect this inherent variability.

In a study from the Santa Barbara Basin that included "flocculent conglomerates of living, senescent diatoms, particularly chain-forming species, and frustules which formed following a diatom bloom," Alldredge and Gotschalk (1988) estimated a mean sinking velocity of 74 ± 39 m/day (5–15 days). Shipe and Brzezinski (2001), working at a trap site 6–8 nmi northeast of this study, estimated a 2-week lag between biogenic silica production in the upper 75 m and deposition into a trap at 470 m. Shipe et al. (2002) observed a lag interval of 2–4 weeks for several chemical measures of particulate composition. Our estimate of 4 weeks is high compared with these. It is possible that a large proportion of cells settle as single cells or single chains, but this contradicts many other observations about the importance of aggregations in vertical transport (Smetacek 1985; Fowler and Knauer 1986) and our own observations of packed aggregates in raw trap material.

Whether the estimated time lag is 2 weeks or 6 weeks, all estimates are longer than the estimated 7-day residence time of near-surface particles in the Santa Barbara Channel (Winant et al. 1999). This suggests that most of the material reaching the sediment traps is produced outside of the Santa Barbara Channel. The correlations between the spring signal in water samples and sediment traps suggest that the spring bloom is a quasi-simultaneous occurrence over a broad region. Flow into the Santa Barbara Channel during the spring is primarily from the north, which characteristically supports much stronger wind-driven coastal upwelling than the Southern California Bight to the south (Huyer 1983). In contrast, the prevailing currents from the southeast in summer, fall, and winter suggest the trap receives flora primarily from the central and southern California Bight. The influence of the prevailing currents will be modified by mesoscale diffusive processes (Siegel et al. 1990). The geographical extent of the trap's footprint remains to be determined.

A surprising result of our comparison is the fundamentally different behavior of methods that group species with similar patterns of abundance (here, recurrent group analysis) and those that group samples according to similarity of species composition (here, dendrograms). In the first case, the water samples seem to produce clearer signals; in the second, the trap samples give clear results while the water samples do not. We interpret this as reflecting the underlying differences in the temporal/spatial scales sampled by individual water and trap samples.

Recurrent group analyses of both data sets capture the spring bloom. Although analogous groups (groups I at $\alpha = 0.55$) share only a few dominant species, their fluctuations through time are correlated. The two sets of samples, however, each produce at least one group that has no analogy to groups in the other set—for instance, the winter coastal flora in the trap samples and the warm-water oceanic flora in the water samples.

Much of the difference between traps and water samples is clearly related to different species compositions of the two data sets. Discrete water samples (especially a single near-surface sample) may miss significant populations that develop in restricted vertical strata; whether this is, in fact, the reason for the absence of a coastal fall-winter group in the water samples remains to be determined. Alternatively, studies that are focused on a restricted component of the phytoplankton, such as the siliceous component, risk diluting and distorting important environmental signals. In fact, the warm-water diatoms are often used as evidence for El Niño conditions (Lange et al. 1987, 1990, 2000). Clearly, their presence or absence must be judged by a different criterion than, for instance, the presence or absence of the spring-bloom species. It is interesting that the warm-water group identified from the water samples showed little change in abundance during the 1993 and 1997–98 El Niño conditions but showed a strong reduction in abundance following the 1999 La Niña event.

Analysis of trap data consistently produces interrelated recurrent groups. Except for species pairs, which are difficult to evaluate, it is not possible to isolate distinct recurrent groups or clusters of groups from the trap data. In contrast, in the water sample analyses, species were consistently grouped with the same species regardless of the affinity level used. At α of 0.55, two clusters of recurrent groups were clearly separated. We speculate that the more distinct relationships between species groups emerging from the water samples reflect the fact that species relationships are best preserved in smaller-scale features, which are better samples by water bottles; the temporal (and hence spatial) averaging by the trap samples smears these small-scale relationships between species.

In contrast, analyses that evaluated the species compositions of individual samples (dendrograms) produce clear signals from the trap data and no interpretable signal from the water sample data. To some extent, this is due to the larger number and higher frequency of the trap samples. However, a comparison of the behavior of ρ in the two data sets shows a higher mean value of similarity between trap samples at virtually all frequencies. This is evidence that the 2-week integration accomplished by each trap sample effectively removes small-scale variability. A single trap sample represents some substantially larger region (Deuser et al. 1990; Siegel et al. 1990), although the precise footprint of this region is uncertain. From the perspective of paleoecological interpretations, this broad representation should be an advantage, although the direction and magnitude of the source region, as well as the lag-time itself, certainly vary through time and probably have strong seasonal components. At the same time, the dendrograms from the water samples suggest limits on the amount of information about seasonal and interannual changes of assemblages that should be expected from water samples from a single location.

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ENVIRONMENTAL INFLUENCES ON SPECIES COMPOSITION OF THE COMMERCIAL HARVEST OF FINFISH AND INVERTEBRATES OFF CALIFORNIA

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ABSTRACT

California commercial finfish and invertebrate landings from catches made in waters off California were examined to evaluate the relationship of fluctuations in species composition to environmental influences during 1930–2000. We considered empirical orthogonal function (EOF) analysis on $\log_e$-transformed annual weight for species and species groups. We developed ocean process indexes by accumulating monthly anomalies of central California sea surface temperature (SST) and southward wind stress (SWS), SST from La Jolla, California, and the Pacific Decadal Oscillation (PDO). Time variation of the first EOF, which explains more than 25% of the variance, is significantly correlated with the La Jolla SST and the PDO indexes. Time variation of the second EOF, which accounts for 20% of the variance, is significantly correlated with the SWS index, and its variability is similar to concurrent ecosystem changes. Individual landings series were not adjusted for fishing effort, so we estimated annual effort using the number of boats in the fishery as a proxy. Correlation of the species composition to the effort proxy and to inflation-adjusted total ex-vessel value indicates that fishery factors have acted together with environmental events and fisheries management regulations to produce nearly continuous change in the species composition of commercial finfish and invertebrate landings from 1930 to 2000.

INTRODUCTION

Changes in the species composition of fish and invertebrates in the ocean off California represent inter- and intraspecies adjustment to harvest and to environmental changes (Ryther 1969; McGowan 1990; McGowan et al. 1998; Stenseth et al. 2002). We have examined and compared annual landings of more than 43 species of commercially harvested fish and invertebrates for indications of environmental forcing. The landings records were compiled by the California Department of Fish and Game and have been available in annual publications dating from 1928 (Bureau of Marine Fisheries 1951; Oliphant 1979; Oliphant et al. 1990; Eres 2002). The Pacific Fisheries Environmental Laboratory of the Southwest Fisheries Science Center has assembled these data and converted them to computer accessible formats (CACom).[1] CACom contains primarily those California landings harvested within about 400 km west of the California coast. Catch-locations were provided by fishers and recorded on landings receipts, which are the source of the CACom data (Bureau of Marine Fisheries 1951; Oliphant 1979; Oliphant et al. 1990; Eres 2002).

Parrish et al. (2000), in their study of environmental variability in the northeastern Pacific Ocean, developed climate indexes consisting of 3-year running means of sea surface temperature (SST) and southward wind stress (SWS). They summarized the Comprehensive Ocean-Atmosphere Data Set (COADS) for a well-sampled coastal area extending 200 km seaward off central California (fig. 1). Their 3-year means (fig. 2) are useful in delineating environmental events that may impact commercial landings. Year-to-year environmental events may be smoothed by market factors, the longevity of harvested species, migrations, and harvest regulation, but longer-lasting events are expected to be evident by changes in the species composition of the landings. Multiyear events extend over larger areas (McGowan 1990) and would be more likely to affect statewide landings.

The central hypothesis of this study is that temporal changes in the proportion of species and species groups in the landings will correspond to the environmental patterns discussed by Parrish et al. (2000) and illustrated in Figure 2. First, central California SST and SWS have fluctuating covariability that may be found in the patterns of change among CACom species. Second, Parrish et al. (2000) found that some of the highest SST means of the twentieth century occurred during the 1957–62 period (fig. 2). CACom variation in species composition may respond to this anomalous event. Third, Figure 2 illustrates a well-documented northeastern Pacific climate change during 1973–82 (Norton et al. 1985; Ebbesmeyer et al. 1991; Miller et al. 1994; Chavez et al. 2003) that may be indicated by persisting shifts in

[Manuscript received 18 April 2003.]

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[1] Mason, J. E. 2003. Historical patterns from 74 years of commercial landings from California waters.

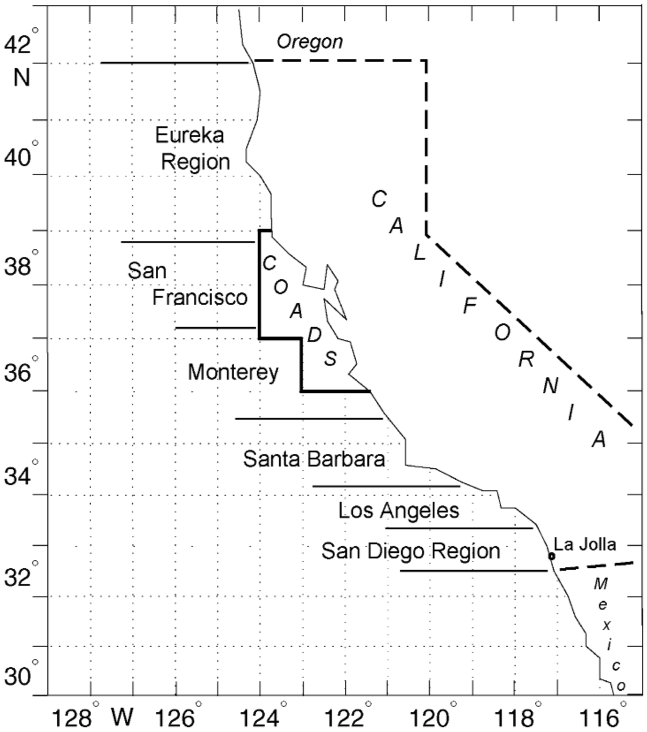

Figure 1. Statistical areas used in the California commercial landings of fish and invertebrates (CACom) data. Weight of catch for the statistical areas was combined for each market group and summed for each year. Region labeled "COADS" indicates central California coastal areas where data from Comprehensive Ocean-Atmosphere Data Set was summarized by Parrish et al. (2000) and for this study.

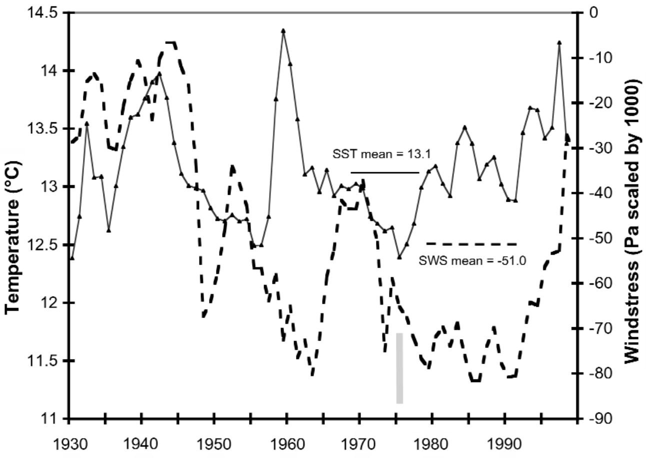

Figure 2. Fluctuations in 3-year seasonally corrected running means of sea surface temperature (SST) in °C and southward wind stress (SWS) in Pa ×1,000 from the central California area (fig. 1). SWS increases downward (right-hand scale); solid line shows SST, and dashed line shows SWS; horizontal lines show the 1930–2000 overall means (revised from Parrish et al. 2000).

CACom species composition. Finally, SST and SWS have similar trends in the late 1990s after a 20-year period of dissimilar trends, suggesting a fourth significant environmental shift (fig. 2) that may have affected the composition of species in the landings.

Previous studies have addressed the fluctuation of certain CACom species over various periods (Godsil 1938; Sund and Norton 1990; Kalvass and Hendrix 1997; Norton 1999; Leet et al. 2001). This is the first examination of temporal variation in the composition of market group ensembles representing more than 85% of the CACom total landings weight from 1930 to 2000.

METHODS

The CACom data were derived from thousands of reports received from hundreds of fish dealers purchasing the catch from fishers in dozens of ports throughout California (fig. 1). CACom data are cataloged as market groups that represent either a single species or a mixture of species caught and sold together. Time series representing ensembles of CACom market groups, environmental indexes, and fishery indicators were developed and compared visually and by simple correlation to evaluate relationships. We limited the analyses to 43 market groups that have landing records throughout the 1930–2000 period and examined two subsets of the 43-group ensemble: (1) all market groups representing a single species (29 species), and (2) all single-species groups that were recorded in the landings in every year from 1930 to 2000 (25 species). Common species names used throughout this report are those of Miller and Lea (1972) and Leet et al. (2001).

Empirical Orthogonal Functions and Their Time Variation

First, the three market group ensembles were assembled into three data matrixes where each market group is represented by a column in the data matrix and the variation in annual landing weight over 71 years is presented as rows. Second, corresponding correlation matrixes were formed after $\log_e$-transformation of each of the three data matrices. Third, the eigenvalues and corresponding eigenvectors (empirical orthogonal functions or EOFs) of each correlation matrix were computed. Reviews and examples of these procedures are given by Kutzbach (1967), Davis (1976), and Cloern and Jassby (1995).

The eigenvalues give estimates of the data matrix variance explained (extracted) by each corresponding empirical orthogonal function (EOF). By convention, EOF1 has the largest eigenvalue, EOF2 the second largest, and so forth. Of the 25–43 possible EOFs, only EOF1 and EOF2, which are significant at less than the 0.05 level (North et al. 1982), are discussed in this report. The products of the EOFs and the corresponding $\log_e$-transformed data matrices give the time-variable coefficients (**C**) and indicate the unique variation of each EOF through the 1930–2000 period (Kutzbach 1967). The time-variable coefficients series (**C**) are also called "principal components."

TABLE 1
Loading Values for First Empirical Orthogonal Function (EOF1)

N = 43, all species and groups	N = 29, all species	N = 25, local species
0.90 California barracuda	0.90 California barracuda	0.88 California barracuda
0.85 Pacific halibut	0.87 Pacific halibut	0.83 Pacific sardine
0.83 Pacific sardine	0.87 Pacific sardine	0.64 giant sea bass
0.64 white seabass	0.71 ocean whitefish	0.53 white seabass
0.63 giant sea bass	0.60 giant sea bass	0.51 yellowtail
0.61 ocean whitefish	0.54 California sheephead	0.50 California sheephead
0.52 California scorpionfish	0.53 California scorpionfish	0.50 California scorpionfish
0.46 bluefin tuna	0.53 white seabass	0.47 bluefin tuna
0.42 turbot[1]	0.45 bluefin tuna	0.34 Pacific mackerel
0.39 California sheephead	0.45 yellowtail	0.20 California halibut
0.37 yellowtail	0.38 Pacific mackerel	−0.09 spiny lobster
0.29 Pacific mackerel	0.22 California halibut	−0.12 Pacific bonito
0.23 smelt[1]	0.00 spiny lobster	−0.26 swordfish
0.20 flounder[1]	−0.18 skipjack tuna	−0.29 white croaker
0.19 abalone[1]	−0.20 Pacific bonito	−0.44 Pacific hake
0.10 California halibut	−0.26 white croaker	−0.44 Dungeness crab
0.08 salmon[1]	−0.27 yellowfin tuna	−0.50 albacore
0.07 sharks[1]	−0.28 swordfish	−0.51 cabezone
0.03 octopus[1]	−0.40 Dungeness crab	−0.56 lingcod
0.03 flyingfish[1]	−0.43 Pacific hake	−0.57 Pacific herring
0.02 perch[1]	−0.47 cabezone	−0.58 Pacific butterfish
−0.03 skates[1]	−0.48 albacore	−0.61 jack mackerel
−0.07 spiny lobster	−0.54 Pacific herring	−0.68 California market squid
−0.21 Pacific bonito	−0.57 Pacific butterfish	−0.78 northern anchovy
−0.21 white croaker	−0.57 lingcod	−0.84 sablefish
−0.27 skipjack tuna	−0.58 jack mackerel	
−0.34 albacore	−0.64 California market squid	
−0.39 Dungeness crab	−0.79 northern anchovy	
−0.41 yellowfin tuna	−0.85 sablefish	
−0.41 Pacific butterfish		
−0.42 swordfish		
−0.42 jack mackerel		
−0.52 lingcod		
−0.59 cabezone		
−0.59 sanddab[1]		
−0.60 Pacific hake		
−0.66 Pacific herring		
−0.69 northern anchovy		
−0.70 California market squid		
−0.77 rock crab[1]		
−0.84 soles[1]		
−0.87 rockfish[1]		
−0.87 sablefish		

[1] Multispecies CACom market group.

The EOFs are vectors or series of loading values that represent unique patterns of species variation. Each column (market group) has a loading value within the EOF. The loading values and their order within the EOF make the EOF series unique. Tables 1 and 2 give EOF1 and EOF2, respectively, for each of the three data matrices. Loading values are also measures of the similarity (or correlation) of temporal variation in that market group to temporal variation in the corresponding **C**-series. Negative loading values (loadings) indicate negative correlation.

The **C**-series shown in Figure 3 are time series of species composition in the landings. Positive trends or slopes of the **C**-series (up and to the right of the graph) show that positively loaded species (tabs. 1 and 2) are becoming more abundant in the landings (relative to their range of abundance). Each market group series has distinct autocorrelation, which is dependent on the life cycle of the fishes as well as the fishery. This autocorrelation is evident in the **C**-series (fig. 3), but the **C**-series are not accumulated or integrated over time.

Accumulated Physical and Environmental Indexes

Environmental time series were examined as monthly anomalies accumulated over the 1930–2000 period. Accumulation (integration through time) adds persistence (autocorrelation) to the physical series, making them similar to the **C**-series. Anomaly accumulation also emphasizes continuity in the processes that produce the anomaly (Norton and McLain 1985; Klyashtorin 2001). In addition to central California time series derived from the same data as those presented by Parrish et al. (2000),

TABLE 2
Loading Values for Second Empirical Orthogonal Function (EOF2)

$N = 43$, all species and groups	$N = 29$, all species	$N = 25$, local species
0.71 jack mackerel	0.63 white seabass	0.61 white seabass
0.68 Pacific butterfish	0.57 Pacific butterfish	0.58 Pacific butterfish
0.65 albacore	0.56 jack mackerel	0.50 jack mackerel
0.60 abalone[1]	0.41 albacore	0.40 northern anchovy
0.58 northern anchovy	0.40 northern anchovy	0.37 albacore
0.56 soles[1]	0.25 giant sea bass	0.34 giant sea bass
0.56 flyingfish[1]	0.16 lingcod	0.26 lingcod
0.52 flounder[1]	0.12 California scorpionfish	0.19 Pacific bonito
0.47 lingcod	0.11 white croaker	0.06 white croaker
0.42 Pacific bonito	0.04 bluefin tuna	0.04 California scorpionfish
0.41 perch[1]	0.02 California barracuda	0.03 bluefin tuna
0.36 salmon[1]	0.01 Pacific bonito	−0.04 California barracuda
0.35 Dungeness crab	0.00 Pacific halibut	−0.08 yellowtail
0.30 white croaker	−0.08 Dungeness crab	−0.13 Dungeness crab
0.28 turbot[1]	−0.08 Pacific sardine	−0.17 Pacific sardine
0.21 white seabass	−0.22 yellowtail	−0.23 sablefish
0.19 sablefish	−0.28 spiny lobster	−0.35 California market squid
0.03 octopus[1]	−0.29 sablefish	−0.45 spiny lobster
−0.02 rockfish[1]	−0.32 California market squid	−0.61 Pacific mackerel
−0.10 rock crab[1]	−0.41 ocean whitefish	−0.61 swordfish
−0.15 spiny lobster	−0.55 Pacific mackerel	−0.62 cabezone
−0.15 yellowfin tuna	−0.57 cabezone	−0.63 Pacific herring
−0.19 Pacific herring	−0.58 skipjack tuna	−0.63 California halibut
−0.19 California scorpionfish	−0.61 Pacific herring	−0.69 Pacific hake
−0.26 sharks[1]	−0.61 California halibut	−0.71 California sheephead
−0.26 bluefin tuna	−0.67 California sheephead	
−0.27 skipjack tuna	−0.68 Pacific hake	
−0.28 swordfish	−0.71 yellowfin tuna	
−0.30 giant sea bass	−0.72 swordfish	
−0.36 yellowtail		
−0.36 sanddab[1]		
−0.41 Pacific halibut		
−0.43 California market squid		
−0.43 Pacific sardine		
−0.46 California barracuda		
−0.46 smelt[1]		
−0.47 Pacific mackerel		
−0.48 Pacific hake		
−0.49 cabezone		
−0.50 ocean whitefish		
−0.50 skates[1]		
−0.55 California halibut		
−0.78 California sheephead		

[1] Multispecies CACom market group.

we examined two other physical data sets: the SST from Scripps Institution of Oceanography at La Jolla and the Pacific Decadal Oscillation (Mantua et al. 1997). The Pacific Decadal Oscillation (PDO) series, derived from fields of extratropical North Pacific SST anomalies was accumulated from monthly values. For the central California series and the La Jolla SST, the mean of the 1930–2000 period was determined for each month and the corresponding monthly anomalies from those means accumulated. Accumulated SST, SWS, and PDO anomaly series are indicated as A-SST, A-SWS, and A-PDO.

Accumulation filters most seasonal and many interannual events from the record. Accumulated series are interpreted in terms of processes that together cause negative or positive anomalies. If a series trends in a positive (negative) direction, processes that lead to positive (negative) anomalies dominate the interval. A steady or horizontal tendency (trend or slope ≅ 0) indicates a period of average temperatures. Changes in trend sign indicate change in anomaly sign and probably changes in ecological effects. If these accumulated anomaly series match the **C**-series, it suggests physical environmental processes have affects lasting from years to decades on species abundance in the CACom landings.

Fishery Variables

We assembled two variable series to describe fishery affects: the total number of boats reporting catch each year and the total dollar value of California landings adjusted to base year 2000.

The 43 market groups with landings reported throughout the 1930–2000 period represent more than 85% of

TABLE 3
Correlation Between Time-variable Coefficients (C_n) and Accumulated Environmental and Fisheries Indexes

Index	C_n EOF1	C_n EOF2
CC A-SST[1]	0.72	0.44
A-SWS[1]	0.08	0.84*
La Jolla A-SST	0.95**	0.04
A-PDO	0.85**	0.01
Boats[2]	−0.59**	0.47**
Value[2]	−0.27*	0.05

[1]Summarized from the central California COADS area (see fig. 1).
[2]Adjusted numbers of boats and adjusted total value.
**$p < 0.01$. Significance levels were corrected for effective degrees of freedom.
*$p < 0.05$.

the California commercial landings throughout 1930–2000. The major fishery not represented in the 43-group ensemble is the red sea urchin fishery that began in about 1975. The numbers of boats used by the urchin fishery (Kalvass and Hendrix 1997; Thomson 2001; P. E. Kalvass, pers. comm.) were subtracted from the total-boats time series, and the percentage of total value contributed by urchin landings was subtracted from the total-value time series. The total-boats index was also adjusted to remove boats that engaged primarily in tropical tuna harvests (Godsil 1938; Herrick 1981; E. Everett, pers. comm.), since the landings from waters south of California were excluded from the CACom data.

Each correlation has an effective number of degrees of freedom, determined by the long-lag correlation method using lags of 20–30% (Chelton 1983). Table 3 summarizes the correlations and significance levels.

RESULTS

The time variations of EOF1 and EOF2, **C**1 and **C**2, respectively, represent two independent patterns of variation in the ensembles of CACom market groups. Corresponding patterns of variation are apparent in the environmental and fishery variables.

Patterns of Species Variation

Patterns of species variation represented by $EOF1_{43}$ account for 26% of the variance in the 43-group data matrix (fig. 3). When the time-variable coefficients for $EOF1_{43}$ ($\mathbf{C}1_{43}$) had higher values, as at the left in figure 3a, there were higher landings of barracuda, Pacific halibut, sardine, and white seabass (positively loaded species, tab. 1) and lower landings of sablefish, rockfish, soles, and rock crab (negatively loaded species), relative to their landings ranges. $\mathbf{C}1_{43}$ has a generally negative trend through the 1930–82 period (fig. 3). The negative trend is followed by a generally positive trend from 1983 until 1998, indicating a moderate resurgence of positively loaded species (tab. 1). $EOF1_{43}$ species-composition patterns ($\mathbf{C}1_{43}$) had low trend during 1976–82, indicating relative stability during this period.

The $EOF2_{43}$-species composition pattern explains 20% of the CACom data variability (tab. 2). $\mathbf{C}2_{43}$ has little trend during 1930–44, suggesting stable $EOF2_{43}$-species composition pattern in the landings (figure 3d). A sharp increase in $\mathbf{C}2_{43}$ occurs in 1946–47 followed by a general increase until 1970, indicating shifts toward positively loaded species, such as white seabass, jack mackerel, and northern anchovy (fig. 3d). After 1977, sharp decreases occurred in $\mathbf{C}2_{43}$ until 1997, indicating shifts to negatively loaded $EOF2_{43}$ species, including California sheephead, Pacific mackerel, and California market squid (tab. 2). A minor $\mathbf{C}2_{43}$-trend reversal occurs in 1998. $\mathbf{C}2_{43}$ undergoes large changes during the 1973–82 period when $\mathbf{C}1_{43}$ becomes most stable. These two temporal patterns, $\mathbf{C}1_{43}$ and $\mathbf{C}2_{43}$, indicate two modes of change in species composition. The species contributing most strongly to each mode are those with the largest positive or negative loading values (tabs. 1 and 2).

To examine EOF_{43} and $\mathbf{C}_{43}$-series robustness, we limited the input data matrices to the 29 single-species market groups and to the 25 single-species market groups with landings recorded in each of the 71 years. A minor difference in **C**-series between the 43-group and the 29-group ensembles (fig. 3b) is a 1975 minimum in $\mathbf{C}1_{29}$ corresponding to the minimum in central California mean SST (fig. 2). The minimum in $\mathbf{C}1_{43}$ occurs in 1982 and the minimum in $\mathbf{C}1_{25}$ is indistinct within the 1975–82 period. $\mathbf{C}1_{25}$ and $\mathbf{C}2_{25}$ have less interannual variability, but long-term trends remain (figs. 3c,f). In addition to the overall trends, two shorter events are apparent in the **C**-series from each data ensemble: (1) there is a transient increase in **C**1 beginning in 1958 and lasting until 1962 that is similar to increases in SST and SWS (fig. 2), and (2) **C**1 and **C**2 have trend reversals involving the last three years of the record.

Correlation of EOF1 and EOF2 with Environmental Variables

Time variation of EOF1 and EOF2 calculated from the ensemble of 29 single-species groups ($\mathbf{C}1_{29}$ and $\mathbf{C}2_{29}$) have the greatest variability (fig. 3) and are used in the correlation to environmental indexes because these correlations have more degrees of freedom (4–15).

Significant correlation (correlation coefficient $r = 0.95$, $p < 0.01$) is found between $\mathbf{C}1_{29}$ and accumulated La Jolla SST anomalies (A-SST). Both series have discontinuities during the 1930–33 and the 1957–62 anomalous events (fig. 4). There is a general decline in positively loaded species and an accumulation of negative SST anomaly from 1930 to 1976. From 1976 to 1982, there is a transitional period when La Jolla SST anomalies were small and the $EOF1_{29}$-species compo-

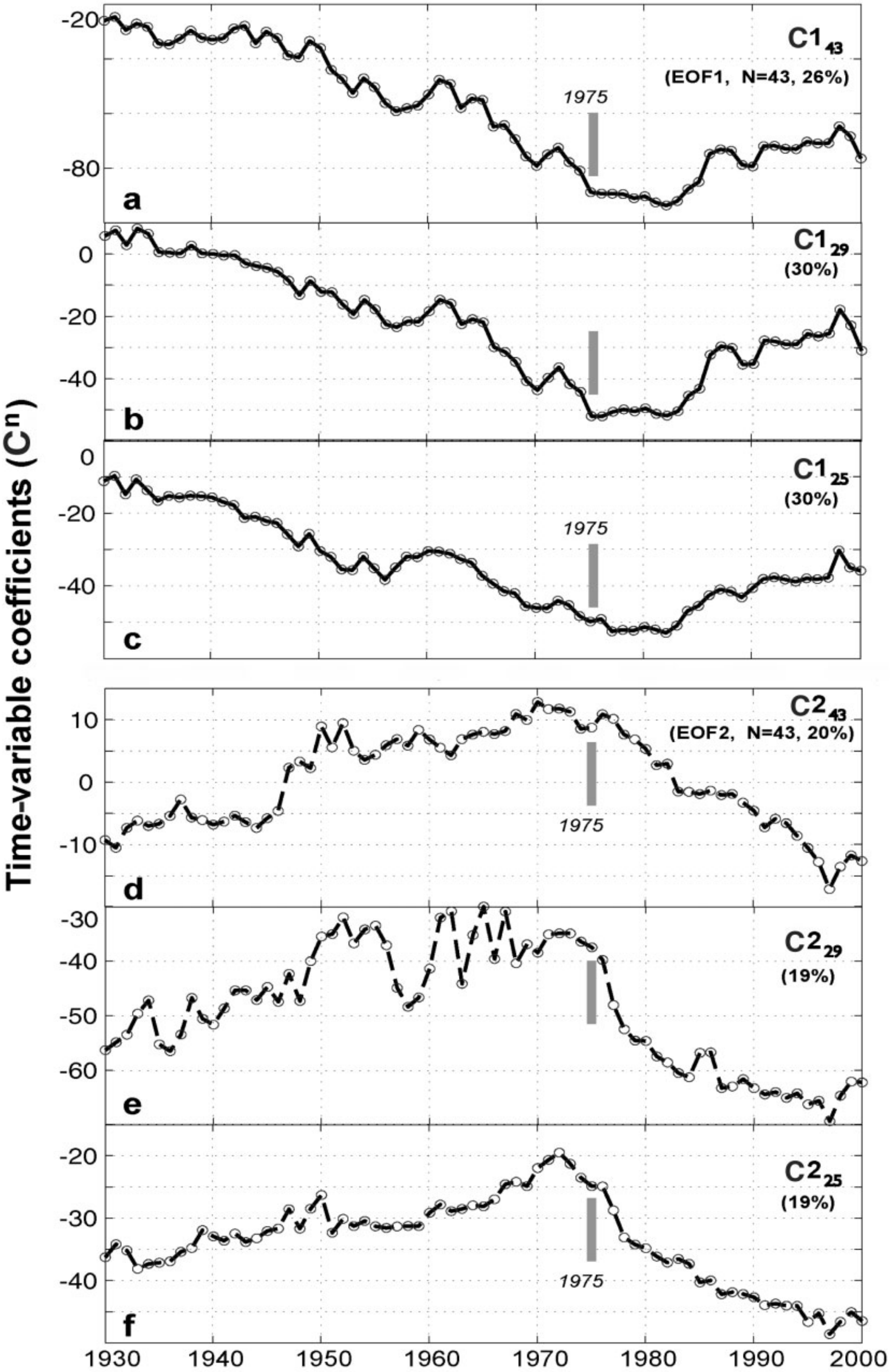

Figure 3. Time-variable coefficients (**C**) for the ensemble of the 43, 29, and 25 market groups having landings throughout 1930–2000. Time-variable coefficients for EOF1 (**C**1, *solid line*) are at the top (*a*, *b*, *c*). Panels *d*, *e*, and *f* give the time-variable coefficients for EOF2 (**C**2, *dashed line*). Circles indicate **C**-values for each year; only the connecting lines are used in Figures 4–7.

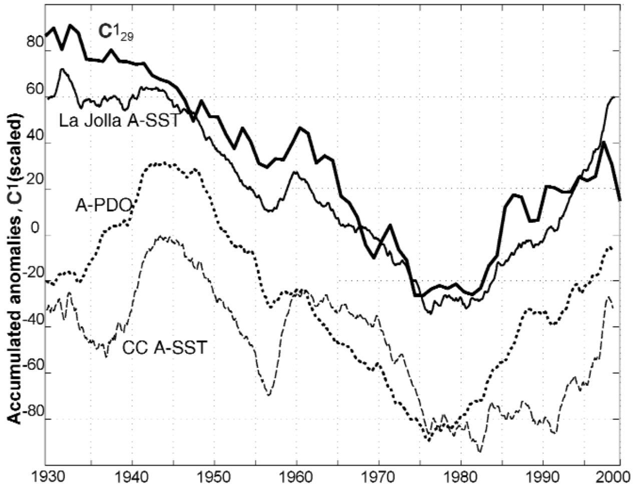

Figure 4. Accumulated monthly anomalies of the environmental indexes discussed in the text and annual **C**1_{29} values for EOF1_{29} (*thick solid line*) are scaled to show similarities. Accumulated SST anomaly from the La Jolla shore station (La Jolla A-SST, *thin solid line*); accumulated Pacific Decadal Oscillation (A-PDO, *dotted line*); and accumulated SST anomaly from the central California area (CC A-SST, *dashed line*).

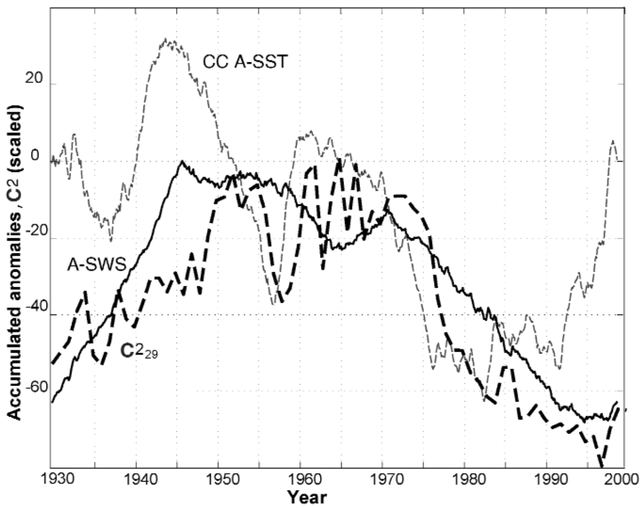

Figure 5. Accumulated monthly anomalies of the environmental indexes discussed in the text and annual time-variable coefficients (**C**2_{29}) values for EOF2_{29} (*thick dashed line*) are scaled to show similarities. Accumulated central California SWS anomaly (A-SWS, *thin solid line*); accumulated SST anomaly for the central California area (CC A-SST, *dashed line*). Scaling and offsets are as follows: **C**2_{29} × 2, +60°C; A-SWS × 10 Pa; CC A-SST, axis.

sition pattern was more stable (fig. 4). After 1982, the EOF1_{29}-species composition pattern trends of 1930–75 are reversed along with the trend in La Jolla A-SST and the A-PDO. The A-PDO, which shows the same trends and discontinuities as the La Jolla A-SST during 1944–2000, is also significantly correlated to **C**1_{29} (r = 0.85, $p < 0.01$), suggesting continuity between EOF1_{29}-species composition pattern changes and North Pacific basinwide forcing. La Jolla SST has variability similar to that found throughout much of the northeastern Pacific Ocean (McGowan et al. 1998).

Significant correlation ($r = 0.84$, $p < 0.05$) is found between **C**2_{29} and central California A-SWS (tab. 3, fig. 5). **C**2_{29} and central California A-SWS have positive trends from 1930 until 1945 in A-SWS and until 1952 in **C**2_{29} (fig. 5). By convention southward stress is given a negative sign, therefore larger SWS values indicate periods of less intense SWS. During the 1950–70 period there is high variability in **C**2_{29} but little overall trend in A-SWS and **C**2_{29}. In 1970 A-SWS starts a period of decline (greater SWS) until 1994. After a 3-year period of essentially no change in EOF2-species composition pattern from 1971 to 1973, **C**2_{29} trends sharply negative from 1974 to 1977 and continues this generally negative trend until 1997 (fig. 5). A trend reversal is indicated during 1998–2000. Major trend changes in A-SWS precede the **C**2_{29}-trend changes by 3 to 8 years (fig. 5), suggesting fishery responses to physical environmental influences.

The patterns discussed by Parrish et al. (2000) and illustrated in Figure 2 correspond to changes in landings patterns in the CACom data. First, dissimilar temporal patterns in **C**1 and **C**2 series are consistent with their apparently unique correlation to La Jolla A-SST and A-SWS, respectively. Second, some of the highest central California SST means of the twentieth century occurred during the 1957–62 period (fig. 2), a period marked by a trend in **C**1 to more positively loaded species. Third, the northeastern Pacific climate change of 1973–82 is indicated by a negative trend in **C**1 during the early 1970s, followed by a relatively stable period. **C**2 shows the 1973–82 climate shift by continuous change to more negatively loaded species (fig. 3). Finally, **C**1 and **C**2 have robust changes during the cooler ocean climate following the 1997–98 California El Niño period.

Fisheries Variation

The numbers of boats reporting landings and the annual ex-vessel value of California landings series (see "Methods" section) indicate year-to-year changes in the fishery. These indexes separate 1930–2000 into three fisheries intervals (figs. 6 and 7). First, the 1930–52 period includes the rise and fall of the great sardine fishery that contributed more than 50% of the value and about 80% of the landings weight. Second, there is a more stable interval in the numbers of boats and total value of the landings from 1953 to 1972. During the third fisheries interval (1973–2000), there was a rapid rise in the number of boats and the value of landings from 1973 to the 1977–80 maxima followed by a 20-year decline in each variable back to pre-1970s levels (figs. 6 and 7).

Significant correlation is found between **C**1_{43} and both boats and total annual ex-vessel value (tab. 3). These relationships are stronger during the last two fisheries intervals (fig. 6). The sign of EOF1_{43} has been reversed

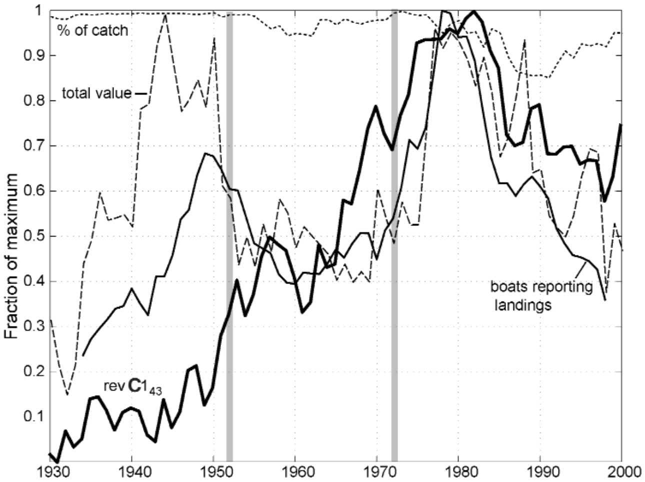

Figure 6. Time-variable coefficients (**C**1$_{43}$) for EOF1$_{43}$ computed from an ensemble of 43 species (*thick solid line*) plotted with reverse sign (rev**C**1$_{43}$) to show relation to total value adjusted to year-2000 dollars (*dashed line*) and adjusted numbers of boats (*thin solid line*). Fraction of total catch taken by the 43 market groups is indicated by the dotted line (*top*). Fishery variables are plotted as the fraction of the maximum values: 7,189 boats and $233,399,911. Vertical lines separate fishery intervals discussed in the text.

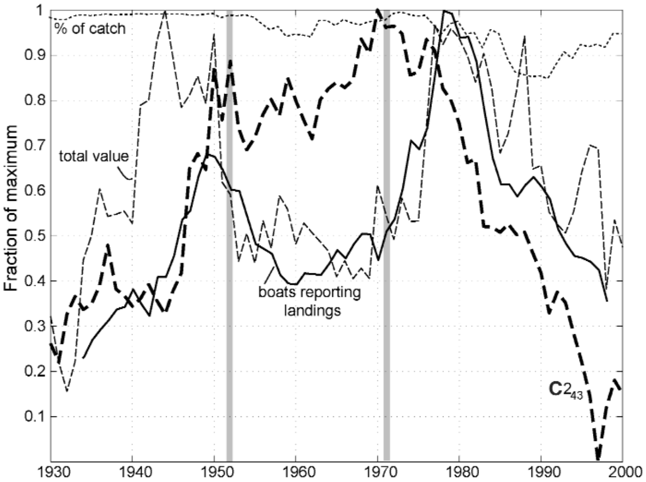

Figure 7. Time-variable coefficients (**C**2$_{43}$) for EOF2 computed from an ensemble of 43 species (*thick dashed line*) compared to corrected total landings value (*thin dashed line*) and corrected numbers of boats (*solid line*). Dotted line indicates fraction of the total catch taken by the 43 market groups. Fishery variables are plotted as the fraction of the maximum values: 7,189 boats and $233,399,911. Vertical lines separate the fishery intervals discussed in the text.

in Figure 6 (rev**C**1$_{43}$) to show similarities in trends. Negative trend in rev**C**1$_{43}$ indicates species composition shifts to positively loaded species (tab. 1). Trends in (rev**C**1$_{43}$) from 1949, the year of maximum boats in the first fisheries interval, to 1955 represent changes in fisheries to alternate species as the sardine fishery declined.

Total boats reporting landings and **C**2$_{43}$ are significantly correlated ($r = 0.47$, $p < 0.01$). **C**2$_{43}$ follows the number of boats in the first fisheries interval, again indicating that the increase in boats after 1945 was not due to increased investment in the sardine fishery (fig. 7). In the second fisheries interval (1953–72) the trend to positively loaded EOF2$_{43}$-fishes persists (fig. 7). Jack mackerel, anchovy, albacore, and salmon are positively loaded EOF2$_{43}$-species that supported the fishery in the 1960s and 1970s.[2] During the third fisheries interval, the number of boats appears to be lagging **C**2$_{43}$ by about 8 years, suggesting that the change in the number of boats may have been partially a response to changes in species composition reflected in EOF2$_{43}$ (tab. 2).

The 1997–98 California El Niño (Schwing et al. 2000) and the subsequent cooler period changed the trend in **C**1 and **C**2 (fig. 3) and in the total value (fig. 6). Much of the 20% drop in total value was due to the failure of the market squid fishery in 1998 (fig. 6). The squid fishery has since rebounded to near record levels, but the catch of Pacific herring, market crab, bluefin tuna, yellowfin tuna, and skipjack has declined since the 1997–98 event.[3]

DISCUSSION

The CACom data have two distinct patterns of variation in species composition that explain more than 45% of the variance through the 1930–2000 period. These patterns, defined by EOF1 and EOF2, appear robust to changes in CACom species ensembles (fig. 3). EOF1 and EOF2 variation through the 71-year period (**C**1 and **C**2) are close fits to physical environmental variables (tab. 3). Association of trends in fisheries variables to trends in **C**1 and **C**2 during parts of the record suggests that the fishery—alert to profitable opportunities, expanding markets, and changes in species availability—readily altered the species composition of the landings. The flexibility of the fishery combined with a changing environment and changing species availability produced nearly continuous change in the species composition of the landings from 1930 to 2000.

Trends in **C**1 and **C**2 match trends in physical environmental variables more closely than they match variation in fisheries variables (tab. 3). This suggests that the changes found in species composition begin as changes in the physical environment that cascade through the food web and create changes in species abundance and availability in the California Current system.

Changes in the physical and biological environment during the 1957–62, 1973–82, and 1998–2000 periods are documented in detail by Norton (1999), Parrish et al. (2000), Bograd et al. (2000), and Lea and Rosenblatt (2000), and in the present study. Sampling by California Cooperative Oceanic Fisheries Investigations (CalCOFI) off Southern California has shown changes in temperature, salinity, and sea level during 1957–62, 1973–82,

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[2] Mason, Historical patterns.

[3] Mason, Historical patterns.

and 1998–2000 to be well-correlated to changes in zooplankton biomass (Sette and Isaacs 1960; Chelton et al. 1982; Roemmich 1992; Roemmich and McGowan 1995; McGowan et al. 1998; Hayward 2000; Schwing et al. 2002). McGowan et al. (1998) present a time series of $\log_e$-zooplankton biomass concentration in the CalCOFI region that is similar to the $C2_{29}$ series (fig. 3). Zooplankton biomass concentration and $C2_{29}$ rose to a relative maximum in the early 1950s, then dipped to a local minimum during 1957–60. Both continuously declined from the early 1970s to the early 1990s, with the sharpest decline occurring from 1973 to 1982 (fig. 3, and McGowan et al. 1998). The relative concentration of dominant euphausiid species also changed during 1973–77 (Brinton 1981), the period of greatest decline in $C2_{29}$ (fig. 3). During the 1998–2000 trend reversal in C2 (fig. 3), the CalCOFI zooplankton biomass concentration off southern California exceeded average concentrations of the previous six years (Hayward 2000; Schwing et al. 2002). These changes in zooplankton concentration during 1957–62, 1973–82, and 1998–2000, concomitant with same-sense C2 changes, link the commercial landings to lower trophic-level events that are not directly influenced by California fisheries.

Sea birds feed on larger zooplankton and fish, and their reproductive success within the central California sampling area (shown in fig. 1) appears tied to the same environmental processes that affect EOF1-species composition patterns. During 1971–91, seasons of poor sea bird reproduction increased after 1981 (Ainley et al. 1995), when there was a clear rebound of positively loaded EOF1 species and a decline in negatively loaded EOF1 species (fig. 3). Juvenile rockfish and anchovies, which are negatively loaded EOF1 species (tab. 1), are important in the diets of central California sea birds (Ainley et al. 1995). The decline of negatively loaded EOF1 species, indicated by the positive trend C1 after 1982 (fig. 3), may have causal relationship to low levels of sea bird reproductive success. The C1-trend reversal toward more negatively loaded species in 1998–2000 had a corresponding response in seabird reproductive success. Seabird reproductive success was below average in 1998, but in the following 3 years reproductive success was above average for the six central California species monitored (Schwing et al. 2002).

These relationships of sea bird reproductive success and zooplankton biomass to the same physical events that are linked to trend changes in C1 and C2 support the hypothesis that C1 and C2 trends are the result of environmental events and are not solely artifacts of directed harvest. Instead, the trend changes observed during 1957–62, 1973–82, and 1998–2000 in C1 and C2 appear to be indicating changes in the physical and biological environment of the California Current system.

The orthogonal property of EOF1 and EOF2 requires that changes in species composition will not be in phase throughout the 71-year series. If changes in the species composition of the California commercial landings, indicated by EOF1 and EOF2, are forced by the physical environment, then at least two modes of physical variability, as suggested by fig. 2, are likely. These modes may be related to combinations of (1) local atmospheric forcing (Parrish et al. 1981; Parrish et al. 1983; Norton and McLain 1994; Schwing et al. 2000); (2) basin-scale forcing that causes variations in input of higher nutrient, cooler water from the north (Chelton et al. 1982; Norton 1999; Parrish et al. 2000); and (3) locally and remotely forced changes in California Current pycnocline and nutricline depth (Norton et al. 1985; Roemmich and McGowan 1995; McGowan et al. 1998). Our results do not detail how these factors interact with seasonal and longer cycles and with California fisheries to produce the two modes of change in species composition patterns. However, the significant correlation of C1 with Pacific Decadal Oscillation (A-PDO), a physical variable related to the extra-tropical North Pacific Ocean, and the significant correlation of C2 with central California southward wind stress (A-SWS) suggest basinwide forcing of C1 and relatively local forcing of C2.

C1 and C2 have changed continuously throughout the 71-year period, with general trends maintaining the same sign over intervals lasting from 6 to 36 years. Effort in the California fishery, proxied by the number of boats reporting landings, appears related to C1 and C2 trends. Effort increased with total ex-vessel value by about 100% in the late 1970s, after enactment of the Fishery Management and Conservation Act (P.L. 94-265) and reached maxima of about 7,200 boats and $233,000,000 during 1977–80. These increases in effort and in value of the landings probably both affected and were affected by rapid changes in species composition that occurred during the mid- and late 1970s. Following the 1977–80 maxima, effort and value of the landings declined to pre-1970s levels. Present results suggest that the dynamics between species composition in the landings, the environment, harvest effort, market factors, and regulation have varied during the 71-year period as species composition in the California Current environment has changed.

CONCLUSION

This is the first analysis of environmental influences on interspecies variability in a 71-year time series from the California commercial fishery landings (CACom) data. Large-scale, long-lasting environmental events in 1957–62, 1973–82, and 1998–2000 are clearly evidenced by changes in species composition. EOF1 and EOF2 account for more than 45% of the variance and indicate two modes of variability among species and market groups. The time-variable coefficients, **C**1 and **C**2, derived from EOF1 and EOF2, and the CACom catch data provide uncorrelated time series that describe species composition as it varied through the 1930–2000 period. The correspondence of **C**1 and **C**2 and the temporal variation of unharvested species during 1957–62, 1973–82, and 1998–2000 suggest that **C**1 and **C**2 indicate changes in the physical and biological environment of the California Current system. Correlation of **C**1 with Pacific Decadal Oscillation (A-PDO) and the correlation of **C**2 with the central California southward wind stress (A-SWS) suggest basinwide forcing of **C**1 and relatively local forcing of **C**2.

Comparison of **C**1 and **C**2 with fisheries variables—numbers of boats reporting landings and total ex-vessel value of the landings—shows close correspondence during specific periods. This suggests that different dynamics involving environmental forcing, investment in boat operation, evolving markets, and species composition were operating at various intervals over the 1930–2000 period.

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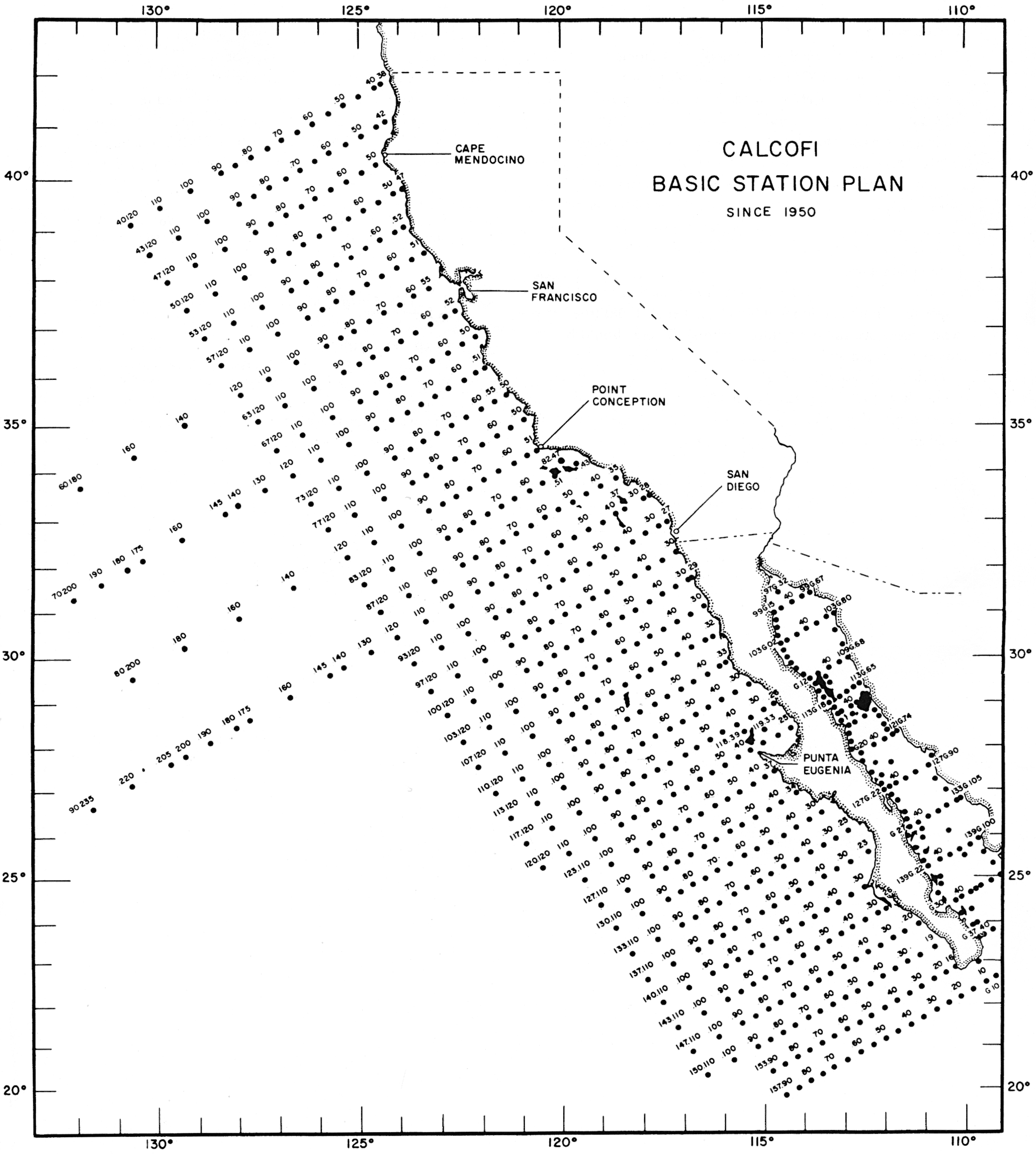

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