CALIFORNIA FISH AND GAME

"Conservation of Wild Life Through Education"

Volume 100 Spring 2014 Number 2

Special Marine Issue


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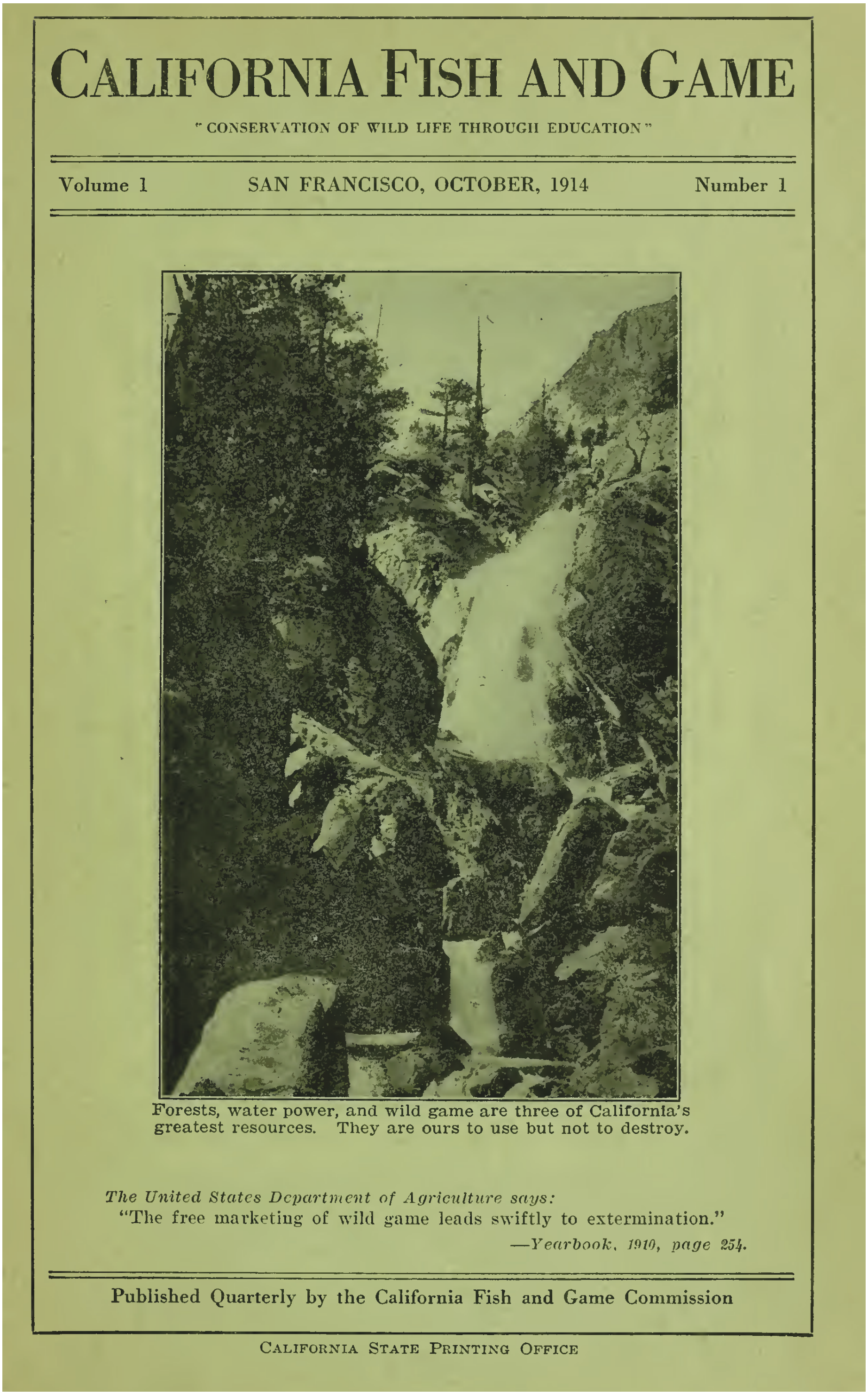
Published Quarterly by the California Department of Fish and Wildlife



CALIFORNIA FISH AND GAME

"CONSERVATION OF WILD LIFE THROUGH EDUCATION"

Volume 1 SAN FRANCISCO, OCTOBER, 1914 Number 1

Forests, water power, and wild game are three of California's greatest resources. They are ours to use but not to destroy.

The United States Department of Agriculture says:
"The free marketing of wild game leads swiftly to extermination."
—*Yearbook, 1910, page 254.*

Published Quarterly by the California Fish and Game Commission

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FRONTISPIECE.—The first issue of *California Fish and Game* was published in October, 1914. Volume 1 consisted of a total of 5 issues, four of which were published in 1915. Publication has occurred on a quarterly basis beginning with volume 2 in 1916.

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Contents

California Fish and Game

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California Fish and Game 100(2):181-182; 2014

Notes from the Editor

Welcome to California Fish and Game 100(2), the second of four special issues assembled to celebrate the centennial anniversary of California's longest-running, continuously published scientific journal. As the Editor-in-Chief, I remain pleased that this journal is celebrating with a series of special issues that ultimately will comprise Volume 100. I am also proud to be responsible for the production of Volume 100, but I am especially proud of the work accomplished by three individuals that took on many responsibilities in addition to their "day jobs" and, thereby, helped to ensure the quality of this special issue. They invited the authors, sought reviews, passed judgment on the acceptability of contributions for publication, assisted with copy editing, and helped to read page proofs. Two of those individuals, Pete Kalvass and Ian Taniguchi, served as Corresponding Editors, a task usually handled by the Editor-in-Chief; Nina Kogut unselfishly lent her editorial expertise to ensure consistency and quality of material published herein. Pete, Ian, and Nina each deserve special recognition and many thanks for their efforts and, as I promised previously (California Fish and Game 100:7-8), am again providing additional background information on those that were so instrumental in creating this special issue.

Pete Kalvass earned his B.S. in Fisheries Science and his M.S. in Natural Resources from Humboldt State University. He has >30 years of experience as a biologist in marine fisheries with the California Department of Fish and Wildlife (CDFW). Pete started out in the Ocean Salmon Project with a primary focus of monitoring the coastwide recreational and commercial harvest of ocean salmon. Following a move to the north coast of California, he embarked on research centered on developing a management program for the rapidly developing commercial sea urchin fishery, in collaboration with academic researchers and the industry. In recent years, he has been the supervisor for the CDFW Invertebrate Management Project, with an emphasis on the abalone, sea urchin and Dungeness crab resources. Mr. Kalvass served as the Corresponding Editor for four of the papers included in this issue, and has served as an Associate Editor for this journal for many years.

Ian Taniguchi received his B.S. in Zoology from the University of California, Berkeley and has worked 22 years as a marine scientist, most of it with CDFW. He initially started as a seasonal aide working on the San Francisco Bay Herring Fishery Project. He transitioned to marine invertebrate fisheries as a biologist with the Pacific States Marine Fisheries Commission working on the commercial red sea urchin fishery with Pete Kalvass in northern California. Ian continued working on marine invertebrate resource management with CDFW in southern California, focusing on sea urchins, abalone and other invertebrates. He is currently a senior scientist on the Invertebrate Management Project within the Marine Region, and is the state coordinator for implementation of the Abalone Recovery and Management Plan. Ian also represents CDFW on several NOAA Fisheries teams involved with recovery of endangered abalone species. Mr. Taniguchi served as the Corresponding Editor for five of the papers included in this issue.

Nina Kogut has 20 years of experience as a biologist, and has been an Environmental Scientist at CDFW since 1999. She earned her B.S. in Biological Sciences at San Jose State University and her M.S. in Conservation Ecology at California State University, Sacramento. Ms. Kogut currently works on marine protected areas and has served as an

Associate Editor for *California Fish and Game* since 2010; as an Associate Editor, she is putting to good use the skills she learned from her mentor and former Editor-in-Chief of this journal, Dave Kohlhorst. Nina's previous experience at CDFW includes mark-recapture studies of sturgeon and striped bass and electro-fishing to assess resident fish populations in the Sacramento and San Joaquin rivers and Sacramento-San Joaquin Delta. From 1995 to 1999, while working for a water utility district, she conducted a variety of field surveys for freshwater fishes (resident and diadromous species) as well as mammals, birds, reptiles, amphibians, and plants in floodplain and riparian habitats. Ms. Kogut served as Copy Editor for each of the papers included in this special issue, and provided invaluable assistance while reading proof pages.

Leadership within the Office of Communications, Education and Outreach—the CDFW administrative unit responsible for the production of *California Fish and Game*—is actively exploring ways to enhance the dissemination of information and simultaneously ensure availability of hard copies of the journal to interested parties. Currently, bids are being sought for a contract to provide combined print on demand (POD) and distribution services. I am optimistic that the contractor will offer good quality printing, notify subscribers as each issue becomes available, make the journal available through other outlets (e.g., Amazon, American Book Exchange), and be easy to work with. I am also hoping that the contractor will allow a link directly from the journal website to their own website to facilitate purchase of hard copies, thereby eliminating the need for maintaining a list of subscribers. To date, I have reviewed several test versions produced by one potential provider, and they were of a quality that generally exceeded that of prior issues produced by the State Printing Office.

Whatever transpires, each issue of *California Fish and Game* will continue to be posted on the CDFW web page, and I anticipate that a link to the contracted POD provider will be available on that page. By doing so, *California Fish and Game* will be immediately available to researchers, whether subscribers or not, on a world-wide basis the instant it is published. Additionally, the journal will continue to be accessed by commercial literature search services, hard copies will continue to be available to libraries and other institutions, and hard copies will be available, through the POD contractor, for those interested in having them. In all, this appears to boil down to a win-win situation. I'll provide an update in the next issue of *California Fish and Game*, which will be dedicated to freshwater ecology and fisheries: stay tuned for special issue 100(3) of this centennial anniversary volume.

Vernon C. Bleich
Editor-in-Chief
California Fish and Game

California Fish and Game 100(2):183; 2014

California Fish and Game 100(2): the special marine issue

It is my privilege to introduce this second issue of *California Fish and Game* in its 100th anniversary year. Having worked extensively for the Monterey Bay Aquarium and other organizations focused on ocean conservation, I am especially pleased that this issue is devoted entirely to the marine ecosystem.

You are reading a highly respected, regional scientific journal with a strong emphasis on the eastern Pacific Ocean and western North America. In this time of rapidly changing media, it is a testament to the quality of this publication that it has survived and continues to thrive into its second century.

Volume 100, Issue 2, is filled with reviews or the results of studies related to California's marine environment and the many species of plants and animals that it supports. On the surface, the Pacific Ocean looks to some rather like an aquatic "desert." We often don't see very much life there. But, from *just beneath* the surface to the depths of Monterey Canyon, our ocean is teeming with plant and animal life.

The many scientists working for the California Department of Fish and Wildlife (formerly California Department of Fish and Game) during the last century have completed a tremendous amount of important research leading to the protection and benefit of our wildlife and ecosystems. They deserve our thanks for the outstanding work they have done, whether in the field, in a lab, or in an office. Their dedication to the conservation of wildlife and habitat in California is unparalleled, and has kept California on the cutting edge of both terrestrial and marine conservation. For example, our new statewide network of marine protected areas—the nation's largest—requires scientific monitoring to inform adaptive management.

California Fish and Game is well known and is read by scientists throughout the world. This is only the second of four special issues that will focus on the science of conservation in our state during the journal's centennial year. Issues 3 and 4 will feature studies on our fresh water ecosystems and fisheries, and terrestrial wildlife, respectively.

As President of the California Fish and Game Commission, I congratulate everyone who has contributed to *California Fish and Game.* I especially want to acknowledge CDFW staff who gather all the parts of each issue, edit and put them together in a logical and attractive format, and then print and distribute the issues to each subscriber. These people are often overlooked, but without them this long-lived publication would not exist.

Thanks to all who have contributed reviews, scientific papers, photos, graphics and charts to *California Fish and Game.* May they continue to do so, and may this professional journal remain atop environmental scientists' "most read" list of publications for another century!

Michael Sutton, President
California Fish and Game Commission

California Fish and Game 100(2):184-185; 2014

Introduction to the special marine issue

Eastern Boundary Upwelling Systems (EBUS), such as the California Current, the Peru-Humboldt, the Canary, and the Benguela Systems, are among the most productive marine ecosystems of the world's oceans. Of these, the best studied is the California Current Ecosystem (CCE) resulting from the vision, collaboration and sustained support from the State of California's Department of Fish and Wildlife, NOAA's National Marine Fisheries Service, University of California San Diego's Scripps Institution of Oceanography and a broad host of academic, agency and non-governmental partners. While EBUS are productive they are also characterized by boom-bust cycles of some of their commercial fisheries that, in turn, affect the health of California's coastal communities, such as that of Monterey's Cannery Row immortalized in John Steinbeck's 1945 novel.

For the better part of the last century, scientific efforts in the CCE, such as the California Cooperative Oceanic Fisheries Investigations (CalCOFI) and others, have provided the conceptual foundation as well as the datasets against which all other major upwelling systems in the world have been compared. The studies in the CCE have provided a baseline for understanding marine ecosystems and their fluctuations ranging from the underlying physical and biogeochemical signals to the propagation of nutrients and energy through food webs resulting ultimately in the health and abundance of higher trophic levels. In turn, the mechanistic understanding we have developed has enabled better management of our fisheries. Fluctuations in fish populations are not only important for recreational and commercial fisheries, but we also have learned that we need to manage certain fisheries as forage for populations of pinnipeds, cetaceans, and birds, as well as the juvenile salmon that leave the watershed as they begin their oceanic migration.

The efforts to understand the broader picture CCE mechanisms have played an instrumental role to improve the science supporting the sustainable management of California's nearshore resources. California's science-based network of Marine Protected Areas is an example of where a broad array of science (both on oceanographic and biological levels) was used to guide a process that balanced conservation goals with the needs and interests of diverse user groups. This network has historical roots in the very journal you are reading today. One hundred years ago, in Volume 1, Number 1 of *California Fish and Game,* the editors published a 1912 letter from the great conservationist Gifford Pinchot to the Game Commission of the State of California expressing his support for establishing a refuge for fish near San Clemente and Santa Catalina islands; that idea that can be seen as a precursor to the network of Marine Protected Areas off California's coastline today.

From its humble beginnings in 1914 as a two-person Department of Commercial Fisheries, the Department of Fish and Wildlife's Marine Region has grown in size and scientific capacity as the scope of responsibilities has increased. No longer focused solely on mainstream commercial fisheries, the Marine Region and its partners employ scientific investigations to understand the ecological underpinnings of natural processes and anthropogenic impacts at the species, community and ecosystem scales.

While we have learned a great deal about the CCE and we have very good reason to celebrate our achievements, we also know that we are in the midst of one the most significant changes in our Earth's climate system. The simultaneous rate of change and the magnitude of the changes in atmospheric greenhouse gases, pollution, land-use practices, and human population increases, etc., are unprecedented in history. We are already witnessing changes in global temperatures, ocean stratification, biogeographic shifts of species, severity of storms, as well as changes in oxygen levels and ocean acidification in our coastal regions. Concurrently, global human population continues to rise adding growing pressure on marine resources to meet nutritional demands and resulting in impacts from increased ocean industry, continued coastal development and growing demands for consumptive and non-consumptive recreational uses. The century-long studies of the CCE will again prove to be fundamental to our ability to determine the nature of the changes we will observe in our waters. The data we collected will give us a critical reference frame relative to which we will be able to assess the nature and the severity of the impending changes, as well as the effect of our mitigation measures. In some ways, we need even more than ever to continue our century-long studies, enhance our collection of new data, and our surveys of the CCE and nearshore habitats.

The landmark California statutes of the Marine Life Protection Act and the Marine Life Management Act introduced the important concepts of adaptive fishery management and ecosystem based management to the lexicon of state marine natural resource management policy. These important management concepts are key to addressing the growing challenges of a changing global climate. The research papers in this issue are examples of some of the important work that the California Department of Fish and Wildlife Marine Region is conducting to fulfill the guiding tenets of these two important statutes. The information presented here will add to the expanding knowledge base for improving and implementing adaptive fishery and ecosystem based management in California.

We close with heartfelt congratulatory remarks to our scientists for what they have accomplished and contributed over the past decades and to the authors of this Marine Issue of the centennial volume of the California Fish and Game Journal. But at the same time we issue a call to action for what is going to be one of the most urgent challenges in the decades to come as we enter the Anthropocene, and into an unknown, no-analogue state. Based on what we achieved in the previous 100 years, there is every reason to believe, that working together as we have in the past, we will continue to provide the necessary science, which will result in the best management advice and ultimately in a healthy California Current Ecosystem supporting our human coastal communities.

Charlton H. Bonham, Director
California Department of Fish and Wildlife

Francisco Werner, Director
NOAA Southwest Fisheries Science Center

California Fish and Game 100(2):186-217; 2014

Implementing California's Nearshore Fishery Management Plan — twelve years later

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The Nearshore Fishery Management Plan (NFMP) mandated by California's Marine Life Management Act of 1998 was adopted by the California Fish and Game Commission in October 2002. The NFMP provides a framework for managing the nearshore species complex under joint state-federal authority using more conservative measures, while in close coordination with federal management. Since 2002, the California Department of Fish and Wildlife (CDFW) has managed 19 nearshore species in accordance with NFMP management measures. Prior to adoption of the NFMP, all nearshore species were considered data-poor. Since implementation, half of the nearshore species have been assessed, moving from data-poor to more informed. The status of assessed stocks is healthy or precautionary, which has resulted in increased total allowable catches. Regional management, as envisioned by the NFMP, has yet to be fully implemented, although progress has been made in the form of regional recreational and commercial catch monitoring and estimation of catch and effort, and a restricted access program instituted on a regional basis in 2003 for the commercial fishery. Since 2003, the number of restricted access permits has been reduced by 29%. Allocation of harvest limits between the recreational and commercial sectors continues to be based on historic landings. Recent implementation of a statewide network of marine protected areas provides protection to approximately 20% of nearshore habitat important to NFMP species and provides the opportunity to investigate the utility of marine protected areas as reference reserves for stock monitoring and assessment. Research on nearshore species is progressing, albeit slowly, given limited CDFW resources and by virtue of collaborative partnerships. Although the state intended to pursue federal transfer of authority to gain sole management authority, most of the NFMP species continue to be jointly managed.

Key words: allocation, fishery control rules, marine protected areas, MPA, nearshore rockfish, Nearshore Fishery Management Plan, regional management, restricted access program, stock assessments

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In the late 1980s the commercial nearshore fishery began to evolve and expanded rapidly as fishermen shifted from the less profitable market for fresh, dead fish to the more lucrative market for live fish (Pattison and Vejar 2000). Fishermen made extra efforts to keep fish alive for markets, including providing onboard oxygen and chilling tanks. The increased fishing pressure in shallow waters raised concerns about the potential for local depletion of these nearshore stocks given their life history characteristics — resident, long-lived, relatively slow growing, and sporadic recruitment success. An additional concern was the absence of a mechanism for quickly implementing management actions and more coordinated management.

To address growing concerns about the nearshore fishery, the Marine Life Management Act (MLMA) specifically mandated the development of a Nearshore Fishery Management Plan (NFMP) by 2001. The MLMA, enacted in 1998, also directed more responsibility toward the California Fish and Game Commission (FGC) and California Department of Fish and Wildlife (CDFW) for ocean fisheries management, prioritized sustainable resources over the long term above all other needs, recognized the economic and cultural importance of recreational and commercial fisheries, required increased constituent involvement, and advocated management grounded in science via fishery management plans.

To provide a mechanism for more responsive management of this nearshore fishery prior to the adoption of the NFMP, the Nearshore Fishery Management Act (NFMA) section of the MLMA granted the FGC more authority to regulate nearshore fish stocks and fisheries, and identified 10 nearshore species of special importance: cabezon (*Scorpaenichthys marmoratus*), California scorpionfish (*Scorpaena guttata*), California sheephead (*Semicossyphus pulcher*), kelp greenling (*Hexagrammos decagrammus*), rock greenling (*H. lagocephalus*), and black-and-yellow (*Sebastes chrysomelas*), China (*S. nebulosus*), gopher (*S. carnatus*), grass (*S. rastrelliger*), and kelp rockfishes (*S. atrovirens*). The NFMA required a Nearshore Fishery Permit (NFP) for their commercial take, set minimum size limits for those species, and directed funding from permit fees for developing the NFMP as well as for conservation and management (Weber and Heneman 2000).

In 2000, the FGC adopted interim regulations, including the NFP, total allowable catches (TACs), commercial trip limits, and minimum size limits to proactively protect cabezon, greenlings, and California sheephead. This set the stage for future state and federal management of these and other nearshore species prior to the completion of the NFMP. Due to insufficient life history information on nearshore stocks and, hence, no science-based harvest strategies, these management actions included development of state and federal harvest levels specific to NFMP species. These harvest levels were then allocated between the recreational and commercial sectors pending better information.

Coincident with NFMP development, the Pacific Fishery Management Council (PFMC), one of eight regional fisheries management councils established by the Magnusen-Stevens Fishery Conservations and Management Act (MSA) of 1976, began closely regulating the recreational and commercial sectors of the groundfish fishery in federal waters. This was due to the need to protect rebuilding rockfish species (cowcod [*Sebastes levis*], bocaccio [*S. paucispinis*], and canary rockfish [*S. pinniger*]) living in deeper waters and recently subject to a federal overfished declaration (PFMC 2003). The overfished status required federal action to rebuild the depleted stocks as quickly as possible, while minimizing impacts on fishing communities (MSA 1976, 1996). In 2000 and 2001, the PFMC initiated the establishment of various management area boundaries to allow for finer scale rockfish and lingcod (*Ophiodon elongatus*) closures (Figure 1), and implemented the first recreational closures. Also in 2001, two Cowcod Conservation Areas were designated to protect overfished cowcod off the coast of southern California; they totaled 10,878 km^2 and fishing for groundfish deeper than 37 m was closed. In 2003, depth-based Rockfish Conservation Areas were established that closed the shelf (61 m to as deep as 274 m) to all groundfish fishing gears so bycatch of rebuilding species was minimized. (Overfishing of

<table>
<tr><th rowspan="2">Geographic Location[a]</th><th colspan="3">State</th><th>State and Federal</th><th>Federal</th></tr>
<tr><th>NFMP and NFP</th><th>DNSFP and CGS Trip Limits</th><th>MPA</th><th>Recreational Groundfish Management</th><th>Nearshore Rockfish Trip Limits[b]</th></tr>
<tr><td>California-Oregon Border</td><td rowspan="2">North Coast</td><td rowspan="8">Statewide</td><td rowspan="3">Northern</td><td rowspan="2">Northern</td><td rowspan="2">North</td></tr>
<tr><td>Cape Mendocino__</td></tr>
<tr><td>Point Arena__</td><td rowspan="3">North-Central Coast</td><td>Mendocino</td><td rowspan="5"></td></tr>
<tr><td>Pigeon Point__</td><td>North-Central</td><td>San Francisco</td></tr>
<tr><td>Año Nuevo</td><td rowspan="3">Central</td><td rowspan="3">Central</td></tr>
<tr><td></td><td rowspan="2">South-Central Coast</td></tr>
<tr><td>Point Conception__</td></tr>
<tr><td>U.S.-Mexico Border</td><td>South Coast</td><td>Southern</td><td>Southern</td><td>South</td></tr>
</table>

[a] Spacing between locations represents relative distance, not to scale; AñoNuevo is only12.1 km from Pigeon Point.

[b] Limits for some species differ north and south of Point Conception (dashed line).

FIGURE 1.—California state and federal regional management boundaries relevant to Nearshore Fisheries Management Plan (NFMP) species. NFP = Nearshore Fishery Permit, DNSFP = Deeper Nearshore Species Fishery Permit, CGS = cabezon, greenlings, California sheephead, MPA = marine protected area network.

these stocks would later turn out to be recognized as partially the result of overly high productivity estimates during what turned out to be a warmer water regime with less favorable recruitment conditions). In that same year, recreational fishing for groundfish also began to be depth-restricted regionally and temporally in nearshore waters. As a PFMC member, CDFW developed recommendations for the groundfish fishery, including the nearshore. These actions were mirrored in state waters through FGC actions. Consequently, at the same time the nearshore stocks were being subjected to an increasingly active and unregulated live-fish fishery, they were in danger of increased fishing pressure shifting to the nearshore from the continental shelf due to these federal shelf closures.

The NFMP (CDFG 2002) was adopted by the FGC in October 2002. Nineteen species were included: all of the NFP shallow nearshore species, as well as eight deeper nearshore rockfish species (black [*Sebastes melanops*], blue [*S. mystinus*], brown [*S. auriculatus*], calico [*S. dallii*], copper [*S. caurinus*], olive [*S. serranoides*], quillback [*S. maliger*], and treefish [*S. serriceps*] and monkeyface prickleback [*Cebidichthys violaceus*]). The NFMP contained five main management measures to sustainably manage the nearshore fishery: fishery control rules (FCRs), regional management, allocation, restricted access, and marine protected areas (MPAs). The NFMP also included sections on research needs, species life histories, history of the fisheries, and implementation of the NFMP. Implementation of the NFMP began a decade of fine tuning groundfish management at both the state and federal levels to maximize fishing opportunity while controlling effort and protecting vulnerable species. Efforts were also initiated to collect essential fisheries information (EFI) on nearshore species and to evaluate stock status. In addition, implementation coincided with the process to develop a network of MPAs along the coast focused, in part, on rocky reef areas that are ideal habitat for nearshore species.

The framework approach used in the NFMP provided a tool chest of measures to implement the plan in accordance with its goals and objectives, consistent with the MLMA mandate for adaptive management (Fish and Game Code Sections 90.1 and 7056[g]), and included flexibility for making progress. In the sections below, we provide a review of the steps that have been taken and progress made in implementing each of the plan's primary management measures or approaches (i.e., FCRs, regional management, allocation, restricted access, and MPAs), as well as other aspects of management (e.g., research and monitoring, transfer of authority, enforcement, bycatch). At the same time, we document the important concurrent state and federal management actions in progress, and lay out the ongoing, complex coordination needed to help provide some context for progress or lack thereof. In addition, a summary of future opportunities and challenges is provided.

FISHERY CONTROL RULES AND STOCK STATUS

Fishery control rules.—Fishery control rules are the primary mechanism for achieving the main objectives of the MLMA for management, including sustainable use, preventing overfishing, and rebuilding depressed stocks (CDFG 2002). The FCRs are management tools used to predict appropriate fishing levels and long-term maximum sustainable yields. Maximum sustainable yield (MSY) is the highest average yield over time that does not result in a continuing reduction in stock abundance, taking into account fluctuations in abundance and environmental variability (Fish and Game Code Section 96.5).

The FCRs also provide a means to determine stock condition (e.g., healthy, overfished) by comparing stock status with pre-determined biological reference points.

The FCR for the NFMP incorporates different approaches to meet its objectives by integrating EFI into the level of precaution used in setting the TAC. Thus, in the absence of information beyond catch data, management should be more precautionary than when additional EFI (e.g., size or age data, abundance indices) is available. The TAC is equivalent to the definition of optimal yield (OY) in Fish and Game Code Section 97, with both describing an amount of fish that can be sustainably harvested in a fishery; this value can never exceed MSY. The framework for the FCR includes three stages, depending on the level of EFI available (Table 1). The PFMC uses similar categories in setting annual catch limits (ACLs) for jointly managed species, although the data and methods used to determine these limits are slightly different, as defined in the West Coast Groundfish Fishery Management Plan (GFMP). For example, the NFMP Stage III (data-rich) category supports ecosystem-based management, particularly incorporating the effect of marine reserves and other environmental factors into assessments. Kaufman et al. (2004) provided examples of what could be incorporated into Stage III management. By definition, a number of the nearshore stocks that have been assessed (e.g., black rockfish) are considered data-rich (Category 1) in the PFMC arena, although considered data-moderate (Stage II) by the NFMP definition (Table 1).

Table 1.— Comparison between state (California Department of Fish and Wildlife) under the Nearshore Fishery Management Plan (NFMP) and federal management (Pacific Fishery Management Council [PFMC]) under the Groundfish Fishery Management Plan (GFMP) and definitions of essential fishery information (EFI) required to determine catch limits.

Stage	NFMP management (CDFW)	Category	GFMP management (PFMC)
I	Data-poor—*Precautionary approach for setting TACs* Data sets used: Catch history	3	Catch based Data sets used: Catch history
II	Data-moderate—*Supports improved single species management* Additional data sets used: Abundance indices Size and/or age data	2	Catch based and abundance indices Additional data sets used: Abundance indices
III	Data-rich—*Supports ecosystem-based management* Additional data sets used: Additional environmental data Reference reserves	1	Full catch at age (or length) structured model Additional data sets used: Size and/or age data Additional environmental data[a] Reference reserves[a]

[a] Not required

During development of the interim regulations, the FGC was presented with differing approaches for management of the nearshore fishery and ultimately chose an approach modeled after Restrepo et al. (1998) as a proxy for MSY and OY (i.e., TAC) in data-poor (Stage I) situations. In simple terms, the proxy for MSY was based on the combined average catch for the recreational and commercial fisheries from 1993 to 1998, a period that included catch estimates from both sectors, had better accounting of individual nearshore rockfish in the commercial fishery, and was a period when stocks were not considered in decline. The proxy for TAC was set at 50% of the proxy MSY. The TAC was then allocated between the recreational and commercial sectors. The framework of the NFMP allows adjustments to the TAC; as information improves, management can be less precautionary.

Following adoption of the NFMP, the FGC used the above approach to set harvest limits because no stock assessments were then available for the NFMP species. Since then, with the availability of more data (i.e., EFI), formal stock assessments have been used to determine the status of a number of the NFMP species and to set TACs under Stage II management. The current management stage for each NFMP species is provided in Table 2.

Table 2.—The 19 nearshore species with relevant federal and state management and stock assessment information. Shallow and Deep permit types refer to the Nearshore Fishery Permit and Deeper Nearshore Species Fishery Permit, respectively.

Species	Managed by	NFMP Species by Permit	Last Assessed	Stage	Status[a]	PSA Vulnerability Score[b]
Black rockfish	Fed/State	Deep	2007	II	healthy	1.94
Black-and-yellow rockfish	Fed/State	Shallow		I		1.70
Blue rockfish	Fed/State	Deep	2007	II	precautionary	2.01
Brown rockfish	Fed/State	Deep	2013	II	precautionary	1.99
Calico rockfish	Fed/State	Deep		I		1.46
China rockfish	Fed/State	Shallow	2013	II	**[c]	2.23
Copper rockfish	Fed/State	Deep	2013	II	**[c]	2.27
Gopher rockfish	Fed/State	Shallow	2005	II	healthy	1.76
Grass rockfish	Fed/State	Shallow		I		1.89
Kelp rockfish	Fed/State	Shallow		I		1.62
Olive rockfish	Fed/State	Deep		I		1.87
Quillback rockfish	Fed/State	Deep		I		2.22
Treefish	Fed/State	Deep		I		1.73
Cabezon	Fed/State	Shallow	2009	II	**[c]	1.68
California scorpionfish	Fed/State	Shallow	2005	II	healthy	1.41
Kelp greenling[d]	Fed/State	Shallow	2011	II		1.56
Rock greenling	State	Shallow		I		1.77
California sheephead[d]	State	Shallow	2004	II		1.7[e]
Monkeyface prickleback[d]	State	--[f]		I		1.6[e]

[a] Status of the stock is based on the Nearshore Fishery Management Plan (NFMP) 60-20 Harvest Control Rule

[b] Productivity-Susceptibility Analysis (PSA) values were taken from Cope et al (2011). A higher PSA score equates to being more vulnerable

[c] “ ** ” indicates the northern portion of the stock was precautionary; the southern portion was healthy

[d] Stock status was not determined or the assessments were deemed inadequate for management

[e] PSA values were taken from Patrick et al. (2009)

[f] No permit required. A commercial fishing license is required as it is for all 19 species

Methodologies for determining stock status have improved since implementation of the NFMP. While TACs were previously set using 50% of recent landings (Stage I), new catch-based methodologies have been developed for estimating sustainable yields and management reference points for data-poor fish stocks. Recently, methods such as Depletion-Corrected Average Catch (MacCall 2009) and Depletion-Based Stock Reduction Analysis (DB-SRA; Dick and MacCall 2011) have been used in setting harvest limits for data-poor stocks in the NFMP (e.g., calico rockfish) when compositional data (e.g., lengths) or indices of abundance are not available. Additionally, the Scientific and Statistical Committee to the PFMC has reviewed and recommended the use of two data-moderate assessment methods for setting harvest limits under Stage II management (PFMC in press): Extended Simple Stock Synthesis and Extended Depletion-based Stock Reduction Analysis (XDB-SRA).

Under Stage II management, the NFMP applies a 60-20 FCR (Figure 2). For a given stock, if the current spawning biomass is estimated to be at or above 60% of the unfished biomass ($B_{Unfished}$; under federal harvest control rules the equivalent would be B_0), it is considered to be “healthy”. Once below 60% of $B_{Unfished}$ (i.e., depletion), the status of the stock is in a “precautionary” zone and the catch must be reduced below the default $F_{50\%}$ fishing rate, along a line where zero catch occurs at 20% of $B_{Unfished}$ (Figure 2). The default $F_{50\%}$ fishing rate may be considered precautionary for some species (e.g., cabezon). A stock is considered overfished if the biomass estimate falls below 30% of $B_{Unfished}$, at which point an interim adjustment is made to harvest levels until a rebuilding plan can be developed. The NFMP FCR is more precautionary than the federal GFMP 40-10 harvest control rule (Figure 2), where a stock must fall below 40% of $B_{Unfished}$ to be considered “precautionary” and must fall below 25% of $B_{Unfished}$ to be considered overfished and with zero catch at 10% of $B_{Unfished}$.

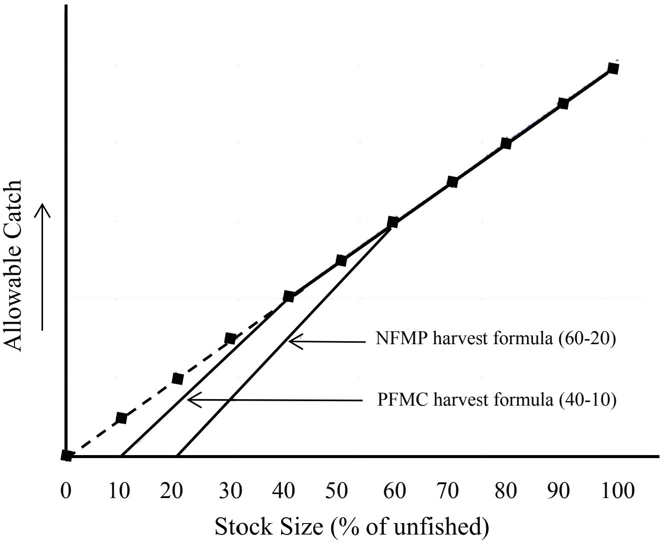

Figure 2.—Comparison of state and federal harvest control rules (60-20 and 40-10, respectively) for groundfish in California. NFMP (state) = Nearshore Fisheries Management Plan, PFMC (federal) = Pacific Fisheries Management Council.

A key objective for MPAs proposed by the NFMP was to act as reference reserves that could be temporally compared to similar fished areas as a means to evaluate stock health, in addition to helping preserve nearshore habitat and ecosystems. The use of MPAs as a part of the FCR under Stage III management is now being considered. Trends in the densities of nearshore species outside and inside MPAs are being evaluated as stock status indicators, along with the reference reserve concept put forward in the NFMP (CDFG 2002, Wilson et al. 2010). Using a ratio of the density of fish outside the MPA to that of density inside the MPA, McGilliard et al. (2011) evaluated a control rule to determine the direction and magnitude of change in the fishing effort in the following year. This density ratio control rule could be used as a potential tool for managing fish stocks on a smaller spatial scale, such as in nearshore waters where localized depletion can occur.

Stock assessments and stock status.—Initially, to prioritize which stocks to assess, CDFW evaluated EFI for each of the 19 nearshore species, including catch data, available length and age compositional data, data sources to provide relative indices of abundance, and relevant life history information. This exercise was used to rank the species, depending on the amount of data available to assess the stock. More recently, another index has been used to help set these priorities, based on productivity of the species and their susceptibility to the fishery. The productivity-susceptibility analysis (PSA) is a way to rank the vulnerability of a species (Cope et al. 2011). While this analysis helps to rank the species warranting assessment, the amount of data available for an assessment is also used to rank the order of species to assess.

Since 2004, CDFW has participated in a number of nearshore stock assessments, acting in such capacities as the lead or member of a stock assessment team, developer of assessment methodology, assessment reviewer, or provider of data and preliminary analyses to the stock assessment team. As many of the NFMP species are jointly managed, this work is often conducted in collaboration with federal partners (e.g., National Marine Fisheries Service [NMFS]). When assessment results are accepted for these jointly managed species, the PFMC has adopted more conservative state harvest limit recommendations to abide by the rules laid out in the NFMP for these species.

Stage II management incorporates population modeling that replaces the precautionary approach to setting TACs laid out under Stage I. Seven of the nearshore species have been assessed under the Stage II scenario (Table 2) using the size and age structured modeling platform of Stock Synthesis (Methot and Wetzel 2013). Numerous types of data can be incorporated into this model, including age and length composition information, fishery-dependent and fishery-independent indices of abundance, and relevant life history information (e.g., growth, maturity). The Stock Synthesis model produces estimates of unfished biomass, depletion, and MSY. However, MSY is a difficult measure to estimate and the uncertainty in this estimate is likely larger than is accounted for when reporting this reference point.

Stock boundaries are typically developed based on stock structure, including regional differences in life history or other biological characteristics that form the basis of management units. If stock structure information is not available, boundaries could be set based on management lines or data availability. Of the seven stocks fully assessed using Stock Synthesis, the following five were used to advise management. The gopher rockfish stock north of Point Conception to the Oregon border was assessed in 2005 (Key et al. 2006) and deemed “healthy”. The California scorpionfish population in the waters off southern California (Point Conception to the U.S.-Mexico border) was also assessed in 2005 (Maunder et al. 2006) and deemed “healthy”. Black rockfish was last assessed in 2007 (Sampson 2008) within waters between Cape Falcon, Oregon and Point Piedras Blancas, California (the southern extent of its range); this stock was also found to be of “healthy” status. Blue rockfish was assessed in 2007 (Key et al. 2008) and included the portion of the stock north of Point Conception to the California-Oregon border. The stock was found to be in a “precautionary” zone at 30% of $B_{Unfished}$; blue rockfish in California was identified as a “species of concern” (i.e., a species about which NMFS has some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the Endangered Species Act [ESA]; species of concern status does not carry any procedural or substantive protections under the ESA). The stock assessment team advised that this assessment be used with caution for management purposes. Lastly, Cope and Key (2010) conducted the most recent assessment of cabezon, separately modeling northern and southern California (i.e., north or south of Point Conception) sub-stocks. The northern stock was found to be “precautionary” and the southern stock was found to be “healthy”.

California sheephead and kelp greenling were also assessed using Stock Synthesis, although the assessment results were not considered adequate for providing management advice. The peer review helped to identify data needs and future research for these species. California sheephead was the first CDFW-sponsored stock assessment, for the area south of Point Conception to the U.S.-Mexico border (Alonzo et al. 2004). This species is a protogynous (female to male) sequential hermaphrodite; therefore, the assessment examined the stock status using various biomass estimates (e.g., female, male, or female+male biomass). Due to the highly uncertain stock status results and numerous other uncertainties (e.g., the behaviors and cues that trigger this species to transition from female to male), the assessment was not considered as a basis for setting harvest limits or revising management measures.

Kelp greenling was assessed in 2005 (Cope and MacCall 2006) for both the Oregon and California sub-stocks. The assessment of the Oregon sub-stock was accepted for management, although a stable model could not be identified for the California sub-stock. The stock assessment review panel concluded that the results for the California sub-stock were inadequate for providing management advice. In 2011, the California population of kelp greenling was re-evaluated using the DB-SRA (Stage I) data-poor method resulting in a three-fold increase to the TAC (Dick and MacCall 2010). The status of stocks under Stage I management is considered unknown.

Brown rockfish, China rockfish, and copper rockfish were assessed in 2013 (Cope et al. 2013) using XDB-SRA, which is an extension of the DB-SRA method with the addition of abundance indices as model inputs and other parameters. Brown rockfish was assessed on a coastwide level (including Oregon and Washington) and deemed “precautionary” based on the NFMP definition. The China rockfish and copper rockfish assessments were split within California, north and south of 40º 10’ N (near Cape Mendocino), and north and south of 34º 27’ N (Point Conception), respectively. The northern portions of those stocks (based on where the assessment was split) were more depleted than the southern portions in both cases, similar to the results for cabezon.

In the absence of information on stock status, 2003 harvest limits were very precautionary. As information has improved and more stocks have been assessed using new methods, changes to state and federal harvest limits have reflected these improvements with a reduced need for precaution. Most of the nearshore rockfishes continue to be managed as complexes under current management. When 2003 harvest limits are compared to 2014 values based on the most recent assessment information (Figure 3), limits have increased for all NFMP species except California sheephead.

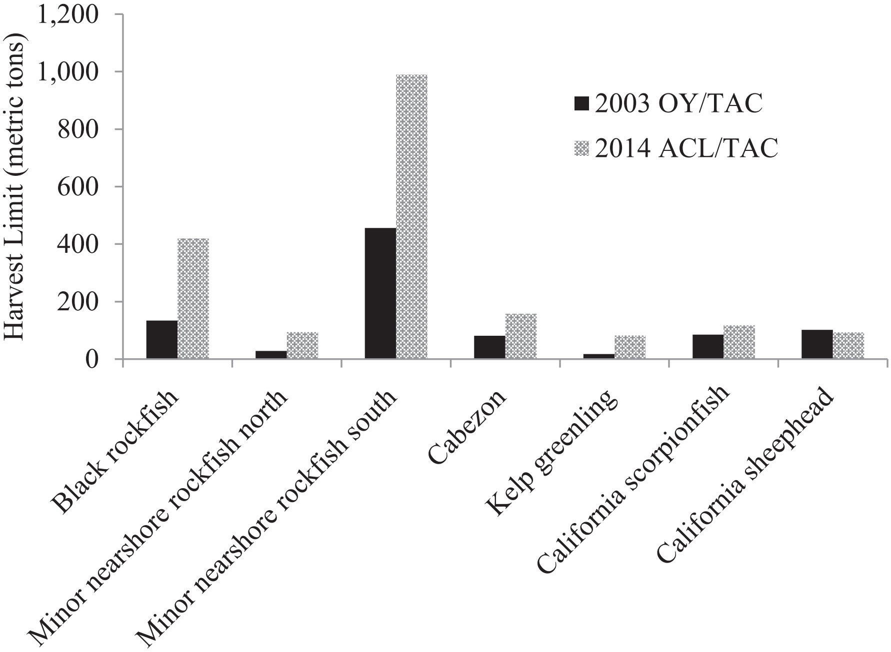

Figure 3.—Comparison of 2003 and 2014 harvest limits for some nearshore complexes and individual species. Minor rockfish complexes are managed separately north and south of 40° 10' N near Cape Mendocino, California. OY = optimal yield, TAC = total allowable catch, ACL = annual catch limit.

Accounting for uncertainty.—The reauthorization of the Magnuson-Stevens Fishery Conversation and Management Act (MSA 2006) changed the requirements for developing management actions for U.S. fisheries. The eight regional fishery management councils are now required to set ACLs for all managed stocks in the fishery. Two sources of uncertainty are now separately considered when establishing ACLs: scientific uncertainty (σ), based on assessment results; and management uncertainty (P*), determined by the risk (or likelihood) of exceeding harvest limits. Ralston et al. (2011) describe an approach to quantifying σ, while P* is a risk of the overfishing probability (0.25–0.45) chosen by the PFMC. These ACLs are equivalent to TACs in the NFMP; as a result, the attempt to quantify uncertainties when setting TACs is more scientifically based than when using the approach of Restrepo et al. (1998). Federal ACLs are now calculated for 16 of the 19 nearshore species in the NFMP that are also in the GFMP (Table 2).

When the NFMP was adopted in 2002, the Department believed there was sufficient information only on cabezon, California scorpionfish and, potentially, California sheephead for conducting formal stock assessments. Assessment of the other 16 nearshore stocks was considered extremely unlikely in the following decade (CDFG 2002). As seen here, there have been a number of assessments completed due, in part, to the state's involvement in stock assessments of the nearshore species as well as the reauthorization of the MSA and the development of several new assessment tools for data-poor species. The methods developed (e.g., DCAC, XDB-SRA) to set harvest limits have substantially improved, and continued efforts will be made to determine the status of these stocks.

Regional Management

During the NFMP development process, statewide differences were identified in the biogeography of the species, characteristics of the fisheries, and current management. The FGC adopted a four region approach for the NFMP partly to address these differences. Regions were the North Coast, from the California-Oregon border (42° N) to near Cape Mendocino (40° 10' N); North-Central Coast, from Cape Mendocino to Point Año Nuevo (37° 06' N); South-Central Coast, from Point Año Nuevo to Point Conception (34° 27' N); and the South Coast, from Point Conception to the U.S.-Mexico border (32°32' N) (Figure 1). The FGC recognized that implementing regional management would require several building blocks that were not yet available: regional catch monitoring of and catch estimates from both fishery sectors; regional harvest limits and regulations; a regional commercial permit program for all fishery sectors; regional stock information; regional MPAs; regional CDFW infrastructure; and regional constituent advisors. However, the FGC did adopt regional management for the NFP due to concerns that fishing effort could be concentrated in a few areas resulting in the localized depletion of some species (e.g., cabezon, a species in which the male guards the egg nest) in the absence of finer scale management. Effective regional management also requires coordination with other processes such as federal management (e.g., harvest and trip limits, regional assessments), MPA development and management, and data collection. The regional scales used in these other components and processes vary widely (Figure 1), adding to the challenges of implementing a regional nearshore approach. Although many of the building blocks required for regional management have been implemented since 2002, management has yet to be fully regional as described in the NFMP and envisioned by the FGC.

Catch monitoring and estimation.—Sampling occurs on a port basis for both recreational and commercial sectors. Catch information is available by region using landings data from the commercial fishery on a port basis, and recreational catch estimates are available by district (Figure 1). These districts are delineated by county boundaries and are combined to align closely with NFMP region boundaries so that regional monitoring is possible.

Harvest limits, permitting, and regulations.—Recreational and commercial fishery management is a coordinated effort to regionally maximize opportunity (e.g., harvest limits, sector allocations, allowable depth, time on the water), while minimizing bycatch of overfished species. This effort has resulted in an evolving suite of management areas (e.g., Rockfish Conservation Areas, Groundfish Management Areas [recreational fishing areas with depth-based closures], Cowcod Conservation Areas) and regulations that have varied by region since 2003. The evolution results from attempting to provide sufficient access to more healthy nearshore stocks throughout the state, while recognizing regional variation in the fishery. Harvest limits and allocations can be statewide or regional, which often translates into region-based mechanisms (e.g., permitting, trip limits, seasonal access) to control effort and catch in the nearshore fishery.

Commercial nearshore fishery management is partially regional, based on a four-region permit system for the shallow nearshore species; however, deeper nearshore species are permitted statewide, and state and federal trip limits for NFMP species do not match the regions (Figure 1). Trip limits for the state-managed species (i.e., cabezon, greenlings, California sheephead) are statewide, while trip limits for the shallow and deeper nearshore rockfishes are different north of Cape Mendocino, and sometimes south of Point Conception (Figure 1). This mismatch in trip limit structure and permits can result in regulatory discarding of NFMP species, affect fishery profitability, or both.

Stock status information.—Some species have been assessed on a scale less than statewide, but not at the scale of NFMP regions with two exceptions; California sheephead and California scorpionfish were assessed for their most common ranges in California, which is only the South Coast Region. The spatial scale of assessments can be based on a variety of factors including available information, management considerations, or biogeographic distribution of species. Splitting assessments into different regions requires considerably more region-specific data; otherwise uncertainty surrounding the assessment results will increase and could result in decreased TACs to account for that uncertainty. As a result, the scale of most NFMP stock assessments has not matched NFMP regions.

Development of marine protected areas.—The four regional MPA management areas are defined by boundaries similar to those established for the NFMP (Figure 1). Consequently, as MPA monitoring progresses on a regional basis, it should be possible to build a better view of each nearshore NFMP region relative to overall ecosystem health, and to obtain some information for individual NFMP species that may apply to an entire region (see the *MPA monitoring* section below).

Regional advisory committees.—The NFMP was developed with a statewide advisory committee representing many different constituent interests, with the intent that regional advisory committees would be established as the NFMP was implemented. The protracted planning process for the Marine Life Protection Act (MLPA) also involved regional stakeholder groups, including many of the same individuals involved in the NFMP development, so limited interest has been expressed by key fishery stakeholders for a new advisory process. In addition, CDFW resources required for maintaining effective advisory groups are scarce; hence nearshore regional advisory groups have not yet been formed. Management actions at the state and federal level are, however, developed through established constituent input processes and these actions often include regional components.

Allocation

Allocation of allowable catch between recreational and commercial fisheries is one of the more difficult aspects of fisheries management, as participants in each sector differ in their concept of fairness in allocating resources. The MLMA provides limited guidance on allocation, calling for coordination of recreational and commercial fishery management; maintenance of sufficient resources to support a reasonable recreational fishery while encouraging the growth of commercial fisheries; observation of the long-term interests of people dependent on fishing for food, livelihood, or recreation, and minimizing impacts of fisheries management on small-scale fisheries, coastal communities, and local economies; and the fair allocation of increases or restrictions to overall harvest among recreational and commercial sectors participating in the fishery (Fish and Game Code Section 7050 et seq.).

The master plan for fishery management (Master Plan; CDFG 2001), adopted by the FGC in 2001, recognized the difficulties of allocating fish resources and called for developing a framework to determine allocation in advance of decision making. The Master Plan provides some factors to consider when making allocation decisions, including present versus historical participation, economics of the fishery, local community impacts, product quality and flow to the consumer, gear conflicts, non-consumptive values, fishing efficiency, and recreational versus commercial sectors (CDFG 2001). During NFMP adoption, these factors were incorporated into the California Code of Regulations Title 14, Section 52.05, which describes how to determine allocation for the nearshore fishery. They were also included in the allocation discussion in the NFMP (CDFG 2002).

Developing the allocation ratio.—The FGC adopted an allocation formula for cabezon, greenlings, and California sheephead in 2002 for use in 2003, which was built on the approach used during the development of interim regulations in 2000 and based on a ratio of statewide catch taken by the recreational and commercial fisheries during the periods 1983–1989 and 1993–1999. This time frame was chosen because the earlier period (1983–1989) had higher recreational catch, while the later period (1993–1999) had higher commercial catch, and regulations during these time periods were largely unchanged. The years 1990–1992 were not used because no recreational data were available during that time period. This resulted in an allocation ratio between the recreational and commercial sectors of 61:39 for cabezon, 91:9 for greenlings, and 63:37 for California sheephead.

In 2003, the PFMC set the overall allocation of the minor nearshore rockfish south complex at 80:20 between the recreational and commercial sectors, respectively. Within that group, the allocations (based on historic use during the same time periods) were: shallow nearshore rockfish 63:37, California scorpionfish 75:25, and deeper nearshore rockfish 86:14 (Barnes 2002).

Developing rockfish TACs.—Proposed groundfish regulations for 2003 were expected to increase pressure on the nearshore species, so the PFMC split the unassessed rockfish into nearshore, shelf, and slope complexes, which provided closer monitoring of the nearshore fishery. The nearshore rockfish were then split into two complexes north and south of Cape Mendocino based on PFMC management areas (Barnes 2002). However, at the time, state recreational catch estimates were determined north and south of Point Conception, not Cape Mendocino. California Department of Fish and Wildlife staff developed a method to split recreational catch estimates for Point Conception to the California-Oregon border at Cape Mendocino to generate contributions to the two nearshore complex OYs (northern complex: a separate contribution from the California-Oregon border to Cape Mendocino; southern complex: the contribution from Cape Mendocino to Point Conception plus southern California [Point Conception south to the U.S.-Mexico border]). The 2003 OYs (TACs) for nearshore rockfish complexes and other jointly managed NFMP species were established based on the rationale used by the FGC in 2000 when the interim regulations were established; however, total catches from 1994–1999 were used because better accounting of individual nearshore rockfish in the commercial fishery began in 1994.

Applying allocation ratios to TACs.—The allocation ratios were applied to the TACs to determine recreational and commercial harvest limits; regulatory changes for all fisheries followed to keep catches within the allowable limits. Once regional management is fully phased in, the allocation ratios could be revised based on criteria in California Code of Regulations Title 14, Section 52.05.

The allocation ratios remained unchanged from 2003 to 2012, when the FGC revised the ratio for greenlings. In 2011, a new (Stage I) assessment for kelp greenling resulted in a substantially higher TAC (55 metric tons compared to 17 metric tons previously). Using the established allocation ratio, this would have resulted in 50 metric tons allocated to the recreational fishery and 5 metric tons to the commercial fishery. A review of the recreational fishery revealed that it was highly unlikely to take the 50 metric ton allocation, even when increasing the bag limit from 2 to 10 fish. The commercial fishery would remain a bycatch fishery at the 5-metric ton allocation. Thus, the FGC decided to adopt a recreational allocation of 30 metric tons, which was equal to the 2003 landings, the year of highest landings between 1998 and 2010. Rather than leave fish unallocated, the FGC increased the commercial allocation to 25 metric tons. This action resulted in higher trip limits closer to those for cabezon, which would reduce discarding because they are often caught together. Thus, the current greenling allocation ratio is 55:45 to the recreational and commercial fisheries, respectively.

RESTRICTED ACCESS

During development of the NFMP, the commercial fishery was significantly over capitalized, and limiting participation in the fishery through restricted access was utilized to keep catches within TACs. The nearshore restricted access program was developed at the same time as the NFMP and was adopted just after the NFMP, thereby building on the previously established NFP program.

The NFP was first required in 1999, after enactment of the Nearshore Fisheries Management Act in 1998, for the take of 10 shallow nearshore species (Table 2). Initially, the NFP was a nonrestrictive permit (no annual renewal requirement) established in response to the expanding live-fish fishery. In 2000, the FGC adopted regulations for the NFP, making it a restrictive permit (annual renewal required), and adding a moratorium on new permits along with a control date for a future restricted access program (Table 3). In 2001, the FGC added a landing requirement to renew a NFP and set a control date for future gear endorsements. These actions reduced the number of permits issued from 1,127 in 1999 to 505 in 2002 (Table 3).

In 2003, the FGC adopted a regional restricted access program for the NFP species (Table 3) in accordance with the FGC policy on restricted access commercial fisheries (FGC 1999). The permits were regional, and reflected the regional approach taken by the FGC when the NFMP was adopted. The NFP restricted access program was considered a first step in developing regional management for the nearshore fishery, while the FGC and the CDFW worked toward managing all aspects of the nearshore fishery on a regional basis.

There are four different regions (Figure 1) with separate NFPs and capacity goals. To qualify for a permit transfer between regions, two permits must be purchased in the management region and one must be retired. The number of NFPs purchased in 2003 totaled 220 but has been reduced through transfers or non-renewal, to 157 permits in 2013, for an attrition rate of 29%. Despite the reduction in the number of NFPs, each region remains above its goal of 14, 9, 20, and 18 transferable NFPs for the North Coast, North-Central Coast, South-Central Coast and South Coast regions, respectively (2013 permits total 18, 26, 54, and 57, respectively). Twenty-year commercial fishermen who had been active in the nearshore fishery were grandfathered in and received a nontransferable NFP; the capacity goal for nontransferable NFPs is, nevertheless, zero.

Table 3.—Legislative and regulatory acton timeline of California nearshore fishery permit (e.g., Nearshore Fishery Permit [NFP], Deeper Nearshore Species Fishery Permit [DNSFP], Nearshore Fishery Bycatch Permit [bycatch permit]); NFMP=Nearshore Fishery Management Plan.

Year	Action	Permits
1998	Legislature established NFP – no annual renewal	
1999	NFP first required for 10 species	1,127
2000	Commission adopted:	1,007
	NFP	
	Minimum size limits	
	Annual NFP renewal required	
	Moratorium on new NFPs	
	One person on boat needs NFP	
2001	Commission adopted:	746
	A NFP control date (31 Dec 1999)	
	Renewal requirement of 45.4 kg NFP species landed between 1994 and 2000	
	Extended NFP moratorium to 2003	
	Adopted a control date for NFP gear endorsements (20 Oct 2000)	
2002	Additional 9 species added to NFMP	505
2003	Commission adopted:	
	NFP restricted access program with regional permits	220
	DNSFP	294
	Bycatch permit	26
2013	NFP restricted access program with regional permits	157
	DNSFP	191
	Bycatch permit	13

A Nearshore Fishery Bycatch Permit (bycatch permit) was adopted at the same time as the nearshore restricted access program (Table 3) for the incidental take of the nine shallow nearshore species with trawl or gill net gear only. The purpose of this permit was to allow fishermen who had been using these gears to continue to take nearshore species (to minimize wastage) while phasing out the use of these gears. There was concern that trawl and gill net methods, if allowed in the nearshore fishery, could utilize large portions of the TACs, adversely impact habitat (trawl), increase bycatch of other species, and market fresh rather than live fish. Two objectives in the NFMP are to limit the bycatch of nearshore species and all species taken by nearshore fisheries, and to maintain the health of marine nearshore fishery habitat. Additionally, since the TACs for these species were low in 2003, one of the objectives of the nearshore restricted access program was to preserve the live fish component of the fishery, which offered a much higher ex-vessel price per kilogram. To ensure that bycatch permit holders did not target nearshore species, the FGC adopted daily trip limits in addition to the state and federal bimonthly trip limits already established.

In 2003, 97 individuals qualified for a bycatch permit but only 26 permits were issued. By 2013, the number of bycatch permits was reduced to 13 permits. In 2013, only 5 bycatch permit holders were active (i.e., making at least one landing of shallow nearshore species). Bycatch permit holders account for less than 1% of the total shallow nearshore species landings each year.

Nine deeper nearshore species (Table 2) were added to the NFMP during development because of the anticipated shift in effort to these unpermitted nearshore species as a result of the upcoming restricted access program. The FGC adopted a Deeper Nearshore Fishery Permit (DNSFP) for the take of eight rockfish species in 2002 (Table 3). The DNSFP is a restrictive permit with no gear restrictions, and is not considered part of a true restricted access program because there is no capacity goal and no transferability. In 2003, 294 DNSFPs were issued; through attrition the number has been reduced 35% to 191 permits in 2013.

The DNSFP is statewide, not regional like the NFP. There were modest qualifying criteria of 200 pounds landed between 1994 and 1999 to receive a permit. A control date of 31 December 1999 was set for participation and a control date of 20 October 2000 for possible gear endorsements in case a formal restricted access program was developed at a later date.

Fishery analysis.—The live-fish fishery targeting nearshore species began in the late 1980s (McKee 1993), and expanded throughout the 1990s, both spatially and volumetrically. In 1993, the live-fish fishery focused on shallow nearshore species in the southern and central parts of the state, as evidenced by the ex-vessel price differential for shallow and deeper nearshore species, \$0.92 and \$0.36/kg, respectively. Coastwide, nearshore landings (shallow and deeper combined) totaled 445 metric tons consisting of both live and fresh (dead) fish, mostly shallow nearshore species (303 metric tons; Figure 4), with an ex-vessel value of \$1.7 million.

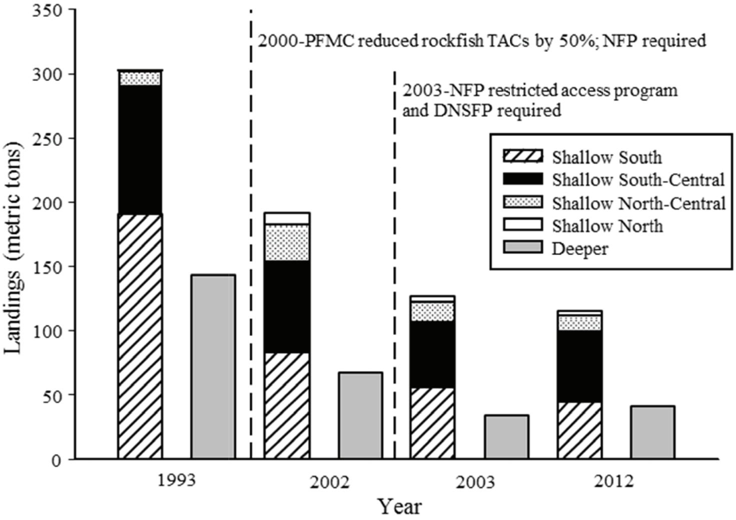

FIGURE 4.—Comparison of nearshore commercial landings before and after implementation of the Nearshore Fishery Management Plan. Total nearshore landings is the combination of the stacked bar and the grey bar for each year. Data are from California Department of Fish and Wildlife commercial landing receipts. PFMC = Pacific Fisheries Management Council, TAC = total allowable catch, NFP = Nearshore Fishery Permit, DNSFP = Deeper Nearshore Species Fishery Permit.

Ten years later, in 2002 and after the federal 50% reduction in TACs, the live-fish fishery, which now included deeper nearshore species, was fully established in the South and South-Central Coast regions and was expanding into the North-Central and North Coast regions. In 2002, landings were almost half what they were in 1993, with a coastwide total of 258 metric tons of shallow and deeper nearshore species landed (Figure 4) and an ex-vessel value of $2.4 million. Shallow nearshore landings continued to dominate the nearshore fishery, accounting for 74% of the landings and 80% of the value.

Implementation of the nearshore restricted access program and the DNSFP in 2003 reduced landings by another 38%, with the North Coast and North-Central Coast regions having the largest reduction in catch (50%). The northern regions were not as well developed at the time of the restricted access program and, despite different qualifying criteria tailored to the region, fewer fishermen qualified for a permit. Coastwide shallow and deeper landings totaled 160 metric tons (Figure 4), with an ex-vessel value of $1.6 million. Ten years later, in 2012, coastwide nearshore landings (shallow and deeper combined) were slightly reduced (9%) to 155 metric tons compared to 2003 (Figure 4); however, the ex-vessel value increased to $2.1 million. Average price per kilogram was similar between the regions, with the highest price paid in the South-Central and North-Central Coast regions. This is perhaps due to proximity to the San Francisco area, where the demand for live fish is at its peak.

Permit analysis.—In the nearshore fishery, there are three de facto permit holder classes excluding bycatch permit holders: NFP only, NFP and DNSFP, and DNSFP only. Of the three permit holder classes, the class with both a NFP and a DNSFP is the most active (i.e., landing ≥250 kg in a year) with 72% participating each year. Those with only a NFP are also quite active with 54% participating in a given year. Those with only a DNSFP are least active, with only 19% participating in a given year.

Regional analysis.—This regional analysis is based on landings from 2003 to 2013, encompassing all the years of the nearshore restricted access program and DNSFP. The North Coast Region accounts for 32% of all nearshore landings (Figure 5), focusing

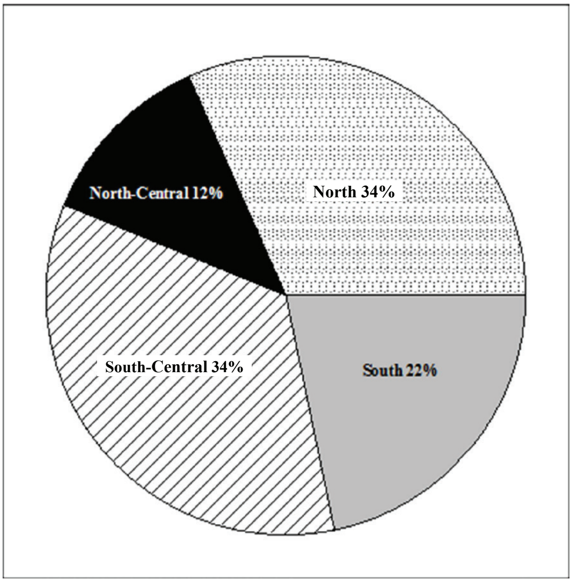

Figure 5.—Commercial nearshore fisheries landings (shallow and deeper combined) by region, 2003–2013. Data are from California Department of Fish and Wildlife commercial landing receipts.

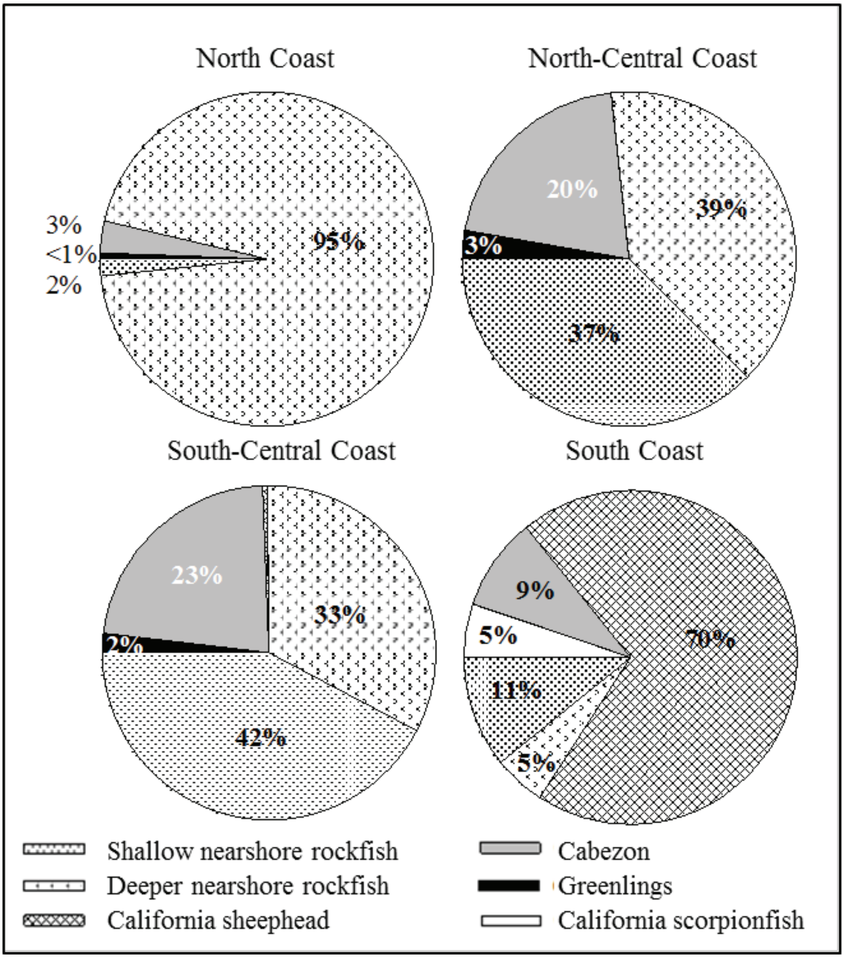

Figure 6.—Nearshore fish species regional commercial landings composition, 2003–2013. Data are from California Department of Fish and Wildlife commercial landing receipts.

on deeper nearshore rockfishes (95% of North Coast Region landings), with small landings of cabezon, shallow nearshore rockfish, and greenlings (Figure 6). This emphasis on deeper nearshore rockfish is due to their much higher trip limits available north of Cape Mendocino. The North-Central Coast Region accounts for 12% of nearshore landings (Figure 5), focusing on deeper and shallow nearshore rockfishes (39 and 37%, respectively), with cabezon and greenling making up the remainder (Figure 6). The South-Central Coast Region accounts for 34% of nearshore landings (Figure 5), focusing on shallow and deeper nearshore rockfishes (42 and 33%, respectively), with cabezon and greenlings making up the remainder (Figure 6). The South Coast Region accounts for 22% of nearshore landings (Figure 5). In this region, the focus shifts dramatically with California sheephead comprising the majority of landings (70%); a mix of shallow nearshore rockfish, cabezon, California scorpionfish, and deeper nearshore rockfish are also present in the landings (Figure 6). The shift to California sheephead is due to its availability in the region as well as its popularity in the live-fish market, where it is called the "fish of good health".

MARINE PROTECTED AREAS

The NFMP considered MPAs as another management tool and proposed design guidelines for their use. These guidelines included protecting 10 to 20% of key habitats for NFMP species from fishing depending on the level and success of management outside the MPAs. Two key objectives for MPAs proposed by the NFMP were to preserve nearshore habitat and ecosystems, and to use MPAs as "reference reserves" that could be compared over time to similar fished areas as a means to evaluate stock health. The NFMP recommendations relative to the use and role of MPAs included the objectives of (1) insuring that MPAs met the goal of conservation of nearshore communities; (2) spacing MPAs as a network so that their connectivity would maximize successful larval transport or movement of the fish they were protecting; (3) sizing individual MPAs large enough to protect adequate spawning biomass for species that were largely resident and had home ranges on the order of a few km^2; and (4) ensuring MPAs encompassed a variety of habitats, which were replicated along the coast (CDFG 2002). At the time, localized benefits of MPAs were well documented (Dugan and Davis 1993, Roberts 1998, Ocean Studies Board 2001, Palumbi 2001), although the full regional effects and true benefits of a network functioning as envisioned in the NFMP were unknown (Palumbi 2001). The NFMP highlighted the need for adequate research and long-term monitoring to determine any real benefits to NFMP species and the fisheries they support. Although the NFMP proposed specific criteria to benefit NFMP nearshore species, the NFMP deferred establishment of MPAs to the concurrent efforts to implement the new MLPA. As a result, it was uncertain how MPA design and monitoring plans would be incorporated into nearshore fishery management.

The MLPA implementation process was initiated in 1999 following enactment of the new statute, so its initial progress was coincident with the development of the NFMP. Ultimately, it took 14 years and three attempts to revise existing or establish new MPAs in four coastal regions (Figure 1). By 2012, the planning process was completed along the coast when the FGC adopted 27 MPAs in the northern region of the state. California now has the largest scientifically designed network of MPAs in the continental U.S. and the second largest in the world, including 124 separate areas with varying levels of protection encompassing almost 2,207 km^2 of the state's coastal waters. The network includes 58 no-take MPAs (State Marine Reserves [SMRs]) encompassing 1,705 km^2 of coastal waters and habitats.

All SMRs and many State Marine Conservation Areas (SMCAs) protect the NFMP species from take and incorporate a variety of habitats vital to NFMP species including the rocky intertidal, kelp forests, and shallow (0–30 m) and deep rocky reefs (30–100 m). The statewide network includes almost 100 linear km of rocky intertidal or cliff habitats and 44 km^2 of subtidal kelp and rocky reef habitats shallower than 100 m closed to most fishing for nearshore species. Together these areas represent 20% of those habitats along the coastline and in state waters (Figure 7), based on existing knowledge of species habitat use and mapped habitat (M. Parker, CDFW, unpublished data). This is likely a conservative estimate of their overall protection, given that these species also make use of other protected habitats (e.g., some soft bottom habitats and submarine canyon habitats out to 100 m), not all state waters have been mapped, and areas within Rockfish Conservation Areas—but not in MPAs—also provide some nearshore species protection.

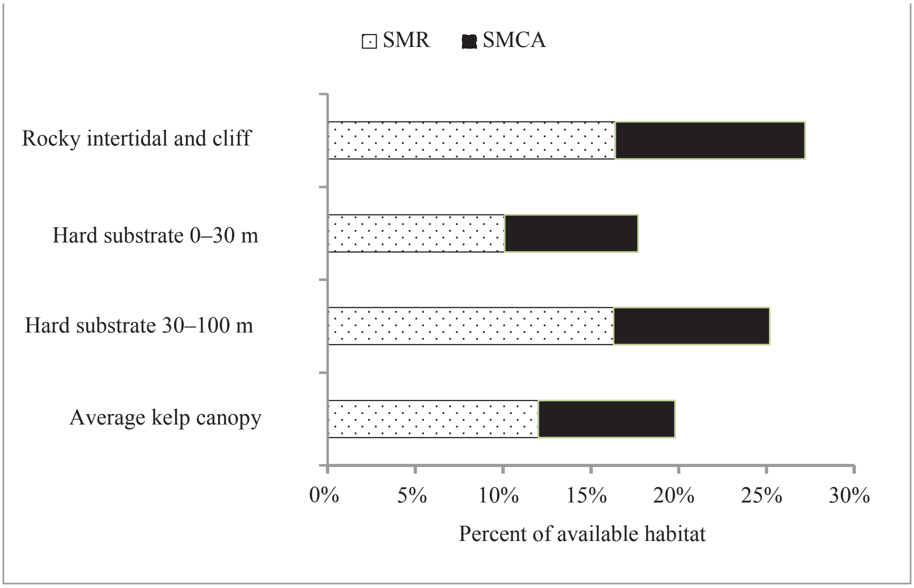

Figure 7.—Percentage of estimated appropriate habitat for Nearshore Fisheries Management Plan (NFMP) species in state waters that are in State Marine Reserves (SMRs) or State Marine Conservation Areas (SCMAs), and in which fishing for NFMP species is prohibited. Data sources: California State University Monterey Bay, Fugro Pelagos Inc., United States Geological Survey, National Oceanographic and Atmospheric Administration, Ocean Imaging, and California Department of Fish and Wildlife. Average kelp canopy was based on the years of available data: 1989, 1999, 2002–2006, and 2008.

MPA monitoring.—The NFMP envisioned MPA monitoring that would include ongoing, cost-effective research to assess the characteristics of NFMP species (e.g., fish size, density, abundance, proportion of adults and juveniles) inside and outside MPAs as a fishery management tool (CDFG 2002, Babcock and MacCall 2011). In fact, comparing NFMP species densities between fished and unfished areas over time was considered a possible alternative to data-intensive full stock assessments (CDFG 2002). However, this approach is dependent on establishing a robust, long term monitoring program focused on tracking trends through time. To be valuable for fisheries management of particular NFMP species, a robust program requires sufficient geographic coverage, sampling and replication to distinguish between trends (e.g., changes in abundance, size) and natural variation. To date, CDFW has not dedicated resources toward an MPA monitoring program with this emphasis. However, in 2011 CDFW hosted a workshop to begin investigating how MPAs could be used in fisheries management and which fisheries might benefit (Wertz et al. 2011). A follow up workshop was held in May 2014.

As MPAs were established in each region, the MPA Monitoring Enterprise (a program of the California Ocean Science Trust), in partnership with CDFW, has completed a collaborative effort including input from agencies, scientists, and the public, to develop an overall MPA baseline and ongoing monitoring framework. The framework includes indicators to track trends in ecosystem condition, evaluate the effectiveness of MPA design, and inform adaptive management (Gleason et al. 2013). To date, regional MPA monitoring plans that apply this framework have been developed for three MLPA regions (MPA Monitoring Enterprise 2010, MPA Monitoring Enterprise 2011). The CDFW also collaborates with the MPA Monitoring Enterprise, California Ocean Protection Council, and California Sea Grant to develop regional MPA baseline monitoring programs that are designed to establish an ecological and socioeconomic benchmark against which future MPA performance can be measured. Baseline MPA monitoring programs have been initiated or completed for all four coastal MLPA regions, and the results from baseline programs are expected to inform the development of cost-effective continuing MPA monitoring programs (Frimodig 2014). Monitoring results may eventually be used for evaluating MPA connectivity, demonstrating network functionality, monitoring impacts from climate change, and assessing ecosystem protection. As such, the overall monitoring will take a broader view of the ecosystem as a whole, rather than a more focused look at particular fisheries as described above. Components of the monitoring plans specifically focused on fisheries management are found in MPA Monitoring Enterprise (2010) and MPA Monitoring Enterprise (2011). Some of the indicator species identified in the plans for monitoring have commercial or recreational importance and are NFMP species.

So far, baseline monitoring has been initiated in three of the four MLPA regions (Frimodig 2014). Results of monitoring California's MPAs have shown some limited benefits to NFMP species within MPAs (COST and CDFW 2013), although much of the current focus has been on establishing a baseline or starting point. Some of the baseline monitoring focused on inside-outside comparisons and trends in fished species (Wendt and Starr 2009) could be useful for assessments in future years when a longer time series becomes available.

OTHER ASPECTS OF NEARSHORE FISHERY MANAGEMENT

Research needs.—The NFMP management framework is based on science and research and, at the time of development, laid out a strategy for the CDFW to improve existing information for more effective and sustainable management. Some of the identified needs included the collection of more EFI, the improvement of information for stock assessments and of existing catch monitoring and estimation methodologies, and the development of a better understanding of the nearshore ecosystem and the importance of the NFMP species within that ecosystem. These were to be accomplished by building on the specific approaches in the NFMP (e.g., sustainable FCRs, effective regional management, MPAs that benefit nearshore ecosystems, and a successful restricted access program; CDFG 2002).

As stated in the NFMP, "The CDFW's research plan rests on two bases: improvement of existing fishery-dependent and fishery-independent monitoring and assessment, and a systematic program of research and monitoring in a discrete set of reference sites" (CDFG 2002). However, available staff and fiscal resources necessary to accomplish this strategy are constrained, so CDFW support of outside efforts through collaborative partnerships has been maximized. Efforts since 2002 have addressed some of the major data gaps and have improved our understanding of the status of the majority of the NFMP species in California waters (Table 2). In addition, the technology and methods available to collect, analyze, store, utilize, share, and convey new and existing information have greatly improved.

Improvement of fishery-dependent and fishery-independent monitoring.—A new recreational sampling program, California Recreational Fisheries Survey (CRFS), was implemented by CDFW in 2004 in partnership with the Pacific States Marine Fisheries Commission, with the intent to improve upon the existing federal recreational fisheries survey program. The new CRFS program divides the state into six districts from the previous two (north and south of Point Conception), which increases the sampling effort for boat-based fishing, where most nearshore species are caught; increases the previous efforts for collecting location specific catch information; and greatly improves the estimation procedures. All of these changes have benefited management of the NFMP species, and have resulted in the collection of recreational data at the resolution required for regional management and monitoring. There have been few changes in the gathering and monitoring of commercial fisheries data in the past 12 years. Biological sampling of the commercial live-fish fishery continues to be challenging due to limited resources and the handling stress caused to the high value live-fish, which impacts sampling efforts. Although a voluntary commercial logbook program was tested, it has not been implemented (Thomson et al. 2007).

Improvements to fishery-independent monitoring for the NFMP species have been modest since 2002, with the exception of those related to MPA monitoring, or already ongoing efforts by outside entities (e.g., Cooperative Research and Assessment of Nearshore Ecosystems [CRANE], Partnership for Interdisciplinary Studies of Coastal Oceans [PISCO]). The focus of the MLPA initiative on nearshore species helped increase available EFI on NFMP species by focusing some research toward information critically important for MPA siting or monitoring. These efforts included tagging and comparing movement patterns of three species (blue rockfish, kelp rockfish, and kelp greenling; Freiwald 2009) and fisheries research conducted from 2007 to 2009 at the Santa Barbara Channel islands as collaborative MPA monitoring (Kay et al. 2007). Focal species in Kay et al. (2007) included cabezon, grass rockfish, and California sheephead, and one study objective was to collect life history data and EFI for use in traditional and alternative (i.e., MPA-based) stock assessment models, which should benefit management and assessment work (Wilson et al. 2010).

As MPAs are implemented, some of the consequent MPA monitoring already occurring focuses on the nearshore ecosystem that includes the NFMP species, and may improve EFI for those species. Monitoring efforts related to MPAs and reference reserves are detailed below.

Improvements to resource assessment.—Over the past 12 years, CDFW has led and contributed effort in many forms to improve stock status information for the NFMP species. CDFW staff collaborated on a NMFS project to complete a historic catch reconstruction for California's recreational and commercial fisheries (Ralston et al. 2010). Although this project is ongoing, the improved catch data have been used in recent stock assessments for brown rockfish, China rockfish, and copper rockfish. The most recent stock assessments for California sheephead, California scorpionfish, gopher rockfish, blue rockfish, and cabezon were supported by CDFW (Alonzo et al. 2004, Maunder et al. 2006, Key et al. 2006, Key et al. 2008, Cope and Key 2010). The CDFW also contributes to efforts to improve methods for data limited species (Field et al. 2010). In late 2008, CDFW sponsored a fisheries management workshop in conjunction with University of California Sea Grant Extension Program to encourage international fishery managers and scientists to seek better ways to manage California's nearshore stocks in data-limited conditions (Starr et al. 2010). One outcome of the workshop was an effort to determine the potential of more formal management procedures to be used as decision-making tools for California fisheries, including the nearshore. This study included a meta-evaluation of the NFMP species to find reasonable management procedures, using available metrics that could be used in lieu of species-specific management (Bentley and Stokes 2011). More recently, a stock assessment review panel evaluated data-moderate assessments of brown rockfish, China rockfish, and copper rockfish (Cope et al. 2013) and those results will be used in management.

To improve EFI for stock assessments, age and growth information have been completed for cabezon (Grebel and Cailliet 2010) and olive rockfish (J. Grebel, CDFW, personal communication, 17 July 2014), and are in progress for copper rockfish (C. McKnight, CDFW, personal communication, 26 March 2014). Schmidt (2014) recently described changes in life history parameters (e.g., age at maturity, fecundity) of female blue rockfish after long term, high fishing pressure on the species. Some efforts to collect EFI have also been useful for MPA monitoring and siting.

Central to improving our understanding of stock status, nearshore ecosystems, and the role of reference reserves is better knowledge of nearshore habitats. The California Ocean Protection Council made surveying and mapping seafloor bottom habitats along the coast a priority in 2006 (COPC 2007), primarily to benefit the MPA siting process. The plan was to complete the mapping of all seafloor habitats within California state waters (shoreline out to 5.6 km). In 2007, they authorized spending up to $15 million for this effort. This effort is ongoing as methods for surveying very nearshore waters improve and should return dividends for many years.

Research and monitoring in reference reserves.—Although CDFW did not have any ongoing long-term monitoring in place prior to the development of the NFMP, there were several programs in place led by other institutions. The CRANE program began as the NFMP was being implemented and was an attempt by CDFW and nine partners (including universities and other government agencies) to build on existing monitoring programs to provide a more comprehensive monitoring effort for the nearshore (Tenera 2006). The goal was a collaborative monitoring program on a scale that could be used for assessment and management of rocky reef ecosystems. The collaborative effort determined which metrics would be most important for assessment and management and, more importantly, developed consistent sampling designs and methodologies to be used with the reference reserve concept. In 2004, CRANE completed a cooperative sampling effort to provide information for managing California's nearshore rocky reef fish and invertebrate populations using the established protocols. The CRANE objectives were to estimate fish densities; measure population size structure for key species; and measure habitat and ecosystem components that can be associated with changes in density and size distributions over space and time (Tenera 2006). Funding for the collaborative sampling effort was provided by the federal Coastal Impact Assistance Program. From 2005 to 2007, a similar, smaller scale study occurred. A subset of the original collaborators studied density measurements and size frequency of nearshore fish at select locations, primarily in conjunction with established MPAs at the Santa Barbara Channel Islands and in areas of the central coast where MPAs were being considered. To date, there have been no additional CRANE surveys that would become incorporated into a routine, long-term monitoring effort.

Many research surveys of varying temporal and spatial scales have been conducted since 2002 and focused on MPA monitoring; benefits to fisheries management vary considerably depending on their scope. One such program is PISCO, which is a long-term monitoring and research program designed to understand the California Current ecosystem. A major focus of PISCO science is the design and monitoring of MPAs using their experience with long-term monitoring programs and baseline monitoring efforts. Another collaborative study, which has been ongoing for several years, involves recreational hook and line monitoring inside and outside MPAs. This study has provided useful information for MPA monitoring along the central California coast (Wendt and Starr 2009). The intent is that the study results could be used to develop abundance indices of nearshore species with enough years of data. Because NFMP species make wide use of habitats in the nearshore ecosystem and vary in their availability for visual or fishery survey methods, some investigators have evaluated and compared the success of various methodologies to survey individual species (Starr et al. 2006, Karpov et al. 2010). These results will contribute to study design for future monitoring and increase confidence for interpreting observed trends.

Recreational fishery.—Early in the development of the NFMP there were discussions regarding limiting recreational access to nearshore fishes via a stamp requirement, although this did not proceed as shorter seasons and lower bag limits designed to protect overfished shelf rockfish species were implemented. The recreational fishery had few limitations prior to 2000. The season was open year-round, the daily bag limit was 15 rockfish (all species combined), and there were no depth restrictions. State and federal actions in 2000 that reduced rockfish TACs by 50%, along with drastic reductions in the harvest guidelines for overfished shelf species resulted in numerous changes to the recreational rockfish fishery in the subsequent years. It was a challenging time for anglers, the fishing industry, coastal communities, and fishery managers. To reduce the take of overfished shelf species, spatial, temporal, and depth-based restrictions that closed the shelf forced fishermen into shallower waters. In 2000, the recreational daily bag limit was reduced to a combination of 10 rockfish, cabezon, and greenlings, and in some years there were sub-limits for some species (e.g., shallow nearshore rockfish, cabezon, and greenlings). The number of hooks was reduced from 15 to 3 in 2000, then to 2 in 2001. The coast was split into various management areas, up to seven different areas in some years, with different seasons and depth restrictions (37–91 m) in an effort to maximize fishing opportunities while limiting the bycatch of overfished species. In the early 2000s, there were times when one or more recreational management areas were closed for six months or longer. Then in several years, emergency in-season actions were taken to close the fishery or otherwise reduce or curtail effort to prevent exceeding harvest limits. Over time, as CDFW and PFMC have become better able to estimate catch and predict fishing activity, and additional nearshore species are assessed and TACs increased, the early closures of the recreational rockfish fishery ended, and the seasons and depth restrictions currently change less frequently.

Transfer of authority.—As mentioned above, most of the nearshore species are co-managed by the state and federal governments, with 16 of the 19 NFMP species also listed in the federal GFMP (Table 2). Fourteen of the 16 species are actively managed by the PFMC; cabezon and kelp greenlings are managed by the PFMC but are more actively managed by the state, which sets trip limits by regulation and can modify trip limits or close sectors if necessary. Three nearshore species are managed exclusively by the state: California sheephead, monkeyface prickleback, and rock greenling. Some of the nearshore species (e.g., black rockfish, cabezon) are also included in fishery management plans of other states, further complicating management of these species at the federal level.

To decrease the complexity of managing these nearshore species and to fully implement the NFMP, that plan proposed that the state request a transfer of authority for some or all 16 nearshore species listed in the GFMP. This action requires an amendment to the GFMP to remove the requested species from the GFMP, and requires that CDFW assumes responsibility for all aspects of management, including management measures, research, stock assessments, monitoring fishing activity, biological sampling, and enforcement.

Transferring authority for these species, which occur in and are fished primarily in state waters, is desired by the FGC and the CDFW; however, lack of stable funding required to fully manage the nearshore species has kept CDFW from requesting a transfer of authority. Instead, CDFW works closely with the PFMC and NMFS to develop management measures so that the nearshore species are managed to the more conservative standards of the NFMP. One example of this coordination is in setting OYs or TACs. In 2005, the PFMC used the state's more restrictive FCR (60-20) to set the cabezon TAC in California waters after a 2004 stock assessment revealed a cabezon biomass at 35% B_{Unfished} off California. The FGC then set the same TAC and recreational and commercial allocations according to the established allocation ratio, and then management measures were appropriately revised.

Because it has been possible to incorporate the more conservative NFMP requirements into the federal management process, it is now questionable whether the benefits of transferring authority to the state (e.g., situations for when the state wants to be less restrictive) would outweigh the costs (i.e., need for additional resources). Even though California does not have sole management authority for the nearshore species, CDFW actively manages the nearshore fishery in many ways (Appendix I).

Enforcement.—Prior to 2002 and during the expansion of the live-fish fishery, enforcement and monitoring of fishing and landings were very challenging. The commercial nearshore fleet was expanding in an unregulated fashion, making it difficult to identify participants from recreational anglers and track activity; vessels were fishing all along the coast and landing fish at all hours of the day or night (sometimes at roadside pullouts), and on-the-water enforcement was limited. There were many small-scale buyers that were hard to identify and track. The amount and locations of stick gear, a type of connected hook-and-line gear of up to 1,000 hooks with multiple vertical lines and flotation at either end to keep gear just off the bottom, in the water was also problematic. Beginning in the early 1990s, gear was everywhere in the nearshore, including within harbor mouths and along their jetties (where high-value cabezon and grass rockfish lived) and interfering with navigation and safety to the point that harbor districts responded in a coordinated fashion with regulations to prevent that activity (S. Cabral, personal communication, 5 August 2014).

Many of these challenges have been addressed over the past 12 years. Rampant fleet expansion and unregulated participation has been replaced with a much reduced number of identifiable permittees. The number of dealers is also much reduced and more organized, making tracking more straightforward. Additionally, new regulations resulted in more accountability of where fish are coming from. The implementation of MPAs and a state commitment to their protection has increased a watchful presence of the nearshore, and enforcement response to potential violations has a high priority. For example, from 2007 to 2012, 9.5% of marine-related violations along the central coast were MPA-related (COST and CDFW 2013). On-the-water presence has also increased with the acquisition of newer, larger, modernized patrol vessels and new agreements or increased coordination with other state and federal enforcement partners. Nearshore commercial fishermen who also fish for groundfish (open access) in federal waters have been required to carry vessel monitoring systems on their vessels since 2008. Limitations on stick gear to reduce the total number of hooks used to take nearshore fish to 150 (and only 15 hooks per line) also were implemented.

Accounting for bycatch.—Information on the amount and type of bycatch is required in state (Fish and Game Code Section 7085) and federal law (MSA 2006). Improvements have been made in collecting information to account for total mortality in both the commercial and recreational nearshore fisheries. Historically, the nearshore commercial fishery has been difficult to observe and does not have the level of coverage as those groundfish fisheries further from shore. The West Coast Groundfish Observer Program (NMFS) produces annual mortality reports (http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/species_management.cfm) that are used by management to evaluate harvest guidelines. The CRFS collects information on fish kept and released, and produces estimates of total marine recreational finfish catch and effort in California, including discards.

With a federal mandate for "total catch accounting", the PFMC developed discard mortality rates to be applied to nearshore groundfish released in the recreational and commercial fisheries. This information is used as part of the catch history in stock assessments and for catch tracking. Since 2012, the PFMC has discussed methods that can be employed to increase survival of rockfish released in the recreational fishery that enable fish to be successfully released at deeper depths; a decrease in discard mortality has been demonstrated when descending devices are used to release fish (Jarvis and Lowe 2008). The PFMC has adopted depth-dependent mortality rates, based on using descending devices (PFMC 2014), to be applied to some overfished species, among which are cowcod, canary rockfish, and yelloweye rockfish. Further research is needed, however, to fully understand the benefits of these descending devices.

In the Future

The CDFW has made substantial progress implementing the NFMP, given the limitations in data and resources. Prior to 2002, none of the nearshore species had been assessed, and in 2013, 10 species (>50%) have been assessed. Regional management has been established, in part, with the NFP restricted access program and regional recreational monitoring and catch estimation. While not all aspects of the nearshore fishery are regional or the same regions as the NFP, there is an effort to conduct stock assessments and set trip limits on a regional basis, when there are sufficient data to support it. As TACs change, the allocation of nearshore fish stocks is reassessed, following the original guidelines or changing the allocation ratios when necessary, to maximize opportunities while preserving historical sector preferences. The NFP restricted access program is getting closer to its regional capacity goals, although these goals may need to be revisited in light of increases to the TACs as shallow nearshore species are assessed. The establishment of a network of MPAs lays the groundwork for future use of these areas as a way to monitor the health of the nearshore ecosystem; however, monitoring is just beginning in some regions, so it will be a long process. The continued collection of EFI for nearshore species, especially for unassessed or vulnerable species with high PSA scores (Table 2), is essential to sustainably manage the nearshore fishery. For those species that have been assessed, better EFI is also important for species to progress from Stage II to Stage III assessments (Table 2) to meet the mandate of ecosystem-based management. Additional EFI could also make it possible to begin allocating fish on a regional basis. Once CDFW increases its stock assessment capabilities and has sufficient funding to assume responsibility for the other aspects of managing the nearshore fishery, it may be time to re-consider transferring authority for the nearshore species in the GFMP to the state, although co-management is working smoothly at this time.

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APPENDIX I: METHODS USED BY THE CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE TO ACTIVELY MANAGE THE NEARSHORE FISHERY

Performing the analyses and providing recommendations on setting state and federal harvest limits (e.g., harvest guidelines, total allowable catches [TACs], optimal yield [OYs], and annual catch limits [ACLs]) and management measures

Allocating between recreational and commercial fisheries

Conducting in-season monitoring of nearshore rockfish, cabezon, California scorpionfish, California sheephead, and greenlings along with overfished shelf rockfish species

Modifying or closing recreational seasons, or adjusting depth restrictions or bag limits to keep within allowed catch

Closing commercial fisheries or adjusting trip limits as needed to keep within allowed catch

Conducting or participating in stock assessments for nearshore species

Conducting or collaborating on research on nearshore species to better understand aspects of their life history

Addressing minimization of bycatch and reducing discard mortality

Enforcing Nearshore Fishery Management Plan implementation through increased monitoring and protection

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The rise of invertebrate fisheries and the fishing down of marine food webs in California

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Invertebrate fisheries are growing in importance worldwide and are now California's most important fisheries by both volume and value. There has been a 174% increase in the value of marine invertebrate fisheries in California since 1980. Although there is a long tradition of fishing for invertebrates in California, recently there has been a rise in their importance and they now (2008–2012) comprise four of the top five fisheries by value. In the 1980s, finfish fisheries dominated both the value and the volume of landings. Finfish and invertebrates were comparable in the 1990s in terms of both value and landings. Since 2000, there has been a shift toward invertebrate fisheries due to decreases in finfish fisheries, increases in invertebrate fisheries, and increases in novel or emerging invertebrate fisheries. The trends observed in California fisheries are consistent with the hypothesis that marine food webs have been fished down. In the 1980s (1980–1989), 90% of the top fisheries by value were for predators, while in the recent past almost half of the top fisheries species were from lower trophic levels such as herbivores and scavengers. This trend in the expansion of California invertebrate fisheries follows global fishery trends. In the eastern Pacific Ocean, there has been a 400% increase in the landings of invertebrate fisheries from 1950 to 2011. Despite this growth, fishery assessment and management of invertebrate fisheries are lagging behind. As we work to sustainably manage California invertebrate fisheries it is imperative that we continue to advance our knowledge of their biology, life history, and drivers of population fluctuations in a variable ocean environment.

Key words: California fisheries, catch, emerging fisheries, fishing down, fishery management, invertebrates

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Invertebrates now dominate California fisheries in terms of both landings and value. Traditionally, the image of California fisheries has been characterized by finfish, including salmon (*Oncorhynchus* spp.), rockfish (*Sebastes* spp.), tuna (*Thunnus* spp.), sardines (*Sardinops sagax*), and sablefish (*Anoplopoma fimbria*). Yet today, four of the top five grossing fisheries are invertebrates with sablefish as the only finfish in the top five. Invertebrates have been on the rise in terms of landings by weight and value since the 1980s. Recognition of the importance of invertebrate fisheries, also known as shellfish fisheries (crustaceans, mollusks, and echinoderms), has developed slowly (but, see Rogers-Bennett 2002, Mason 2004). California squid and crab fisheries were worth a total of $152 million ex-vessel in 2012 compared with the total for groundfish and salmon of $32 million. With these changes in the landscape of California fisheries the question arises as to whether management funding and priorities will adapt once invertebrate fisheries are recognized as the most important fisheries in the state.

This rising trend of invertebrate fisheries in California has also been observed around the world. Food and Agriculture Organization statistics (FAO) show that from 1984 to 1995 there was a 46% increase in the catch of invertebrates (Perry et al. 1999). In the Pacific Northwest, the change was greater with Canadian invertebrate fisheries increasing 130% over the same period (Perry et al. 1999). Globally, this trend is part of a bigger picture of fishing out long-lived species (Jennings et al. 1998) and fishing down predators in marine food webs (Pauly et al. 1998). There may also be shifts in marine communities that favor invertebrates, such as the presence of large scale jellyfish blooms, taking place as a result of fewer predatory finfish (Mills 2001). The growing importance of invertebrate fisheries necessitates increased research including quantifying spatial and temporal patterns in landings, determining life history parameters, examining key drivers of productivity, and developing strategies for sustainable invertebrate management.

Invertebrate populations are, however, notoriously difficult to manage. Invertebrates tend to have poor stock per recruit relationships and poor yield per recruit relationships (Caddy 1989). On top of this, we know that even for well-studied finfish, fishery management has not always been successful (Walters and MacGuire 1996, Pauly et al. 2002). Despite their productivity, invertebrate populations are not immune to overfishing and fishery collapse. The white abalone (*Haliotis sorenseni*), once part of the commercial abalone fishery in California, is now found at exceedingly low densities (<1% of the estimated baseline) and is on the verge of extinction (Hobday et al. 2001, Rogers-Bennett et al. 2002). In 2001, white abalone was added to the federal endangered species list (US Federal Register 2001), and at least one other marine snail has gone extinct in the last century (Carlton et al. 1991). Exploited marine invertebrates are particularly vulnerable to local extirpations based on local population genetics (Thorpe et al. 2000), fine scale distribution (Orensanz and Jamieson 1998), and high market value (Purcell et al. 2014).

Fisheries management principles have been based on concepts derived largely from finfish (Caddy 1989), such as the work of Beverton and Holt (1957) using North Sea groundfish that are long-lived and relatively easy to age. Similarly, the concept of stock recruitment relationships came from smolt production in salmon (Ricker 1976). Surplus production models were first developed for use with Pacific tuna biomass due to problems associated with aging tunas (Gulland 1983). Yet, managing invertebrates may not simply be a matter of applying strategies developed for finfish (Perry et al. 1999) but rather developing whole new approaches to sustainably manage invertebrate fisheries (Winemiller 2005). One way forward for benthic invertebrate management was suggested by Thorson (1957), who argued the importance of examining and maintaining sustainable densities.

In this paper, we examine trends in the landings and values of California marine fisheries from 1980 to 2012, dividing fisheries into invertebrates and finfish. We look for patterns in the relative dominance of invertebrate fisheries over space and time. We examine patterns in the fisheries across regions in California from the north, central, and southern coasts as well as nearshore, benthic, and pelagic habitats. We examine the fishery landings data to see if they are consistent with the hypothesis that there are fewer predators in the top ten fisheries today. Finally, trends in invertebrate landings are also examined across the wider spatial scale of the eastern Pacific Ocean.

Methods

We examined landings data of marine commercial fisheries in California from the Marine Fisheries Statistical Unit of the California Department of Fish and Wildlife (CDFW) from 1980 to 2012. This time period encompasses three distinct decadal time periods: 1980–1990, 1991–2000, and 2001–2012, which allowed us to examine the hypothesis that there has been a shift from finfish to invertebrates comprising California's most valuable fisheries. Landings summary data were extracted from the CDFW California Fisheries Information System (CFIS) database where daily landing receipt records are maintained. Landings summary information included year of landing, port where landed, total pounds caught, and ex-vessel value for each species or species complex. Species landings were categorized by year as either invertebrates or finfish. Pounds landed were converted to metric tons (t). Value data from 1980 to 2011 were adjusted for inflation to 2012 dollars using the Consumer Price Index (Bureau of Labor Statistics 2014).

Annual landings were summarized by one of three regions based on port of landing: northern (Mendocino County to the California-Oregon border), central (Sonoma County to Point Conception), and southern (south of Point Conception to California-Mexico border). Landings were classified by habitat by categorizing each species according to its life history traits as demersal, sessile, or pelagic. Demersal and sessile species were then further defined by general fishing depth, either nearshore (≤50 m depth) or offshore benthic (>50 m).

The species with the highest average ex-vessel price per kilogram was examined for the period from 2008 to 2012. Average price was calculated by dividing the sum total value by the sum total landings from 2008 to 2012. Only those species that had substantial landings, which we defined as more than 2.3 t, during the time span were considered.

Changes in the trophic level of the top 10 fisheries over time were examined by comparing trophic levels dominating the catch from the first and last decades of the time series. Each of the top 10 species was characterized by one of three trophic levels: predator, herbivore, or scavenger. The ranking was determined by the sum total value of each fishery during the decade. Percentage of each category was calculated using the total value for each trophic level divided by the total value of the 10 species during this time period.

The values (adjusted for inflation) from 1980 to 2012 of the four most valuable invertebrate fisheries and two emergent fisheries were examined. The top four invertebrate fisheries were market squid (*Doryteuthis* [*Loligo*] *opalescens*), Dungeness crab (*Metacarcinus* [*Cancer*] *magister*), spiny lobster (*Panulirus interruptus*), and red sea urchin (*Mesocentrotus* [*Strongylocentrotus*] *franciscanus*), and two then emergent invertebrate fisheries for sea cucumber, which includes warty sea cucumber (*Parastichopus parvimensis*) and giant red sea cucumber (*P. californicus*), and Kellet's whelk (*Kelletia kelletii*).

Eastern Pacific Ocean landings data from 1950 to 2011 (FAO 2014) were reported as capture production in metric tons and include subsistence, commercial, and recreational catch for marine invertebrate species. This dataset for the eastern Pacific Ocean includes two regions, the Central Pacific and North Eastern Pacific (Latitude: 60° N to 25° S, Longitude: 175° W to 77° W), which encompass the West Coast of the United States.

RESULTS

There is a clear increasing linear trend in the value of invertebrate fisheries in California as a percentage of the total fisheries value over time (Figure 1). From 1980 to 2012, the total value of invertebrate fisheries grew by 174% (Figure 2a). Conversely, the value of finfish declined sharply by 96% (Figure 2a). A 90% decline was also observed in the catch of finfish during the same time period (Figure 2b). There was a steep and steady rise (increase of 223%) in landings of invertebrate fisheries in California from 1980 to 2012 (Figure 2b). At the same time, there was a sharp drop of 81% and 61%, respectively, in the total value and landings of California fisheries from 1980 to 2012 (Figure 2a, Figure 2b). From 1980 to 1990 finfish made up the majority of the total value. From 1991 to 2000, approximately half of California fisheries value came from invertebrates as their value increased over this time period. In the most recent time period, 2001–2012, more than 50% of the total value of all California fisheries was derived from invertebrate fisheries (Figure 1).

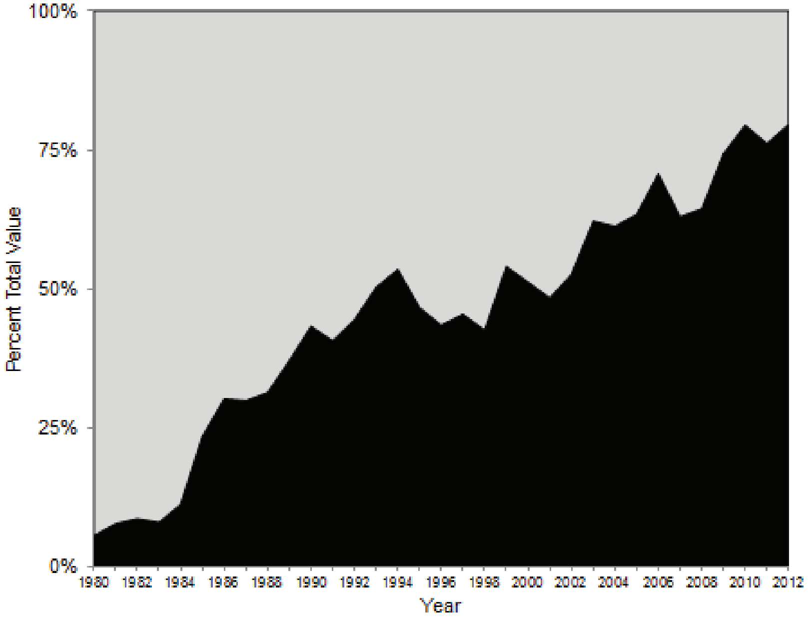

FIGURE 1.—Percent of the total value of invertebrate (black area) and finfish (gray area) commercial marine fisheries in California, USA from 1980 to 2012.

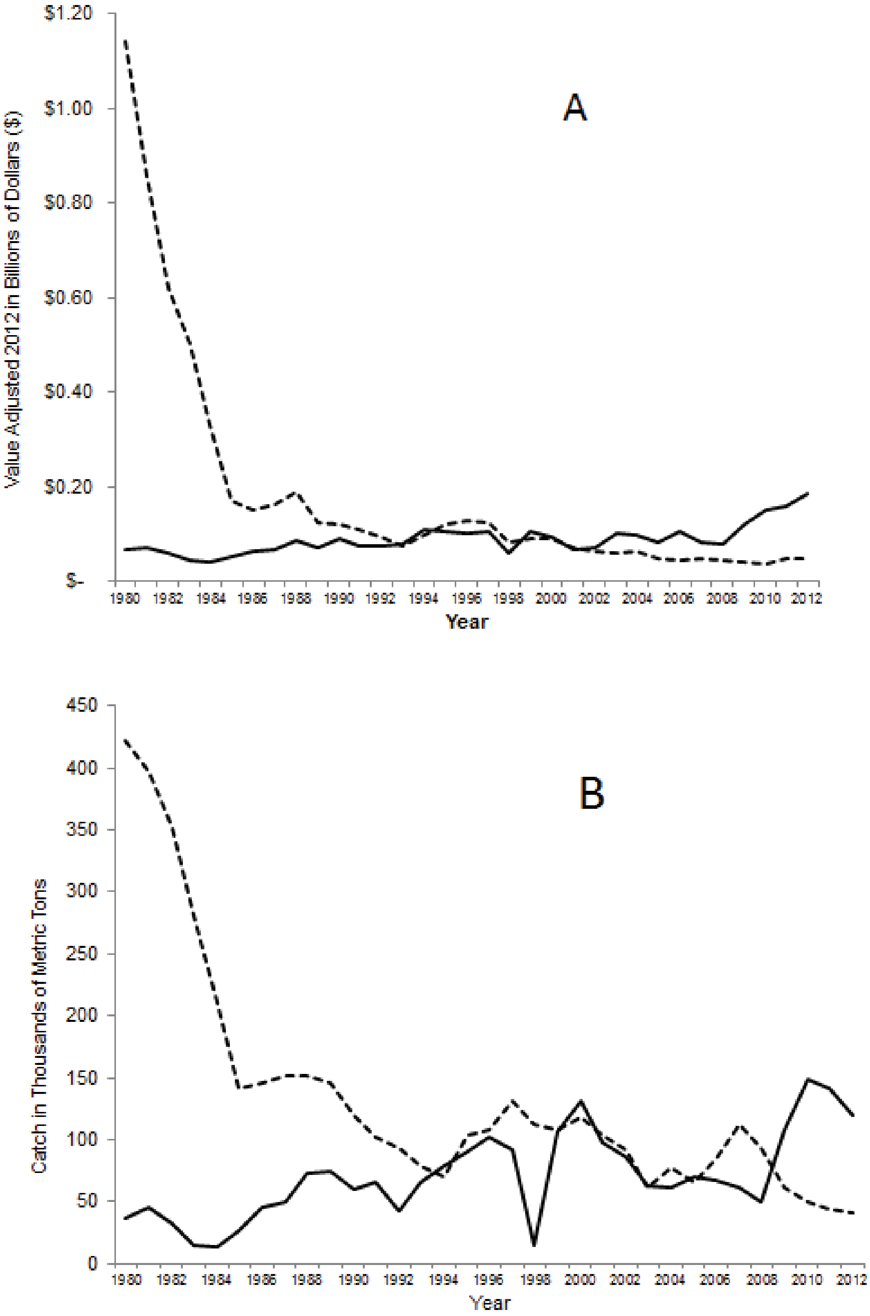

Figure 2.—Total value (a) of California's commercial fisheries in billions of dollars, and total catch (b) in thousands of metric tons from 1980 to 2012 for invertebrates (solid line) and finfish (dashed line). Yearly value is adjusted for inflation to year 2012 dollars with the Consumer Price Index (Bureau of Labor Statistics 2014).

Invertebrates made up four out of the top five fisheries in California from 2008 to 2012 (Table 1). Market squid, Dungeness crab, and spiny lobster were the top three fisheries by value, while sablefish and red sea urchin rounded out the top five (Table 1). The high-value fisheries in terms of annual average price per kilogram, from 2008 to 2012, were dominated by invertebrate fisheries in the top three positions (Table 2). Spiny lobster was the top fishery by price, followed by spot prawn (*Pandalus platyceros*) and sea hare (*Aplysia californica*). The five next most valuable species were rockfish, many of which are sold live in the local restaurant trade. The mantis shrimp (*Hemisquilla californiensis*), object of a relatively small fishery, was next highest and followed by kelp greenling (*Hexagrammos decagrammus*), another live market finfish.

Table 1.—Average annual value of the top five commercial marine fisheries, California, USA, 2008–2012.

Ranking	Common Name	Millions of U.S. Dollars per Year
1	market squid	58.0
2	Dungeness crab	46.3
3	California spiny lobster	10.8
4	sablefish	10.3
5	red sea urchin	7.7

Table 2.—Average price per kilogram of the top ten commercial marine fisheries, California, USA, 2008–2012.

Ranking	Common Name	Price ($US) per kg
1	California spiny lobster	31.32
2	Spot prawn	24.49
3	Sea hare	21.37
4	Grass rockfish	20.52
5	Treefish	19.14
6	China rockfish	16.34
7	Black-and-yellow rockfish	15.53
8	Gopher rockfish	15.35
9	Mantis shrimp	14.64
10	Kelp greenling	13.74

When we examined the value of landings trend by region within the state, invertebrate fisheries in the southern California region exhibited the greatest increase, from 4% of the catch value in 1980 to 34% by 2012, with a high of 50% in 2009 (Figure 3). However, in the southern region, the value of finfish declined markedly from 80% in 1980 to 40% in 1990, and to just 6% of the total value in 2012. In central California, invertebrate fisheries did not rise above 15% until 2002, up dramatically from 2% in 1980, but then declined in 2009 to about 6%, while in the last three years of the period they made up about 20% of total value. Coincidentally, finfish in the central region increased from 7% in 1980 to a high in 1991 of 31%, and then fell to about 10% in 2012. Northern California invertebrates made up <10% of the total value in the 1980s, began to increase in the 1990s to between 11% and 20%, and continued this trend in the 2000s from a low of 8% to a high of 26% in 2012. Finfish in the northern region changed little from 1980 to 2012, remaining at 5% of total landings. However, they did experience an increase from 1985 to 1997 of between 11% and 15% of total value.

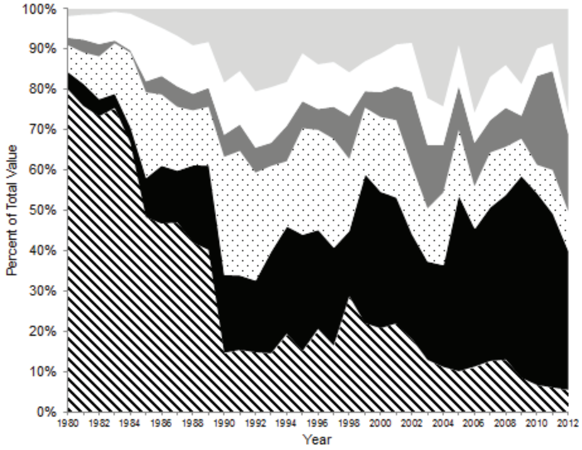

FIGURE 3.—The geographic distribution of the value, as percent of total value, of invertebrate and finfish commercial fisheries in northern, central and southern California from 1980 to 2012. The regions and fisheries are represented as follows (from top of graphic): northern invertebrates (light gray), northern finfish (white), central invertebrates (dark gray), central finfish (dotted pattern), southern invertebrates (black), and southern finfish (diagonal stripes).

Invertebrates in both the benthic and pelagic habitats exhibited the most dramatic increases in percent total value from 1980 to 2012 (Figure 4). Benthic invertebrates comprised 3% of total value in 1980, rose past 30% by 2003, and climbed to a high in 2012

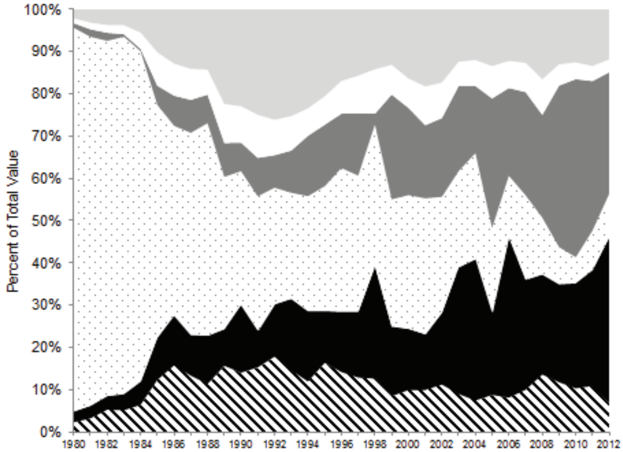

FIGURE 4.—The habitat distribution of the value (percent of total value) of invertebrate and finfish commercial fisheries in nearshore, pelagic and benthic habitats in California from 1980 to 2012. The habitats are defined as nearshore (≤50 m depth), pelagic (in the water column), and benthic (>50m depth). The habitats and fisheries are represented as follows (from top of graphic): nearshore invertebrates (light gray), nearshore finfish (white), pelagic invertebrates (dark gray), pelagic finfish (dotted pattern), benthic invertebrates (black), and benthic finfish (diagonal stripes).

of 41%. The pelagic invertebrates rose from a low of 1% in 1980, surpassing 20% in 1999, to a high of 41% in 2010 and were at 28% in 2012. Nearshore invertebrates rose from 2% in 1980 to a high in 1992 of 27%, then fell to <16% after 2003. Contributing to these increased invertebrate percentages was the precipitous decline in pelagic finfish from 88% in 1980 to 32% in 1989, and finally dropping below 10% by 2009. Nearshore and benthic finfish, however, changed very little between 1980 and 2012, and never exceeded 20% of value during the entire time series (Figure 4).

The last decade saw some of the peak fishery years for the top three ranked invertebrates (Figure 5a, Figure 5b). Market squid was the most valued species on average for the last five years (Table 1), and reached a peak ex-vessel value in 2010 of $78 million.

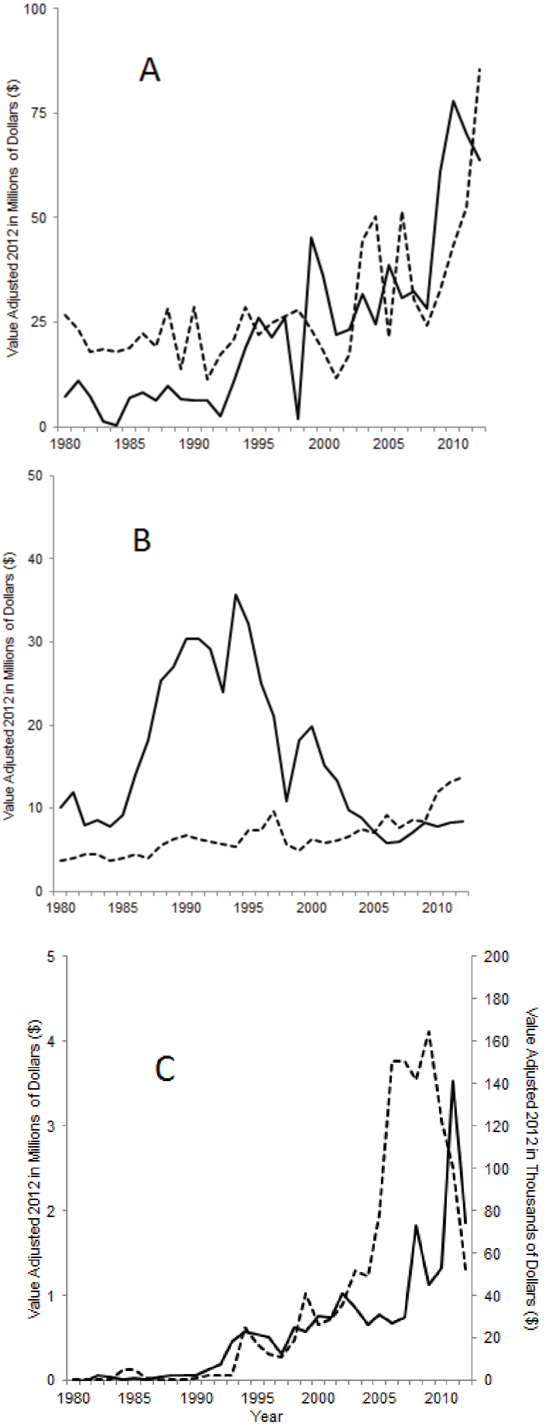

FIGURE 5.—Total value (in millions of dollars) of individual species of some of the top invertebrates in California commercial fisheries from 1980 to 2012: (a) market squid (solid line) and Dungeness crab (dashed line); (b) red sea urchin (solid line) and spiny lobster (dashed line); and (c) sea cucumber (solid line), in millions of dollars (left vertical axis), and Kellet's whelk (dashed line), in thousands of dollars (right vertical axis). Yearly value is adjusted for inflation to 2012 dollars using the Consumer Price Index (Bureau of Labor Statistics 2014).

Market squid has rapidly increased in value and, by 2012, it was 8.5× the value in 1980 (Figure 5a). The Dungeness crab fishery is generally characterized by cyclical landings, but trended upward since 1980, and rose in value since 2001 (Figure 5a). On average, crab was the second most valuable fishery in the state after market squid (Table 1); in 2012, the fishery reached a maximum of $85.6 million in total value, a historic high.

Spiny lobster was another high-value fishery as measured by total value and price per kilogram (Tables 1 and 2). The fishery steadily climbed since 1980, when it brought in $3.7 million. It increased to $13.8 million during the most recent year (2012), which was a record for that fishery (Figure 5b). A major invertebrate fishery that did not increase steadily in value since 1980 was red sea urchin (Figure 5b). The value of the red sea urchin fishery has undergone a classic boom and bust cycle, with the boom from 1989 to 1996, and peaked in 1994 at $35.7 million. Despite the nearly five-fold decline from this maximum to its average value during 2008–2012, it remained one of California's five most valuable fisheries (Table 1), and the value of the southern California landings continues to make this an important fishery in the state.

Both the sea cucumber and Kellet's whelk fisheries were low-value in the 1980s, but value of both fisheries increased during the 1990s by an order of magnitude and continued to rise rapidly thereafter (Figure 5c). This increase began in 1991 for sea cucumber ($126,400) and in 1994 for Kellet's whelk ($25,200). For the recent five-year period, the sea cucumber fishery was the 13th most valuable in California, and reached >$3.5 million in 2011, a record for the fishery. The smaller Kellet's whelk fishery, meanwhile, reached a peak year in 2009 of more than $164,600, more than 6.5× its 1994 value.

Along with the rise in invertebrate fisheries we saw an increase in the number of lower trophic level species making up the top ten fisheries in California (Figure 6). The

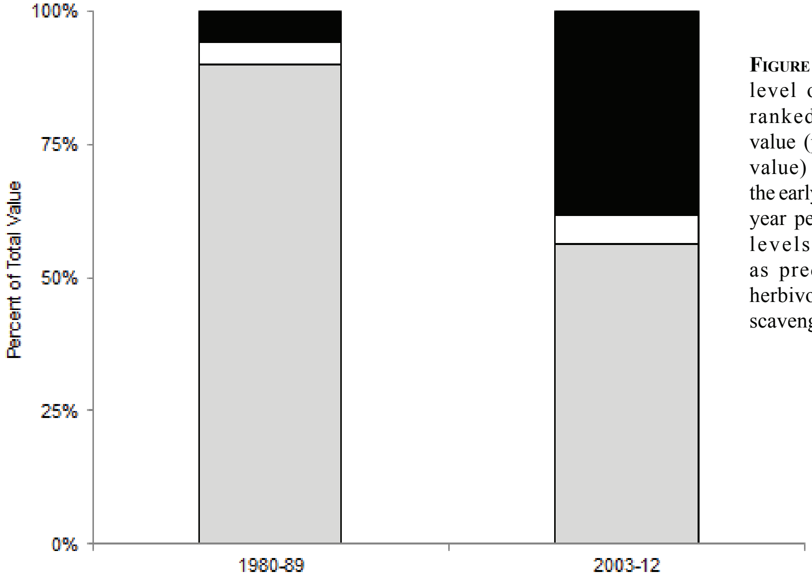

Figure 6.—The trophic level of the top ten ranked fisheries by value (percent of total value) calculated for the early and recent ten-year periods. Trophic levels are defined as predators (gray), herbivores (white), or scavengers (black).

species that made up the top 10 fisheries in the state were predominantly predators (90%) in the 1980s, while in the most recent decade they were divided about equally between predators and lower trophic level species (herbivores and scavengers; Figure 6). When yellowfin tuna (*Thunnus albacares*), a tropical species found offshore, were removed from the trophic level analysis, predators represented 75% of the top ten fished species in the 1980s, but the recent ten-year period remained unchanged.

The increasing trend in the tonnage, and hence value, of invertebrate fisheries also occurred across the eastern Pacific Ocean (Figure 7). In this region, invertebrate fisheries increased to 4× the value they were in 1950.

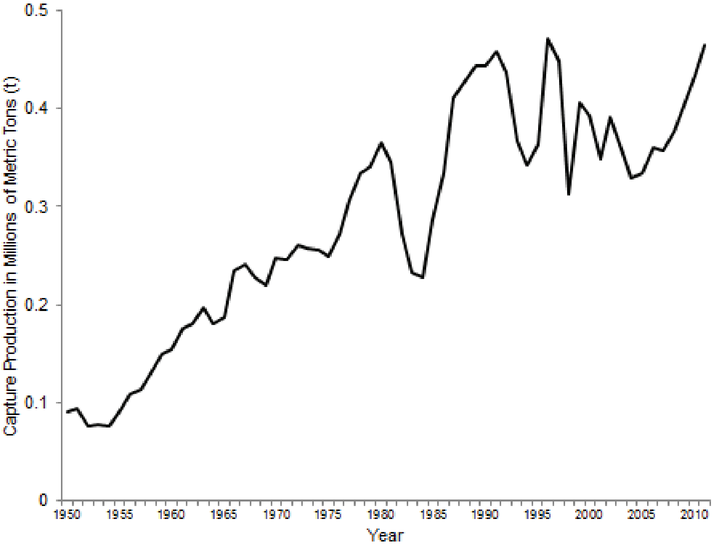

Figure 7.—Invertebrate fisheries capture production from the eastern Pacific Ocean in millions of metric tons from 1950 to 2011 as reported by the Food and Agriculture Organization of the United Nations (FAO 2014).

Discussion

Fishery trends in California.—Invertebrates make up the majority of the value of California fisheries. Since 1980, there has been a steady, linear increase in the proportion of the total value made up by invertebrate fisheries, starting at <10% and increasing to >75% of the total fisheries value in 2012 (Figure 1). In addition, we have seen a rise in some of the traditional invertebrate fisheries such as spiny lobster and Dungeness crab, as well as the emergence of novel invertebrate fisheries after 1980. Two of the more recent invertebrate fisheries that have expanded since 1980 include those for market squid and red sea urchin (Figure 5a, Figure 5b), the first and fifth most valuable fisheries in the state (Table 1). The market squid fishery grew rapidly in fleet size and landings in the 1980s due to increasing world-wide demand. Market squid is a high volume fishery with landings that began to increase in the early 1990s, reaching 100,000 t for the first time in the 1996–1997 season. During 2008–2012, the average annual invertebrate fisheries catch was 113,094 t, with market squid accounting for 96,292 t (85%) of the total by weight. The peak in red sea urchin landings was fueled by an ever-increasing market demand, which precipitated the increase in landings from the northern California portion of the fishery, where previously unexploited stocks were quickly fished down and reduced by almost 90% (Kalvass and Hendrix 1997). Red sea urchin landings in southern California have fallen more slowly, declining by >50% since the peak in 1990. Since the 1980s, sea cucumber and Kellet's whelk have also contributed to the overall value of invertebrate fisheries (Figure 5c).

Dungeness crab and spiny lobster, two mainstays of California invertebrate fisheries over many decades, have also expanded since 1980 (Figure 5a, Figure 5b) and are now two of the top five most valuable fisheries in the state (Table 1). During the 2010–2011 Dungeness crab season, the majority of landings came from central California, a shift from northern California that had traditionally produced the majority of the landings. The recent record crab years have been driven by increased landings from central California, coupled with higher-than-average landings in the north and higher than average ex-vessel prices ($5.53/kg). Records of spiny lobster landings since 1917 peaked in the early 1950s. Since 1980, there has been a steady rise in lobster landings with some of the recent years near the historic peak, as well as a concomitant increase in value. This suggests that the productivity in this fishery has benefitted from warmer oceanographic conditions since 1980 (NOAA 2014). Regulation changes in 1976 requiring lobster traps with mandatory escape ports might also have bolstered fishery productivity during the last 30 years.

Coincident with the increase in invertebrate fisheries since 1980, the overall value of California fisheries has declined sharply (Figure 2a). This decline is particularly concerning since landings by weight have not been declining (Mason 2004). The value of finfish dropped from a high of >$200 million in 1979 to $46 million in 2001 (Mason 2004), and have not increased since then (Figure 2a). The steepest decline was during the 1980s, when a combination of factors, including the relocation of California's high-value tuna fisheries, impacted the value (Figure 2a). During the early 1980–1984 period, subtropical tunas (yellowfin tuna, Pacific bluefin tuna (*Thunnus orientalis*), and blackfin tuna (*Thunnus atlanticus*), made up 29% of the finfish landings value but, after that, they had little impact on the landings. The relocation of California's subtropical tuna fishery was due, in part, to socio-economic factors arising from the requirement for "dolphin-safe" canned tuna, which effectively removed the Eastern Tropical Pacific fishing grounds from availability to the U.S. fleet. The abundance of subtropical tunas in California waters prior to 1985 was also impacted by the warm water years, such as the strong El Niño in 1983–1984, when the tunas shifted their distribution north into California (Mason 2004, Norton and Mason 2004). Since 1985, subtropical tunas have made up less than 10% of the finfish landings. If we remove subtropical tunas from the analyses, there is a slight decrease in the total value (vertical axis in Figure 2a) but no change in the dramatic downward trend of the finfish fisheries compared with the rise of invertebrates in value and catch.

The decline in finfish in the 1980s can also be seen regionally in the sharp decline of finfish landings from northern and southern California, with finfish values holding relatively steady in central California until 2002 (Figure 3). The value in the central coast was maintained, in part, due to the emergence of the live fish market where rockfish and other nearshore fishes are caught and sold alive at a premium price. In the past decade however, the value of finfish landings has declined even in central California despite the high price per kilogram for many nearshore finfish (Table 2). Management measures such as gear restrictions, closed fishing areas, and quotas implemented during this time period have been responsible for declining rockfish landings, which is reflected in the benthic habitats analysis for the central California region (Figure 3, Figure 4).

Spiny lobster brought in more than $10 million annually during the past five years as the highest per unit value fishery in California (Table 2). Spot prawn, the second most valuable fishery per kilogram, is a small-volume, high-value fishery that has brought in an average $3.4 million for each of the past five years. The third most valuable fishery per kilogram is the sea hare fishery, which has brought in less than $50,000 per year for the past five years; the price per kilogram, however, is very high. Sea hares are fished primarily for experimental use in neurological research (Medina et al. 2001), as well as for the aquarium trade.

Emerging fisheries in the 1990s have also contributed to the rise in invertebrate fisheries in California (Figure 5c). Over the recent five years (2008–2012), warty and giant red sea cucumber fisheries annually averaged more than $1.9 million, more than the average value of white seabass (*Atractoscion nobilis*), albacore tuna (*Thunnus alalunga*), or petrale sole (*Eopsetta jordani)*. Giant red sea cucumbers are fished primarily by trawl, while the warty sea cucumbers are taken by commercial divers. The average price for sea cucumbers has also increased more than four-fold in the past decade, starting at $2/kg in 2003 and increasing to $8/kg in 2012, an increase that has been fueled by escalating demand from Asia. Aside from a limited entry program, there currently are no management measures in place for this data-poor fishery. Kellet's whelk is primarily a bycatch fishery in lobster and crab traps, with a small targeted dive fishery. Following the start of the fishery during the mid-1990s, landings grew substantially to a peak of 86.7 t in 2006. From the start of the fishery to 2006, an estimated 2.6 million whelk have been taken (approximately 150 g/whelk; L. Rogers-Bennett, unpublished data). By 2010, there was concern for the sustainability of the whelk fishery and a total allowable catch (TAC) of 45 t was imposed in 2012 by the California Fish and Game Commission. The most recent (2013–2014) landings finished at 38 t, just under the new TAC.

Invertebrate fisheries management and fishing down food webs.—There has been an increase in lower trophic level species comprising California's top fisheries (Figure 6), consistent with the hypothesis of fishing down marine food webs (Pauly et al. 1998). Crab and lobster are scavengers holding lower trophic positions than some of the species that dominated California landings in the early 1980s, such as salmon and tunas (both of which are top level predators). Red sea urchins are herbivores holding a lower trophic position. One of the newer invertebrate fisheries targets the sea cucumber, a detritivore that occupies a lower trophic position than most fin-fish. Having a low position in the trophic level does not appear to make fisheries resistant to collapse (Pinsky et al. 2011). For example, the sardine fishery in California suffered one of the most famous fishery collapses in history (Radovich 1982), and that species is a not a predator but a planktivore. Similarly, abalone are herbivores, but the fisheries south of San Francisco are now closed due to overfishing (Hobday et al. 2001, Rogers-Bennett et al. 2002).

The question arises, how will we sustainably manage California invertebrate fisheries, especially in the face of variable ocean conditions? We know that sea surface temperatures are a major influence on California's top fisheries. Catches of market squid, for example, fluctuate dramatically with environmental conditions, with radically reduced catches in warm water years such as 1982–1983, 1992, and 1998 (Zeidberg et al. 2006, Koslow and Allen 2011). Similarly, the new recruits of many commercially important invertebrate species, such as spiny lobster, also appear to show trends in recruitment associated with oceanographic conditions (Koslow et al. 2012) such as the Pacific Decadal Oscillation (Mantua et al. 1997). For example, 2004 was one of the best lobster phyllosoma seasons in the past 60 years (Koslow et al. 2012). In contrast, species such as Dungeness crab appear to have increased productivity during cold water years, suggesting good years for some species of invertebrates may not be good years for others. Invertebrates are famous for having large temporal fluctuations in productivity (driven by oceanographic processes) and this may need to be taken into consideration when future fishery management strategies are developed. Even small changes in mortality rates of early life history stages of fished species can translate into large changes in their population dynamics (Koslow 1992). So, what are some options for managing invertebrate fisheries given wide fluctuations in populations and varying ocean conditions?

One option would be to manage the fishery assuming the productivity of an "average" year, knowing we would overfish in some years and "underfish" in other years (Parma 2002). Such a fixed exploitation rate strategy (Walters and Parma 1996) may work with long-lived invertebrates but may not be sustainable for short-lived species, when just a few years of overfishing during bad years could have serious negative population consequences. Short-lived species, while they may bounce back from overfishing faster than long-lived species, may have more unstable population dynamics (Charnov 1993). Therefore, it may be necessary to manage species based on their population dynamics. However, there appears to be little evidence that the species comprising California's top fisheries have similar population dynamics or respond to ocean conditions in the same way. This may pose new challenges for ecosystem-based management if, for example, the productivities of squid (which do poorly in warm years) and lobster (which do well in warm years) differ in the same year. Another option would be to incorporate what is known about the impacts of temperature on productivity into harvest control rules, as is done in California for Pacific sardine (PFMC 2014). Temperature data can also be used as recruitment proxies in models examining productivity (White and Rogers-Bennett 2010).

There have been a number of arguments for adaptive management (fishery experiments) to learn from the application of management strategies and to apply these lessons in setting sustainable fishing levels (Walters and Hilborn 1978). In the case of marine invertebrates in California, monitoring the density of adult stocks, coupled with adaptive management, could be one way forward. This innovative strategy is now employed in northern California to manage the recreational red abalone (*Haliotis rufescens*) fishery (Kashiwada and Taniguchi 2007). Knowing the metapopulation dynamics of larval production coupled with the status of adult stocks at the local level could be another successful approach. In this way, adaptive management could be useful despite the suite of problems associated with invertebrate stock-recruit relationships and violations in assumptions of equilibrium traditionally used when setting maximum sustainable yields. Whatever fishery management methods are used, the continued tracking of fisheries landings (fishery-dependent data), particularly of top invertebrate fisheries, will be key to the success of sustainably managing invertebrate fisheries in California and the broader eastern Pacific Ocean.

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Effects of fishing and the environment on the long-term sustainability of the recreational saltwater bass fishery in southern California

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Unlike several boom-and-bust fisheries of the last century, the recreational saltwater bass (*Paralabrax* spp.) fishery in southern California has endured oceanographic regime cycles and nearly a century of increasing anthropogenic impacts. We examined regulatory changes and several fishery-dependent and fishery-independent time series to determine historical influences on the fishery and causes of dramatic catch declines in recent years. Our results reveal a complex relationship between bass abundance and harvest rules, fishery recruitment, giant kelp (*Macrocystis pyrifera*), ocean regimes, and fishing. Recent trends in larval abundance and lengths of harvested fish suggest recruitment failure occurred during the last oceanographic regime shift coincident with a peak in exploitation rates. We believe this contributed to poor fishery recruitment, associated declines in catch-per-unit-effort, and a depressed population since the mid-2000s. Although long-standing regulations and periods of optimal environmental conditions appear to have sustained the fishery, we recommend an adaptive management approach to mitigate the effects of fishing pressure during unfavorable ocean conditions.

Key words: barred sand bass, exploitation rate, fishery recruitment, hyperstability, kelp bass, natural mortality, overfishing, *Paralabrax*, population recruitment failure, sustainable fisheries

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The popular southern California recreational fishery for barred sand bass (*Paralabrax nebulifer*), kelp bass (*P. clathratus*), and spotted sand bass (*P. maculatofasciatus*) dates back to 1916. After nearly a century of oceanographic regime cycles and increasing anthropogenic impacts, barred sand bass and kelp bass still consistently rank among the top five species caught in southern California, and popularity of spotted sand bass fishing continues to grow. Nevertheless, saltwater bass catches have decreased for over a decade and increased take restrictions were implemented in 2013 (California Code of Regulations Title 14, Section 28.30). A recent publication concluded that the recreational bass fishery in southern California was collapsed (Erisman 2011). After the Atlantic cod (*Gadus morhua*) tragedy in the early 1990s (Hutchings and Myers 1995), the term "collapse" conjures up depleted fish stocks and fishing moratoriums.

Fisheries that are either undermanaged or lack traditional fishery statistics have been more recently assessed by examining current catches relative to a historic maximum (Worm et al. 2006), whereby those fisheries exhibiting catch declines of 90% or more are classified as collapsed. For fisheries without long-term fishery-independent indices of abundance or other important fishery statistics (e.g., size class distributions, exploitation rates), using this benchmark may be the only tool available for assessing fishery status; however, its use may still be misleading (de Mutsert et al. 2008). The basses have been managed for over 50 years with a minimum size limit (MSL) and bag limit. Although spawning biomass estimates do not exist for the basses, several traditional fishery statistics are available to better assess the health of the bass fishery than the 90% benchmark referenced by Erisman et al. (2011). Given the ecological and economic importance of the saltwater bass resource to the coastal waters of southern California and the long-standing popularity of the fishery, we feel a more thorough investigation of the fishery is warranted.

Examples of fishery collapse over the last century have generally included commercial fisheries characterized by fish populations that form large schools or aggregations (e.g., Radovich 1982, Hutchings and Myers 1995). In these fisheries, hyperstable catches exist due to density-dependent population dynamics, increases in fishing efficiency, and the ability of fishing fleets to target areas of higher fish abundance or density (Hilborn and Walters 1992). Over time, the severity of harvest impacts can reportedly go unnoticed until the fishery is forced to close due to the scarcity of the resource (Sadovy and Domeier 2005, Murphy and Munyandorero 2009). The basses have not been commercially fished since 1953, but they do form spawning aggregations that are targeted to varying degrees (depending on the species) by the Commercial Passenger Fishing Vessel (CPFV) fleet and private boaters (Love et al. 1996a, Allen and Hovey 2001). The nature of a fishery that is primarily dependent on large, seasonal aggregations is expected to exhibit hyperstable catches (Harley et al. 2001, Shelton 2005); thus, evidence of hyperstability alone (Erisman et al. 2011) does not provide the extent to which fishing has affected local bass populations or confirm that the fishery has collapsed.

The lack of management regulations to prevent recruitment overfishing or growth overfishing is often cited as the cause of fishery collapse. Traditional indicators of overfishing include significantly reduced catches of larger, older individuals (recruitment overfishing) and a decrease in the average size of fish caught over time (growth overfishing). The basses were managed under a 30.5-cm MSL from 1959 to 2012. Based on age-at-maturity, this limit afforded the basses one to three spawning seasons before recruiting into the fishery (Allen et al. 1995, Love et al. 1996b) and was intended to provide a maximum yield per recruit. Thus, growth overfishing was not likely to occur. Biological reference points, however, for curbing recruitment overfishing have been less clear for the basses because no estimates of population size or spawning stock biomass have been available. This is of concern, especially for barred sand bass, given that they are targeted by anglers when they aggregate to spawn. Once harvesting has reduced the spawning population below some critical level, recruitment can fail for several years, resulting in a collapsed fishery (Sadovy and Domeier 2005). Well known examples of fishery extirpation of spawning aggregations include the tropical serranids (e.g., Nassau grouper [*Epinephelus striatus*]), of which eight are listed as endangered or critically endangered on the IUCN Red List of Threatened Species in 2012 (IUCN 2012). Fishing pressure on schooling fish or spawning aggregations can also affect the distribution of fish catches over time (Hilborn and Walters 1992). Rose and Kulka (1999) demonstrated a large reduction in the geographic range fished for Atlantic cod over a 12-year period, but this possibility has never been assessed for the basses.

In addition to harvest impacts, changing oceanographic conditions could also influence southern California bass populations by affecting larval survival, habitat-dependent recruitment success (e.g., giant kelp [*Macrocystis pyrifera*]), and spawning behavior cues. Over the last century, the Southern California Bight (SCB) has experienced several ocean regime shifts (e.g., Pacific Decadal Oscillation; PDO) resulting in significant changes in seasonal temperature amplitudes within the upper ocean (Gelpi and Norris 2008). Hsieh et al. (2005) reported long-term positive bass population responses to the warm phases of the PDO, but no study has documented direct relationships between sea surface temperature (SST) and bass fishery recruitment strength. Coastal SSTs from Alaska to southern California vary in phase with the PDO (Mantua et al. 1997), and although the PDO index is primarily a measure of SST anomalies, the PDO also drives atmospheric and oceanographic changes in the Pacific northwest of North America and northeast Pacific Ocean. Regimes typically last 30 years or more; the last extended warm water period occurred in the 1980s and 1990s (NOAA 2012) and cooler conditions since then may have contributed to decreased bass fishery recruitment.

Habitat requirements could introduce complexity in interpretations of oceanographic and fishing effects on bass populations. For example, kelp bass are associated with giant kelp and rocky reef habitat and are generally more abundant when giant kelp is more abundant (Graves et al. 2006). Giant kelp densities can be reduced during warm ocean regimes, especially after El Niño events (Tegner et al. 1997), and this may negatively affect juvenile kelp bass abundance during warm regimes, even though conditions for successful reproduction or larval development, or both, are optimized. Increases in giant kelp generally have a positive effect on kelp bass larval recruitment depending on successful larval transport (White and Caselle 2008).

The objectives of this paper are to provide a historical review of the saltwater bass fishery with emphasis on barred sand bass and kelp bass, and to investigate the factors contributing to their catch declines in recent years. We examined (1) fishery-dependent data (e.g., exploitation rates, catch distribution, size composition); (2) fishery-independent data (e.g., larval and adult abundance); and (3) relationships between bass fishery recruitment strength and larval abundance, giant kelp canopy, and SST. A comprehensive fishery analysis leading up to the saltwater bass regulation changes in 2013 should provide historical perspective and an increased ability to adaptively manage the fishery.

History of the Fishery

The first in-depth fishery analysis for the basses was conducted in the early 1930s by the California Department of Fish and Game (CDFG; now the California Department of Fish and Wildlife [CDFW]) in response to sport fishermen appealing for prohibition of the commercial take of bass. At that time, minor numbers of barred sand bass and kelp bass were caught only incidentally in commercial fishing gear, and so it was recommended that prohibiting commercial harvest would do little to conserve the resource (Clark 1933). It is important to note that prior to recreational catch reporting, the early record distinguished barred sand bass as "rock bass"; however, the rock bass category later came to include all three species of bass on sport fishing logbooks. Although commercial landings were made by many different types of fishing gear, catches were primarily by hand and set line targeting rockfishes (*Sebastes* spp.) and California sheephead (*Semicossyphus pulcher*) during summer months out of the Los Angeles Harbor at San Pedro (Clark 1933, Collyer 1949, Pinkas et al. 1967).

Small-scale recreational charter fishing trips began at the turn of the century after the Tuna Club of Santa Catalina Island was formed in 1898, but the expansion of the "partyboat" (= CPFV) fleet did not occur until after 1929 (Young 1969). During this time, barred sand bass and kelp bass were reportedly numerous in CPFV catches out of Santa Monica Bay, Long Beach, and Newport Beach (Figure 1); spotted sand bass was only a minor component of "rock bass" catches on CPFVs.

Figure 1.—Commercial passenger fishing vessel *Ramona* off Rocky Point, Santa Monica Bay, California on 3 July 1938. Note the fish sacks hanging off the side of the boat. Photo credit: R. S. Croker, California Department of Fish and Game.

Early on, a certain portion of the CPFV catch was sold to the fresh fish markets and comprised about 10% of the commercial landings (Clark 1933). Later, the practice became increasingly popular until it became illegal in 1947 (Collyer 1949). Monthly logbook records became a requirement for all CPFV operators in 1935 (Young 1969), and from 1935 to 1947 (with the exception of 1941–1946 when World War II halted nearly all partyboat activity), recreational rock bass landings were, on average, about three times the commercial landings by weight.

All three basses have been managed together since the early 20th century. In 1939, the state legislature limited take of "kelp bass and rock bass" to a 15-fish aggregate bag limit including several other species (Table 1). After World War II, the CPFV fishery experienced a second expansion and concerns were again raised, this time over declining

Table 1.—Historical record of southern California saltwater bass (*Paralabrax* spp.) minimum size and bag limit regulations.

Year	Saltwater Bass Species Listed	Regulation
1939[a]	kelp bass, rock bass	Bag limit: 15 fish in aggregate
1949[b]	kelp bass, rock bass	Bag limit: 10 fish in aggregate
1951[b]	kelp bass, rock bass	Bag limit: 15 fish in aggregate, with not more than 10 of any one species
1953[c]	kelp bass, rock bass, sand bass, spotted sand bass	Cannot be sold or purchased. Minimum size limit: 26.7 cm (10.5 in) total length
1957[b]	kelp bass, sand bass, and spotted sand bass	Minimum size limit: 27.9 cm (11 in) total length
1958[b]	kelp bass, sand bass, and spotted sand bass	Minimum size limit: 29.2 cm (11.5 in) total length
1959[b]	kelp bass, sand bass, and spotted sand bass	Minimum size limit: 30.5 cm (12 in) total length
1972[b]	kelp bass, sand bass, and spotted sand bass	Bag limit: 20 fish in aggregate, with not more than 10 of any one species
1975[d]	kelp bass, sand bass, and spotted sand bass	Bag limit: 10 fish in aggregate, with not more than 10 of any one species
2013[d]	kelp bass, barred sand bass, and spotted sand bass	Bag limit: 5 fish in aggregate; Minimum size limit: 35.6 cm (14 in) total length

[a] California Fish and Game Code Section 746.
[b] California Code of Regulations Title 14, Section 62
[c] California Fish and Game Code Section 714.7
[d] California Code of Regulations Title 14, Section 28.30

bass catches and the size of kelp bass caught (Young 1963). Following another CDFW fishery analysis, commercial take for all three basses was banned in 1953 and a 26.7-cm (10.5-in) MSL was implemented. The size limit was raised by 1.3-cm (0.5 in) increments in 1957 and 1958, and by 1959 a 30.5-cm (12-in) MSL was implemented. This size limit was based on kelp bass size-at-maturity and size at which to achieve the greatest yield in catch by weight (Young 1963). Contrary to previous reports (Allen and Hovey 2001, Miller and Erisman 2014), the bag limit regulation for the saltwater basses changed several times during the century, ranging among aggregate limits of 10, 15, and 20 fish with no more than 10 per species (Table 1). The most long-standing were the 15- and 10-fish aggregate bag limits during the periods 1951–1971 and 1975–2012, respectively.

During the 1950s and 1960s, kelp bass was referred to as the "mainstay" of the fishery and barred sand bass was considered "scarce". However, barred sand bass became more available in the 1980s and CPFV fishing effort for them increased. According to surveyed CPFV skippers in the late 1980s, the ease of catching legal-sized barred sand bass relative to legal-sized kelp bass was the primary reason for the increase in effort (Ally et al. 1991). By 1985, barred sand bass catches had exceeded kelp bass catches. Two separate fishery analyses conducted in the late 1980s and mid-1990s (CDFG 1991, Love et al. 1996a) concluded that the kelp bass and barred sand bass fisheries were healthy. Love et al. (1996a) cited the transition to warmer ocean conditions in the late 1970s as perhaps contributing to increased recruitment success in the 1980s and 1990s. Nevertheless, catches declined again, and new take restrictions consisting of a 35.6-cm (14-in) MSL and an aggregate bag limit of five fish were implemented for the saltwater basses in 2013 (Table 1, FGC 2012).

Kelp bass are commonly fished along the rocky mainland and island coasts. In contrast, the sand basses have fewer island populations and are much less abundant at these locations. Barred sand bass prefer sand-reef ecotonal habitat (Mason and Lowe 2010, McKinzie et al. 2014) and are fished near structure year-round, except when they form large spawning aggregations over sand flats in water 10–30 m deep (Love et al. 1996a). Spotted sand bass are associated with bays and harbors (Allen and Hovey 2001). Popularity for spotted sand bass fishing quickly rose in the 1980s, becoming primarily a catch-and-release fishery (Hovey and Allen 2000, Sweetnam 2010). Thus, harvested catches have never rivaled the other two basses, and management has considered potential harvest impacts to this species to be minimal.

TEMPORAL TRENDS IN FISHERY-DEPENDENT DATA

Description of catch data sets.—Most of the effort and landings for barred sand bass and kelp bass are from CPFVs and private or rental boats (Table 2). We used CPFV logbook data extracted from the CDFW California Fisheries Information System (CFIS) database (1980–2012) to examine recent CPFV catch trends. Commercial passenger fishing vessel logbook data in the CFIS database are available per vessel-trip since 1980 and include date, number of anglers, number of fish kept, number of fish discarded (since 1995), CDFW fishing block (10-minute latitude by 10-minute longitude), time fished, and other relevant data.

Historical logbook data for species catches prior to 1980 are summarized by month and fishing block and are available from 1935 to 2008 (Hill and Schneider 1999). Reporting requirements for fishing effort changed several times over the century; however, Hill and Schneider (1999) used a conversion factor to standardize effort to angler hours throughout the time series. This historical dataset was also examined for trends in catch and catch-per-

Table 2.—Percent of southern California saltwater bass (*Paralabrax* spp.) catches in the recreational fishery by species and fishing mode from 2004 to 2012.

	Percent of Catch		
Fishing Mode	barred sand bass	kelp bass	spotted sand bass
Party/charter	70.2	59.0	0.4
Private/rental	26.4	35.4	71.0
Man-made	1.5	2.0	19.6
Beach/bank	2.0	3.5	9.0
Total fish (thousands)	2,398.3	1,785.0	154.6

unit-effort (CPUE) from 1947 to 2008. Due to changes in logbook reporting requirements, individual species landings were not consistently reported until 1975; thus, for historical analyses, we queried the catch data for each species and for the aggregate category ("rock bass") and summed the catches by year. Because the historical CPFV data are summarized by month-block, only a single value is provided for the total number of angler hours for a given month-block, regardless of the species queried. Therefore, it was necessary to remove duplicate fishing-effort records when multiple catch records (individual bass species and "rock bass" records) were reported from the same month-block.

We used California Recreational Fisheries Survey (CRFS) data (RecFIN 2013) to capture CPUE trends in the private-rental boat mode from 2004 to 2012. The CRFS began in 2004 and replaced the federal Marine Recreational Fisheries Statistics Survey (MRFSS) conducted by the National Oceanic and Atmospheric Adminstation (NOAA) in California from 1980 to 2003. California Recreational Fisheries Survey landings estimates are not directly comparable to the MRFSS estimates, and the CRFS and MRFSS party or charter estimates are not directly comparable with the CPFV logbook data. Catch data collected by CRFS samplers on a subset of fishing trips are extrapolated to total estimates based on effort (angler days) derived from a phone survey.

Harvested fish (landings and CPUE).—Temporal trends in the historical CPFV logbook data indicate landings and CPUE have fluctuated similarly over the last 60 years. Following the regulation changes of the 1950s, saltwater bass ("rock bass") catches and catch rates increased to an all-time high in the early 1960s (Figure 2a). Both decreased into the 1970s before increasing again in the 1980s and 1990s. The more recent CPFV logbook record, which delineates catches by species, indicated barred sand bass landings and CPUE declined sharply (86% and 70%, respectively) from 2000 to 2012 (Figure 2a). Kelp bass declines were more gradual; from 1982 to 2012, kelp bass landings declined by 72% and CPUE declined by 48% between the peaks in 1992 and 2012 (Figure 2a). Since 1997, the total number of vessel-trips that reported catches of barred sand bass and kelp bass declined by 51% and 40%, respectively.

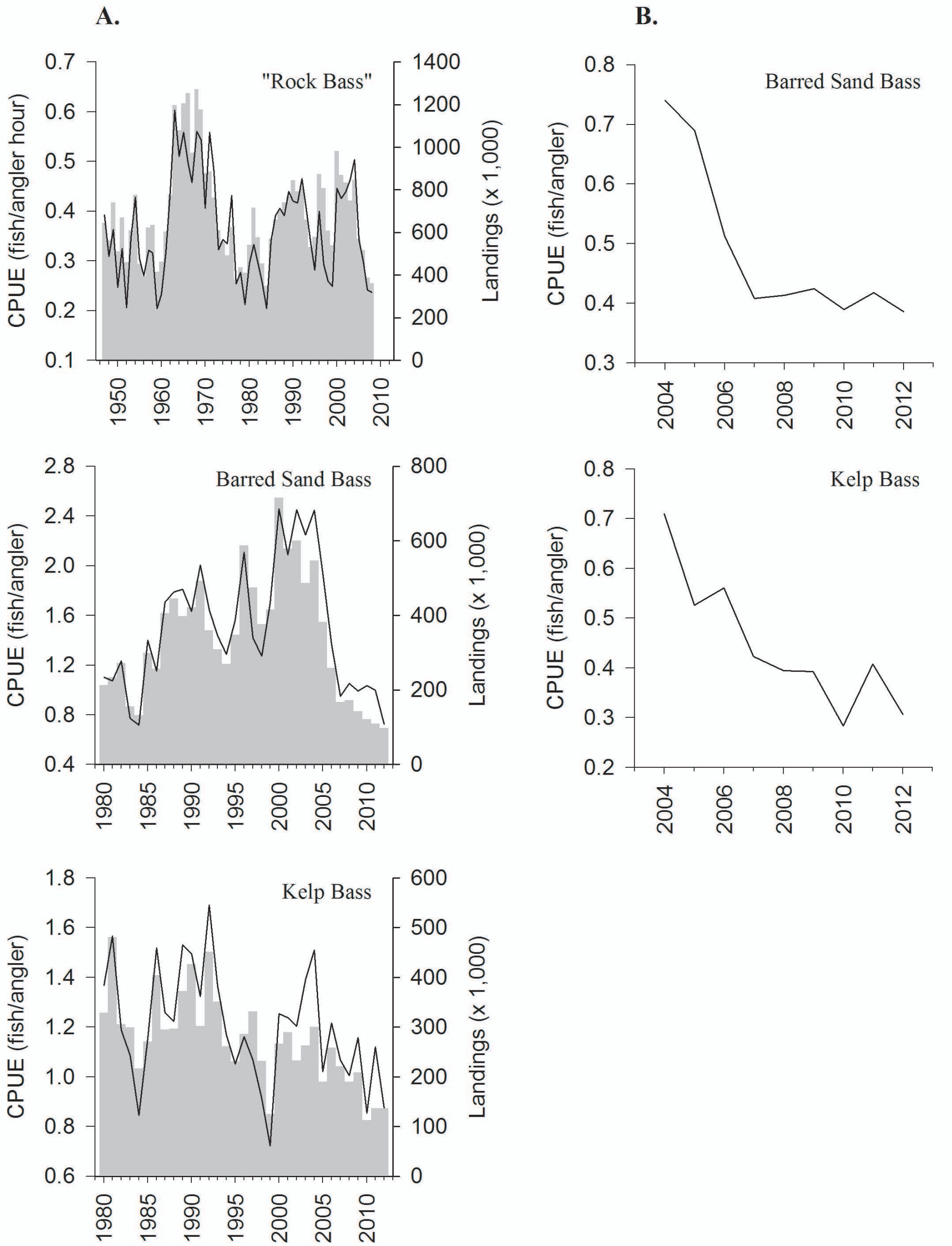

Figure 2.—Temporal trends in landings (grey bars) and catch-per-unit-of-effort (CPUE, line) of harvested saltwater bass (*Paralabrax* spp.) by A) commercial passenger fishing vessel and B) private and rental boat fishing modes in southern California. Data in A) represent California Department of Fish and Wildlife commercial passenger fishing vessel logbook data; data in B) represent California Recreational Fisheries Survey data.

Private and rental boat data showed similar declining trends for barred sand bass and kelp bass. Barred sand bass CPUE declined sharply from 2004 to 2007 (62%) and remained at that low level in 2012 (Figure 2b). Kelp bass CPUE steadily declined by 60% from 2004 to 2010 and remained at that level in 2012 (Figure 2b).

Total catch.—Total catch includes number of fish kept and discarded dead, and fish that are released alive. The number of fish released can make up a substantial part of a recreational fishery. Since 2004, the CRFS estimates of fish released from all fishing modes expressed as percentages of the total catch were 54% and 71% for barred sand bass and kelp bass, respectively. Despite recent declines in harvested CPUE, catch ranks using total catch estimates for all fishing modes reported in southern California by decade and sampling survey show that kelp bass and barred sand bass have remained within the top five recreational species caught since the 1980s (Table 3).

Spatial distribution of the catch.—We examined spatial trends in the distribution of southern California barred sand bass and kelp bass catches in the CPFV fleet from 2000 to 2012 by calculating CPFV catch rates by fishing block during peak spawning season (June–August). Fishing blocks that did not contain depth contours from 0-40 m were excluded from the analysis. We first examined temporal trends in the number of fishing blocks reporting bass catches and the percentage of those blocks with high catch rates (>3 fish/angler) from 2000 to 2012. Although the number of blocks with reported bass catches remained stable over the 12-yr period, the percentage of blocks with high catch rates peaked in 2004 at 47% (barred sand bass) and 28% (kelp bass), and then fell to 0% by 2012 (Figure 3).

Table 3.—Rank in southern California recreational fishing catch estimates by species, decade, and survey type from 1980 to 2012. Total catch estimates were derived from catch and effort surveys for all fishing modes and include fish kept and discarded. Bold values highlight those species catches within the top 10 ranks.

		MRFSS[a]			CRFS[b]
Common Name	Scientific Name	1980s	1990s	2000–2003	2004–2012
Pacific chub mackerel	*Scomber japonicus*	**1**	**1**	**1**	**1**
white croaker	*Genyonemus lineatus*	**2**	**3**	**10**	15
kelp bass	*Paralabrax clathratus*	**3**	**2**	**3**	**3**
Pacific bonito	*Sarda chiliensis*	**4**	16	32	**8**
barred sand bass	*Paralabrax nebulifer*	**5**	**4**	**2**	**4**
California halibut	*Paralichthys californicus*	**6**	**10**	**7**	14
bocaccio	*Sebastes paucispinis*	**7**	25	45	22
Pacific barracuda	*Sphyraena argentea*	**8**	**5**	**9**	13
blue rockfish	*Sebastes mystinus*	**9**	38	26	42
California lizardfish	*Synodus lucioceps*	**10**	24	23	16

[a] National Oceanic and Atmospheric Administration, Marine Recreational Fisheries Statistics Survey, 1980–2003.
[b] California Recreational Fisheries Survey, 2004–2012.

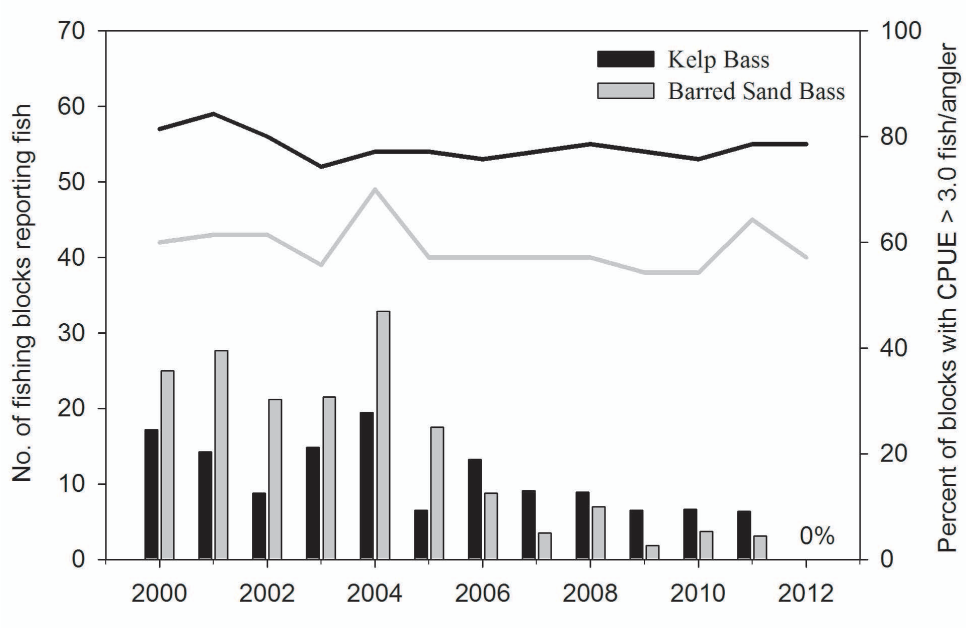

FIGURE 3.—Number of southern California fishing blocks with reported catches of kelp bass and barred sand bass (lines) and percent of fishing blocks with reported catch-per-unit-effort (CPUE) >3 fish/angler (bars) during peak spawning season (June-August) from 2000 to 2012. Data represent California Department of Fish and Wildlife commercial passenger fishing vessel logbook data.

To determine if the declines in CPUE occurred in isolated areas (e.g., hot spots) or throughout the catch range, we plotted the percent change in average CPUE by fishing block between the periods with higher (2000–2004) and lower (2005–2012) catch rates. We used a graduated color scheme to plot the percent change in CPUE using the following categories: declines greater than 50%, 49% to 10%, or 9% to 0%; increases of 1% to 10% or greater than 10%. Localized depletion of stocks between the two catch periods was not evident with barred sand bass or kelp bass. For example, CPUE between the two catch periods declined throughout the catch range, and not only at isolated locations (i.e., fishing hot spots or spawning locations). Known barred sand bass spawning locations off Ventura, Santa Monica, Huntington Beach, San Onofre, and Silver Strand all showed declines similar to declines in other locations throughout the SCB (Figure 4a). Of blocks where barred sand bass was caught, most showed declines in CPUE of greater than 50% (Figure 4a) and occurred throughout southern California (Figure 4a), indicating an overall decrease in barred sand bass availability. Percent increases in barred sand bass CPUE occurred in a few blocks throughout the SCB, including off Silver Strand, San Clemente Island, Santa Cruz Island, and Carpinteria. Most blocks where kelp bass were caught showed declines ranging between 10% and 49% (Figure 4b); these blocks also occurred throughout southern California. Five of eight blocks showing declines greater than 50% occurred in the higher latitude fishing blocks off Ventura and Santa Barbara. Increases in kelp bass CPUE occurred off Encinitas, and San Clemente, Santa Catalina, Santa Rosa, and San Miguel islands.

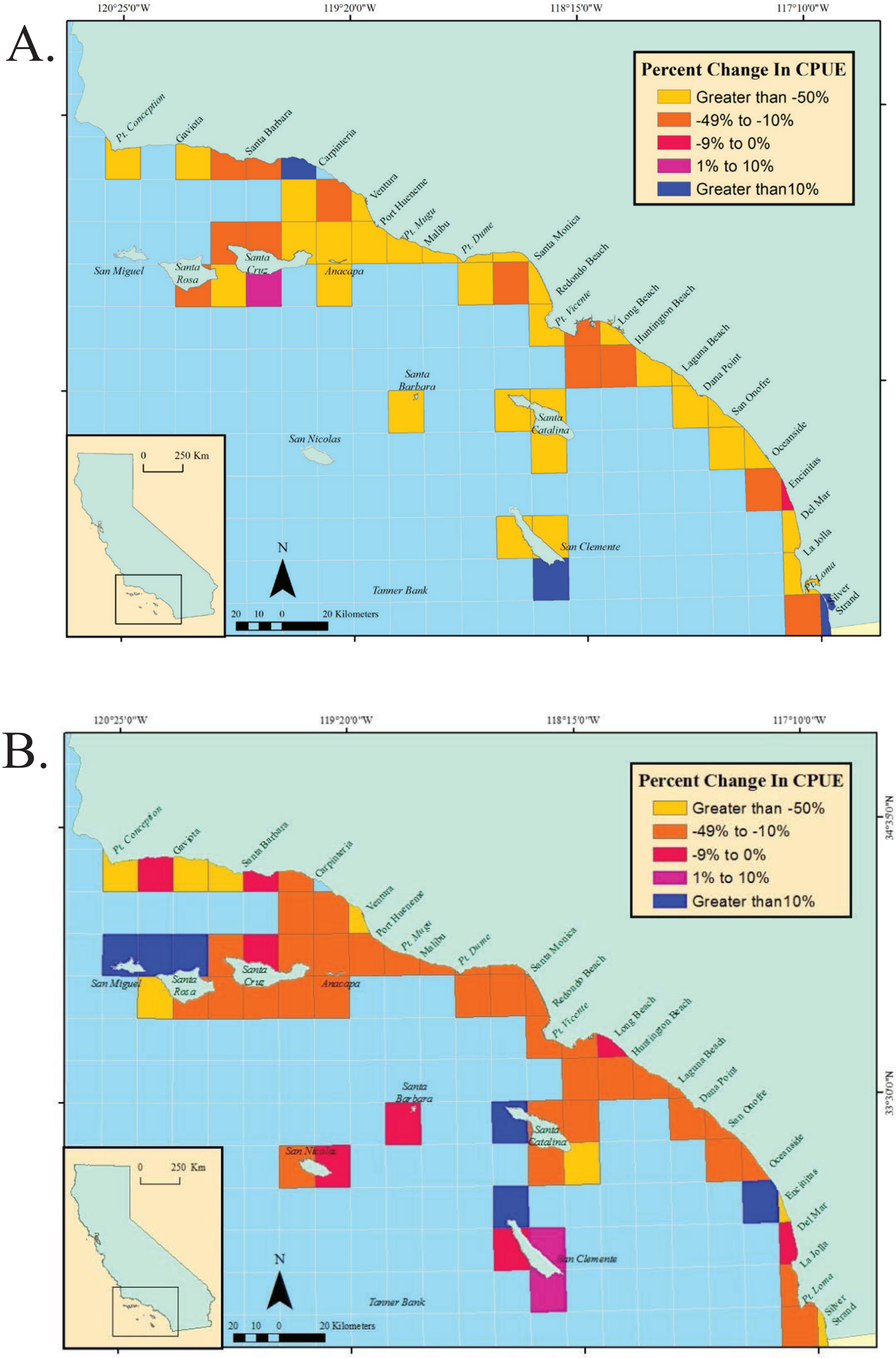

Figure 4.—Percent change in catch-per-unit-effort (CPUE) by fishing block during peak spawning season (June-August) for A) barred aand bass and B) kelp bass in southern California between the early (2000–2004) and late (2005–2012) 2000s. Data represent California Department of Fish and Wildlife commercial passenger fishing vessel logbook data.

Exploitation rates.—Using catch-at-length data, we constructed annual catch curves to investigate temporal trends in the annual rate of exploitation (*u*). Data from 1980 to 2012 were obtained from the MRFSS and CRFS from all fishing modes. Additional length data (1975–1978) were obtained from fish sampled on CPFV trips by CDFW biologists. Lengths were binned into 2.5 cm increments and the rate of exploitation was obtained from the slope of the regression line through the descending portion of the catch curve (instantaneous mortality rate, *Z*) and its relationship with the annual expectation of natural death (*v*), total annual mortality (*A*), and total annual survival (*S*) (e.g., $A=u+v$) where $S=e^{-z}$, $A=1-S$, and $v=MA/Z$. The natural mortality coefficient (*M*) was derived from Pauly's (1980) equation, using age and growth parameters (L_{inf}, *K*) reported in Love et al (1996b) and a mean annual water temperature of 17.0° C. For barred sand bass, $M=0.218$ and for kelp bass, $M=0.178$. The mean annual water temperature was derived from SST data obtained from the Southern California Coastal Ocean Observing System (SCCOOS) website (SCCOOS 2013); the annual mean was calculated from the average annual SST sampled at four stations within the SCB (Santa Barbara, Pt. Dume, Newport Beach, and La Jolla) from 1975 to 2012. Station data for Santa Barbara, Pt. Dume, and Newport Beach in 2011 and 2012 were not available, so these data were substituted with the automated SST data off Stearn's Wharf (Santa Barbara), Santa Monica Pier, and Newport Pier. Although simple regression analysis from catch curves may underestimate total annual mortality (Dunn 2002, Smith 2012), our analysis was focused on the relative change in exploitation rates over time.

The proportion of barred sand bass and kelp bass taken by fishing was lowest in 1976 and 1977 (Figure 5). The barred sand bass exploitation rate then increased to a peak in 1989, decreased in the 1990s, and was above the period mean for most of the 2000s (Figure 5a). Between 1977 and 2012, the exploitation rate of kelp bass increased by 14%

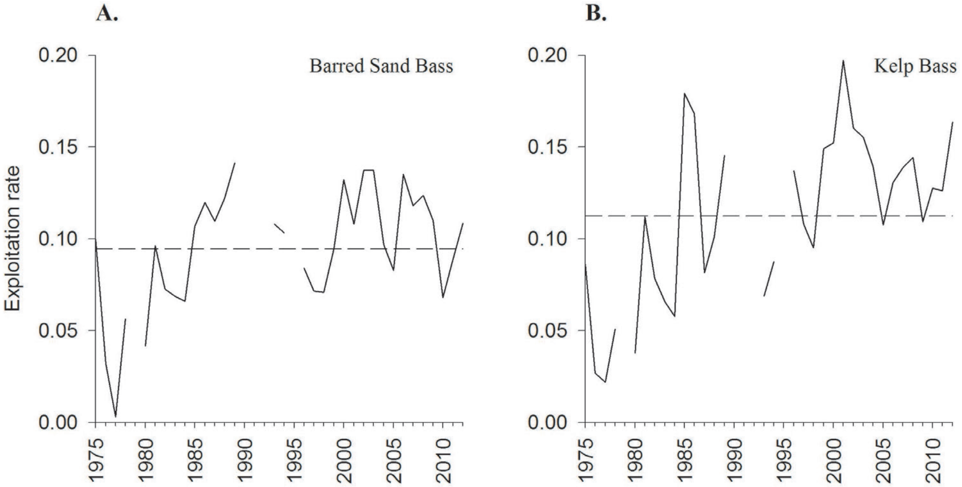

Figure 5.—Annual trends in southern California recreational fishery exploitation rates for A) barred sand bass and B) kelp bass from 1975 to 2012. Dashed lines represent the period means. See text for a detailed description of exploitation rate calculations. Lengths used to derive exploitation rates were obtained from California Department of Fish and Wildlife archives (1975–1978), the National Oceanic and Atmospheric Administration Marine Recreational Fisheries Statistics Survey (1980–2003), and the California Recreational Fisheries Survey (2004–2012).

and, like barred sand bass, was higher than the period mean for most of the 2000s (Figure 5b). Elevated exploitation rates of barred sand bass and kelp bass that occurred between 1999 and 2004 were coincident with increased CPUE observed in both fisheries (Figure 2, Figure 5). The exploitation rate for kelp bass has generally been higher than that of barred sand bass since 1996 (Figure 5).

Size composition of the catch.—To investigate evidence of overfishing, we plotted annual trends in the harvested length data from 1980 to 2012 for (1) percentage of catch that is mature; (2) percentage of catch at optimal length (L_{opt}); and (3) percentage of catch that is mega-spawners (Froese 2004). Ideally, 100% of the harvested catch should be mature and within ± 10% of L_{opt}, the size allowing for the highest yield by weight of the catch. However, because there is no maximum size limit to prevent harvest of larger barred sand bass and kelp bass, the harvested catch represented several size or age classes. In this case, a desirable size structure occurs when approximately 60–80% of the harvested catch is ±10% of L_{opt} and the remaining 20–40% are mega-spawner size (>[L_{opt}±10%]). If the percentage of mega-spawners declines to below 20%, this may be a sign of prolonged recruitment overfishing and a stock that is less resilient against population recruitment failure (Froese 2004).

Optimal size was estimated from natural mortality (*M*, see *Exploitation rates*, above) and growth parameters using the equation $L_{opt}=L_{inf} \times [3/(3+M/K)]$ (Beverton 1992). Size at first maturity (L_m), maximum length (L_{inf}), and the growth coefficient (*K*) were obtained from Love et al. (1996b). For both species, L_m=27.0 cm TL. For barred sand bass, L_{opt}=34.7 cm TL and for kelp bass, L_{opt}=35.1 cm TL. It is important to note that L_{opt} minus 10% for both species was slightly higher than the 30.5-cm (12-in) MSL during the analysis period; thus, the percentages of optimum size and mega-spawner individuals in the harvested catch did not always sum to 100% (Figure 6).

The percentage of the mature harvested catch was near, or at, 100% during the years examined, showing no signs of growth overfishing (e.g., depletion of mature individuals) of either species (Figure 6a, Figure 6b). The percentages of optimum size and mega-spawner individuals in the barred sand bass catch remained somewhat stable from 1980 to 2002 (Figure 6a). However, after 2002 the percentages of fish harvested at optimum and mega-spawner size decreased and increased, respectively, and became nearly equal at less healthy levels and remained there through 2012. The percentage of barred sand bass mega-spawners harvested exceeded the percentage of optimum size individuals in 2007 and again in 2012 (Figure 6a).

The size distribution of the kelp bass catch remained somewhat stable and within the ranges of a healthy fishery (Figure 6b). Although there were a few years when optimum size was less than 60% and the proportion of mega-spawners dipped below the 20% threshold, these fluctuations were short-term rather than following a long-term trajectory (Figure 6b). Likewise, the declining percentage of mega-spawners in the kelp bass catch since 2005 was most likely driven by a steady increase in fishery recruitment strength rather than long-term recruitment overfishing (see *Fishery recruitment*, below).

Fishery recruitment.—To gauge relative fishery recruitment strength over time, catch-at- length data were binned according to size-at-age (Love et al. 1996b). We calculated the proportion of the catch comprising the fishery recruits (e.g., the first two age classes), and converted the values to Z-scores. The Z-scores provided a relative index of abundance where scores greater than 1 and less than -1 indicated above and below average recruitment strength, respectively. Using a 30.5-cm (12-in) MSL, barred sand bass and kelp bass fishery recruits were approximately 5–7 years old. Fishery recruitment strength for barred sand bass

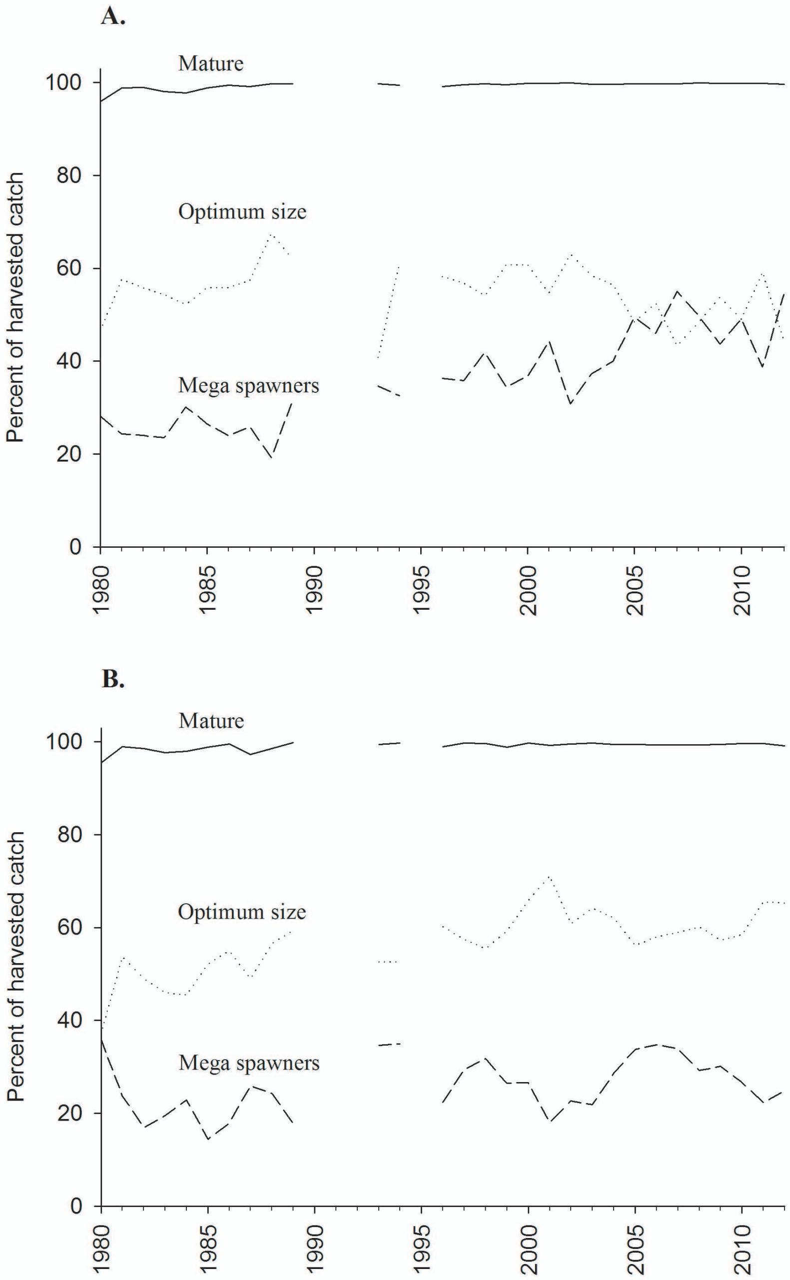

FIGURE 6.—Percentages of the harvested A) barred sand bass and B) kelp bass recreational catch in southern California comprised of mature, optimum size, and mega-spawner individuals from 1980 to 2012. Sizes (TL) for each category: mature, 270 mm (both species, Love et al. 1996b); optimum size, 312–382 mm for barred sand bass and 316–386 mm for kelp bass; mega-spawners, >382 mm for barred sand bass and >386 mm for kelp bass. See text for a description of optimum and mega-spawner size calculations. Length data were obtained from the National Oceanic and Atmospheric Administration Marine Recreational Fisheries Statistics Survey (1980–2003) and the California Recreational Fishery Survey (2004–2012).

and kelp bass was low in the late 1970s and high in the 1980s; however, fishery recruitment strength returned to below average from 2005 to 2008 (barred sand bass) and from 2005 to 2007 (kelp bass) (Figure 7a). From 2008 to 2011, kelp bass fishery recruitment strength steadily increased and was near average in 2012 (Figure 7a); barred sand bass recruitment dipped below average in 2010 and again in 2012 (Figure 7b).

For both species, the modal length (mm TL) of the catch was determined for each year of length data. During the mid-2000s, the modal length successively increased in the barred sand bass and kelp bass catch (Figure 7b). In effect, the fishery was sustained by a successively older and smaller population of fish for a consecutive 3-4 year period. This

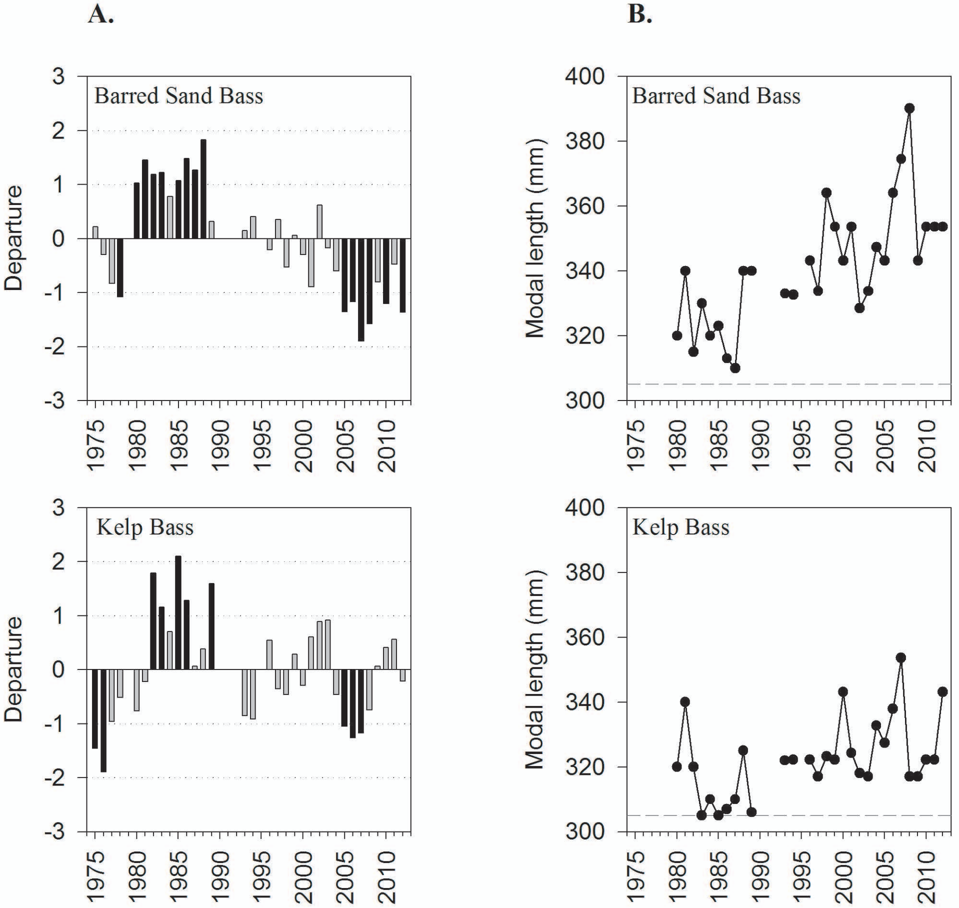

FIGURE 7.—Temporal trends in A) fishery recruitment and B) modal length of the legal, harvested catch for barred sand bass and kelp bass (1975–2012) in southern California. Fishery recruitment indices greater than 1 or less than -1 represent above and below average recruitment strength, respectively (darker bars). Dashed lines in right panels indicate length at harvestable size (= 305 mm) during the study period. Length data were obtained from California Department of Fish and Wildlife archives (1975–1978), the National Oceanic and Atmospheric Administration Marine Recreational Fisheries Statistics Survey (1980–2003), and the California Recreational Fishery Survey (2004–2012).

result was substantiated by the coincident and dramatic decline in harvested CPUE for both species and the increase in the percentage of mega-spawners in the catch (Figure 2, Figure 6).

We hypothesized that the decrease in barred sand bass and kelp bass fishery recruitment strength in the mid-2000s was due to decreased larval survival or recruitment and (or) decreasing numbers of adult bass. We examined temporal trends in larval abundance in the SCB to gauge relative larval recruitment strength during this period, and adult indices of abundance in scuba surveys to determine whether adult populations had substantially decreased prior to this period.

Temporal Trends in Fishery-independent Data

Larval abundance.—Average annual *Paralabrax* spp. larval abundance taken in the SCB during the California Cooperative Oceanic Fisheries Investigations surveys from 1951 to 2011 was obtained from the NOAA Fisheries Southwest Fisheries Science Center, La Jolla, CA; data from 2012 were not available. *Paralabrax* larvae could not be differentiated into species and include spotted sand bass. Densities were used as a measure of abundance, with numbers of larvae per 10 m^2 summarized by station and month according to their primary distribution during spawning season (Moser et al. 2001) and then averaged for the year. From 1951 to 2011, peaks in larval abundance frequently occurred during the 1980s and 1990s; the periods before and after consisted of sustained below-average abundance (Figure 8). From 1999 to 2003, *Paralabrax* larval abundance was consistently low (Figure 8) suggesting a period of population recruitment failure. This timing coincided with negative SST anomalies (1998–2001; Bjorkstedt et al. 2011) and higher adult exploitation rates (Figure 5).

Diver surveys of adults at the mainland.—Diver surveys of fishes have been

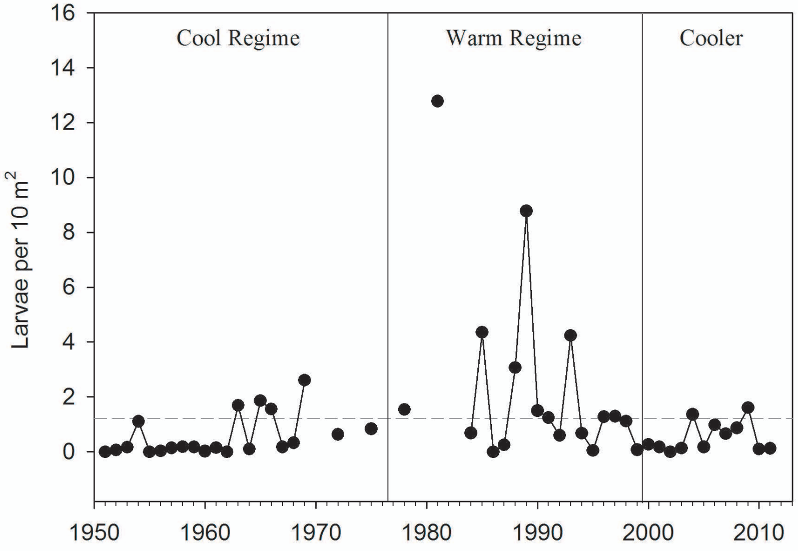

Figure 8.—Temporal trends in southern California *Paralabrax* spp. larval abundance by oceanographic regime from 1951 to 2011. Larvae include kelp bass, barred sand bass, and spotted sand bass. Dashed line represents the period mean. Oceanographic temperature regimes are indicated at the top of the figure and defined in the text. Data source: National Oceanic and Atmospheric Administration, Southwest Fisheries Science Center; 2012 data not available.

conducted from 1974 to the present at King Harbor in Redondo Beach, and off Palos Verdes (Love et al. 1996b). We obtained adult barred sand bass and kelp bass (>25.0 cm TL) densities (fish/transect) at both sites from the Vantuna Research Group at Occidental College, Los Angeles, California. Both survey sites contain biologically relevant habitat for both species, although the giant kelp habitat off PV typically contains more kelp bass than barred sand bass.

Abundances of both species at King Harbor closely followed trends in CPFV CPUE (Figure 2, Figure 9a, Figure 9b). From 2000 to 2004 (the years leading up to the period of below-average fishery recruitment), adult barred sand bass and kelp bass abundance was decreasing at both locations, albeit more so with barred sand bass (Figure 9a, Figure 9b). Barred sand bass abundance peaked twice at King Harbor, once in 1985 and again in 2000.

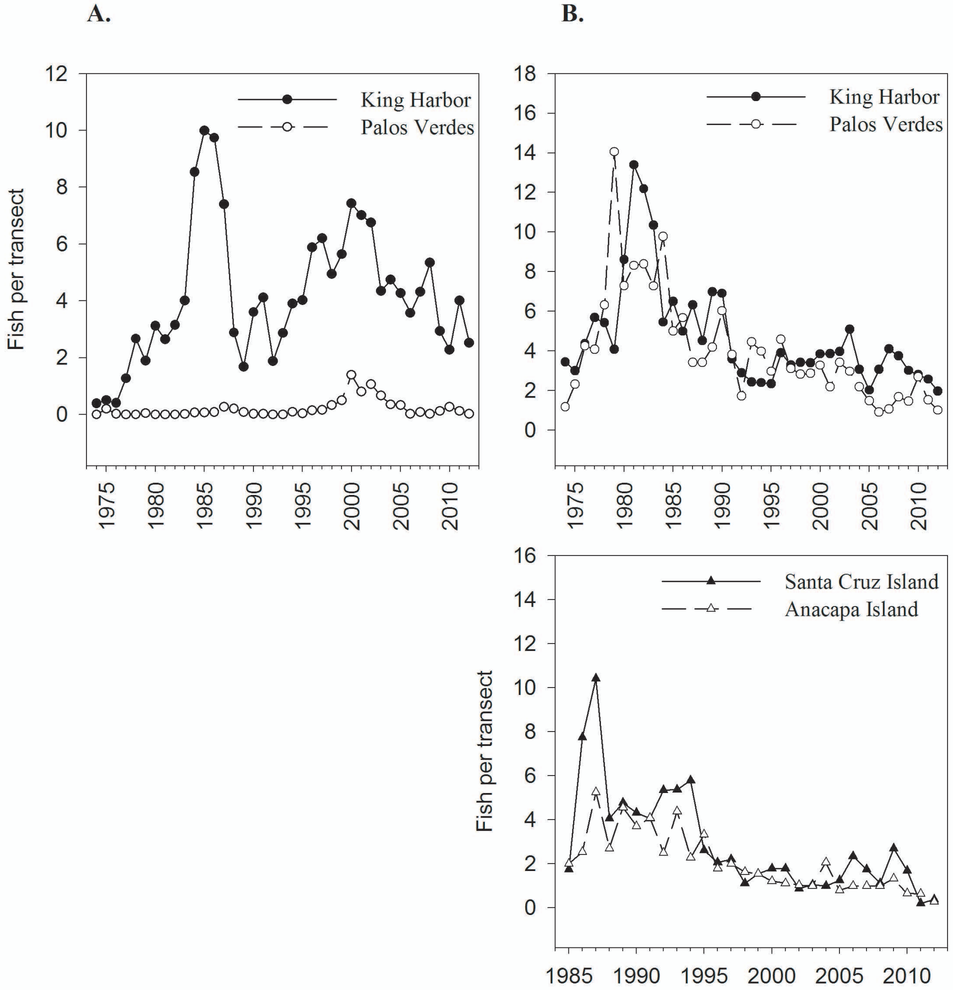

Figure 9.—Temporal trends in scuba transect densities of A) adult barred sand bass at King Harbor and Palos Verdes and B) adult kelp bass at King Harbor and Palos Verdes (top), and Santa Cruz and Anacapa islands, California (bottom). Data source: mainland transects (1972–2012), Vantuna Research Group, Occidental College; island transects (1985–2012), Kelp Forest Monitoring, National Parks Service.

Although barred sand bass abundances at the Palos Verdes site did not compare numerically to the King Harbor site, the Palos Verdes site also showed a peak in 2000 followed by a decrease through 2012 (Figure 9a). Kelp bass abundances at both locations increased into the early 1980s followed by a substantial decline by the early 1990s (Figure 9b). In all data sets, abundances of both species by 2012 were near or at the same lower level in the earliest part of the time series.

Diver surveys of adult kelp bass at the islands.—We also obtained Channel Islands Kelp Forest Monitoring kelp bass data from the National Park Service, Ventura, California for the years 1985–2010. Densities (fish/transect) of adult kelp bass (>25.0 cm TL) at Santa Cruz and Anacapa islands were highest in the 1980s before dropping off to low levels by the mid-1990s (Figure 9c). In contrast to the two mainland sites, adult kelp bass densities were somewhat stable (albeit at low levels) at the islands sites in the years (2000–2004) leading up to below average fishery recruitment.

Environmental relationships.—We conducted a time delay analysis using larval abundance, SST, and giant kelp canopy coverage data to determine whether these variables were a predictor of fishery recruitment strength. Correlation coefficients were calculated between these variables and fishery recruitment strength separately for barred sand bass and kelp bass. Bass fishery recruitment was measured as the annual proportion of the first two age classes in the harvested catch (see *Fishery recruitment*, above). Average annual SST was obtained from the SCCOOS website (SCCOOS 2013). Annual values of Region Nine Kelp Survey Consortium total giant kelp canopy coverage (km^2) were obtained for Orange County and San Diego County and summed (MBC 2012; data from the northern region of the SCB were only available from 2002 and were not included). We used the 17-yr period from 1996 to 2012 because it was a continuous time series spanning above and below average periods of bass fishery recruitment strength and the transition from warmer to cooler SSTs in the SCB. To account for autocorrelation present in the residuals of the kelp bass fishery recruitment data sets (Durbin-Watson test, k=1, α=0.05: $d_{1996\text{-}2011}$=0.76, $d_{1996–2012}$=0.83) and possible autocorrelation in the residuals of one of the barred sand bass fishery recruitment data sets ($d_{1996–2012}$=1.36), we used an adjusted degrees of freedom and critical value for r for testing correlations at zero to seven-year lags (Modified Chelton at N/5 lags; Pyper and Peterman 1998).

Trends in barred sand bass and kelp bass fishery recruitment strength showed significant, positive correlations with trends in *Paralabrax* larval abundance and coastal SSTs (Table 4). Bass fishery recruitment was most positively correlated with *Paralabrax* larval abundance and with coastal SSTs at five-year lags (Table 4). Barred sand bass fishery recruitment was negatively correlated with kelp canopy coverage at a six-year lag, and kelp bass fishery recruitment showed a very strong negative correlation with kelp canopy coverage at a five-year lag (Table 4).

DISCUSSION

This is the first in-depth fishery analysis conducted for the saltwater basses in several decades, documenting both long-term changes in fishery-dependent and fishery-independent indices of abundance, fishery size-at-catch and catch distribution data, exploitation rates, and relationships with environmental variables (SST and kelp canopy). Our analyses indicate the environment and fishing have affected saltwater bass populations in southern California for nearly a century. Episodic successful recruitment and early implementation of catch

Table 4.—Seven-year time-delay correlations between California saltwater bass (*Paralabrax* spp.) fishery recruitment and larval abundance, coastal sea surface temperature, and giant kelp canopy coverage from 1996 to 2012. Bold values indicate significant correlations relative to the $\pm r_{crit}$ significance level at $P<0.05$.

	Correlation Coefficient		
Common Name	Larval Abundance[a]	Temperature[b]	Giant Kelp[c]
Barred sand bass[d]			
0	-0.074	0.158	-0.332
1	-0.198	-0.257	-0.001
2	0.048	0.197	-0.016
3	-0.063	-0.202	-0.058
4	0.215	0.013	-0.146
5	**0.689**	**0.570**	-0.420
6	**0.625**	0.394	**-0.628**
7	**0.616**	0.114	-0.322
Kelp bass[e]			
0	-0.387	-0.359	0.236
1	-0.279	-0.110	0.433
2	-0.069	-0.135	0.325
3	0.124	-0.133	-0.131
4	0.359	0.189	-0.485
5	**0.788**	**0.602**	**-0.803**
6	**0.650**	**0.519**	-0.391
7	0.360	0.009	0.129

[a] California Cooperative Oceanic Fisheries Investigations *Paralabrax* larval abundance data (data include barred sand bass, kelp bass, and spotted sand bass; no 2012 data available).

[b] Mean annual sea surface temperature obtained from Southern California Coastal Ocean Observing System website (www.sccoos.org).

[c] Annual values of Region Nine Kelp Survey Consortium total giant kelp (*Macrocystis pyrifera*) canopy coverage for Orange County and San Diego (MBC 2012).

[d] r_{crit} values: larval abundance, 0.497; temperature, 0.524; giant kelp, 0.613.

[e] r_{crit} values: larval abundance, 0.556; temperature, 0.512; giant kelp, 0.701.

regulations managed to sustain the fishery for several decades. However, dramatic catch declines in recent years were attributed to a very critical period during the early 2000s when relatively high exploitation rates, combined with cooler-than-average SSTs, resulted in an overall decrease in bass availability and ultimately, recruitment overfishing. Overall CPUE and population declines began earlier with kelp bass (in the mid-1980s) than with barred sand bass (in the early 2000s). Our results suggest this earlier decline resulted from increased exploitation rates of kelp bass into the 1980s, combined with declines in giant kelp during the same period.

Interestingly, barred sand bass and kelp bass catches continued to rank among the top five species caught in southern California in recent years despite decreases in bass availability and fishing effort. This suggests an overall decline in the availability of nearshore sport fishes in the region. In fact, the total estimated southern California recreational catch declined by 44% between 2004 and 2012 (RecFIN 2013). Coastal power plant entrapment data also indicated region-wide declines in southern California's nearshore fishes, including non-game fishes, since the 1970s (Miller and McGowen 2013). The relative degree of anthropogenic and oceanographic influence on this trend for exploited fishes likely depends on the fishery. However, our findings on the saltwater basses do not substantiate the claim of bass fishery collapse due to overfishing (Erisman et al. 2011). Although there is little doubt that exploitation partly contributed to decreases in saltwater bass availability, we found no evidence of growth overfishing and no evidence of serial depletion (e.g., localized depletion due to fishing), the common trademarks of under-regulated hyperstable fisheries. Temporal trends in the catch distribution of barred sand bass and kelp bass indicated availability decreased over the entire catch range, rather than in isolated fishing areas.

Overall, the catch distribution for both species in southern California has remained relatively unchanged since the mid-1980s, as reported by Love et al. (1996a). In addition, nearly four decades of size composition data indicated a somewhat stable size or age distribution leading up to the recent catch declines. We believe the long-term sustainability (>90 years) of the saltwater bass fishery is largely due to the implementation of the size and bag limits in the 1950s, the subsequent reduction in the bag limit in 1975, and the return to warmer oceanographic conditions in the 1980s and 1990s.

The 1959 implementation of the MSL to correspond with size-at-maturity was a biologically relevant management tool that showed almost immediate and measurable effects in subsequent years. Although CPUE dramatically decreased again during the cool regime of the 1960s and 1970s, CPUE during the warm regime of the 1980s and 1990s increased, but never reached the historic maximum. This occurred despite major advances in fish-finding technology and navigational systems that should have otherwise yielded higher catch rates had the bass populations been as historically abundant. Thus, the exploitation rate just prior to the 1980s and 1990s was probably high. Indeed, during that earlier time the bag limit was higher and the overall bass population was probably smaller (Love et al. 1996a, Jarvis et al. 2010); the aggregate bag limit remained at 15 fish for 22 years (1951–1972), and then increased to 20 fish for an additional three years. The rapid decline in the exploitation rate between 1975 and 1978 probably reflects the bag limit reduction from 20 to 10 fish in 1975. Even though exploitation rates increased again in the 1980s and 1990s, this bag limit reduction, along with successful episodic recruitment, is likely responsible for sustaining the fishery into the next cool oceanographic regime.

The increase in exploitation rate from 1999 to 2002 may be explained by fishing effort shifts. During this period, CPUE for the saltwater basses was increasing and fishery recruitment levels remained stable during those years. Just prior, during the 1997–1998 El Niño, saltwater bass catches had dropped as larger, more desirable migrant fishes (e.g., yellowtail jack [*Seriola lalandi*]) became more available (Dotson and Charter 2001). After the El Niño, saltwater bass catches increased again as CPFVs shifted their effort back to the basses during the summer months. Winter saltwater bass fishing also increased, probably in response to the January–February moratorium on southern California nearshore and shelf rockfishes that began in 2000.

Although there is no fishery-independent index of adult saltwater bass abundance prior to the early 1970s, long-term fluctuations in CPUE and larval abundance indicate that saltwater bass populations fluctuated over time in response to changing oceanographic conditions, being relatively more abundant during warmer ocean conditions (Moser et al. 2001, Hsieh et al. 2005, this study). More recent declines appeared to have been influenced by increases in exploitation rates and coincident low larval abundances (population recruitment failure) during the ocean regime shift to cooler temperatures between 1999 and 2003. Kelp bass larval recruitment data collected via Standard Monitoring Units for the Recruitment of Fishes (SMURFs) at the northern Channel Islands from 1999 to 2003 also indicated a sustained period of kelp bass population recruitment failure (White and Casselle 2008), and Miller and Erisman (2014) reported especially low values of their southern California power plant entrapment young-of-the-year (YOY) index for kelp bass from 1998 to 2003 and for barred sand bass from 2000 to 2004. The subsequent fishery recruitment failure we identified in this study ultimately resulted in recruitment overfishing that occurred from 2005 to 2008, when CPUE dramatically declined and the modal length of the catch successively increased for 3–4 consecutive years. Consequently, the percentage of mega-spawners in the barred sand bass catch twice exceeded the percentage of optimum size individuals in recent years. Given that barred sand bass are targeted during peak spawning season and that fishery recruitment remains below average, this is especially a cause for concern.

The timing between the apparent barred sand bass and kelp bass population recruitment failure (1999–2003) and subsequent fishery recruitment failure (2005–2008) corresponds well with the significant time delay correlations we identified between bass fishery recruitment strength and larval abundance (5–7 year lag), and between fishery recruitment strength and SST (5–6 year lag). Moreover, our results are biologically meaningful since barred sand bass and kelp bass fishery recruits during the era of the 30.5-cm MSL ranged from five to seven years of age (Love et al. 1996b).

The positive correlations we reported between SST and fishery recruitment for both species corroborate previously published reports that cooler SSTs have negatively influenced *Paralabrax* larval abundance in southern California (Moser et al. 2001, Hsieh et al. 2005) and that warmer temperatures are more conducive to successful larval survival for barred sand bass (Gadomski and Caddell 1996). Miller and Erisman (2014) identified a positive correlation between SST and their southern California power plant entrapment YOY index for barred sand bass at a lag of 7 years, but no SST correlation was found for kelp bass. Although we reported strong positive correlations between SST and fishery recruitment of both species, barred sand bass may be especially sensitive to cooler oceanographic conditions than kelp bass; barred sand bass range from central California to southern Baja California, whereas kelp bass range farther north to Washington (Miller and Lea 1972). Likewise, although fishery recruitment for both species was negatively correlated with kelp canopy, kelp bass populations could be especially sensitive to changes in kelp habitat.

From 1950 to 1960, the giant kelp beds in southern California seriously declined (Quast 1968) and again after the oceanographic regime shift to warm water conditions in the late 1970s (Parnell et al. 2010). Holbrook et al. (1990) suggested that a prolonged period of regional giant kelp declines could result in a "recruitment bottleneck" that would eventually lead to a reduction in adult kelp bass density. Thus, despite more favorable oceanographic conditions for bass larval survival during the warm regime of the 1980s and 1990s, regional declines in giant kelp habitat most likely decreased larval settlement rates, which would have contributed to the observed declines in adult kelp bass catches a few years later. The declines we observed in fishery-independent indices of adult kelp bass abundance showed similar timing. As to direct impacts to adult kelp bass, we found that kelp bass fishery recruitment strength was negatively correlated with giant kelp canopy coverage at a five-year lag. This result is likely an artifact of temperature effects on larval survival, whereby favorable conditions (cooler years) for giant kelp are suboptimal for kelp bass larval survival. Nevertheless, our results also support previous studies. Holbrook et al. (1990) reported that densities of adult kelp bass were not strongly related to the density of giant kelp among reefs and that older kelp bass, unlike YOY, were common on reefs without giant kelp. And, White and Casselle (2008) showed a negative relationship between older kelp bass (age 1–2 yr+) and giant kelp densities, with larval supply being the only significant predictor of older kelp bass densities.

The increased kelp bass exploitation rate spanning 1993–2003 appeared to primarily affect mainland kelp bass populations as abundances of adult kelp bass at Anacapa and Santa Cruz islands remained somewhat stable while mainland abundances decreased again after 2003. We were not able to distinguish between exploitation rates at the islands when compared to the mainland, but recreational fishing pressure at the islands tends to be lower due to their greater distances from harbors. The only island to show a prominent decline in kelp bass CPUE after 2004 was Santa Catalina Island, and this was primarily in fishing blocks closest to the mainland.

Management changes implemented in 2013 could help offset recent saltwater bass catch declines by decreasing exploitation rates; however, it might take several years before regulation effectiveness can be addressed. The L_{opt}±10% size range we reported for barred sand bass (31.2–38.2 cm TL) and kelp bass (31.6–38.6 cm TL) is inclusive of the 35.6-cm (14-in) MSL implemented in 2013, but the fishery could also benefit from several years of strong larval or fishery recruitment, or both. Unfortunately, recent oceanographic data collected from the SCB indicate mixed-layer temperature anomalies remain below-average (Wells et al. 2013). Thus, continued active monitoring of fishery discard lengths, fishery recruitment indices, and the proportion of optimum and mega-spawner size individuals in the harvested catch will be important for determining whether further management action is necessary, especially for barred sand bass. In addition, continuing to obtain more robust reproductive (Jarvis et al. 2014) and age and growth estimates for the basses should enhance our ability to monitor stock resilience and sustainability of this historic, long-standing fishery in southern California.

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Aerial sardine surveys in the Southern California Bight

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Current survey indices used in annual stock assessments to manage the federal Pacific sardine (*Sardinops sagax caerulea*) fishery do not include nearshore sardine biomass in southern California waters. This survey uses direct observer estimates of sardine biomass in nearshore and offshore waters of the Southern California Bight to calculate an index of relative abundance. Surveys have been conducted since summer of 2012 and have continued through the spring and summer 2013 seasons. Aerial identifications of fish school species have been validated using boat sampling of aerial sightings, and demographic information obtained from collected samples. Additionally, habitat analyses compared sardine distribution with environmental variables (sea surface temperature and chlorophyll *a* concentrations).

Key Words: sardine, *Sardinops sagax caerulea*, Southern California Bight, aerial survey, fishery management

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Pacific sardine (*Sardinops sagax caerulea*; sardine) is an important commercial fishery off the Pacific coast of North America. Once the largest fishery in North America, it has rebounded from a stock collapse in the 1940s to rank among the top fisheries in California since the early 1990s. Two seasonally migrating stocks inhabit the waters of the California Current, a northern stock ranging from Punta Eugenia, Mexico to southern Alaska; and a southern stock from southern Baja California, Mexico to Point Conception, California (Felix-Uraga et al. 2004, 2005; Smith 2005). The fishery, as defined by the northern stock, has been federally managed since 2000 by the Pacific Fishery Management Council (PFMC) under the Coastal Pelagic Species Fishery Management Plan (PFMC 1998). Annual coast-wide harvest limits for the northern stock are derived from biomass estimates generated by an annual stock assessment (Hill et al. 2014). The stock assessment develops a population model that incorporates various data sources, such as age, other biological information, and multiple research surveys. Surveys have included daily and total egg production (DEPM, TEP) surveys conducted in the spring by the Southwest Fisheries Science Center (SWFSC) of the National Marine Fisheries Service (NMFS) in offshore waters within and around the Southern California Bight (SCB) and off the central coast of California (Lasker 1985, Lo et al. 2011); SWFSC coast-wide acoustic-trawl surveys (Demer et al. 2012); and an aerial survey in the Pacific Northwest conducted since 2009 by the northwest sardine fishing industry (NWSS; Jagielo et al. 2012). The sardine stock assessment has previously used aerial survey results from a spotter pilot survey, which was flown from 1985 to 2005 and covered the area from central California to Baja California, Mexico; however, this survey was removed from the assessment in 2007 (Lo et al. 1992, Hill et al. 2007).

The primary goal of our study was to collect data on distribution and abundance of sardine to ultimately determine a relative index of abundance for use in management. The survey added other pelagic species (CPS) such as northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicas*), and jack mackerel (*Trachurus sympetricus*) beginning with the summer season in 2013. These data were collected adapting previous aerial survey methods for use over southern California waters (Lo et al. 1992, Jagielo et al. 2012). In collaboration with the California Wetfish Producers Association (CWPA), we conducted daytime aerial surveys of southern California waters in 2012 and 2013, and included sampling effort in both open water areas and along mainland and island coastlines. The sampling of nearshore waters inside of 5.6 km from shore was important for two principal reasons: (1) in contrast to sardine aggregations typically observed in offshore, or open, waters of Washington and Oregon, sardine in California waters are more often seen in aggregations along the coast (Diane Pleschner-Steele, CWPA, personal communication); and, (2) no other survey adequately covers the coastal nearshore area within the 2.8-km range from shore. By covering nearshore areas, this survey can restore information about nearshore sardine abundance that was lost in removal of the spotter pilot survey from recent stock assessments. If results from future aging analyses indicate that the fish observed during the present survey are predominantly young recruits, the survey index would also constitute an index of recruitment. Through application of boat-sampling methods, we have not only sought to validate aerial species identification but also to collect data on size and age composition of sardine observed during the survey. Finally, data on environmental conditions such as sea surface temperature (SST; °C) and chlorophyll *a* concentrations associated with sardine observations were collected and mapped to characterize sardine habitat.

Materials and Methods

Study areas.—Our survey was conducted in waters off southern California, from near Point Conception to the U.S.-Mexico border, extending to approximately 120 km offshore. Specifically, the study area was defined by a straight line from Point Conception south to the western edge of California Department of Fish and Wildlife (CDFW) fishing block 657, south to block 732, and continuing southeastward from the southwest corner of block 732 to the southwest corner of block 884, along the southern boundary of block 884 to the southwest corner of block 878 and extending to the mainland (Figure 1).

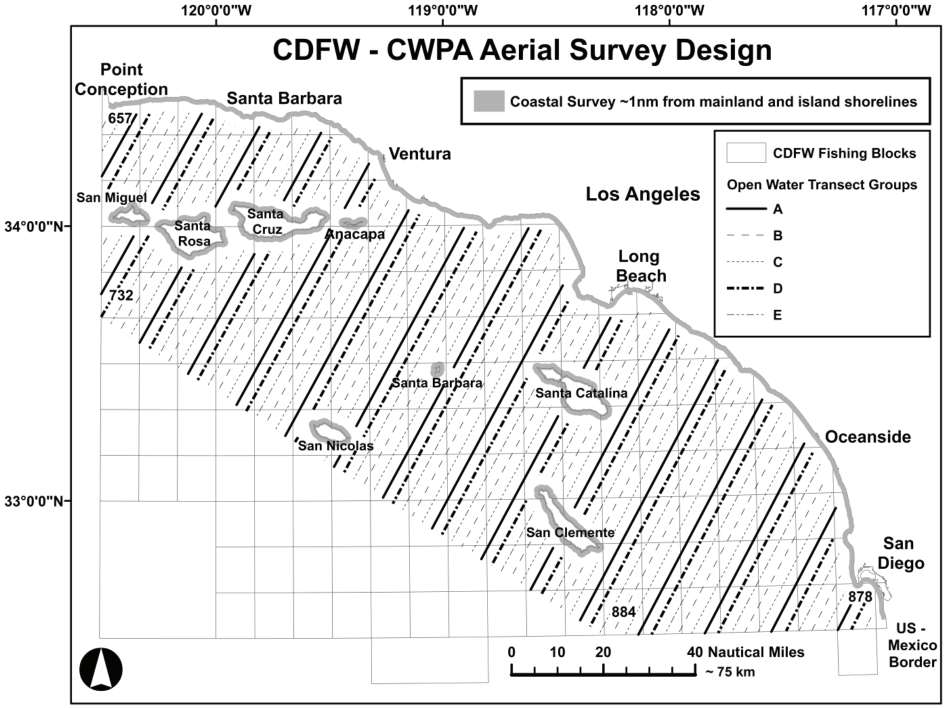

FIGURE 1.—Sampling design for aerial sardine surveys on coastal and open water transects in the Southern California Bight during 2012 and 2013. The surveys included coastal areas of the mainland and Channel Islands in the Southern California Bight, in addition to 16 open-water transects extending from shore. Open-water transects (Groups A-E) for random selection were arranged in five staggered groups separated by three nautical miles (~5.6 km). Group A was flown in summer 2012, and Group D in both spring and summer 2013.

The survey included two types of transects, one for the nearshore coastal area and one for the offshore open water area (Figure 1). For each season, transects were flown only once. Nearshore coastal transects were flown along the coastlines of the mainland and each of the Channel Islands, and were 1.8–2.8 km offshore, depending on the presence of macroalgae and variable contours of the coastline. Coastal transect width extended to the shore, except where visibility was limited by macroalgae. Open water transects were flown along sixteen transect lines spaced 27.8 km apart, originating at 5.6 km from the mainland and extending offshore to the outer Channel Islands. Open water transects were specifically designed to avoid intersection with coastal sampling areas; if these transects passed over islands, they ended and resumed at 5.6 km from island shorelines. Ocean surface area that did not fall either within the defined coastal sampling area of 1.8 km from shore, or within a 2.8-km strip on one side of an open water transect line was considered to be unsampled open water area.

We surveyed in summer (July–August) 2012, spring (April–May) 2013, and summer (August–October) 2013. The summer 2012 survey design used Group A for the open water transects (Figure 1). In 2013, open water transects were randomly chosen from 5 options: the 2012 design (Group A) and four others (Groups B, C, D, and E) based on offsetting the Group A transects by 5.6-km increments. Group D was selected for both the spring and summer 2013 surveys.

Aerial surveys.—Timing and selection of transects to be flown during a field season were dependent on weather conditions and availability of staff and aircraft. For a chosen flight day, the determination of which specific transects were to be flown was contingent on local weather conditions and military and other airspace restrictions that day. Strip transects were flown using a CDFW Partenavia P.68 observer aircraft with an experienced industry spotter pilot serving as observer looking to the right. Coastal transects were flown at 325 m altitude to maximize observer identification, and open water transects at 650 m to maximize observer coverage and transect width. When fish schools were identified and confirmed, the aircraft was redirected directly over the fish. Photos were taken with a forward motion compensating (FMC) Nikon D700 camera system oriented downward through the open belly port of the plane. Images were taken at 60 percent photo overlap during the summer 2012 and spring 2013 seasons, and at 80 percent overlap for the summer 2013 season. The camera system software was interfaced with a GPS unit to record time, location, speed, altitude, and other information with each image taken. We recorded on a log sheet the time and frame number when photos of fish were being taken, the observer-estimated number of schools and metric tonnage (mt), including percent species composition of mixed schools, and other relevant comments such as weather, viewing conditions, and plane actions. Photos were used to supplement field notes for school location, size, and count. Additional schools seen on photos were verified with the observer, and if confirmed, were added to field-collected data and included in analyses. After observed schools were photographed, the plane and crew returned to the transect flight line path and resumed the survey. Starting in summer 2013, at the conclusion of each flight day on which fish were observed, we reviewed the photos and identified and matched those photos with log sheet information on time, location, and estimated mt and numbers of schools.

Boat sampling.—Separate flights from the transect flights were paired with boat-based sampling of CPS schools observed from the air. Boat surveys were guided by aircraft observations of CPS to specific areas for sampling. For both 2012 and 2013, we sampled in waters off Santa Catalina Island and off the northern Orange County coast. We used an 8.2-m Almar rigid hull inflatable vessel equipped with two 200 HP Yamaha marine outboard engines. Underwater video and hook-and-line sampling methods were used to validate aerial observer identification of species, and to provide information on size, maturity, and age of the observed fish. The 2012 sampling was done using a Deep Blue Pro Color tow camera and hook-and-line gear. Due to challenges from the tow camera disrupting fish behaviors and also to poor image visibility, beginning in 2013 video sampling was done by divers using a GoPro black edition (12 mp, F/2.8, 1080p) camera. Hook-and-line samples were collected using sabiki rigs with sizes 4, 6, and 8 hooks. A Secchi disk was used to determine water clarity, and a Bio Marine model ABMTC refractometer was used to measure salinity and specific gravity of the water. We also collected information on SST, temperature at depth, school density at relative depths, and water depth from SONAR. Sampled fish were bagged, tagged according to school, and preserved in ice for lab work. Once in the lab, we processed samples and recorded weight, length, sex, maturity, and age data (Yaremko 1996). Aerial species identifications were noted and compared with results of boat sampling.

Data analyses.—We calculated separate estimates of abundance for each season based on transect type. Estimates of abundance for mainland areas were the observer estimates in the field. Abundance estimates and standard errors for both island and open water areas were calculated using islands (n=8) and open water transects (n=16) as sampling units, respectively. The coastal mainland and island transects were considered to be a census of those areas, and we extrapolated the densities seen on the open water transects out to the entire open water area covered by those transects. We used 1.8 km as the coastal transect width and 2.8 km as the open water transect width. These were determined in consultation with the observer, as best representing the visible range and thus width of the survey strip for each type of transect.

Standard errors were calculated from estimates of variance for sampling with variable transect lengths (Buckland et al. 2001). We used R statistical software (Version 3.0.0) to run statistical comparison tests to determine if transect type (coastal mainland, coastal island, and open water) made a significant difference for any of three variables (mt, school count, and average school size) for each season and paired-season combination. The data failed to meet assumptions for ANOVA, so we tested for significance within season variables with a Kruskal-Wallis Rank Sum Test (Kruskal and Wallis 1952). Significant results from this test were then run through a Mann-Whitney *U* Test with Bonferroni correction to identify the source of the significant differences (Mann and Whitney 1942, Abdi 2007).

Habitat mapping.—Sea surface temperature and chlorophyll *a* (mg/m^3) were used as measures of habitat characteristics associated with the fish school observations. These data were collected from the NASA Aqua MODIS sensor, and were obtained by download from the NOAA Coastwatch website (http://coastwatch.noaa.gov/). Sea surface temperature data were downloaded as grid data at 0.0125 degrees resolution for daytime Western US coverage in a .nc file format suitable for import into ESRI ArcMap 10.1. For each fish school observation, SST or chlorophyll *a* data were selected based on the minimum temporal duration available for that observation date. In most cases, intraday or three-day average data were available; however, in a small number of cases, eight-day average data were used. Field data on sardine location, SST, and chlorophyll *a* were then imported and mapped in ArcMap 10.1 to determine the value of SST or chlorophyll *a* located nearest to each fish school observation. For those fish school observations that did not fall directly within a SST or chlorophyll *a* grid cell, the value of SST or chlorophyll *a* nearest each such observation was used.

Results

Aerial surveys.—A total of 105 observations (observations = positive fish sightings) were made (Table 1) on sardine and other CPS aggregations during the three combined seasons of summer 2012, spring 2013, and summer 2013. These sightings were predominantly nearshore (Figure 2), with 90 of 105 (86%) of total observations occurring within coastal areas. Of these 90 coastal observations, 60 (67%) were made along the mainland and 30 (33%) were made along islands. Across all three seasons, island coastal observations were made primarily around Santa Catalina (9), Santa Cruz (8), and San Clemente (7) islands. Flights at Anacapa, San Nicolas, and Santa Barbara islands yielded two observations each and no observations were made near San Miguel Island. Observations were either single-school observations or multiple school observations. More than half (57; 54%) of all observations were single-school observations. Biomass estimates for these schools ranged from 0.5 to 80 mt. More than half of all single-school observations (29) were ≤5 mt and 81% of single-school observations were ≤15 mt.

Table 1. —Aerial observation data for the first three seasons of surveys conducted in the Southern California Bight during 2012 and 2013. Observations include single or multiple schools and estimates of tonnage are metric tons. Variation in open-water sampled areas exists because some transect segments could not be flown as a result of adverse weather conditions.

	2012 Summer	2013 Spring	2013 Summer
Number of observations	34	27	44
Estimated metric tons (observer)			
Mainland	5,069	1,186	5,362
Island	1,475	213	333
Open water	3,020	1,133	24
Total	9,564	2,531	5,718
Estimated schools (observer)			
Mainland	208	37	476
Island	97	12	44
Open water	101	17	6
Total	327	66	526
Average metric tons per school			
Mainland	24	32	11
Island	15	18	8
Open water	30	67	4
Total	29	38	11
Range of estimated metric tons per observation	1 - 3,053	1 - 1,146	1 - 3,426
Sampled Area (km^2)			
Mainland	864	864	864
Island	889	889	889
Open water	3,816	3,810	3,728
Total	5,569	5,563	5,481
Density (metric tons/km^2)			
Mainland	5.9	1.4	6.2
Island	1.7	0.2	0.4
Open water	0.8	0.3	0.006
Total	1.7	0.5	1.0

Twenty-eight single-school observations occurred along the mainland, 17 occurred off islands and 12 occurred in open water areas. Multi-school observations comprised the balance of the data set (48; 46%), with school counts per observation ranging from 2 to 366 schools and estimated biomass ranging from 1 to 3,426 mt. The majority of multi-school observations (37) consisted of 10 schools or fewer and all but three were observed along coastal areas; of these, 32 observations were from mainland transects, and 13 were from island coastal transects. Only three multi-school observations occurred in open water. Of the six largest pure sardine observations, ranging from 1,000 to 3,426 mt, three were observed along the mainland coast, two in open water and one along an island coast (San Clemente).

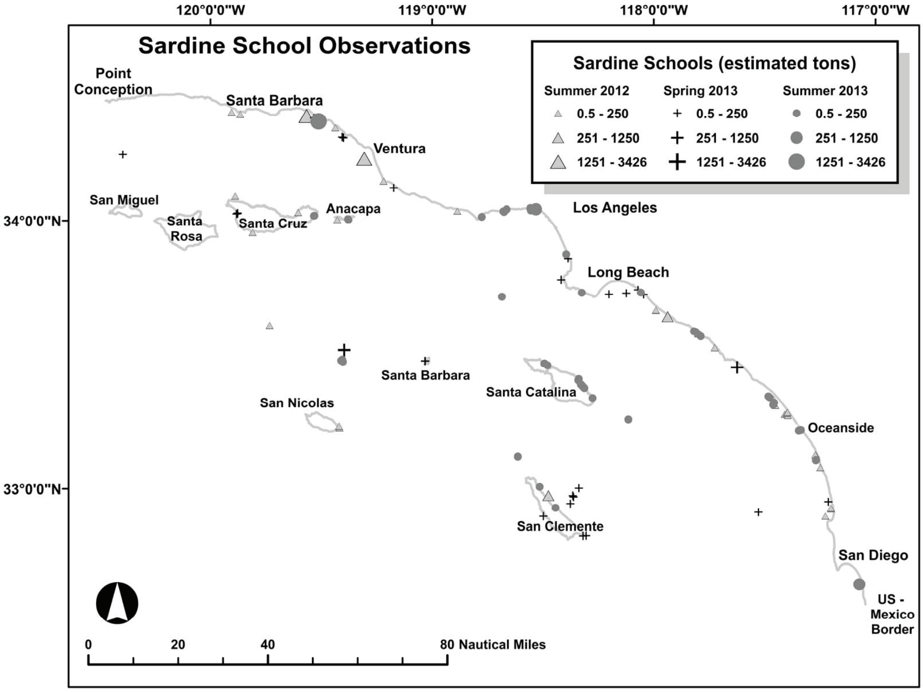

Figure 2.—Locations of sardine schools observed during aerial surveys in the Southern California Bight during 2012 and 2013. The largest schools were seen on the coastal shoreline between Santa Barbara and Ventura.

With respect to mixed CPS-sardine aggregations, sardine-anchovy mixes were observed along the mainland, while sardine-Pacific mackerel mixes were observed around island coasts at Santa Catalina and San Clemente. Two extremely large sardine-anchovy aggregations — in excess of 3,000 estimated mt of sardine in each case — were observed along the mainland coast between Santa Barbara and Ventura during summer 2012 and summer 2013, respectively.

During the summer 2012 season, nine survey flights were conducted from 30 July to 17 August, yielding 34 observations comprising 327 sardine schools and a total observer-estimated biomass of 9,564 mt (Table 1). Of the 34 seasonal observations, 32 (94%) were coastal, with 25 made along the mainland coast and 7 along island coasts. Most of the mainland observations (19) were made along the southern half of the coast south of Redondo Beach, Los Angeles County. Only two open water observations were made during this season. Noteworthy was the occurrence of four observations estimated at >1,000 mt and up to ≈3,000 mt. An extremely large aggregation estimated at 3,000 mt was observed along the mainland coast off Punta Gorda, Santa Barbara County.

For the spring 2013 season, during eight survey flights conducted between 22 April and 21 May, 27 observations were made on 66 sardine and mixed CPS schools estimated to comprise 2,531 mt. Of 27 observations, 20 (74%) were noted as coastal, with 12 of 20 near the mainland and eight near islands. For the seven open water observations, one was noted as consisting of 8–10 schools estimated at 1,000 mt.

The summer 2013 season was plagued with unfavorable weather conditions (persistent overcast, high winds), in addition to the challenge of flying around airspace restrictions. During 12 flight days from 1 August to 4 October, 44 observations were made, consisting of 520 schools estimated at 5,718 mt. During this season, CPS other than sardine were formally included in the survey, and aggregations were noted for sardine mixed with Pacific mackerel or northern anchovy. Total sardine biomass for these schools was estimated at 5,718 mt.

Boat sampling.—Sardine schools proved very difficult to locate and sample by boat during daytime hours. Commercial fishery landing records (CDFW Commercial Fisheries Information System [CFIS]) and personal communications with fishery participants indicated that sardine and mixed CPS schools were captured by the fishing fleet at night around Santa Catalina Island during our study periods. During the time periods of our study, more single-species and mixed Pacific mackerel and northern anchovy schools were observed during the day relative to sardine schools.

During summer 2012, six schools were examined around Santa Catalina Island and the Seal Beach, Orange County, breakwall from surveys conducted 7–8 August and 27 September (Table 2). Site conditions averaged 21.7° C SST with up to 12.2 m of visibility, and underwater footage was best on 7 and 8 August. At Santa Catalina Island, five mixed CPS schools were positively identified using frame-by-frame underwater footage at depths

Table 2.—Comparison of aerial fish species identifications with species identified by boat sampling techniques in the Southern California Bight. These paired plane-boat surveys were conducted around Santa Catalina Island, with the exception of the second rows for 27 September 2013 and 27 April 2013 off Seal Beach, and for the last two rows for 18 October 2013 off Huntington Beach Pier. There were no attempts to sample the last two aerial sightings on 18 October 2013 because of extreme surface water conditions. Samples were taken for additional lab work to characterize sardine at the time of the surveys. PS = Pacific sardine, PM = Pacific mackerel, JM = jack mackerel, NA = northern anchovy.

		Boat ID			
Date	Aerial ID	Dive ID	Video ID	Hook and Line ID	Samples Taken
8/7/2012					
	PM, PS	-	UNID	PM, JM	5PM
	PM, PS	-	PM, JM	PM, PS	2PM, 1PS
8/8/2012					
	PM, PS (mostly PM)	-	UNID	PM, JM	05PM, 1JM
	PM, PS	-	PM?, PS?	PM, JM, Blacksmith	9PM, 1JM
9/27/2012					
	PS, PM? (mostly PS)	-	PM, PS	PM	0
	PS, NA	-	-	lizardfish, croaker, smelt spp.	0
4/27/2013					
	Mackerel (mixed?)	PM, PS	PS, PM	PM, JM, Blacksmith	0
	NA	None	None	NA	0
5/2/2013					
	Mixed	PS	PS?	PM, PS, JM	0
	Mixed	PM, PS	PS?	PM, PS, JM	4PM, 2PS, 1JM
10/18/2013					
	Mixed, mostly PM, some PS	PM, JM, a few PS under boat	PM, JM	PM, JM	1PM, 2JM
	Mostly PM	PM, JM	PM, JM	PM, JM	20PM, 4JM
	NA	None	None	None	0
	NA	None	None	None	0

ranging from 9 to18 m ($\bar{x}$ = 10.7 m) and results from hook-and-line sampling. Overall site depths at Santa Catalina Island and Seal Beach ranged from 7.6 to 31.1 m. Depths of school and overall site depths were confirmed by SONAR images.

On 7 August 2012, one sardine was caught using a sabiki rig size 8 hook on the backside of Santa Catalina Island near Eagle Rock. Despite aerial identification of a sardine/anchovy mixed school on 27 September, green, murky conditions as well as buoyed traps at the Seal Beach breakwall made it difficult to capture them with underwater footage or hook-and-line methods. Species caught incidentally and released by hook-and-line during the three days of boat sampling included: Pacific mackerel, California lizardfish (*Synodus lucioceps*), blacksmith (*Chromis pinctipinnis*), jack mackerel (*Trachurus symmetricus*), white croaker (G*enyonemus lineatus*), and jacksmelt (*Atherinopsis californiensis*).

During 2013, eight schools were observed around Santa Catalina Island, Huntington Beach Pier (Orange County), and the Seal Beach breakwall (Orange County). Boat sampling was conducted on 27 April and 2 May during the spring, and on 18 October as a follow-up to the summer 2013 portion of the survey. Site conditions averaged 18.8 °C with visibility up to 15.0 m, and underwater footage was best on 2 May and 18 October. At Santa Catalina Island, five mixed CPS schools were positively identified by divers, frame-by-frame underwater footage at depths ranging from 7.6 to 15.2 m ($\bar{x}$ = 11.4 m), and results from hook-and-line catches. Overall site depths at Santa Catalina Island, Huntington Beach, and Seal Beach ranged from 6.1 to 76.2 m. School depths and overall site depths were confirmed by SONAR pictures.

Aerial confirmation of northern anchovy was established by hook-and-line catches outside the Seal Beach breakwall for the spring 2013 survey on 27 August. However, aerial identification of northern anchovy around Huntington Beach Pier on 18 October was not confirmed on the boat due to windy and choppy conditions. For surveys on 2 May and 18 October at Santa Catalina Island, Pacific mackerel, sardine, and jack mackerel were caught by hook-and-line; these samples confirmed aerial identification of mixed schools of sardine and Pacific mackerel. Blacksmith was also caught incidentally and released.

Results from the boat sampling were generally consistent with CPS schools identified from the aircraft (Table 2). For the 2012 boat surveys, species identification of five of six schools (84%) identified by plane were confirmed by boat sampling; in 2013, all six schools were confirmed. Two additional anchovy schools in summer 2013 were identified from the aircraft, but boat sampling was not attempted due to rough waters. In some cases, positive identification of species was difficult due to poor video quality or potentially insufficient sampling by hook-and-line.

Data analyses.—Overall sardine biomass estimates have declined since the first season in summer 2012 (Table 3). Mainland biomass has remained relatively constant over the two summer seasons, but estimated biomass for island and open water areas greatly declined across all seasons. Large standard errors are due to the small number of sampling units, but the estimates still illustrate a decline in observed abundance.

The Kruskal-Wallis test revealed three season-variables as significant: summer 2013 mt, summer 2013 school count, and (spring 2013+summer 2013) school count (Table 4). This result indicated that within these season-variables was a pair of transect types that differed significantly. Subsequent Mann-Whitney multiple comparison tests with a Bonferroni correction revealed significant differences between coastal mainland and open water data for summer 2013 mt, summer 2013 school count, and (spring 2013+summer 2013) school count (Table 5).

TABLE 3.—Sardine biomass estimates by transect type and season in the Southern California Bight during 2012 and 2013. Mainland estimates are from single-survey replicates. Island and open water estimates and standard errors are calculated from multiple sampling units per season (individual islands and open water transects, respectively).

	Biomass estimates (mt)		
Location	2012 Summer	2013 Spring	2013 Summer
Mainland	5,069	1,186	5,362
Island (*n*=8)	1,475	213	333
Standard error	957	194	196
Open water (*n*=16)	23,321	8,501	199
Standard error	25,085	8,107	136

Season	Variable	KW χ2	*df*	*P*
Summer 2012	Tons	1.85	2	0.40
	School count	0.51	2	0.77
	Mean school size	2.10	2	0.35
Spring 2013	Tons	0.55	2	0.76
	School count	0.55	2	0.76
	Mean school size	1.38	2	0.50
Summer 2013	Tons	8.47	2	< 0.05
	School count	7.74	2	< 0.05
	Mean school size	3.82	2	0.15
Summer 2012 + Spring 2013	Tons	0.96	2	0.62
	School count	0.27	2	0.88
	Mean school size	2.66	2	0.26
Summer 2012 + Summer 2013	Tons	4.28	2	0.12
	School count	3.84	2	0.15
	Mean School Size	3.08	2	0.21
Spring 2013 + Summer 2013	Tons	3.12	2	0.21
	School count	7.47	2	< 0.05
	Mean school size	0.61	2	0.74

TABLE 4.—Results of Kruskal-Wallis tests comparing season-variables for transect types (nearshore coastal and open water) from aerial sardine surveys conducted in the Southern California Bight during 2012 and 2013.

Table 5.—Mann Whitney *U* test results for significance among transect types for season-variables from aerial sardine surveys conducted in the Southern California Bight during 2012 and 2013. A Bonferroni correction was applied, resulting in α=0.0167.

Season	Variable	Comparison	*W*	*P*
Summer 2013	Metric tons	Coastal Mainland v. Coastal Island	118.5	0.1098
		Coastal Mainland v. Open Water	117.5	< 0.0167
		Coastal Island v. Open Water	69.0	0.0660
	Schools (*n*)	Coastal Mainland v. Coastal Island	123.0	0.1209
		Coastal Mainland v. Open Water	114.0	< 0.0167
		Coastal Island v. Open Water	60.0	0.1307
Spring 2013 + Summer 2013	Schools (*n*)	Coastal Mainland v. Coastal Island	303.5	0.0910
		Coastal Mainland v. Open Water	325.5	< 0.0167
		Coastal Island v. Open Water	178.5	0.2343

Habitat mapping.—Sardine were observed in warmer waters during the summer 2012 and 2013 seasons compared to the spring 2013 season (Table 6). The observations during spring 2013 were also associated with higher productivity, based on chlorophyll *a* levels.

Table 6.—Number of sardine schools and associated sea surface temperatures and chlorophyll *a* concentrations observed during aerial surveys conducted in the Southern California Bight during 2012 and 2013.

SST (°C)

Date	*n*	Mean	Median	Range	
				Low	High
Summer 2012	34	20.8	21.2	17.3	23.1
Spring 2013	27	16.2	16.1	12.1	19.1
Summer 2013	44	20.5	20.5	18.6	22.9

Chlorophyll *a* (mg/m^3)

Date	*n*	Mean	Median	Range	
				Low	High
Summer 2012	34	3.9	1.3	0.3	23.4
Spring 2013	27	35.9	4.1	0.3	367.1
Summer 2013	44	0.9	0.8	0.2	2.6

Discussion

We found much higher density and larger aggregations of sardine in the coastal waters of the Southern California Bight than in offshore open water areas (Figure 2, Table 1, Table 5). The high percentage of coastal observations within 0.54 km of the mainland and island coasts indicates that this survey provides a unique window into nearshore sardine and mixed CPS distribution and abundance not accounted for by other surveys. In particular, mainland coastal areas yielded the largest number of observations within and across seasons. On a seasonal basis, the two summer seasons showed higher school counts and biomass than did the spring season. However, the relatively low frequency of open water observations does not mean open water areas are lacking in abundance of sardine or other CPS. Rather, it is probable that schools are typically below some visibility threshold in deeper waters and not detectable during daylight hours (N. Lo, NMFS, personal communication), and may also reflect a tendency for sardine to be at depth during the day (Giannoulaki et al. 1999) and thus more available for sampling at shallower depths at night (Krutzikowsy and Emmett 2005). Our observations of sardine primarily in specific nearshore areas corresponds with commercial landings of sardine during the time of our surveys, especially off the northern coastal areas near Ventura, Ventura County, for both summer seasons (CFIS).

Aerial species identification of fish was consistent with identification from boat surveys. Additional sampling for pure sardine schools and other species such as northern anchovy would help establish aerial identification accuracy across a broader range of species. Also, a more varied geographic range for boat sampling, such as off the north coast or one of the northern Channel Islands, would be helpful, as logistics allow. Further attempts to collect greater numbers of sardine samples across more of the study area would better describe the demographics of sardine at the time of the survey, and inform size and age selectivity within the assessment model used for management.

We observed sardine in relatively warmer SST conditions (>17°C, Table 6) in both summer 2012 and 2013 compared to spring 2013. This is consistent with a habitat model for sardine developed by Zwolinski et al. (2011), which indicated the suitability of the SCB environmental regime during summer for the southern stock. Felix-Uraga (2004, 2005) proposed using temperature to partition commercial landings into northern and southern stocks. Much of the northern stock migrates northward during a transitional period during May and June as surface temperatures increase (Emmett et al. 2005). The results from the spring 2013 survey (median SST=16.1°C, range 12.1–19.1°C) suggest a mixed group of northern and southern stock sardine; this may be due to northern stock sardine in the process of their northward migration. Our results can be used to determine the presence of sardine in SCB waters at specific times of the year and under specific environmental regimes. This information can help apportion commercial sardine landings information to the appropriate stock, for use in stock assessment modeling. Allocation of catch to stock has been done (Demer and Zwolinski 2014) by applying habitat models and SST data to catch data. These stock differentiation studies based on environmental factors can supplement other work that distinguishes stocks based on other factors, such as otolith morphometrics (Felix-Uraga et al. 2005, Javor et al. 2011).

Chlorophyll *a* values associated with sardine observations were lower in both summer 2012 and 2013 compared to the spring 2013. Other studies have indicated chlorophyll *a* levels tied to both sardine landings (Lanz et al. 2009, George et al. 2012) and recruitment (Gomez et al. 2012), with evidence showing a stronger relationship between chlorophyll *a* and fish abundance than with SST (Lanz et al. 2009). Our results showed no relationship between SST or chlorophyll *a* levels and abundance, but with more data over time may serve as a measure of sardine-habitat associations, especially for nearshore areas.

The spotter pilot index that was formerly used in the sardine stock assessment was no longer considered suitable for the assessment in 2007 for a number of reasons (Hill et al. 2007). In addition to reduced sampling due to less usage of spotter pilots, there were difficulties in reconciling the results with other research surveys within the assessment model. There were also concerns over the lack of a formal survey design, since it did not have set transects, but was an adaptive survey based on areas and seasons frequented by the fishery. Finally, there were also questions about survey age selectivity. Our survey uses spotter pilot identifications, but is based on a set transect design, and boat sampling is used to validate species identification as well as collect biological information on sardine within the study area. The inclusion of nearshore areas in this survey, formerly addressed by the previous spotter survey, supplements the current coverage in offshore waters by ship-based surveys.

These nearshore surveys can supplement the current acoustic surveys. The abundance of sardine within a few miles of the coast can account for many fish missed by the furthest nearshore extent of acoustic surveys of about 2 km or shallower than 40 m (D. Demer, NMFS, personal communication). This survey observed 74% of the total sardine biomass and 83% of the total number of sardine schools within 2 km of shore. However, the acoustic surveys are not as constrained by weather conditions and the limits of visibility through the water column. Comparative studies of both methods over the same time and space may be useful in assessing the strengths and weaknesses of each (K. Hill, NMFS, personal communication). The expansion of open water biomass estimates over the total open water area assumes homogeneity in habitat; the use of habitat models, such as those developed by Zwolinski et al. (2011) can account for habitat variation within the study area when estimating abundance. In addition, the possibility of the survey missing fish in deeper offshore areas that sardine frequent during the day is problematic. As a result, estimates from this survey are minimum biomass estimates. A focus on the nearshore shallow water areas for future surveys may be warranted to best use resources and possibly obtain multiple replicates. Because younger (0–2 years) sardine are more frequently found in waters within 27 km of shore (N. Lo, NMFS, personal communication), these results likely represent an index of sardine recruitment, pending confirmation from age and maturity analyses from boat survey samples. If these are shown to be young fish, they may be from the northern stock that are not fit to migrate during the summer months.

With the recent decline of the northern stock of sardine (Hill et al. 2014), it has been posited that the northern anchovy (Chavez et al. 2005) stock will become more prominent and perhaps replace sardine as the dominant California CPS fishery under a changing environmental regime towards cooler sea temperatures. Beginning in summer of 2013, other CPS (including northern anchovy and Pacific mackerel) in addition to sardine have been included in our survey protocol. Data from this survey may be useful in future stock assessments and management of other species within the CPS assemblage, especially northern anchovy, which are commonly found in coastal waters (Baxter 1967).

This survey collected data on sardine and other CPS from nearshore areas using direct observations in identifying and estimating abundance of schools. Observer species identifications were verified with boat survey results. The information obtained can be used to track abundance of nearshore sardine that are not sampled by other existing surveys, provide data on sardine population structure and dynamics, and describe sardine habitat associations in terms of environmental variables. These survey results can provide additional information for stock assessments for these species not only for management purposes, but also to elucidate questions related to stock migration and differentiation. Future aerial surveys should consider increased sampling and focused range of coverage to better gauge uncertainty and improve confidence in the accuracy of results.

Acknowledgments

We are grateful to a number of individuals for their part in this survey. We thank the CWPA and their executive director, D. Pleschner-Steele, for collaboration on this project. CWPA provided the services of our observer and loaned the FMC camera system. Collaborative Fisheries Research West generously supported CWPA for the observer and imaging software. T. Evans of CDFW Air Services ably piloted the survey aircraft on all aerial transects, and D. Reed was vital in identifying and describing fish in the field. B. Miller was instrumental in the initial design and planning of this survey, and M. Yaremko provided support and guidance. A. Holder assisted greatly with statistical and analytical input. We also thank the CDFW Office of Spill Prevention and Response for the use of their boat and staff for their contributions to the boat sampling work: C. Corbo, M. Crossland, S. Moe, and S. Garcia. In addition, T. Nguyen, B. Miller, K. Greer, P. Ton, M. Horeczko, E. Hellmers, J. Taylor and M. Roberts assisted in the field and with lab work. Finally, we acknowledge the helpful discussions and comments from the rest of the CDFW aerial survey team comprised of B. Brady, M. Horeczko, and C. Protasio; NMFS staff members E. Dorval, K. Hill, M. Lowry, D. Demer, P. Crone, and D. Sweetnam; and reviewers N. Lo and R. Parrish. This publication was supported in part by the California Natural Resources Agency and California Ocean Protection Council, under Grant Agreement 11-027, Project R/OPCCFRW-10MG, through the California Sea Grant College Program. The views expressed herein do not necessarily reflect the views of any of these organizations.

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Changes in biological characteristics of the California market squid (*Doryteuthis opalescens*) from the California commercial fishery from 2000–01 to 2012–13

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The commercial market squid (*Doryteuthis opalescens*) fishery began in Monterey, California during the mid-1800s. In the 1990s, increased market demand emerged overseas, primarily in Europe and Asia, and caused the fishery to grow substantially over the past two decades, and eventually becoming California's top commercial fishery in terms of value and volume. Biological data were obtained through the California Department of Fish and Wildlife sampling program for commercial landings of market squid. Commercial samples were collected at ports from San Francisco to southern California, from the 2000–01 to 2012–13 seasons. This study examines the spatial and temporal trends in biological aspects of captured market squid to determine if dorsal mantle length, whole mass, and sex ratios have significantly changed through time, and if these variables presently differ among seasons, geographic region, or by sex. The length and mass of market squid have fluctuated from season to season, and there were significant differences between regions. Likewise, there are statistically significant interactions between season, region, and sex for both the length and mass of market squid. Specifically, the length and mass of squid depends on the combined interactions of season, region, and sex. Monitoring these biological trends can help inform management about the health of the current stock.

Key words: Squid, coastal pelagic species, commercial fishery, cephalopod, *Doryteuthis (Loligo) opalescens*

Commercial fishing for market squid (*Doryteuthis opalescens*) began in Monterey Bay during the 1860s when Chinese fishermen used torches to attract squid into their nets (Pomeroy and Fitzsimmons 1998). The squid was then dried and exported to China. Starting in the 1990s, increased demand for squid, mainly in Asia, made the California market squid fishery one of the most valuable commercial fisheries in the state (Porzio 2013). In the 2012–13 season, approximately 96,000 metric tons (mt) of squid were landed in California

(Figure 1). Oceanic squid are commonly the largest biomass of all commercially harvested invertebrates globally, and California has one of the largest nearshore squid fisheries in the world (Jereb et al. 2010).

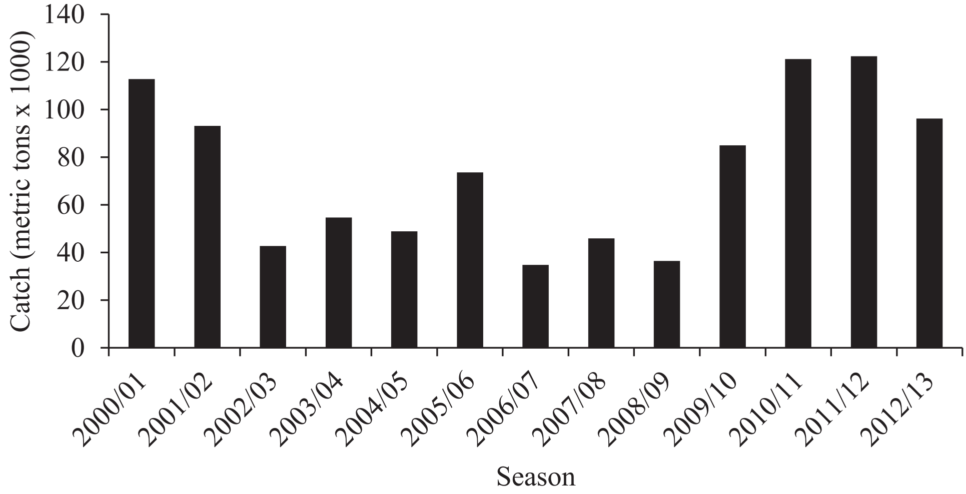

Figure 1.— Statewide commercial landings of California market squid by fishing season, from 2000–2001 to 2012–2013. The commercial fishing season runs from 1 April to 31 March the following year.

Market squid habitat ranges from Alaska to Baja California along the west coast of North America (Okutani and McGowan 1969, Jackson 1998). Typically, seine or brail gear, combined with the use of lights as an attractant, are used to capture shallow spawning populations in nearshore areas (Recksiek and Frey 1978). Spawning can occur year-round; however, the fishery is typically most active from April to October in Monterey and from October to May in the Channel Islands (Vojkovich 1998). In the last three years, however, substantial landings have occurred during the summer in southern California. Declines in overall commercial squid catch and paralarva densities occur after El Niño events, which suggests that environmental changes have strong influences on squid population size and abundance, as well as on recruitment (McInnis and Broenkow 1978, Jackson and Domeier 2003, Reiss et al. 2004, Koslow et al. 2011).

Management of the California market squid fishery focuses on evaluation of squid using the "egg escapement method" (Macewiz et al. 2004, CDFG 2005). Market squid are terminal spawners, and spawning occurs multiple times over their last few days of life (Fields 1965). Market squid usually live four to nine months, reproduce at the end of their lifespan, and are harvested on spawning grounds; for the fishery to be sustainable, it is critically important that an adequate number of eggs are spawned prior to harvest (CDFG 2005).

Biological data were developed and initially collected by Fields (1965) from 1946 until 1962. Biological samples were again collected in 1972 when morphometric comparisons were made between squid from the Monterey Bay and southern California (Evans 1976). Monterey port sampling was initiated in 1989 to re-establish a database of biological information from locally caught market squid (Leos 1998). The sampling design has changed slightly over the years, with the current sampling design adopted in

2000. The current California Department of Fish and Wildlife (CDFW) fishery-dependent sampling program was designed to monitor biological characteristics of the proportion of the population allowed to spawn (escape) prior to capture by the fishery (CDFG 2005). This “egg escapement method” (Macewicz et al. 2004) is used to evaluate the population dynamics of the species (Dorval et al. 2013).

Spatial and temporal trends in biological aspects of market squid collected in the current CDFW sampling regime (2000–01 to 2012–13) were examined to determine if length and mass have changed through time and if these variables differ between geographic regions or by sex. Sex ratios were also examined to determine if they have changed through time or differ by geographic region.

Materials and Methods

Dorsal mantle length (DML, mm), mass (whole body, g), and sex ratios for California market squid samples (30 individuals) collected between 2000–01 and 2012–13 were compared spatially, temporally, and by sex. We categorized the samples used in these analyses geographically as northern California (NCA, north of Point Piedras Blancas) or southern California (SCA, south of Point Piedras Blancas) (Figure 2). Data were eliminated from analyses if the sex was undetermined.

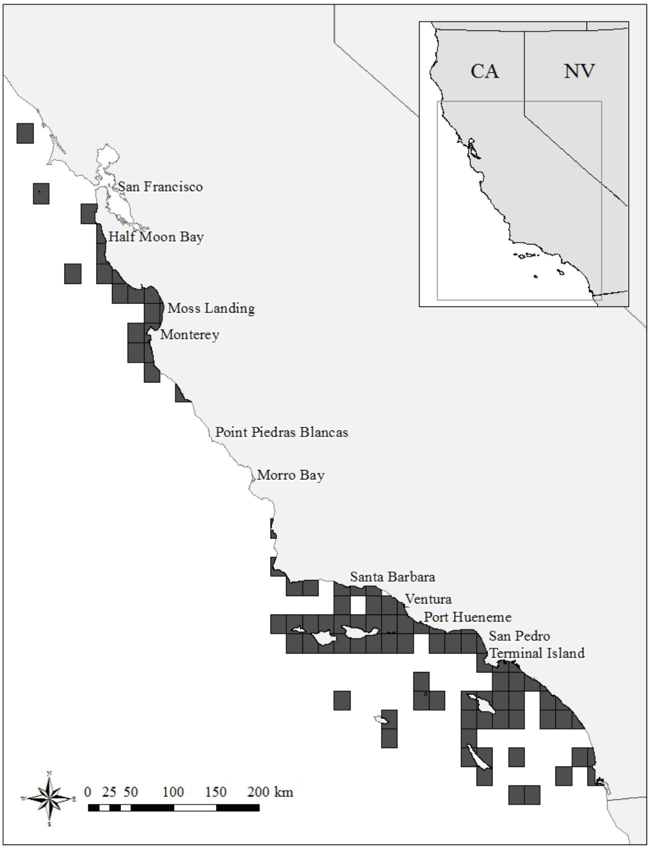

Figure 2.— Commercial landing locations for California market squid from from the 2000–2001 to the 2012–2013 fishing seasons sampled by CDFW fishing blocks (displayed in dark grey). Each block measures 10 × 10 minutes. The commercial fishing season runs from 1 April to 31 March the following year.

CDFW sampling procedure. — The regulatory season for the commercial market squid fishery in California is 1 April through 31 March of the following year. CDFW commercial fishery sample collection methods (2000–01 to 2012–13) were based on a stratified random sampling design. In January of 2000, sampling goals were set to 25 monthly samples. In 2004, the sampling protocol was reduced to 12 samples per month, following the previously established guidelines already used by the CDFW to collect Pacific sardine and Pacific mackerel samples. When the market squid fishery was active, 12 days were randomly sampled within each month and at each each of the following ports: Monterey—Moss Landing, Ventura—Port Hueneme, and Terminal Island—San Pedro (Figure 2).

Samples consisted of 30 squid selected randomly from a single commercial fishery landing. Squid were collected throughout the offloading process using a hand held dip net. Landing information was obtained from the captain of each sampled vessel, and included sample date, a landing number based on the number of annual commercial squid landings, sample number, vessel name and Fish and Game number (FGN), captain's estimate of landing weight (short tons), net set location (FG block number), number of sets, gear used, whether a light boat was used, light boat name and FGN, port, dealer's name, and landing receipt number. In the lab, each squid was laid out to drain for at least five minutes before being measured for DML and mass, and sex was determined. A sub-sample of one male and six females was sampled for gonad weight, and a mantle-punch sample and statoliths were removed for egg escapement determination and ageing, respectively (CDFG 2005). Data for ageing and egg escapement were not analyzed in this study.

Data analysis. —All statistical analyses were performed using R software (Version 3.0.0). One sample, consisting of 30 individual squid, was considered to be a sampling unit. DML and mass of a sample each was calculated using the average DML and mass of all squid in each sample. A 3-way analysis of variance (ANOVA) was used to examine the main effects and interactions of season, region, and sex for DML and mass. The assumptions of normality and homogeneity of variance were tested through visual inspection of a Residuals and Fitted Values plot and a Normal Q-Q plot; data met all assumptions. ANOVA results were supported by interaction plots, which were used to inspect significant interactions. A Pearson's Chi-squared test was used to compare sex ratios among and within seasons separated by region (NCA and SCA). Based on Fields' (1965) findings, the expected sex ratio was 1:1 for all Chi-squared analyses. Values are expressed as means ± 1 standard deviation (*SD*).

RESULTS

A total of 50,744 individual male (3,092 samples) and 41,277 individual female (3,088 samples) squid were collected from each region from 2000–01 to 2012–13. Throughout the state, male DML averaged 128.4 mm (± 9.6 mm) and female DML averaged 125.2 mm (± 7.7 mm), with average masses of 44.8 g (± 9.7 g) and 35.9 g (± 7.0 g), respectively. Overall, more males were collected than females, and males were, on average, larger than females (Table 1). Statewide sex ratios pooled by all seasons were dominated by males (1.2:1). Although sex ratios differed slightly among regions, they were similar (NCA 1.3:1; SCA 1.2:1).

Mean DML and mass of males and females experienced similar fluctuations over the past 13 seasons (Figure 3). Statewide and across seasons, the lowest mean DML was

	Male	Female
Number of samples	3,092	3,088
Number of squid	50,744	41,277
Average DML (mm)	128.4	125.2
Range	93.5-158.3	94.0-159.0
SD	9.6	7.7
Average mass (g)	44.8	35.9
Range	20.4-82.4	14.8-61.0
SD	9.7	7.0

Table 1.—Length and mass of male and female squid collected from the California market squid fishery during commercial fishing seasons from 2000–2001 to 2012–2013. The commercial fishing season runs from 1 April to 31 March the following year.

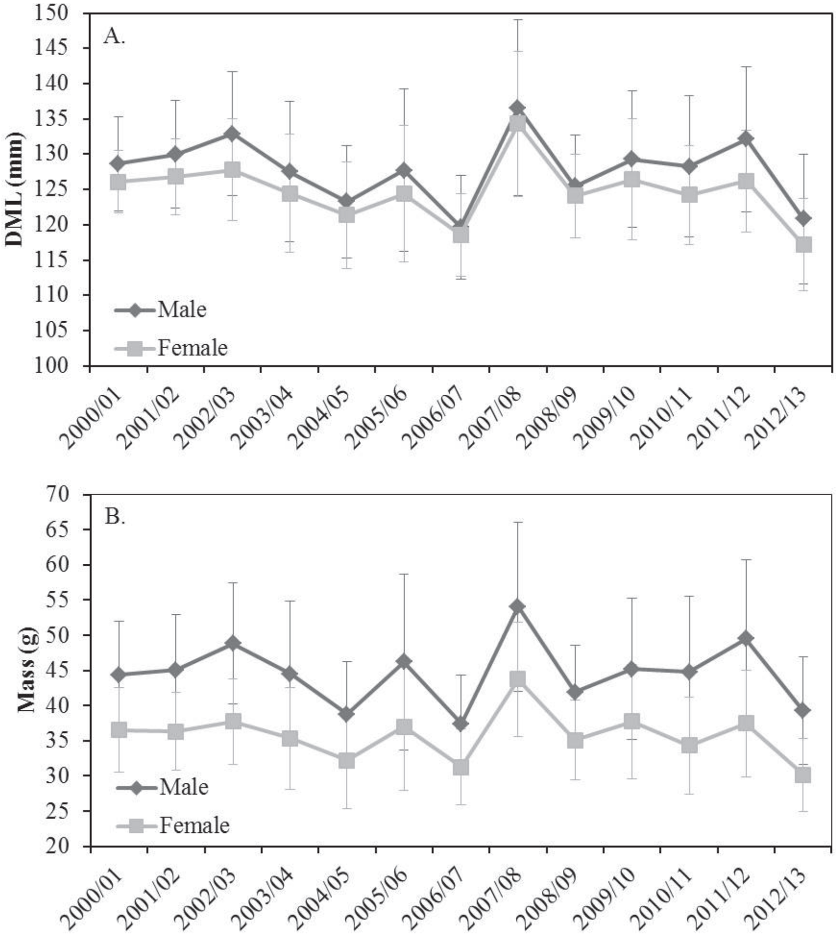

Figure 3.—Mean (±*SD*) dorsal mantle length (DML; A) and mass (B) for male and female California market squid across all regions by commercial fishing season. The commercial fishing season runs from 1 April to 31 March the following year.

119.7 mm (± 7.3 mm) for males and was observed during the 2006–07 season, whereas the lowest DML observed for females was 117.2 mm (± 6.5 mm) during the 2012–13 season. The greatest mean DML for males was 136.6 mm (± 12.5 mm) and the greatest mean DML for females was 134.3 mm (± 10.3 mm), both of which were observed during the 2007–08 season. Mean squid DML varied within 17 mm in the 13 season time period. Minimum and maximum average mass for males occurred in the 2006–07 and 2007–08 seasons and were 37.4 g (± 6.9 g) and 54.1 g (± 12.0 g), respectively. The minimum female mass (30.2 g ± 5.2 g) was observed in the 2012–13 season. Similar to males, maximum female mass (43.7 g ± 8.1 g) was observed in the 2007–08 season.

Results from 3-way ANOVA for DML indicate that the 3-way interaction between season, region, and sex, were not significant ($F_{11,\,6130} = 1.44$, $P = 0.15$; Table 2). However, DML is significantly influenced by the interactions between season and region ($F_{11,\,6130} = 60.60$, $P < 0.001$), season and sex ($F_{12,\,6130} = 2.99$, $P < 0.001$), and region and sex ($F_{11,\,6130}$

Table 2.—Results of three-way ANOVA for dorsal mantle length (A) and mass (B) of California market squid collected during commercial fishing seasons from 2000–2001 to 2012–2013 with season, region, and sex as factors. The commercial fishing season runs from 1 April to 31 March the following year.

(A) Dorsal Mantle Length

Factor	*df*	Sum of Squares	Mean Square	*F*	*P*
Main Effects					
Season	12	76,080	6,340	113.26	< 0.001
Region	1	3,466	3,466	61.92	< 0.001
Sex	1	16,388	16,388	292.76	< 0.001
Two-way interactions					
Season:Region	11	37,316	3,392	60.60	< 0.001
Season:Sex	12	2,010	167	2.99	< 0.001
Region:Sex	1	2,007	2,007	35.86	< 0.001
Three-way interaction					
Season:Region:Sex	11	889	81	1.44	0.15
Residuals	6,130	343,140	56		

(B) Mass

Factor	*df*	Sum of Squares	Mean Square	*F*	*P*
Main Effects					
Season	12	54,730	4,561	83.10	< 0.001
Region	1	8,468	8,468	154.29	< 0.001
Sex	1	123,451	123,451	2,249.26	< 0.001
Two-way interactions					
Season:Region	11	35,985	3,271	59.60	< 0.001
Season:Sex	12	3,410	284	5.18	< 0.001
Region:Sex	1	1,854	1,854	33.78	< 0.001
Three-way interaction					
Season:Region:Sex	11	2,181	198	3.61	< 0.001
Residuals	6,130	336,447	55		

= 35.85, $P < 0.001$) (Table 2). Plots indicate that the strongest interactions were between season and region (Figure 4A). That is, DML was highly dependent upon the season and region in which the squid were present. Interactions between season and sex (Figure 4B),

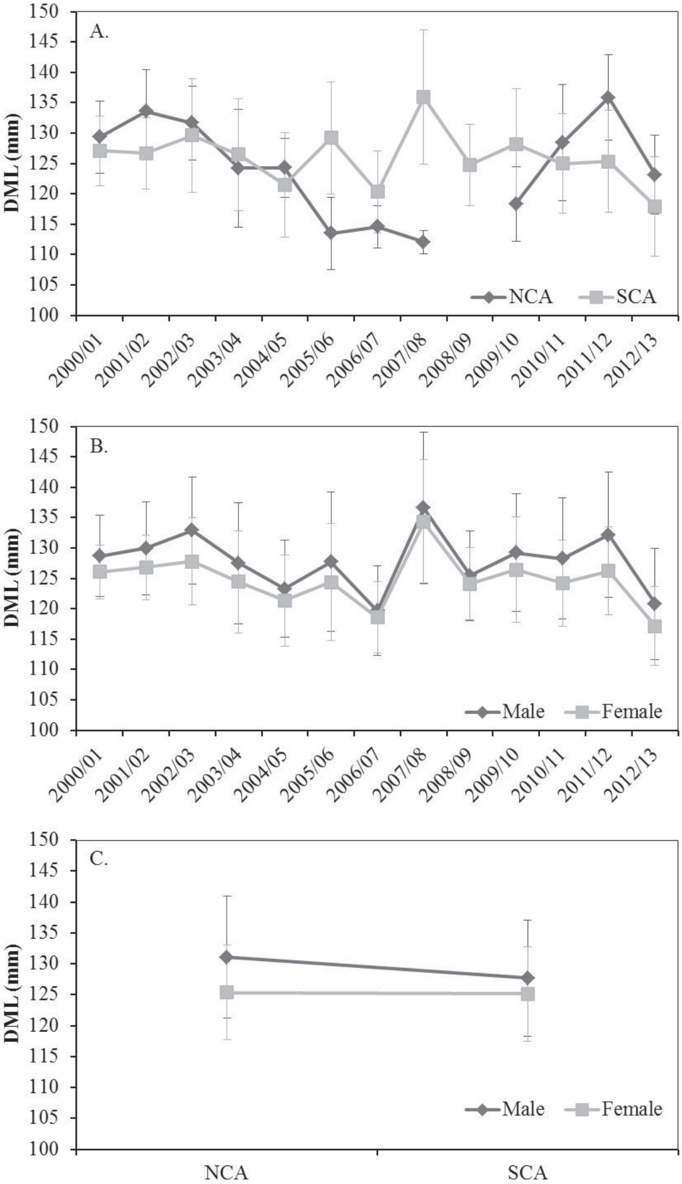

Figure 4.—Mean (±*SD*) dorsal mantle length (DML) by (A) commercial fishing season and geographic region, (B) commercial fishing season and sex, and (C) geographic region and sex. The commercial fishing season runs from 1 April to 31 March the following year.

and region and sex (Figure 4C), while still significant, were moderate and show that, regardless of season or region, male DML is always greater than female DML. The plot of region and sex (Figure 4C) also indicated that DML for males and females in NCA tended to be greater than those squid in SCA. Unlike squid DML, mass was significantly impacted by the combined interactions between season, region, and sex ($F_{11,\ 6130} = 3.61$, $P < 0.001$, Table 2). The interaction plots illustrate that mass fluctuated among seasons as well as between regions and that the pattern of fluctuations was similar for males (Figure 5A) and females (Figure 5B). The pattern of interactions also showed that the scale of fluctuations for males and females differed. Namely, the interaction of season and region on male squid generally resulted in greater mass and more extreme fluctuations than the same interaction on female squid.

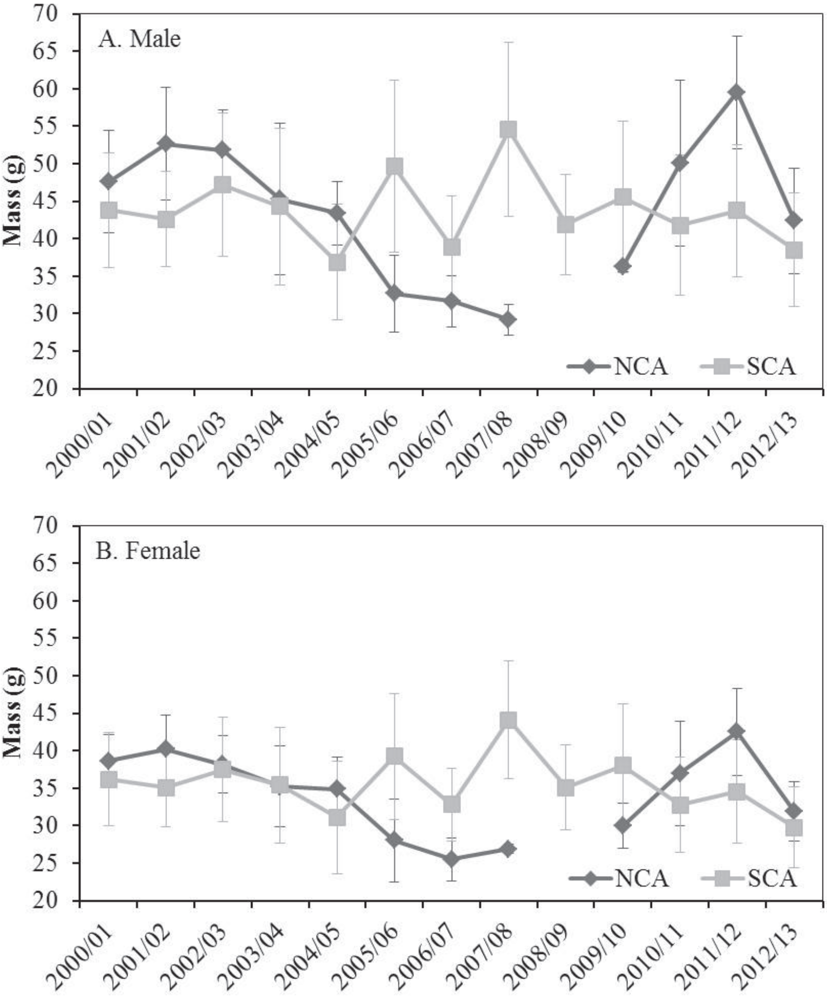

Figure 5.—Mean mass (±*SD*) by commercial fishing season and geographic region for male (A) and female (B) California market squid. No samples were collected in the Northern California Area during the 2008–2009 commercial fishing season. The commercial fishing season runs from 1 April to 31 March the following year.

Trends north of Point Piedras Blancas.—A total of 1,366 samples were collected in NCA, containing 11,669 males and 8,725 females. Examination of season means displayed in the interaction plots reveals that there was a decrease in size (DML and mass) for both sexes from 2001-02 through 2007-08; squid size increased to the largest mean size in 2011-2012 and then decreased the following season (Figure 5A, Figure 5B; DML not shown).

Chi-squared results indicate a significant difference in sex ratios among seasons ($\chi^2_{11} = 23.4$, $P < 0.05$). Chi-square results within seasons show that, for more recent seasons, there was a significant difference in expected (1:1) and observed sex ratios (Table 3). During these seasons, there tended to be at least 1.5 times more males than females.

Table 3.— Sex of California market squid collected from the Northern California Area (A) and Southern California Area (B) during commercial fishing seasons from 2000–2001 to 2012–2013, and results of χ^2 tests with an assumed sex ratio of 1:1. The commercial fishing season runs from 1 April to 31 March the following year.

(A)	Male		Female				
Season	Number	Percent	Number	Percent	χ^2	*df*	*P*
2000/01	1,060	50.8	1,025	49.2	0.03	1	0.87
2001/02	2,170	52.2	1,989	47.8	0.19	1	0.66
2002/03	2,302	57.9	1,675	42.1	2.49	1	0.11
2003/04	1,450	55.0	1,185	45.0	1.01	1	0.31
2004/05	804	61.2	509	38.8	5.05	1	0.02
2005/06	684	63.5	394	36.5	7.24	1	0.01
2006/07	567	72.8	212	27.2	20.77	1	<0.01
2007/08	37	61.7	23	38.3	5.44	1	0.02
2008/09	-	-	-	-	-	-	-
2009/10	53	46.1	62	53.9	0.61	1	0.43
2010/11	908	61.6	567	38.4	5.34	1	0.02
2011/12	999	64.1	560	35.9	7.93	1	<0.01
2012/13	635	54.8	524	45.2	0.92	1	0.34
Total	11,669		8,725				

(B)	Male		Female				
Season	Number	Percent	Number	Percent	χ^2	*df*	*P*
2000/01	6,921	51.9	6,421	48.1	0.14	1	0.71
2001/02	6,447	50.7	6,270	49.3	0.02	1	0.89
2002/03	4,088	56.8	3,112	43.2	1.84	1	0.18
2003/04	4,956	55.2	4,022	44.8	1.08	1	0.30
2004/05	1,740	55.3	1,409	44.7	1.10	1	0.29
2005/06	2,243	53.3	1,967	46.7	0.43	1	0.51
2006/07	1,526	52.0	1,408	48.0	0.16	1	0.69
2007/08	1,788	58.5	1,266	41.5	2.92	1	0.09
2008/09	1,710	58.4	1,219	41.6	2.81	1	0.09
2009/10	1,624	51.1	1,553	48.9	0.05	1	0.82
2010/11	1,476	57.0	1,115	43.0	1.94	1	0.16
2011/12	1,620	59.9	1,086	40.1	3.89	1	0.05
2012/13	2,936	63.3	1,704	36.7	7.05	1	0.01
Total	39,075		32,552				

Trends south of Point Piedras Blancas.—The 4,814 SCA samples were comprised of 39,075 males and 32,552 females. There was no consistent trend in the size (DML and mass) of male and female squid from season to season in SCA (Figure 5A, Figure 5B; DML not shown). Rather, fluctuations were moderate from 2000–01 to 2004–05, increased substantially from 2005–06 to 2007–08, and returned to moderate during the 2008–09 to 2012–13 seasons.

Chi-squared results for SCA indicate that there was no significant difference in sex ratios among seasons ($\chi^2_{12} = 7.04$, $P = 0.85$). Results from Chi-square tests within seasons show significant differences in the expected (1:1) and observed sex ratios in the 2011–12 and 2012–13 seasons, when the percent of males increased to approximately 60 % (Table 3).

Discussion

Given that market squid are a valuable commodity for California's economy and are a vital forage species, it is important to document biological characteristics of specimens captured in the fishery. Biological characteristics of market squid tend to oscillate over time as shown in seasonal fluctuations of DML and mass from 2000–01 to 2012–13. As evident from this study, seasonal mean DML may fluctuate in excess of 14 mm from season to season in market squid. Research indicates that these differences may be correlated with long-term climatic patterns, such as the El Niño Southern Oscillation (ENSO), influencing nutrients and food sources among seasons and within regions (Jackson and Domeier 2003, Reiss et al. 2004, Koslow and Allen 2011). Growth and development in Cephalopoda are also highly influenced by seasonal fluctuations in temperature (Grist and des Clers 1998, Jackson and Domeier 2003). It has been suggested that growth rates and life cycles of cephalopods can be greatly accelerated by locality and temperature (Jackson et al. 1997).

Resulting size differences could reflect the species' ability to adjust to changing environmental conditions. Specifically, when conditions are not ideal, squid tend to have smaller DML and mass. However, when conditions are preeminent, squid take advantage of the favored conditions and increase in size. Increased biological productivity on spawning grounds may provide a framework for highly productive nursery grounds contributing to larger DML and mass (Ichii et al. 2004). Differences in size could also potentially be attributed to different cohorts. However, since age data have not been analyzed, this cannot be confirmed or denied. The size and "freshness" of squid greatly impacts its economic value. Larger, high quality squid is ideal for market demands and is vital for higher prices paid to fishermen.

Improved metrics of environmental and oceanographic conditions have greatly contributed to the ability to link those conditions to recruitment in squid populations of South America and Japan (Sakurai et al. 2000, Agnew et al. 2002). Statewide, from season to season, the lowest mean DML occurred in 2006–07, and the greatest mean DML was observed in 2002–03. In 2002, biological productivity in the California Current was higher than usual (Schwing et al. 2002), which may have led to larger mean squid size in the 2002–03 season. During the 2005–06 (July to June) season, the California Current experienced a delay in upwelling along with recruitment failure for various marine organisms (Peterson et al. 2006); the smaller market squid size in the 2006–07 fishing season may have been a result of the 2005–06 environmental conditions. Additionally in 2006-07, there was also a late onset of upwelling (Goericke et al. 2007), and market squid spawning activity is usually associated with local and seasonal influxes of nutrients from upwelling or winter mixing events (Zeidberg 2006).

Males have remained the more abundant sex in the fishery. Previous studies have found sex ratios to fluctuate rapidly, although sex ratios tended to be dominated by males (Hanlon et al. 2004). Most observations have not included lone females on mating grounds. Extra males observed on spawning grounds tend to be larger, competitive males or smaller "sneaker" males (Hanlon et al. 2004, Zeidberg 2008). These "sneaker" males insert their spermatophores into the mantle cavity of females mating with larger males. It has been suggested that paired males are able to out compete unpaired sneaker males in other squid species (Janzen and Havenhand 2003). Moreover, skewed operational sex ratios on mating grounds have been found to set up the gradient for sexual selection in cephalopods (Hanlon et al. 2002).

Additionally, differences in squid size from season to season may also reflect the time of year in which the samples were taken. Future research should be conducted to find clearer relationships linking environmental, oceanographic, and biological variables of market squid. Comparison of historical biological datasets and the current CDFW study would provide a clearer representation of how the fishery and the biology have changed through time. Comparing these changes to environmental variability, and on a finer scale, could provide additional insights useful in the management of this short-lived species.

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Reproductive potential and spawning periodicity in barred sand bass (*Paralabrax nebulifer*) from the San Pedro Shelf, southern California

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Barred sand bass (*Paralabrax nebulifer*) form large, predictable spawning aggregations that are heavily exploited in the recreational fishery, but robust reproductive estimates (i.e., essential fishery information) are lacking for this species. Barred sand bass were collected on the San Pedro Shelf during June–September 2011 to improve estimates of gonadosomatic index (GSI), spawning fraction, batch fecundity, and spawning periodicity. We calculated spawning fraction using the post-ovulatory follicle method; batch fecundity was estimated using the hydrated oocyte method. Blood plasma samples were analyzed for concentrations of 17β-estradiol (E2, n=160), 11-ketotestosterone (11KT, n=96), and progesterone (P4, n=153) to examine spawning periodicity. Spawning occurred predominantly in July and August, peaking just days before the new and full moon phases. Sea surface temperature (β=0.45) and time of capture (β=-0.35) were the most significant predictors of female E2 (R^2=0.38, $F_{(6,139)}$=9.2, P<0.001); E2 concentrations positively fluctuated with temperature and were significantly higher before noon than after noon (W=10263.5, P=0.0001). The relationship between batch fecundity (n=40, range 204 to 461 mm SL) and ovary mass was $\text{Log}_{10}y=0.9815(\text{Log}_{10}x)+3.1353$ (R^2=0.94); batch fecundity ranged from 23,536 to 330,443 oocytes, and females were estimated to spawn 42 times. Based on our estimates of spawning frequency and batch fecundity, potential annual fecundity for female barred sand bass ranged from 0.98 to 13.9 million oocytes, and averaged 3.5±2.5 million. These newly available reproductive estimates should enhance fishery assessments and management of this popular sport fish.

Key words: barred sand bass, *Paralabrax nebulifer*, spawning periodicity, reproductive potential, batch fecundity, potential annual fecundity, spawning fraction, gonadosomatic index, 17β-estradiol, 11-ketotestosterone, progesterone

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Barred sand bass (*Paralabrax nebulifer*; Family Serranidae [BSB]) has been a popular sport fish in southern California for decades; however, BSB catch-per-unit-effort has notably declined in recent years due to fishing and suboptimal environmental conditions (Jarvis et al. 2014). Barred sand bass are primarily targeted in the summer months when they form large spawning aggregations comprised of hundreds to thousands of resident and migrant fish (Turner et al. 1969, Love et al. 1996, Jarvis et al. 2010). Each year the peak fishing season typically lasts from one to three months and fishing occurs at well-known spawning aggregation hotspots. In response to concerns over the sustainability of the resource, more restrictive harvest regulations for this fishery were implemented in 2013 (FGC 2012, Jarvis et al. 2014). Evaluating the effectiveness of these regulations is important for monitoring the fishery's sustainability and for maximizing fishing opportunities. Unfortunately, no biological reference points such as maximum sustainable yield exist for BSB, primarily due to an absence of biomass estimates and data on their reproductive potential. To evaluate the effectiveness of these regulations and the health of the fishery, a future fishery assessment will depend on the best available essential fishery information, which includes the species' reproductive biology (Phipps et al. 2010).

Barred sand bass are gonochoristic (Sadovy and Domeier 2005) and females are indeterminate serial spawners, in which oocytes (presumptive eggs) develop throughout the spawning season and are spawned in multiple batches (DeMartini 1987, Oda et al. 1993). Annual fecundity, the number of eggs produced by a female in a single year, is a measure of reproductive potential and can be used to predict stock sustainability (Pitman et al. 2013). For serial spawners, potential annual fecundity can be calculated using estimates of batch fecundity (the number of eggs released in a single batch), the spawning fraction (the proportion of females spawning per day), and spawning frequency (the number of spawning events per season) (Hunter and Macewicz 1985). The BSB spawning fraction was estimated by Oda et al. (1993); however, the samples were collected during a two-week period in July, which the authors noted was the reproductive "subseason" and may not accurately have reflected the spawning fraction over the entire spawning season. Since the spawning fraction can vary depending on when samples are collected, knowledge of spawning seasonality and sufficient temporal resolution in sampling effort is critically important to obtaining unbiased results.

Reports of BSB spawning seasonality in the literature range from three months (June–August; Clark 1933) to seven months (April–November; Allen and Hovey 2001). Clark's (1933) estimate was based on gross observations of BSB ovaries in commercially landed fish from May to September, but information upon which the other estimates were based is unclear. *Paralabrax* spp. in the Southern California Bight have a plankton larval duration of approximately one lunar month (Allen and Block 2013) and eggs or larvae occur from June through October (Moser et al. 2001); however, this group includes kelp bass (*P. clathratus*), which spawn from May to October (Erisman and Allen 2006) and spotted sand bass (*P. maculatofasciatus*), which spawn from June to August (Allen et al. 1995). Thus, there is a need to better define spawning seasonality in BSB.

An update on BSB batch fecundity estimates is also needed to better estimate annual fecundity. Previous estimates were based on small sample sizes and differed considerably from each other (DeMartini 1987, Oda et al. 1993). Batch fecundity estimates obtained from active or recent spawners might underestimate batch fecundity because ovaries from these individuals could contain partially-spawned batches (Hunter et al. 1992, Ganias et al. 2010). Thus, more accurate batch fecundity estimates might be difficult to obtain in adequate sample sizes because samples are limited to only females with ovaries that contain hydrated oocytes and no new post-ovulatory follicles (Hunter et al. 1985, Ganias et al. 2010). Batch fecundity estimates would be improved by sampling more fish over a wider size range and by increasing our understanding of how samples obtained from females with partially spawned batches affect BSB batch fecundity estimates.

Reproductive hormones such as 17β-estradiol (E2) and 11-ketotestosterone (11KT) typically fluctuate with spawning activity and may peak during spawning aggregation pulses. Individual BSB are capable of daily spawning (Oda et al. 1993), but it is unknown whether BSB spawning peaks occur with regular periodicity throughout the spawning season. Tag and recapture data suggest that formation of BSB spawning aggregations occurs at monthly intervals during spawning season (Jarvis et al. 2010), and ovarian histology suggests that BSB spawning peaks mid-day (Oda et al. 1993), but this was not confirmed by visual spawning observations or steroid hormone profiles. Within-day and within-season spawning periodicity could be driven by environmental cues that are ultimate or proximate in nature. For many animals, the ultimate environmental cue is photoperiod (Bradshaw and Holzapfel 2007). However, proximate cues, such as water temperature and lunar phase, can trigger or enhance a physiological reproductive response (Frisch et al. 2007). These cues are important for some species to synchronize spawning, and could represent optimal conditions for survival of fertilized eggs and larvae (Colin 1992, Sancho et al. 2000).

Our first objective was to investigate BSB spawning seasonality and to determine how BSB reproductive parameters vary across the spawning season. Our second objective was to determine BSB spawning frequency and batch fecundity to enable estimates of annual reproductive potential. Our final objective was to determine any within-season and within-day spawning periodicity for BSB, and the relationship between environmental factors and concentrations of E2, progesterone (P4) and 11KT in male and female BSB during the spawning season. Understanding which cues affect BSB spawning will be important for understanding how, or if, reproductive potential varies from year to year.

Materials and Methods

Study animals.—All BSB were collected during 0700–1500 or 2000–2200 by hook and line, baited trap, or spear from 21 June 2011 to 22 September 2011 along the San Pedro Shelf in southern California (Figure 1). After capture, blood was drawn from the caudal vein using an 18- or 20-gauge needle and heparinized syringe. Standard length (SL, mm) and total length (TL, mm), somatic weight (to the nearest 0.01kg), and time of capture were recorded for each fish. Fish were then euthanized by placing them on ice. The gonads were excised, placed in 10% neutral buffered formalin for 7 to 10 days, and then weighed to the nearest 0.001 g. The sex of the fish was identified macroscopically and confirmed histologically at a later date. Gonadosomatic index (GSI) was calculated for each individual as gonad mass divided by somatic mass (SM) multiplied by 100.

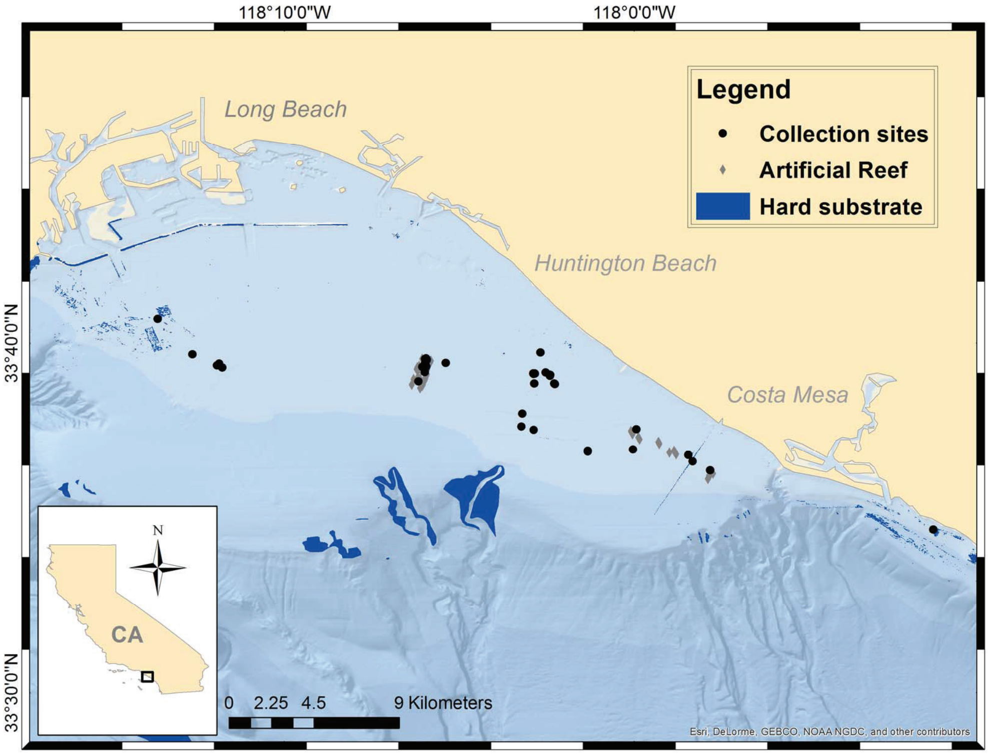

FIGURE 1.—Barred sand bass collection sites on the San Pedro Shelf in southern California, June–September 2011.

Histology.—Following preservation, a cross-section 2–3 mm thick was taken from the center of one of the gonad lobes of each fish, transferred to 70% ethanol, and saved for histological analysis. Gonad histology was conducted by Diagnostic Pathology Medical Group, Inc. (Sacramento, California); additional sections for select individuals were prepared at California State University, Long Beach using standard paraffin embedding, sectioning, and hematoxylin and eosin staining procedures (Loke-Smith et al. 2010). Upon examination, oocytes were categorized into one of eight developmental stages (Lowerre-Barbieri et al. 2011a: primary growth [PG], cortical alveolar [CA], vitellogenic I, II, and III [vtg-I,II,III], germinal vesicle migration [MN], hydrated [H], and postovulatory follicle [POF]; Figure 2). The spawning fraction (*S*) was estimated using the POF method to determine the proportion of spawning females (females with POFs <25 hours old). A BSB postovulatory follicle aging key based on timed serial tissue collection (Oda et al. 1993) was generated from labeled histological slides archived at the Natural History Museum of Los Angeles County. The ageing key was used to assign POF ages to fish collected for the current study (Day 0 = less than 4 hours old [POF$_0$], Day 1 = 4 to 24 hours old [POF$_1$], and Day 2+ = greater than 24 hours old [POF$_2$]; Figure 3). The average sea surface temperature (SST) during the current study (18.9±1.3° C) was within the range of water temperatures reported by Oda et al. (1993; 16.9–19.9° C); thus, POF absorption rates in both periods were assumed to be similar.

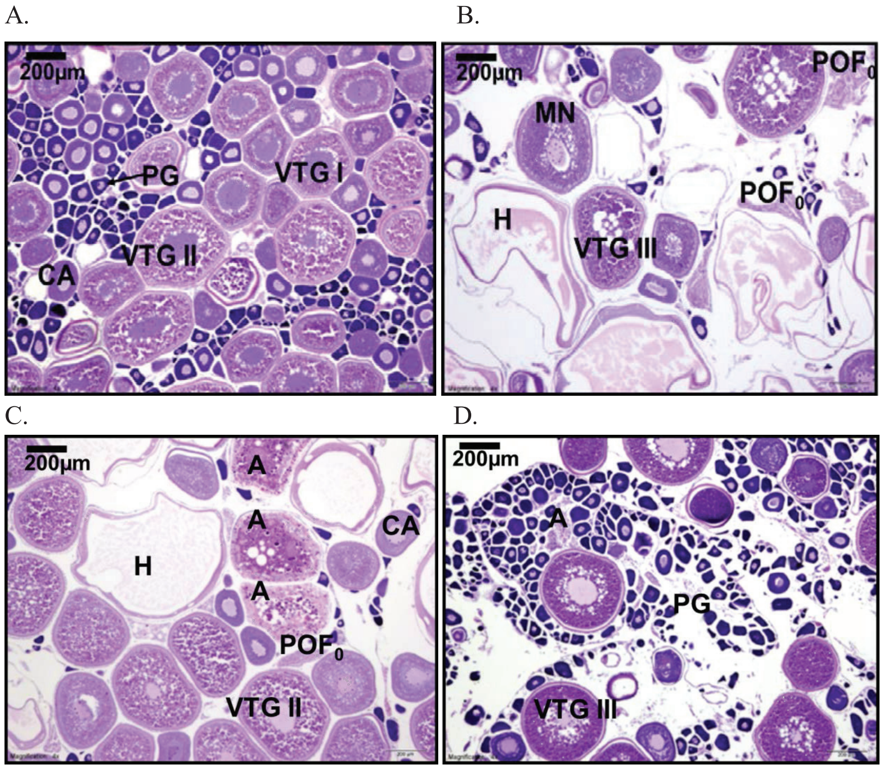

FIGURE 2.—Images of barred sand bass ovary sections at 4 × magnification depicting oocyte development stages and follicles during various reproductive stages including developing (A), spawning capable (B and C) , and regressing (D). PG = primary growth; CA = cortical alveolar; VTG (I,II,III) = vitellogenic (I,II,III); MN = migratory nucleus; H = hydrated oocyte; POF_0 = Day 0 postovulatory follicle; A=atretic follicle.

Females with no evidence of new or old postovulatory follicles or hydrated oocytes, but having ovaries containing vitellogenic oocytes, were classified as non-spawning (Figure 2a). Daily spawning activity was identified by the presence of at least one of the five following combinations of follicle or oocyte developmental stages (Oda et al. 1993: POF_1 and MN, POF_1 and H, POF_1 and POF_2, POF_0 and POF_1, and POF_0 and H; Figure 2b, Figure 2c, Figure 3). The presence of ovarian follicular atresia was assigned to females having multiple atretic follicles.

Batch fecundity.—Ovaries identified as having hydrated oocytes or POFs were retained to estimate batch fecundity using the hydrated oocyte method (Hunter et al. 1985). The number of hydrated oocytes in a subsample of ovarian tissue was counted, whereby a tissue sample weight of approximately 0.100±0.025 g was determined to contain 100–200 hydrated oocytes for analysis. Tissue samples were removed from each ovarian lobe in a pie-shaped wedge (weighed to 0.001 g), mounted in 33% glycerol, and allowed to sit for ten minutes to loosen connective tissue before gently tapping and teasing them apart. Oda et al. (1993) and DeMartini (1987) determined that neither the location of gonad tissue sample nor the specific lobe influenced batch fecundity estimates for BSB.

Oocytes were covered with a glass cover slip and the hydrated oocytes from each lobe were counted ≥2 times under a compound microscope (Figure 4). In addition, the

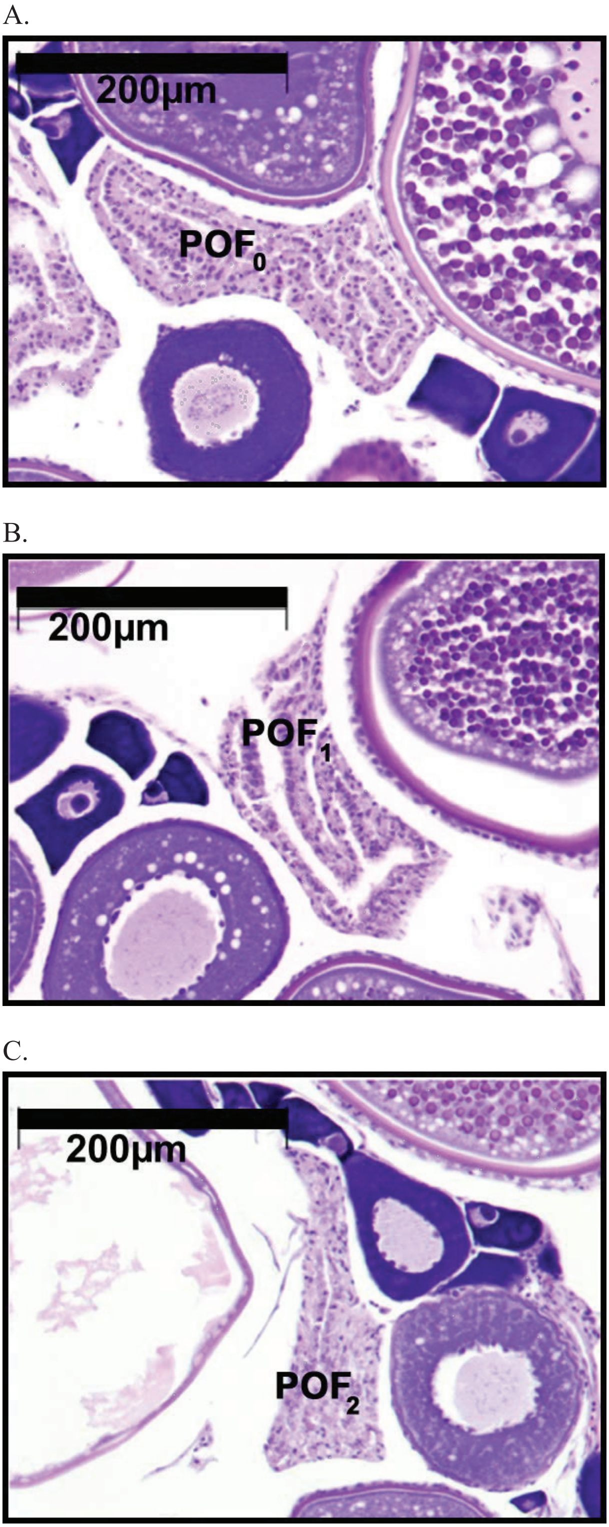

FIGURE 3.—Images of representative ovary sections at 20× magnification for barred sand bass females collected on the San Pedro Shelf in southern California, June–September 2011 with (A) POF_0 (spawned within 4 hours of collection); (B) POF_1 (spawned between 4 and 24 hours prior to collection); and (C) POF_2 (spawned greater than 24 hours prior to collection). POF = post-ovulatory follicle.

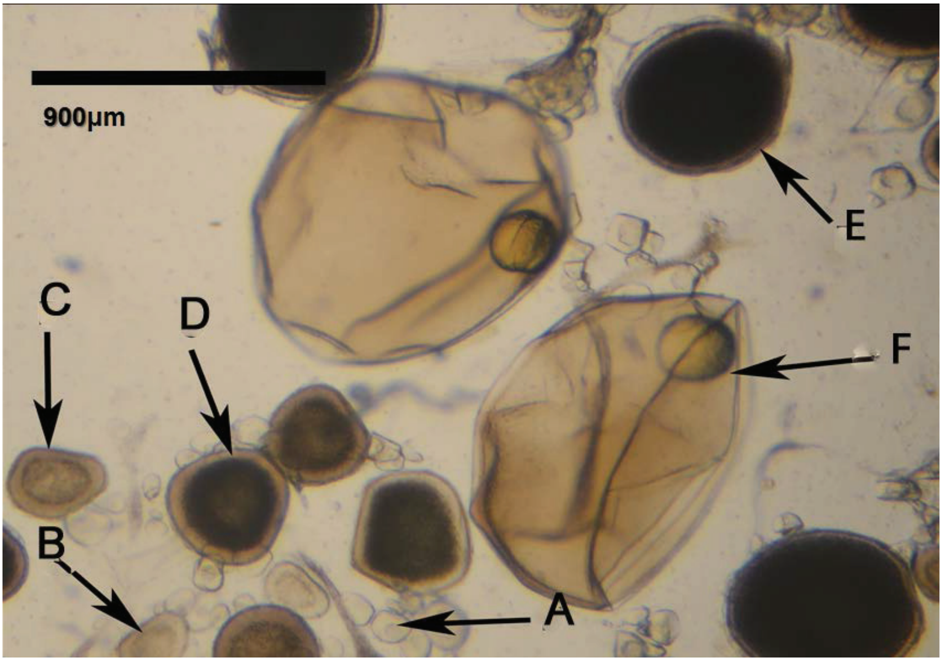

FIGURE 4.—Image of barred sand bass ovarian tissue wet mount highlighting the various oocyte development stages, including (A) primary growth, (B) cortical alveolar, (C) vitellogenic stage I, (D) vitellogenic stage II, (E) vitellogenic stage III, and (F) hydrated oocyte.

mean diameters of thirty oocytes of each developmental stage were measured to the nearest millimeter for each fish using a Max ERB dissecting scope with an eyepiece micrometer calibrated at 100× for hydrated oocytes and 200× for all other developmental stages. We multiplied the mean number of hydrated oocytes per gram of ovarian tissue by the total mass of the ovary (OM) to estimate the number of hydrated oocytes to be spawned in a batch.

Reproductive hormones.—Blood samples were centrifuged at 5000 revolutions/minute for 5 minutes to separate the blood plasma. Plasma was removed and stored at -80 °C until hormone assays were conducted. Female plasma E2 and P4 concentrations were measured using Cayman Chemical ACE™ competitive enzyme immunoassays (17β-estradiol EIA kit; Cayman Chemical Item 582251 and progesterone EIA kit; Cayman Chemical Item 582601), and male plasma 11KT concentrations were measured using the 11-keto Testosterone EIA kit (Cayman Chemical Item 582751).

Two dilutions of each blood plasma sample that were between 20% and 80% of B/B_0 (the ratio of sample absorbance to that of a maximum binding control) were used in hormone assays. The dilutions were analyzed in duplicate and values were averaged. Plates were read using a Powerwave XS Bio-Tek microplate spectrophotometer at 412 nm. Raw data (absorbances) were analyzed using 2006 Cayman Chemical Enzyme Immunoassay Tools software. Intra-assay coefficients of variability (CV) ranged from 8.7 to 16.3% for E2, from 9.7 to 16.1% for P, and from 4.6 to 10.1% for 11KT. Inter-assay CV was 14.8, 8.8, and 16.5% for E2, P, and 11KT, respectively.

Data analysis.—Male and female GSI data from June to September 2011 were analyzed with historic monthly BSB GSI data (collected during 1993–1995 and archived by the California Department of Fish and Wildlife) to look for seasonal patterns and to identify a best fit curve for predicting sex-specific GSI by month. Barred sand bass in the 1990s study were collected throughout southern California.

The spawning fraction (*S*) is the fraction of mature females whose ovaries contain hydrated oocytes and (or) POF_0 or POF_1 (imminent, active, or recent spawners; Lowerre-Barbieri et al. 2011a). We calculated the monthly spawning fraction, spawning interval (i.e., time lag between spawning events, $1/S_{month}$), and monthly spawning frequency (monthly spawning events [the number of days in the month divided by $1/S_{month}$]). Monthly differences in spawning fraction were tested using a Chi Square Test of Homogeneity (or Fisher's Exact Test in cases with expected values <5%), and Bonferroni multiple comparisons *ad hoc*. We report Adjusted Wald 95% binary confidence intervals with proportion data and LaPlace point estimates for proportion data equal to zero females (Sauro and Lewis 2005).

The seasonal spawning fraction was calculated as the number of imminent, active, or recent spawners divided by the total number of mature females sampled from June to September 2011; the seasonal spawning interval was the inverse of this value. The total seasonal spawning frequency was calculated as the sum of the monthly number of estimated spawning events per female.

Batch fecundity, OM, SM, ovary-free weight wet (OFWW), and SL were $\log_{10}$-transformed and batch fecundity-size relationships were examined with linear regression. Since gonad wet weights were not obtained for all fish, OFWW was calculated from the formalin preserved gonad weight, which did not significantly differ from the fresh weight for a subsample of BSB (Preserved Weight=1.0137(Wet Weight)+0.4813, n=106, R^2=0.9984). Females with ovaries showing signs of active or recent spawning (e.g., tissue counts <100 hydrated oocytes in each lobe or presence of POF_0 or POF_1) were assumed to contain partially spawned batches; therefore, batch fecundity curves were compared with and without these data. A Kruskal-Wallis test was used to determine if there was a difference in the condition factor (i.e., fish health, K) and relative fecundity (hydrated oocytes/g OFWW) among POF_2 females, POF_0 or POF_1 females, and females with low hydrated oocyte counts; this was followed by a Mann-Whitney test for pairwise comparisons. The condition factor was calculated using the equation, $K=(SM\times10^2)/SL^3$, where SM was in grams and SL was in centimeters (Moyle and Cech 1988). Potential annual fecundity was calculated as the estimated batch fecundity for POF_2 females multiplied by the total estimated spawning events per female per year (i.e., total seasonal spawning frequency).

We calculated mean hourly and daily concentrations (pg/ml) of each reproductive hormone to identify any peak(s) in hormone concentration during a 24-hr period and also throughout the spawning season. For temporal comparison, daily E2 concentrations were plotted relative to new and full moon phases and average daily values of SST for Newport Pier in Newport Beach, California (SCCOOS 2013) and tidal flux (m) obtained for Balboa Pier in Newport Beach, California (Nobeltec Tides and Currents Pro v 3.5 software). Tidal flux was calculated as the difference between the lowest and highest tide heights on the day of capture. A Wilcoxon Mann-Whitney test compared E2 concentrations in females sampled in July and August between 0700–1200 hours and 1200–1500 hours.

A standard multiple regression analysis was conducted to determine how well fish size (TL), time of capture, SST, tidal flux, chlorophyll concentration, and photoperiod predicted female E2 and male 11KT reproductive hormone concentrations; SST and chlorophyll concentrations for each sampling date and time were obtained from SCCOOS (2013). Hormone concentrations were normalized by square-root transformation, all variables were converted to *Z*-scores, and an extreme E2 outlier was removed for one female. We did not include interactions because these variables could not be controlled in the field. All statistical analyses were performed using Minitab 16.2.2 statistical software with α=0.05. Curve-fitting for GSI and batch fecundity relationships was done using SigmaPlot 10.0.

Results

We collected 352 BSB (212 females, 138 males) over 29 sampling days (June = 8 days, July = 13 days, August = 7 days, September = 1 day). All fish were mature, ranging in size from 204 to 509 mm SL and from 0.18 to 3.40 kg.

Spawning seasonality and fraction.—A subset of 272 fish (192 females, 80 males) with associated somatic and gonadal weights was available for GSI analysis. An additional 282 BSB GSI records from the 1990s (135 females, 91 males, 56 unknown; size range: 138–474 mm SL, 0.07–2.25 kg) were obtained from CDFW archives. For individual fish, GSI values ranged from <1.0 to 18.1%. Mean monthly GSI by sex (females and males) peaked during June, July, and August (Figure 5a); this trend was the same when the 1990s data and 2011 data were examined separately. No data were available for April, October, or December; however, a non-linear best-fit curve of the data suggested GSI was low during those months (Figure 5a). Although average daily GSI was highly variable, females and males showed five coincident peaks of differing magnitudes between late June and late August of 2011 (Figure 5b).

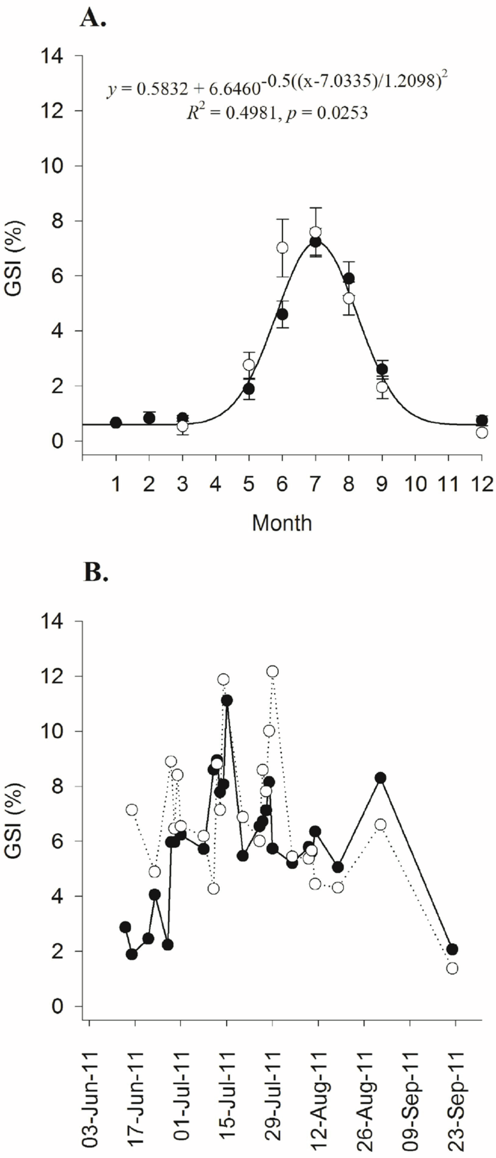

Figure 5.—Mean (A) monthly (± 2 *SE*) gonadosomatic index (GSI; males, *n*=171; females, *n*=327; 1993–1995 and 2011) and (B) daily GSI (males, *n*=80; females, *n*=192; 2011 only) for male (open circles) and female (black circles) barred sand bass collected in southern California. Non-linear fit through monthly data is based on data for all fish (*n*=553), including individuals of unknown sex.

Although female GSI was highest from June to August, the spawning fraction showed daily variability, and peaked twice in July and once in August (Figure 6a). There was a significant difference in spawning fraction by sampling month (χ^2_3, 208=23.1, P<0.001) with the proportion of spawning females being 2- to 6-fold higher in July and August when compared with June or September (Figure 6b). The spawning interval and spawning frequency likewise varied by sampling month, as did the proportion of daily spawners (Table 1). Although we found no significant difference between the July and August spawning fraction (χ^2_1, 166=0.836, P=0.361), the incidence of active spawning (i.e., females with POF$_0$) was significantly higher in July than August (χ^2_1, 166=6.75, P=0.009). The proportion of

Table 1.—Monthly spawning interval (days), spawning frequency (events), and proportion of daily spawners estimated for female barred sand bass collected on the San Pedro Shelf in southern California, June–September 2011.

Month	Spawning interval (days)	Spawning frequency (events)	Proportion daily spawners
June	6.0	5.0	0.08
July	1.7	17.8	0.44
August	2.0	15.5	0.38
September	9.0	3.3	0.00

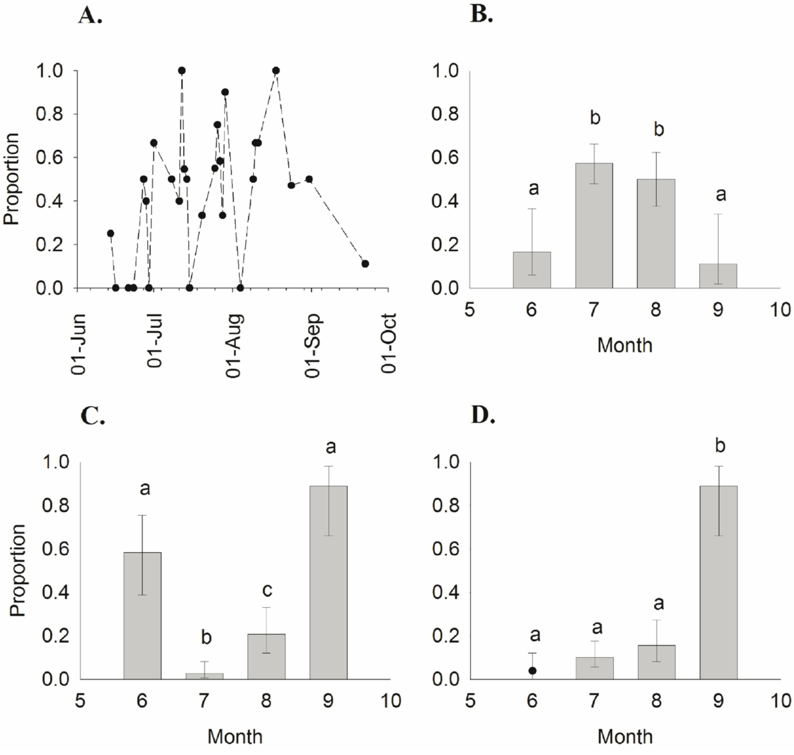

Figure 6.—Spawning fraction of barred sand bass females collected on the San Pedro Shelf in southern California (June–September 2011) by collection date (A) and by collection month (B), and the monthly proportion of females (C) in non-spawning condition and (D) with mass follicular atresia. Error bars are 95% binomial confidence intervals; the black circle represents a LaPlace point estimate. Sample sizes for June, July, August, and September were 24,108, 58, and 18, respectively.

non-spawning females also differed by sampling month (Fisher's Exact Test, $P=0.008$), with June and September showing the highest non-spawning fractions, and September showing the highest incidence of follicular atresia (i.e., spawning cessation; Figure 6c, Figure 6d). Females spawned approximately 42 times from June to September 2011 (Table 1).

The percent of females with hydrated oocytes steadily decreased between the sampling hours of 0700 and 1300; no females with hydrated oocytes were sampled between 1300 and 1500 hours (Figure 7). Only four females were sampled between 2000 and 2200 hours and the most advanced oocyte stages present were early vitellogenic (vtg-I,II; $n=3$) and advanced vitellogenic (vtg-III; $n=1$); these fish were sampled in mid-June and had no POFs. The mean (±*SD*) percent of non-spawners between 0700 and 1300 hours was 14±14% ($n=256$), while the mean between 1300 and 1500 hours was 58±13% ($n=26$).

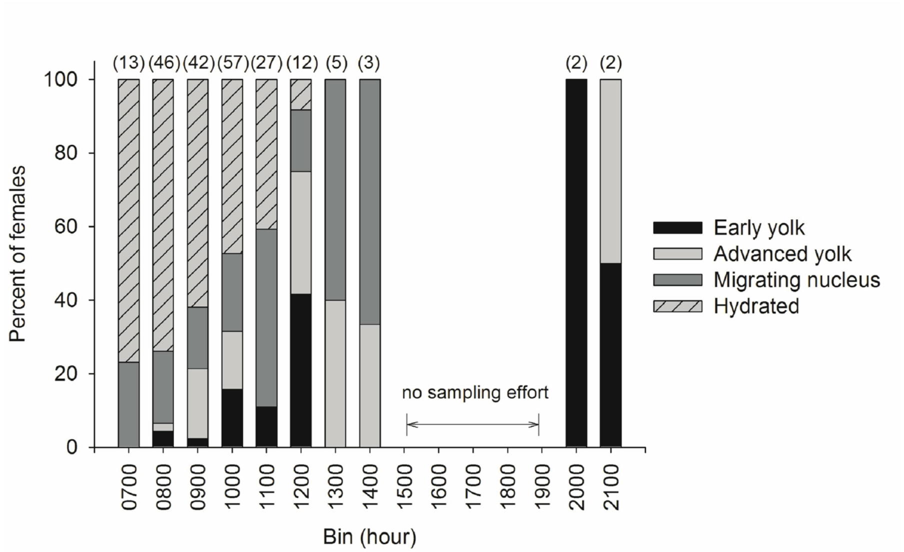

Figure 7.—Percent of barred sand bass females collected on the San Pedro Shelf in southern California (June–September 2011) grouped by the most advanced oocyte development stage present in the ovary and the hour of collection. Early yolk = vitellogenic stage I and II; advanced yolk = vitellogenic stage III. No sampling occurred between 1500 and 2000 or between 2200 and 0700.

Batch fecundity.—Oocyte development stages differed in mean diameter ($F_{5, 11594}=135{,}152$, $P<0.001$) and all pairwise comparisons were significant. The mean (±*SD*) diameters (mm) for each stage were 0.07±0.02 (PG, $n=1{,}945$), 0.14±0.02 (CA, $n=1{,}942$), 0.22±0.03 (VtgI, $n=1{,}942$), 0.33±0.04 (VtgII, $n=1{,}944$), 0.46±0.03 (VtgIII, $n=1{,}944$), and 0.89±0.06 (H, $n=1{,}883$). Batch fecundity estimates were analyzed for 63 females (size range: 204–461 mm SL, 0.18–2.85 kg; ovary weights: 13.90–200.71 g; capture dates: 28 June to 31 August 2011). The $\log_{10}$-transformed linear relationships between batch fecundity and OM, OFWW, and SL were all significant ($P<0.001$); however, subsequent removal of active or potential recent spawners (i.e., females with hydrated oocyte counts <100 or POF_0, POF_1) greatly improved these relationships, especially for SL (Figure 8a, Figure 8b, Figure 8c). Batch fecundity for POF_2 females ($n=40$; size range: 204-461 mm SL, 0.18–2.85 kg; average size: 299 mm SL, 0.77 kg; capture dates: 28 June to 31 August 2011) ranged from 23,536 to 330,443 oocytes and averaged 84,032. Potential annual fecundity ranged from 0.98 to 13.9 million oocytes and averaged 3.5±2.5 million. The relationship between SL and OFWW for the 40 POF_2 females was defined by the function $OFWW=0.00004*SL^{2.9019}$ ($R^2=0.94$); the mean (±*SD*) ratio of OFWW to SM was 0.91±0.2, and the mean (±*SD*) number of hydrated oocytes per gram of ovarian tissue was 1,278±199.

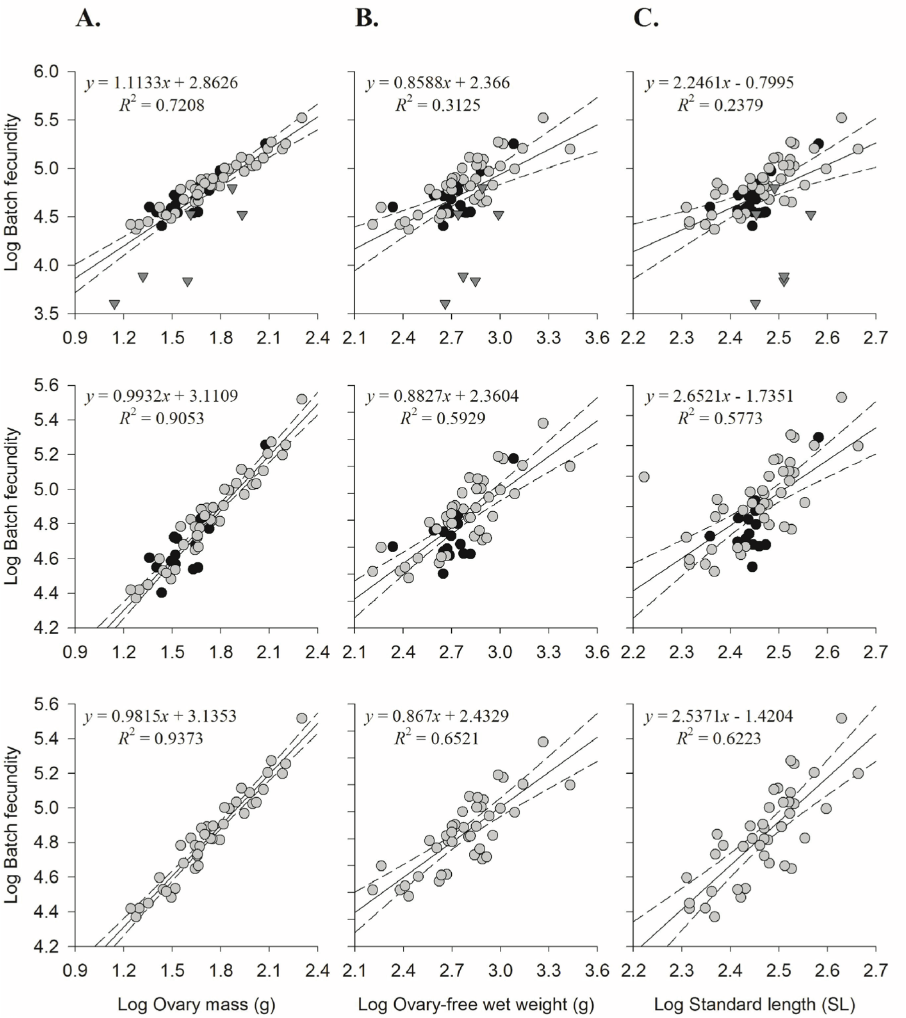

FIGURE 8.—Relationship between Log_{10} batch fecundity (±95% *CI*) of barred sand bass females collected on the San Pedro Shelf in southern California (June–September 2011) and (A) Log_{10} ovary mass (g); (B) Log_{10} ovary-free wet weight (g); and (C) Log_{10} standard length (SL). The top panels include females with POF_2 (gray dots, *n*=40) and females with recently spawned batches having POF_0 or POF_1 (black dots, *n*=17) or low hydrated oocyte counts (gray inverted triangles, *n*=6). The middle and bottom panels represent the subsequent removal of these females until all potential recent spawners are excluded.

Mean (±*SD*) relative fecundity (number of hydrated oocytes/g OFWW) was highest for POF_2 females (123.46±43.08, *n*=40), followed by POF_0 and POF_1 females combined (99.31±38.84, *n*=17) and females with low hydrated oocyte counts (34.83±30.42, *n*=6). Relative fecundity was different among the three groups (*H*=14.98, *df*=2, *P*=0.001); however, the difference between POF_2 females and females with POF_0/POF_1 was marginally nonsignificant (*W*=387.0, *P*=0.07). There was no relationship between OFWW and relative fecundity, and there was no significant difference in the condition factor among POF_2 females (median: 2.54, mean: 2.62), POF_0/POF_1 females (2.62, 2.65), and females with low hydrated oocyte counts (2.26, 2.22; *H*=3.74, *df*=2, *P*=0.154).

Spawning periodicity.—We assayed 160 female E2, 153 female P4, and 96 male 11KT blood plasma samples. Female E2 and male 11KT concentrations varied among individuals and across the spawning season (Figure 9). Mean daily E2 concentrations

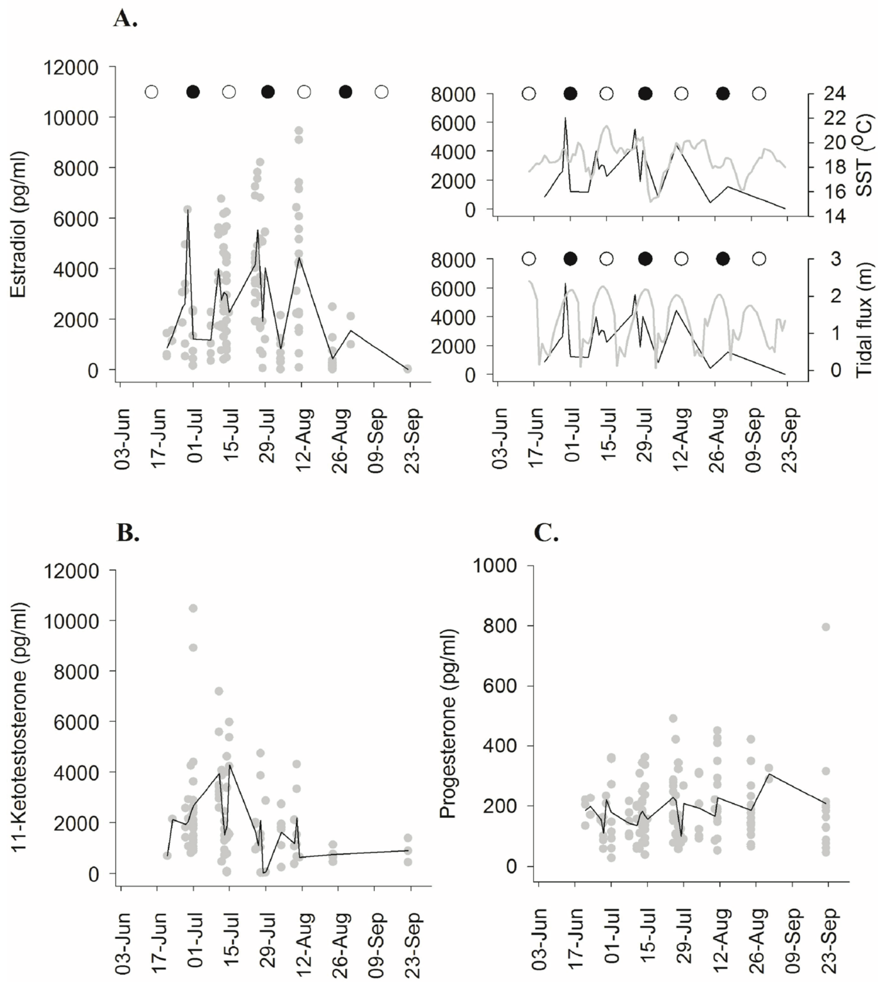

Figure 9.—Mean daily concentrations of (A) female 17β-estradiol (pg/ml, black line) relative to moon phase (full moon, open circles; new moon, black circles), SST (°C), and tidal flux (m); (B) male 11-ketotestosterone (pg/ml); and (C) female progesterone (pg/ml) sampled from barred sand bass collected on the San Pedro Shelf in southern California, June–September 2011. Gray circles represent raw data.

in female BSB blood plasma peaked in late June, mid-July, late July, and mid-August, occurring just days before the new and full moons (Figure 9a). The peaks were an average of 15 (±1 *SD*) days apart and an average of 3.3 (±1.2 *SD*) days prior to the new or full moon phases. Fluctuations in SST and tidal flux tended to correspond with these peaks, albeit with different magnitudes (Figure 9a). By mid-September, E2 concentrations measured in nine females were near zero. In contrast, mean daily concentrations of 11KT in male blood plasma peaked once in mid-July, just before the full moon (Figure 9b). Low 11KT concentrations in late June and late August were similar to values obtained on a single sampling date in mid-September. Although female P4 concentrations varied among individuals, mean daily values were relatively stable from late June to mid-August, peaking only in late August; the highest individual value occurred in September (Figure 9c). Mean hourly concentrations of E2 in females sampled in July and August remained elevated between 0700 and 1200 hours and were low between 1200 and 1500 hours (Figure 10); median E2 concentrations before 1200 and after 1200 were significantly different (*W*=10263.5, *P*<0.001). In contrast, male 11KT concentrations peaked at 0700 and decreased through 1200; no males were sampled after 1200 (Figure 10b).

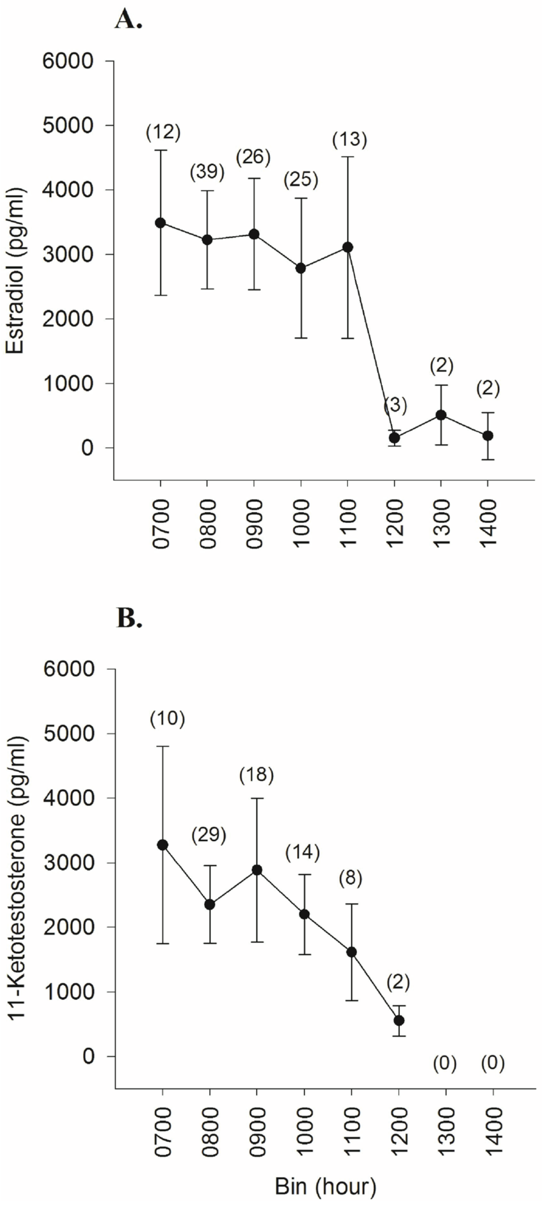

FIGURE 10.—Mean (±2 *SE*) hourly concentrations of (A) female 17β-estradiol (pg/ml) and (B) male 11-ketotestosterone (pg/ml) measured in barred sand bass collected on the San Pedro Shelf in southern California, June–September 2011. No sampling occurred between 1500 and 0700.

The full model for E2 concentrations in female BSB was significant (R^2=0.38, $F_{6,139}$ = 9.2, P<0.001), but the coefficient for TL was not significant; the reduced model explained 37% of the variability in E2, and SST and time of capture were the most significant predictors (R^2=0.37, $F_{5,140}$=16.5, P<0.001; Table 2). Photoperiod was the only significant predictor of BSB male 11KT concentrations (R^2=0.91, $F_{1,103}$=10.3, P=0.002).

Table 2.—Multiple regression results of the full and reduced model for 17β-estradiol concentrations in female barred sand bass collected on the San Pedro Shelf in southern California, June–September 2011. SST = sea surface temperature.

Predictor	Coefficient, *β*	*SE* Coefficient	*T*	*P*
Full Model				
Constant	0.0000	0.0665	0.00	1.000
Total length	-0.1091	0.0691	-1.58	0.117
SST	0.4297	0.0928	4.63	0.000
Time of capture	-0.3560	0.0819	-4.34	0.000
Tidal flux	-0.2139	0.1067	-2.00	0.047
Chlorophyll	-0.2027	0.0809	-2.51	0.013
Photoperiod	0.1776	0.0792	2.54	0.027
Reduced Model				
Constant	0.0000	0.0668	0.00	1.000
SST	0.4537	0.0920	4.93	0.000
Time of capture	-0.3510	0.0823	-4.26	0.000
Tidal flux	-0.2151	0.1072	-2.01	0.047
Chlorophyll	-0.2052	0.0813	-2.52	0.013
Photoperiod	0.1893	0.0793	2.39	0.018

DISCUSSION

Reproductive potential.—The results of the reproductive parameters of the current study combined with historic monthly GSI data from the 1990s agree with the June to August spawning season reported for BSB by Clark (1933) over eighty years ago. By September, female E2 and male 11KT concentrations were low, and females showed a high incidence of follicular atresia and a peak in P4, both indicators of spawning cessation. Although BSB males appeared primed for spawning in June (e.g., elevated GSI), male 11KT concentrations didn't peak until July, and evidence of spawning for most BSB females occurred in July and August as elevated GSI, E2, and POFs). Unfortunately, we did not sample during the early part of June; however, GSI from fish collected during June in the 1990s was between 0.46 and 1.49%, suggesting we captured the onset of spawning from mid to late June. Using our monthly spawning fractions for June to September, female BSB were estimated to spawn approximately 42 times per year. This is in contrast to 55 times per year estimated by Oda et al. (1993) using spawning fraction from late July, which highlights the importance of sampling throughout the spawning season.

In addition to differences in the temporal resolution of sampling effort, spawning frequency estimates can be affected by individual variability in spawning periods, including variation in spawning residence times of migrant fish and oversampling of aggregative females (i.e., only sampling spawning hot spots; Lowerre-Barbieri et al. 2011b). McKinzie et al. (2014) analyzed the fine-scale horizontal and vertical movement patterns of BSB and during spawning season found that presumed spawning individuals spent most of their time in the mid-water over sand habitat during the day and remained more closely associated with the seafloor at night, exhibiting a positive edge response (i.e., showing preference for a rock-sand ecotone; Mason and Lowe 2010). Although tag and recapture data suggest a BSB spawning ground residence time of 7 to 35 days for individual fish, only a portion of BSB on the spawning grounds appear to be migrant, and average BSB migration distances are inclusive of the area we sampled (Jarvis et al. 2010). Therefore, we feel confident in our spawning frequencies estimated during June – September 2011, since a large size range of mature individuals was sampled and because BSB were collected on reefs and within spawning aggregations over sand flats using a variety of sampling methods.

Our batch fecundity and size relationships were improved by the exclusion of females with hydrated oocyte counts less than 100 and females with POF_0 or POF_1. We assumed the six females with low hydrated oocyte counts contained partially spawned batches; these fish were captured from late June through peak spawning and atretic follicles were not more prevalent in these samples than samples without low hydrated oocyte counts. POF_0 females likely contained partially spawned batches since these fish provided evidence of active spawning (POF ages <4 hrs). The post-ovulatory follicles of POF_1 females ranged in age from new to old (from 4 to 24 hours). Thus, it is possible that at least some of these females also contained partially spawned batches, especially since removal of POF_0 and POF_1 females shifted our batch fecundity curve slightly higher. Although we found no significant difference in relative fecundity between POF_0 and POF_1 females and POF_2 females, the significance level was marginal and may have been affected by a low sample size of POF_0 and POF_1 females, in addition to the variability introduced within the POF ages themselves. For example, different POF ages may actually represent similar spawning times prior to collection, whereby a female that spawned 23 hours prior to collection would theoretically be assigned POF_1, while a female that spawned 25 hours prior to collection would be assigned POF_2.

It is important to note that if lower relative fecundity in POF_1 females is due to subsequent spawns of daily spawners being less fecund than females that spawn every 2–3 days, then excluding POF_1 females may have overestimated our batch fecundity results (batch fecundity including the 12 POF_1 females [i.e., POF_2 AND POF_1 females combined] averaged 79,156 oocytes; average size was 297 mm SL and 0.75 kg). However, it is not known whether this occurs with BSB. Without improved resolution in assigning POF ages of POF_1 females, future BSB batch fecundity estimates should attempt to exclude these females through histological analysis or by exclusively sampling fish at times of the day when they are not likely spawning.

In comparing our results with previous *Paralabrax* batch fecundity estimates for kelp bass (Oda et al. 1993) and for kelp bass and BSB combined (DeMartini 1987), our BSB estimations were higher than those determined by DeMartini (1987), but very similar to what Oda et al. (1993) reported for similarly sized fish. For example, based on our batch fecundity estimate using OFWW, a 700-g OFWW female BSB would average about 79,000 eggs per batch, while the same size fish in Oda et al. (1993) was reported to average 81,000 and in DeMartini (1987), only 43,000. Oda et al. (1993) noted that DeMartini's results may have been influenced by temperature, since fish in that study were collected during an El Niño period. However, based on the effect of temperature on fecundity for other species, one might expect warmer temperatures to result in higher fecundity (Lambert 2008). It is also possible that DeMartini's (1987) results were influenced by females with partially spawned batches. Unlike Oda et al. (1993) and the current study, Demartini (1987) did not distinguish between females with new and old POFs and most females were collected between 0900 and 1100 hours when females were likely spawning.

Potential annual fecundity for female BSB in this study was very similar to the estimate reported for another temperate serranid, blacktail comber (*Serranus atricauda*): 0.91 to 15.5 million oocytes, with an average of 5.1±4.1 million (Garcia-Diaz et al. 2006). Monitoring annual fecundity can be useful for understanding the effects of fishing, individual variability (e.g., condition, lipid content, morphological constraints), and environmental conditions on this reproductive parameter (Lambert 2008, Pitman et al. 2013). For example, Pitman et al. (2013) found that fecundity was negatively related to the stock size of orange roughy (*Hoplostethus atlanticus*), with exploitation having a density-dependent compensatory effect on fecundity. Moreover, an increasing number of studies have shown the relationship between spawning stock biomass and stock egg production might not always be reliable (Lambert 2008). Although BSB batch fecundity can be predicted based on the size relationships provided here, obtaining actual batch fecundity estimates along with monthly spawning frequency estimates is better for monitoring potential annual fecundity. Our results from 2011 should provide a baseline from which to measure changes in BSB potential annual fecundity before and after the 2013 implementation of more restrictive harvest regulations.

Spawning periodicity.—Reproductive hormone concentrations were highly variable among individuals; however, a few trends were apparent. Between late June and mid-August, E2 in female BSB peaked with regular periodicity just days before the new and full moons, which were coincident with high tidal fluxes. These peaks also appeared to occur with increases in SST, which had the highest significant coefficient for predicting female E2 concentrations in our model. Unlike for some tropical aggregative spawners, lunar spawning synchronicity would not necessarily be expected for BSB, which are capable of daily spawning and have a protracted spawning season. For example, spawning aggregation formation or activity was not related to the lunar cycle in dusky grouper (*Epinephelus marginatus*) (Herue et al. 2006) or kelp bass (Erisman and Allen 2006), and both are temperate serranids that have protracted spawning seasons like BSB. Erisman et al. (2007) also did not find evidence for lunar synchronicity in the aggregative daily spawner, leopard grouper (*Mycteroperca rosacea*). However, evidence for lunar spawning synchronicity in these studies was measured by examining temporal changes in GSI or *in situ* with visual observations of spawning behavior or activity, rather than with analysis of individual reproductive hormone concentrations, which may provide finer-scale resolution in these relationships for some species. In addition, lag times, sample sizes, and sampling frequency can also distort possible relationships.

E2 is known to regulate vitellogenesis in many teleosts (Redding and Patino 1993); thus, although a fraction of BSB females spawned every few days in July and August, it appears there are specific times when vitellogenesis in BSB females is ramped up, and this would result in peak recruitment of primary oocytes into vitellogenic growth (Cheek et al. 2000). Interestingly, we observed regular peaks in average daily BSB GSI over the spawning season, which upon further examination appear to coincide with the peaks in E2, which coincided with peaks in water temperature. Thus, despite the variability we observed in GSI and E2 among individuals, the overall average daily fluctuations in GSI suggest there are peak periods of gonadal growth followed by gamete release.

Optimal water temperatures could be causing an increase in hydration and subsequent ovulation that coincides with high tidal flows. Such conditions could increase egg or larval survival (Colin 1992, Sancho et al. 2000). The fine-scale vertical movements of BSB acoustically tracked during spawning season indicate that BSB are associated with the thermocline and make repeated vertical dives toward the seafloor during the day (McKinzie et al. 2014); those authors noted the thermocline association may facilitate rapid hydration and egg development. Furthermore, BSB have positively buoyant eggs, and Gadomski and Caddell (1996) reported that successful hatching of viable BSB embryos occurred only at 16–28° C, which is inclusive of typical summertime surface waters in the local region (~15–22° C). Finally, daily tidal fluxes in the region during this study were high (~3 m), which could provide swift transport of eggs or larvae away from schooling ichthyoplankton predators.

Within-day trends in periodicity were limited to the hours of our sampling effort, which was primarily from 0700 to 1500. Nevertheless, results from this study and previous studies potentially provide insight into BSB diel spawning periodicity. Hourly trends in the most advanced oocyte stage present in the BSB ovary and in female E2 and male 11KT concentrations suggest spawning ceased after 1200. Although the ovaries of the four females sampled at night (2000–2200) did not contain hydrated oocytes or POFs, these fish were collected in mid-June when the spawning fraction was low (17%), so this alone does not rule out the potential for evening spawning. Oda et al. (1993) reported a mid-day spawning peak for BSB (1200–1400); however, those authors also collected ovulating BSB females into the night (1900–2300). It is unclear what measure they used to classify an ovulating female since none of the BSB collected at that time contained hydrated oocytes or new POFs; thus, spawning was not likely occurring. In addition, McKinzie et al. (2014) noted that diving behavior of presumed spawning or courting BSB individuals occurred during daylight hours and resting (non-diving) behavior occurred at night. The one exception was a fish acoustically tracked during a full moon that exhibited diving behavior during both day and night, suggesting that spawning-related behavior at night occurs during full moon periods.

Given the results reported here and in previous studies, BSB spawning appears to begin at dawn and ceases for most females by the early afternoon. Following the drop in E2 at that time (i.e., following the peak in vitellogenesis), the process of BSB oocyte hydration likely begins. This scenario would yield an approximate 15-hour hydration period for BSB (1300–0600), as reported by Oda et al. (1993) for kelp bass; DeMartini (1989) also predicted “a long hydration period” for BSB. Prolonged diel spawning in BSB may be reserved for within-season periods of optimal environmental conditions for eggs and larvae.

The within-season trends in periodicity reported here offer an alternative, or additional, fishery management option for BSB. For example, a partial spawning season closure that straddled a full moon and new moon phase would likely provide valuable protection during a period of the spawning season when the fish are most vulnerable and when spawning output is potentially higher due to spawning synchronicity.

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Influence of bucket trap hole diameter on retention of immature hagfish

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In California, the commercial fishery for Pacific hagfish (*Eptatretus stoutii*) has exported over one million pounds annually in recent years, primarily to South Korea where they are considered a delicacy. Comparatively little research exists to support management decisions for this species. The California Department of Fish and Wildlife (CDFW) sought to evaluate the influence of trap hole diameter, which is presently unregulated, on the take of immature hagfish. Using standard 20-L bucket trap gear, we tested four hole diameters (9.5 mm, 12.7 mm, 14.3 mm, and 15.9 mm), which are currently or have been previously used by the fishery. We found that the percentage of immature female hagfish declined with increasing trap hole diameter. The smallest hole diameter tested resulted in catch where approximately 17.5% of female fish were of immature size. Although the take of immature hagfish was not completely eliminated until the largest of these hole diameters was used, a 10.5% reduction in the percentage of immature female hagfish occurred between 12.7 and 14.3 mm. The number of larger hagfish increased with increasing hole diameter, yet overall catch weight decreased, suggesting that hole diameter currently utilized by fishermen represents a conscious tradeoff between these competing factors.

Key words: California, bucket traps, *Eptatretus stoutii,* gonad condition, hole diameter, immature, Pacific hagfish

The Pacific hagfish (*Eptatretus stoutii*) is one of approximately 60 species in the hagfish family (Myxinidae), which constitutes the most primitive family of fishes. Hagfish inhabit relatively deep, temperate regions of the world's oceans, and are highly adapted to the low oxygen (Cox et al. 2011) and high salinity conditions (Adam and Strahan 1963) that occur at depth. They may be the most abundant fish inhabiting the upper continental slope, though previous population estimates are limited and likely underestimate abundance due to their cryptic burrowing behavior (Martini 1998). Hagfish are ecologically important, providing ecosystem services as scavengers and as a food source to several fish species (Martini 1998, Buckley et al. 1999). Pacific hagfish were also shown to provide a significant portion of the year-round diet for the harbor seal (*Phoca vitulina*) (Hanson 1993, Oxman 1995).

In California, an unprecedented commercial fishery for hagfish emerged in the late 1980s to provide skins for the South Korean "eel skin" industry, and peaked in 1990 with approximately 4.9 million pounds in landings. Soon thereafter landings abruptly declined as Korean demand for California-caught hagfish diminished due to blemishes found in the tanned hides (Kato 1990). Demand remained low until 2005, when the fishery re-emerged, but this time for human consumption. Since 2007, commercial landings for hagfish have remained relatively stable and have ranged from one to two million pounds annually. Hagfish are caught along the entire length of the state, and Oceanside, Morro Bay, Bodega Bay, and Fields Landing are the primary ports of landing. The fishery is managed by the California Department of Fish and Wildlife (CDFW).

Though Pacific hagfish have been studied extensively in an evolutionary context, there is limited information on the species as it relates to fishery management. There is evidence that they are slow-growing and long-lived and may reach ages upward of 25 years (Johnson 1994, Nakamura 1994). Several studies suggest that they have a low fecundity, with females only carrying 20–30 eggs per breeding cycle (Gorbman and Dickhoff 1978, Kato 1990). Female hagfish are estimated to attain reproductive maturity between 7 and 12 years of age (Nakamura 1994), while males mature at a somewhat younger age (Reid 1990). These life history characteristics suggest that hagfish could be susceptible to overexploitation, provided effective management actions are not implemented.

Limiting the take of immature fish is a common fishery management strategy, but has not yet been applied to the Pacific hagfish fishery. Presently, the fishery is subject to few regulations. It is open access, and has no quota or other direct limitations imposed on catch biomass; however, gear type and quantity are regulated and fishermen are limited to 500 Korean-style traps or 200 20-L bucket traps (Figure 1). The bucket trap is larger by volume

Figure 1.—A 20-L bucket trap (left) and standard Korean-style trap (right), legal gear in the commercial fishery for Pacific hagfish. Photograph by T. Tanaka, California Department of Fish and Wildlife.

and is the primary gear type used in California. Hagfish traps are covered with many holes of the same diameter, which allow water to flow through the trap, helping the bucket ascend or descend during deployment or retrieval. The holes also provide an additional means for hagfish to enter the trap and an opportunity for small hagfish to exit, consequently having a large influence over the size structure of fish in the catch. California Department of Fish and Wildlife currently does not have a minimum hole diameter requirement for hagfish traps, and at present the fishery uses hole diameters ranging from 9.5 to 15.9 mm.

Previous trap studies in California have examined various aspects of hagfish catch characteristics, but none so far have examined the influence of hole diameter on the take of immature hagfish. Melvin and Osborn (1992) tested variations of trap gear, including hole diameter, on mean hagfish size and catch weight. However, their main objective was to provide industry with information on identifying ways to control the potential for trap-induced skin quality issues such as holes and blemishes, and gear development for selecting a higher proportion of larger hagfish. Johnson (1994) used Korean-style traps in an effort to test hagfish distribution at various depths and retain samples for a maturation study, but did not examine the effects of variations in trap gear. In the present study, we aimed to provide specific information that could be directly incorporated into fishery management decisions by testing the influence of trap-hole diameter on the retention of immature hagfish. We also assessed the potential economic consequences of regulating hole diameter by evaluating its relationship to overall catch weight and average fish size.

Materials And Methods

The experimental design used in this study was adapted from previous research efforts (Melvin and Osborn 1992); unlike previous studies, we examined the influence of trap hole diameter on the retention of immature fish, rather than catch marketability. We also incorporated hagfish-fishermen knowledge into the study design to improve catch rate, and provide results that were more reflective of the hagfish fishery itself. We interviewed current fishery participants from Eureka, Morro Bay, and Oceanside either in person or by phone to determine the number of traps typically fished, the hole diameter(s) used in the fishery, and the reason(s) that each hole diameter was selected. Fisherman also provided us with information on their preferred bait type, as well as optimal gear-soak times. Based on fishermen responses, we were able to (1) test the influence of hole diameters used by the industry; (2) increase our sampling success; and (3) develop successful working relationships with fishery participants.

Sampling procedures.—A typical bucket trap consists of a 20-L bucket, a single cone-shaped entrance funnel fixed to the bucket lid, a weight fixed to the inside wall of the bucket, and many holes drilled in the walls and bottom. Ninety-six 20-L bucket traps were constructed, which were secured to four 250-m strings, with twenty-four traps per string. Each string contained six replicate traps of each of four hole diameters (9.5 mm, 12.7 mm, 14.3 mm, and 15.9 mm). Traps were placed 10.7 m apart along the string in alternating order. Each trap was secured to the string with a short leash. All traps were standardized, each with 50 holes drilled in the same pattern, one entry funnel, and a single weight to ensure correct orientation when the trap contacted the sea floor. All sampling was conducted onboard the F/V *Donna Kathleen* with gear deployed by the experienced crew.

Four days of sampling were conducted in Monterey Bay, west of Moss Landing, Monterey County, California (36° 49.4' N, 121° 51.2' W; depths ranged from 106 to 155 m (58–85 fathoms) over soft sediment. The study area was chosen because hagfish were fished there commercially in the recent past (CDFW commercial landings data) and is located in the geographic center of the California fishery. We targeted areas that were identified as soft benthic sediment by the captain's interpretation of the onboard sonar signature. On the first day of the survey, we deployed 48 traps at depths between 90 and 150 m in a series of short (<4 hour) soaks to determine relative abundance of hagfish. Locations where hagfish were present were recorded and used as sampling sites in the subsequent days of standardized sampling (survey days 2–4). All fish captured on day 1 were released alive, and were not included in any of the subsequent analyses.

On each of the subsequent survey days, we deployed four standardized strings of bucket traps, baited with approximately 0.7 kg of sardines per trap, at sites where hagfish were present on day 1. Strings were soaked overnight for up to 24 hours, and were retrieved in the order of deployment. To avoid repeatedly sampling previously fished areas, strings were moved between 0.21 and 0.24 km between deployments. Upon retrieval of each string, all captured fish were grouped by hole diameter, weighed to the nearest tenth of a kilogram, and counted. The total number of hagfish and total hagfish weight for the survey was the sum of the data collected from each string for each of the four hole diameters. Of all hagfish captured, 160 fish were randomly selected from each hole diameter over the span of the three-day survey. These fish were retained for further analysis, placed in labeled plastic bags, stored on ice for the duration of the cruise, and frozen at the conclusion of each sampling day. All remaining hagfish were released immediately in live condition. We also recorded any observed bycatch by species and condition at capture.

Laboratory and statistical analyses.—Sub-sampled fish were defrosted and 125 of the 160 fish collected from each hole diameter were randomly sub-sampled for laboratory analysis. Weight (g) and total length (mm) were measured for each individual fish, and one-way analysis of variance (ANOVA) was used to assess whether the sub-sampled length and weight data from each of the four hole diameters were significantly different from one another.

Sex was determined for each individual by visually examining either the testis or ovarian tissue. Gonad condition was determined for each fish using a scale from 1 to 5 developed by Barss (1993), where stage 1 = immature; stage 2 = maturing; stage 3 = mature-developing; stage 4 = mature-developed; and stage 5 = mature-spent. The criteria for determining female gonad condition were primarily average egg size and presence or absence of spent egg capsules, while the criteria for determining male gonad condition were primarily size and color of the testis.

We estimated the size at first maturity for female hagfish by determining the size above which no stage 1 fish were observed in our sub-sample, since hagfish of mature size range between stages 2 and 5. Hagfish do not appear to exhibit any significant seasonal trends in their reproductive cycle (Nakamura 1991) that may have added potential bias to the somewhat shorter sampling timeframe within this study. We calculated the percentage of immature female hagfish using the fraction of sub-sampled lengths below our estimate of size at first maturity for each of the four hole diameters.

To evaluate the possible economic consequences of variations in hole diameter, we examined both overall catch weight and the number of hagfish per kilogram within each bucket, or count-per-kilogram (CPkg). CPkg is a metric utilized by the industry to evaluate size and assign a grade to the catch. Hagfish catches with a lower average CPkg are larger and, consequently, are more desirable. Exporters of California-caught hagfish reported that the market preferred 8 to 9 hagfish per kilogram at the time of this study. Korean dealers historically preferred hagfish 356 mm total length (TL) or greater (Kato 1990), but currently the hagfish export market emphasizes weight over length; additionally, live hagfish are difficult to measure.

RESULTS

The survey collectively yielded 7,595 hagfish weighing 825 kilograms. The mean soak time for each trap was 21.6 hours, ranging from 19.63 to 24.57 hours. Seven of the 288 buckets included in the study design did not produce any data as a result of user error during deployment. Consequently, data were missing from one 9.5-mm trap, one 12.7-mm trap, one 14.3-mm trap, and four traps with 15.9-mm holes. Since a small but variable percentage of data was missing from hole diameters tested (1.4–5.6%), we estimated the missing data in an effort to provide a more accurate comparison of total catch data across hole diameters. We replaced each missing trap with the overall average weight for each respective hole diameter, and calculated the total catch weight both with and without the added estimates (Figure 2).

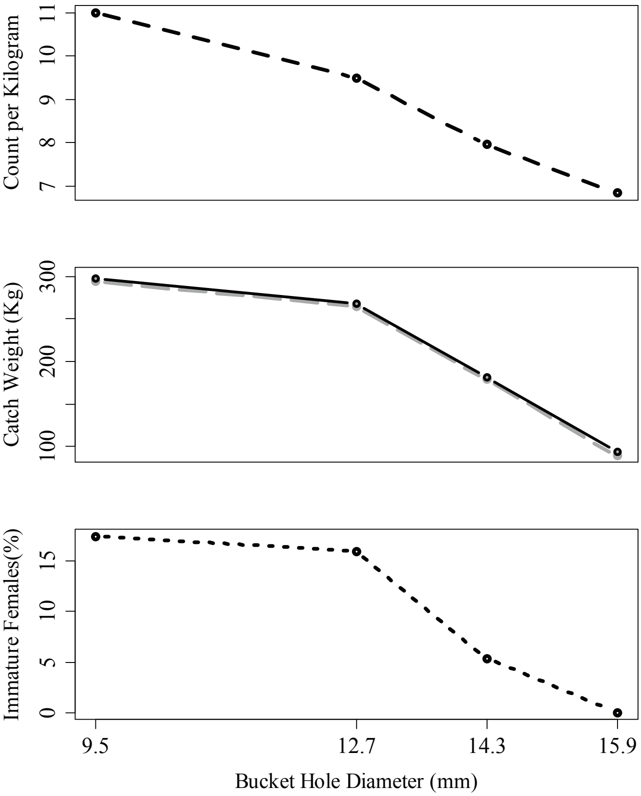

FIGURE 2.—Panel plot showing the effect of bucket trap hole diameter on three main catch characteristics of Pacific hagfish, count-per-kilogram (top); total catch weight (middle); and percentage of immature female fish in the catch (bottom) during March 2013. The two lines in the middle plot represent total catch-weight (dashed grey), and total catch-weight corrected for missing trap data (solid black).

Based on two separate one-way ANOVAs conducted on the randomly sub-sampled catch data, we determined that hagfish length ($F_{3,496}$=9.315, P<0.0001) and hagfish weight ($F_{3,496}$=12.52 , P<0.0001) were significantly different among the four hole diameters tested. As hole diameter increased, the average length and weight of fish per trap increased, while smaller hole diameters retained smaller hagfish (Table 1). Accordingly, CPkg decreased with increasing hole diameter (Figure 2), indicating average size increase. As hole diameter increased, CPkg did not reach the desired market threshold of eight until the second largest hole diameter (14.3 mm) was used (Figure 2). Of the sub-sampled hagfish dissected in this study (n=500), we found no mature female hagfish (stage 2 or higher) less than 338 mm total length (TL). The proportion of hagfish below 338 mm TL in the catch decreased as hole diameter increased, ranging from 0 to 17.5 % (Figure 2). The total bycatch for the study included one octopus (*Octopus* spp.) and one Pacific sanddab (*Citharichys sordidus*), both of which were alive.

Table 1.—Mean (± *SD*) total lengths and weights of female and male hagfish captured in bucket traps near Moss Landing, California, 25–28 March 2013.

	Trap Hole Diameter			
	9.5 mm	12.7 mm	14.3 mm	15.9 mm
Female				
Mean length (mm)	382±52.3	386±43.2	402±44.9	410±31.9
Range (mm)	258–479	302–494	312–502	346–532
Mean weight (g)	95.8±36.4	99.7±30.2	110.1±36.2	117.8±27.8
Range (g)	31.8–178.7	42.8–177.1	52.4–225.5	75.8–189.5
Male				
Mean length (mm)	409±44.8	404±43.7	408±39.5	428±43.4
Range (mm)	310–497	315–486	323–493	351–532
Mean weight (g)	111.9±34.4	105.7±28.6	112.4±30.3	127.9±33.0
Range (g)	44.8–175.2	47.0–165.8	58.0–184.9	75.3–219.4

Discussion

We found that hole diameter, which influences size of retained hagfish, also had a large influence on the proportion of immature hagfish retained in the catch. Observed trends in hagfish size (length, weight) in relation to hole diameter were similar to that determined during previous research, even though the diameters tested were slightly different (Melvin and Osborn 1992, Johnson 1994, Nakamura 1994). The proportion of immature fish decreased as hole diameter increased, suggesting that larger hole diameters are more desirable for fishery conservation purposes. Count-per-kilogram (CPkg), a proxy for overall hagfish size and marketability used by the industry, also decreased as hole diameter increased, demonstrating that larger hole diameters also produced the most highly desired fish in terms of size. However, overall catch weight declined precipitously with increasing hole diameter, suggesting the existence of an industry tradeoff between average size and total weight of captured hagfish.

Our assessment of size at first maturity appears consistent with previous research into Pacific hagfish maturity. In central California, Pacific hagfish size at maturity was estimated to be 325 mm (Nakamura 1994), and size at 50% maturity in Oregon was 340 mm (Barss 1993). Compared with seven years of data from our monitoring of the fishery, these results fall slightly above our estimate of 338 mm to the north and slightly below our estimate to the south. This could be a direct result of north-south differences in growth and size at maturity, or simply slight differences in sampling methodology. In either case, we used a relatively conservative estimate of size at maturity to assess retention of immature hagfish. Knowledge of hagfish reproduction remains limited and warrants future research. Pacific hagfish populations do not exhibit seasonal reproduction, and it is common to find female hagfish carrying eggs at various stages of development throughout the year (Johnson 1994, CDFW unpublished sampling data), complicating assessment of mature individuals somewhat more complex.

Based on fisherman interviews and previous research (Melvin and Osborn 1992), we know that trap soak time is a potentially confounding factor when assessing the effects of hole diameter on catch characteristics. Hagfish will remain in a trap until the bait source is exhausted and, consequently, no size selection occurs for an extended period of time after trap deployment. Previous research indicates that this time period is roughly 24 hours (Melvin and Osborn 1992), though it is most likely variable depending on bait quantity and hagfish abundance. We allowed traps to soak for an average of 21.6 hours (range 19.6–24.6) so that we could examine the performance of each hole diameter while minimizing the confounding effects of shorter soak-time. Future regulatory change involving minimum hole diameter should address these confounding effects as they relate to size retention of hagfish. It may be possible for fishermen to avoid the impacts of an increase in hole diameter on catch weight by reducing soak-time.

Some fishermen have used 9.5-mm hole diameters on their traps, the smallest size tested in the present study. While this hole diameter would maximize catch weight, we have demonstrated that this diameter hole retains a large proportion of immature-sized female hagfish. This smallest diameter also produces the lowest percentage of large hagfish, as reported by the industry, which may be economically offset by greater catch weight. As the diameter increases, the proportion of immature hagfish retained is greatly reduced and, with 15.9-mm holes, immature hagfish are virtually absent. From a conservation and marketability perspective, the largest hole diameter would clearly benefit the fishery by protecting the immature segment of the population and by ensuring the lowest CPkg for the industry. Nonetheless, this benefit is clearly offset by the reduction in catch that occurs with increasing hole diameter, suggesting the need to identify an appropriate conservation-industry compromise in the event of future regulatory action.

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Descriptive analyses and extended distribution records of macroinvertebrates based on remotely operated vehicle surveys offshore of the northern Channel Islands

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In 2003, marine protected areas (MPAs) were established offshore of the northern Channel Islands, California. The MPAs are surveyed by remotely operated vehicle (ROV) as part of a larger, ongoing effort to evaluate their effectiveness. To determine macroinvertebrate species distribution and richness, we analyzed the ROV video data collected at five paired sites during 2007–2009. Percent occurrence was used to estimate species richness. Macroinvertebrates observed included harvested species and species with structure-forming potential. Fifty-three invertebrate species were identified along with 20 higher taxonomic complex level classifications when identification to species level was not possible. Two of the five site-pairs formed clusters in two different cluster analyses. Site clustering suggested an island effect or clinal change in the biogeographic regions from the Oregonian Province through the Transition Zone to the Californian Province. The ROV surveys yielded new depth records for three invertebrate species. In addition, the cnidarian *Stylaster californicus* was found offshore of Santa Rosa Island, expanding its documented distribution within the northern Channel Islands.

Key words: California, Channel Islands, Channel Islands National Marine Sanctuary, macroinvertebrates, marine invertebrates, marine protected areas, remotely operated vehicle

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In 2003, marine protected areas (MPAs) were established within the Channel Islands National Marine Sanctuary (CINMS) located in the coastal waters off southern California. The MPAs were expanded into federal waters in 2006 and 2007. The northern Channel Islands within the CINMS consist of San Miguel, Santa Rosa, Santa Cruz, and Anacapa islands. These islands reside in a unique geographical setting influenced by two major currents, the southerly flowing California current and the northerly flowing Davidson current, with corresponding faunas resulting in three distinct biogeographic regions—the Oregonian Province, Californian Province, and a Transition Zone (Airame et al. 2003). During planning for the MPAs, representative habitat groups were identified based on the type of coastline and exposure, depth, substrate, and dominant plant communities, along with areas of coastline appropriate for nesting seabirds and haul-out areas for pinnipeds (Airame et al. 2003). Between 30 and 50% of the identified representative habitat in each biogeographic region was placed into the northern Channel Island MPAs (Airame et al. 2003). The MPAs include State Marine Reserves (SMRs) where take, damage, injury or possession of any marine resource is prohibited, and State Marine Conservation Areas (SMCAs) that allow limited recreational or commercial take. Biological monitoring within MPAs and their control sites was designed to measure MPA effects in terms of changes in populations, ecosystem structure, habitats, and spillover (CDFG 2004). Marine protected area effects are expected to occur from increased species reproduction and growth inside MPAs, with spillover of individuals to adjacent areas (Russ et al. 2004). Monitoring activities were prioritized to target habitats defined during the design of the MPAs. The highest priority was given to shallow (0–30 m) and deep (31–100 m) hard-substrate habitats.

Remotely operated vehicles (ROVs) have proven to be a useful tool to survey benthic invertebrates (Tissot et al. 2006, Tissot et al. 2007, Lundsten et al. 2009, Hannah et al. 2010). Beginning in August 2003, the California Department of Fish and Wildlife (CDFW)—formerly California Department of Fish and Game—conducted exploratory video sampling using a ROV in the deep zone at four paired MPA and control sites adjacent to San Miguel, Santa Rosa, Santa Cruz, and Anacapa islands. Monitoring began in 2004 and expanded in 2005 to five site-pairs. Sites were quantitatively sampled using a video strip of known length and width. Three site-pairs were located in the Oregonian Province, one in the Transition Zone, and one in the Californian Province (Figure 1, Table 1).

Following guidance from the monitoring plan for the Channel Islands MPAs (CDFG 2004), the ROV surveys focused on rocky substrate in depths ≥20 meters; however, the average depth of two of the 393 transect lines was between 19.1 and 19.95 meters (Table 2). Control sites were selected for comparable habitat, depth (if practical), and exposure to their associated MPA site. The entire north side of Anacapa Island contains MPAs; therefore, the Anacapa Island SMR MPA site was paired with an Anacapa SMCA control site (Karpov et al. 2012). The Anacapa Island SMCA prohibits all take of living marine resources except for the recreational take of California spiny lobster (*Panulirus interruptus*) and pelagic finfish, and the commercial take of California spiny lobster (CDFG 2013).

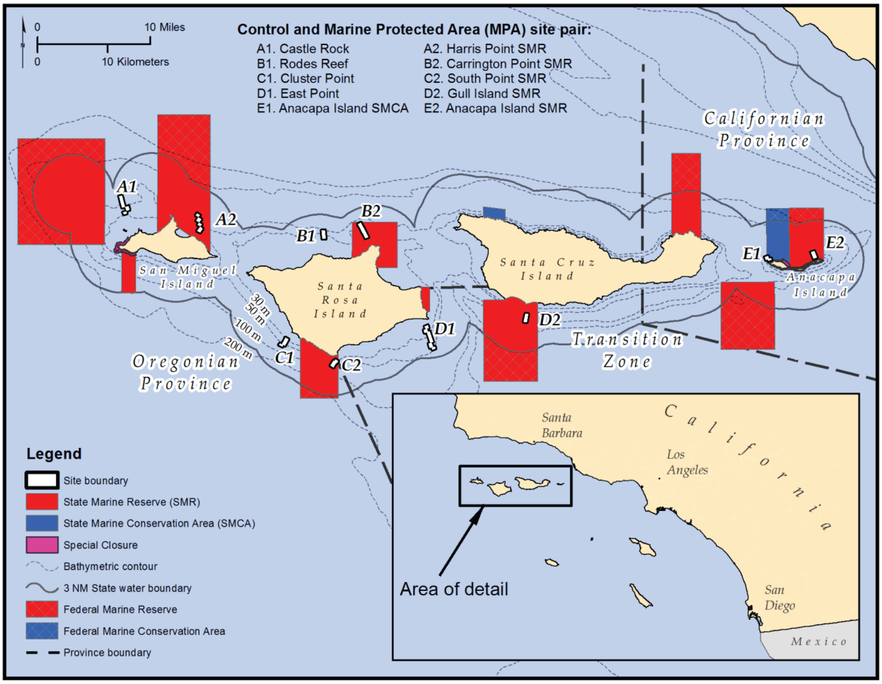

FIGURE 1.—Marine protected area (MPA) and control sites monitored by remotely operated vehicle offshore of the northern Channel Islands, California, 2007–2009.

TABLE 1.—Biogeographic provinces, islands, sites, number of transect lines surveyed, and species or complexes observed per site at marine protected area (MPA) and control sites offshore of the northern Channel Islands, California, 2007–2009.

Biogeographic Province	Island/ Site	Number of Transect Lines Surveyed[a] 2007	2008	2009	Total	Species/ complexes[b]
Oregonian						
San Miguel						
MPA	Harris Point SMR	13	13	11	37	40
Control	Castle Rock	8	8	7	23	38
Santa Rosa						
MPA	Carrington Point SMR	13	13	14	40	39
Control	Rodes Reef	12	12	11	35	40
MPA	South Point SMR	13	15	16	44	39
Control	Cluster Point	11	9	5	25	39
Oregonian Total Transect Lines		70	70	64	204	
Transition						
Santa Cruz						
MPA	Gull Island SMR	21	21	19	61	44
Santa Rosa						
Control	East Point	18	11	18	47	45
Transition Total Transect Lines		39	32	37	108	
Californian						
Anacapa						
MPA	Anacapa Island SMR	17	13	12	42	37
Control	Anacapa Island SMCA	13	14	12	39	31
Californian Total Transect Lines		30	27	24	81	

[a] Does not include transect lines excluded from analysis.
[b] Total species/complexes compiled by site.

Table 2.—Number of transect lines by depth bin, marine protected area (MPA) and control site, year, and years combined and invertebrate percent occurrences by years combined at locations surveyed offshore of the northern Channel Islands, California, 2007–2009.

Average Depth Bin[a] (meters)	MPA/ Control	Transect Lines per Year 2007	2008	2009	Years Combined Transect Lines	Percent Occurrence
15	MPA	0	0	0	0	n/a
	Control	0	2	0	2	12.3
20	MPA	8	4	1	13	12.9
	Control	19	3	7	29	16.1
25	MPA	10	11	9	30	15.1
	Control	12	19	20	51	18.3
30	MPA	6	6	8	20	19.6
	Control	10	8	6	24	17.6
35	MPA	8	5	5	18	18.2
	Control	7	8	4	19	14.6
40	MPA	10	14	12	36	19.0
	Control	6	4	5	15	18.2
45	MPA	8	14	11	33	18.5
	Control	4	2	6	12	13.7
50	MPA	10	7	11	28	17.1
	Control	4	5	5	14	14.0
55	MPA	10	10	6	26	16.1
	Control	0	3	0	3	9.6
60	MPA	7	4	7	18	14.2
	Control	0	0	0	0	n/a
65	MPA	0	0	2	2	16.4
	Control	0	0	0	0	n/a

[a] Depth bin 15 contains transect lines ≥15<19.9 meters in depth (average); subsequent depth bins follow the same parameters.

Finfish monitoring methods developed and used by CDFW for ROV video transect sampling include precision and accuracy of strip transect protocols (Karpov et al. 2006), statistical power by transect size and area sampled (Karpov et al. 2010), and MPA effects on finfish abundances at six of the ten sites (Karpov et al. 2012). Previous analyses of these video recordings, however, have not focused on invertebrate abundances.

The primary purpose of our study was to identify macroinvertebrates within five paired MPA and control sites during 2007–2009 using percent occurrence (PO) as a measure of species richness. Secondarily, we examined species distribution by depth, location, and year.

Materials and Methods

Study area.—The northern Channel Islands are located off the coast of Santa Barbara, California. The sites are within the CINMS and offshore of San Miguel, Santa Rosa, Santa Cruz, and Anacapa islands (Figure 1).

Site selection.—Sites were selected using sonar and exploratory ROV surveys. Sites were delineated by a rectangle 500 meters wide and parallel to shore across varying depths (Figure 1). Transect lines within the rectangle were randomly placed 20 m apart per each survey year (lines were 10 m apart at Anacapa Island SMCA and Gull Island SMR).

Depths reported were averaged across the 500-m transect lines. The number of transect lines per rectangle varied each year in order to insure the targeted rocky substrate was adequately sampled. Therefore, sites with higher amounts of soft-only substrate resulted in more transect lines than those with greater hard substrate.

Video collection.—The 2007 and 2008 surveys were conducted in August; the 2009 survey was conducted in July. All sampling was collected using a Deep Ocean Engineering (DOE) model Phantom® HD 2+2 ROV equipped with a video camera (for methods, see Karpov et al. 2006, Karpov et al. 2010, and Karpov et al. 2012). A DOE 460 TVL camera was used in 2007 and 2008. A downward video camera was used for the 2007 invertebrate identifications. ROV modifications in 2008 resulted in the removal of the downward facing camera. A forward-facing video camera was used during the 2008 and 2009 surveys. In 2009 a higher resolution camera, the Sidus 800 TVL, was used. All surveys were conducted during daylight hours between 0730 and 1700, with ROV lighting consistent throughout the survey years.

Habitat assessment.—Substrate was interpreted using a simplified version of a classification scheme detailed by Greene et al. (1999). Rock, boulder, cobble, or sand substrates were logged into the database independently. Each substrate was considered continuous until a break of ≥2 m occurred, or the substrate fell below 20% of total combined substrates for ≥3 m. Following processing, substrates were combined into three habitat types described by Karpov et al. (2010) as hard (consisting of rock or boulders or a combination of both), soft (cobble or sand or a combination of both), or mixed (combination of hard and soft habitat), and were recorded as percentages (Table 3).

Table 3.—Percent composition of habitat type by island, marine protected area (MPA) and control site, and year at locations surveyed offshore of the northern Channel Islands, California, 2007–2009.

		2007			2008			2009		
		Percent Habitat Type								
Island/ Site	Site Name	Hard[a]	Mixed[b]	Soft[c]	Hard[a]	Mixed[b]	Soft[c]	Hard[a]	Mixed[b]	Soft[c]
San Miguel										
MPA	Harris Point SMR	23	34	43	27	29	44	28	23	49
Control	Castle Rock	55	40	5	60	30	10	76	22	3
Santa Rosa										
MPA	Carrington Point SMR	6	39	45	18	34	47	19	43	38
Control	Rodes Reef	16	46	38	32	39	29	31	40	30
MPA	South Point SMR	15	29	56	18	22	60	13	23	64
Control	Cluster Point	27	44	29	36	32	32	42	30	28
Santa Cruz										
MPA	Gull Island SMR	9	27	64	12	22	66	14	18	68
Santa Rosa										
Control	East Point	17	25	58	22	27	51	27	18	55
Anacapa										
MPA	Anacapa Island SMR	14	37	49	21	29	50	20	26	53
Control	Anacapa Island SMCA	23	34	43	21	31	48	28	28	44
	Average	22	35	43	27	30	44	30	27	43

[a] Rock and/or boulder.

[b] A combination of rock and/or boulder with cobble and/or sand.

[c] Cobble and/or sand.

Video processing.—Invertebrate occurrences were identified to the lowest taxon possible using available literature (Behrens and Hermosillo 2005, Gotshall 2005, Lamb and Hanby 2005, Lee et al. 2007) and by consulting established experts in their respective fields. Identifications did not include data from transect lines removed due to prolonged poor visibility resulting from lighting, mysid swarms, dense algae, or kelp.

The 2007 observations were entered into a spreadsheet and then compiled into a Microsoft Access® database. The 2008 and 2009 observations were processed using an X-keys Pro programmable key pad to log the invertebrate identifications into an Access® database. The X-key system was linked to a DVD player and to a Horita II TCW-50 time code wedge. The X-key and Horita linked together with the database. Once an identified invertebrate reached the bottom of the video monitor, the reviewer used the X-key system to record the invertebrate. This process maintained consistency with species recording and time notations among reviewers. The database automatically logged species-encounter time along with the species Taxonomic Serial Number (ITIS 2010). These data can be cross-referenced with substrate type, depth, and water temperature for future analysis.

Statistical analyses.—All statistical tests were *a posteriori*. The PO of invertebrates was used as a measure of species richness, and was calculated by summing the number of lines on which a species was observed and then dividing by the total number of lines examined at each site per survey year. Percent occurrence is a method of normalizing to reduce the effect of different sample sizes among sites and years.

Using PO, we looked at year effects, MPA and control sites, species distribution by depth, the influences of oceanic regimes on species distribution, island comparisons, and the effect of sample size on the number of observed species. Site comparisons were made using cluster analysis from the statistical package "R" (R Project Contributors 2011). For cluster analysis, both the agglomerate and the divisive procedures in R were used with Euclidean and Manhattan metrics. The agglomerative clustering method (R function "agnes") begins by calculating a number of clusters that are then combined into larger clusters until only a single cluster remains. The divisive clustering method (R function "diana") begins with all data in one cluster and then systematically divides the data into smaller clusters. Kaufman and Rousseeuw (1990) described both methods of clustering. The Euclidean distance is derived from computing the square root of the sum of squares of absolute differences, whereas the Manhattan distance is the sum of the differences (Data Analysis Products Division 1999). All years were combined for the cluster analyses.

Percent occurrence was reviewed by sites. To estimate adequate sample size, we ran a regression of sample size using the mean number of species and complexes observed for the ten sites across three years (n=30). Two ANOVAs were run, one using the number of species and complexes per transect line with year and site as independent variables, and the other using year and site type (MPA and control sites separated) as factors to determine year, site, and MPA and control effects on the number of species observed by transect line.

The effect of depth on the number of species and complexes observed was examined by combining all years and sites and regressing the transect line-depth against the number of species and complexes observed on each line. We also ran an ANOVA of the number of species or complexes observed by site, year, and depth. All ANOVAs and the multiple regression were run using R (R Project Contributors 2011). The multiple regression was run using species count as the dependent variable and year, site, and depth as the independent variables. This approach was used to obtain a slope for depth when the site and year effects were accounted for.

Results

Sites combined.—During the 2007–2009 surveys, 413 transect lines were examined. Twenty lines were excluded from analysis due to poor visibility, including two from 2007, ten from 2008, and eight from 2009. The total number of transect lines included in the analysis was 393, with depths ranging from 19 m to 67 m (Table 1, Table 2).

Members of some genera could not consistently be assigned to species level due to the inability to see finer structures resulting from camera resolution, lighting, or water clarity. When this occurred, these invertebrates were assigned to a higher taxonomic complex level. Fifty-three invertebrates were identified to species along with 20 higher taxonomic complex level classifications (Table 4). The 2008 survey yielded 47% fewer invertebrates or complexes than the 2007 survey (Table 4), whereas, the 2009 survey yielded 64% more invertebrates or complexes when compared separately to the 2008 and 2007 surveys (Table 4).

Most of the poriferans observed were low-profile encrusting forms. Seven sponges were identified to species and seven complexes (Table 4). Two species of the genus *Polymastia*, *P. pachymastia* and *P. pacifica*, are found in the northern Channel Islands (Lee et al. 2007). *Polymastia* observed are only identifiable to species by close examination; therefore, they were recorded as *Polymastia* spp. Occurrences of *Rhabdocalyptus* spp. likely included *R. dawsoni, R. nodulosus, R. asper*, and *R. tener*. *Xestospongia* spp. included *X. edapha* and *X. diprosopia* (Lee et al. 2007). *Staurocalyptus* spp. observations included *S. dowlingi, S. solidus,* and *S. fasciculatus*.

Seventeen cnidarian genera were identified to species and four were recorded as complexes (Table 4). Gorgonians placed in the Gorgonacea complex were individuals that could not be identified further because they were completely covered with zoanthids or were dead. *Muricea* spp. likely included *M. fruticosa* and *M. californica*. Red gorgonians observed in this study likely included two genera, *Swiftia* and *Chromoplexaura* (G. Williams, California Academy of Sciences, personal communication); these are indistinguishable in the field and were recorded together as the Family Plexauridae. Four *Urticina* species were observed, along with an *Urticina* complex likely including *U. columbiana, U. lofotensis*, *U. mcpeaki*, or *U. piscivora*, when identification to species was not possible.

Three genera of molluscs were identified to species, including market squid (*Doryteuthis opalescens*) egg cases, along with two complexes (Table 4). The unknown Dorididae (nudibranch) complex consisted of white dorids (likely the genus *Doris*) and yellow dorids (genus *Doris* or *Peltodoris*) (Behrens and Hermosillo 2005). The *Octopus* complex likely included *O. bimaculatus* or *O. rubescens.*

Four arthropod species were identified, along with one arthropod complex (Table 4). The Cancridae complex may contain *Romaleon antennarium*, *Metacarcinus anthonyi*, and *Cancer productus*.

The phylum Echinodermata was represented by 12 sea star species, 3 urchin species, and 5 complexes (Table 4). Echinoderms identified to the complex level consisted of three sea stars, one brittle star, and one sea cucumber. The *Pisaster* complex consisted of *P. giganteus* and *P. brevispinus*. The *Henricia* complex included *H. leviuscula* and *H. aspera*. The *Astropecten* complex likely consisted of *A. armatus* and *A. verrilli. Parastichopus californicus* and *P. parvimensis* were recorded as *Parastichopus* spp. All brittle stars encountered were recorded as Ophiurida. In addition to the above, three species of bryozoans were recorded, four chordates were identified to species, and the genus of one chordate was determined (Table 4).

Table 4.—Percent occurrence by invertebrate species and complex, year, and years combined at locations surveyed offshore of the northern Channel Islands, California, 2007–2009.

Phylum	Species/complexes	2007	2008	2009	All Years
Porifera					
	Acarnus erithacus	23.7	13.2	40.8	25.7
	Craniella arb	18.0	24.8	47.2	29.5
	Geodia mesotriaena	5.8	54.3	60.0	38.9
	Halichondria panicea	0.0	0.0	8.0	2.5
	Neopetrosia zumi	0.0	0.8	0.8	0.5
	Polymastia spp.	35.3	28.7	56.8	39.9
	Red sponge	0.0	0.0	4.8	1.5
	Rhabdocalyptus spp.	3.6	4.7	3.2	3.8
	Spheciospongia confoederata	2.2	0.0	3.2	1.8
	Staurocalyptus spp.	1.4	0.0	0.8	0.8
	Tethya aurantia	52.5	54.3	62.4	56.2
	White sponge	29.5	0.0	0.0	10.4
	White sponge branching	0.0	8.5	3.2	3.8
	Xestospongia spp.	0.0	7.0	8.8	5.1
Cnidaria					
	Adelogorgia phyllosclera	12.9	10.9	8.8	10.9
	Aglaophenia struthionides	0.7	0.8	0.8	0.8
	Balanophyllia elegans	1.4	0.8	0.8	1.0
	Coenocyathus bowersi	9.4	4.7	8.8	7.6
	Corynactis californica	52.5	36.4	53.6	47.6
	Epizoanthus scotinus	0.0	0.8	0.0	0.3
	Eugorgia rubens	43.2	39.5	36.8	39.9
	Gorgonacea	0.0	5.4	0.8	2.0
	Halipteris californica	36.0	39.5	38.4	37.9
	Muricea spp.	12.2	8.5	6.4	9.2
	Pachycerianthus fimbriatus	0.0	11.6	11.2	7.4
	Parazoanthus lucificum	0.0	4.7	14.4	6.1
	Plexauridae	73.4	78.3	87.2	79.4
	Ptilosarcus gurneyi	7.9	6.2	11.2	8.4
	Stylaster californicus	5.0	1.6	0.8	2.5
	Stylatula elongata	20.9	38.0	45.6	34.4
	Urticina columbiana	59.7	59.7	60.8	60.1
	Urticina lofotensis	0.0	2.3	13.6	5.1
	Urticina mcpeaki	0.7	0.0	0.0	0.3
	Urticina piscivora	1.4	2.3	1.6	1.8
	Urticina spp.	1.4	0.0	0.8	0.8
Bryozoa					
	Diaperoforma californica	36.0	3.1	12.0	17.6
	Heteropora pacifica	20.9	34.1	53.6	35.6
	Hippoporina insculpta	3.6	24.8	27.2	18.1

Table 4.—Continued

Phylum	Species/complexes	2007	2008	2009	All Years
Mollusca					
	Dorididea	3.6	7.0	9.6	6.6
	Doryteuthis opalescens (eggs)	0.0	0.8	1.6	0.8
	Leopecten diegensis	2.2	0.0	0.0	0.8
	Megathura crenulata	5.8	4.7	5.6	5.3
	Octopus spp.	0.0	0.0	0.8	0.3
Arthropoda					
	Cancer productus	0.0	0.0	0.8	0.3
	Cancridae	0.0	0.0	3.2	1.0
	Loxorhynchus crispatus	0.0	0.0	0.8	0.3
	Loxorhynchus grandis	5.8	0.8	0.0	2.3
	Panulirus interruptus	0.0	0.0	0.8	0.3
Echinodermata					
	Astrometis sertulifera	2.9	0.0	0.0	1.0
	Astropecten spp.	7.2	7.0	6.4	6.9
	Ceramaster patagonicus	0.0	2.3	0.8	1.0
	Dermasterias imbricata	19.4	8.5	19.2	15.8
	Henricia spp.	34.5	33.3	51.2	39.4
	Luidia foliolata	28.8	10.1	32.0	23.7
	Lytechinus pictus	0.0	1.6	0.0	0.5
	Mediaster aequalis	77.0	66.7	75.2	73.0
	Ophioderma panamensis	0.0	0.0	2.4	0.8
	Ophiopsila californica	0.0	0.0	0.8	0.3
	Ophiothrix spiculata	29.5	24.8	19.2	24.7
	Ophiurida	0.0	4.7	34.4	12.5
	Orthasterias koehleri	17.3	10.9	11.2	13.2
	Parastichopus spp.	87.8	87.6	82.4	86.0
	Patiria miniata	95.0	89.9	96.0	93.6
	Pisaster spp.	54.0	60.5	56.8	57.0
	Poraniopsis inflata	4.3	0.8	4.8	3.3
	Pycnopodia helianthoides	64.0	57.4	67.2	62.8
	Strongylocentrotus franciscanus	23.7	14.0	19.2	19.1
	Strongylocentrotus purpuratus	0.7	0.0	0.0	0.3
Chordata					
	Ascidia paratropa	0.0	0.0	0.8	0.3
	Botrylloides spp.	0.0	0.0	1.6	0.5
	Cystodytes lobatus	1.4	0.8	3.2	1.8
	Polyclinum planum	9.4	10.1	14.4	11.2
	Styela montereyensis	0.0	7.8	8.0	5.1
Number of Species/complexes		49	54	65	73
Number of Transect Lines[a]		139	129	125	393

[a] Does not include transect lines excluded from analysis.

Data by year, all sites, and MPA and control sites.—Two ANOVAs were run, one with year and all sites as independent variables, the other using year and site type (MPA or control), as factors with the number of species observed by line as the metric. With the first ANOVA we found year and site were significant ($P < 0.05$, $df = 373$). The second ANOVA year was also significant ($P < 0.01$, $df = 390$), site type was not significant ($P > 0.10$, $df = 390$).

Data by MPA and control site.—We reviewed the number of species and complexes observed by the number of lines at each site for all years. A small increase in the number of species and complexes was observed as the number of lines increased (Figure 2). The smallest sample size, 23 transect lines, was at Castle Rock located offshore of San Miguel Island, with 38 species and complexes observed (Table 1). The largest sample size (61 lines) was at Gull Island SMR located offshore of Santa Cruz Island, with 44 species and complexes observed (Table 1). The lowest count of species and complexes was 31 at Anacapa Island SMCA with a sample size of 39 transect lines (Table 1).

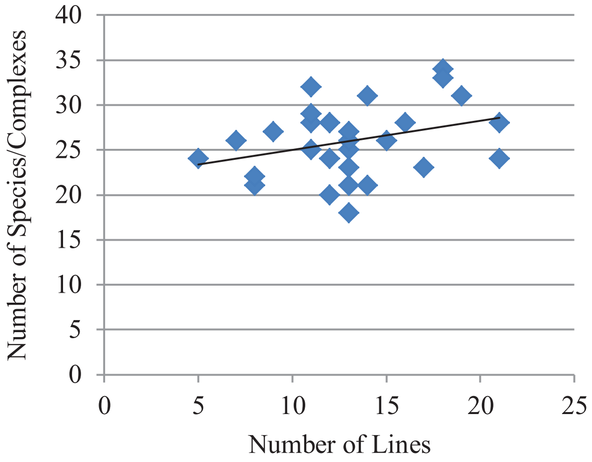

FIGURE 2.—The number of invertebrate species and complexes observed and number of transect lines at all sites each year, offshore of the northern Channel Islands, California, 2007–2009.

While the MPA and control sites were initially addressed separately, combining them provided a broader sample size (number of lines surveyed). The best regression line based on the correlation coefficient for both MPA and control sites was $y = 0.153 \ln(x) + 33.183$ ($R^2 < 0.19$, $df = 28$), where x is the number of transect lines surveyed and y is the number of species and complexes observed from 2007 to 2009 (Figure 3).

The results of both agglomerate R agnes and divisive R diana algorithms with Euclidean and Manhattan metrics were fairly consistent, with two site-pairs always clustering (see Figure 4 for R diana method with metric Manhattan). The pairs forming consistent clusters were South Point SMR with Cluster Point, and Anacapa Island SMR with Anacapa Island SMCA. The three remaining site-pairs never clustered together. The five Santa Rosa sites consistently formed their own cluster. Harris Point SMR clustered with the Santa Rosa sites. Although not a site-pair, Gull Island SMR clustered with Castle Rock. Gull Island SMR and Castle Rock clustered with the two Anacapa sites. All of the other clusters more or less fit the actual spatial distribution of the sites.

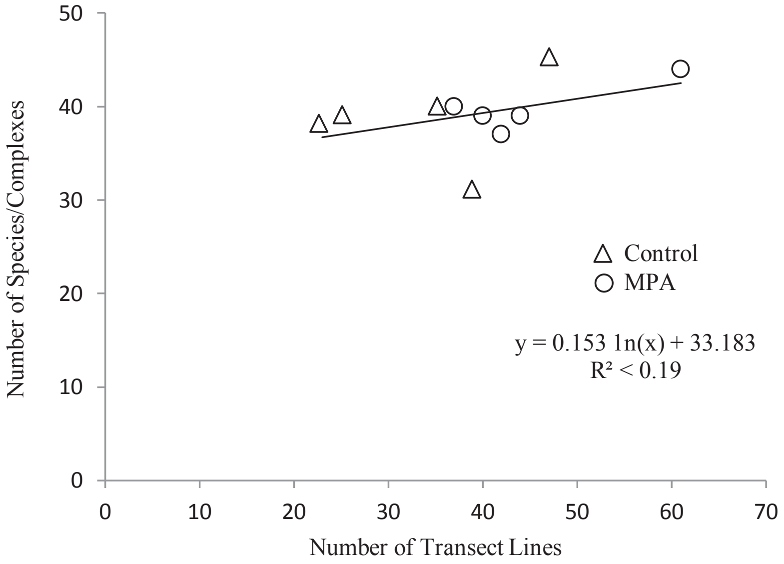

Figure 3.—The number of invertebrate species or complexes observed over the number of transect lines surveyed by remotely operated vehicle at marine protected area (MPA) and control sites offshore of the northern Channel Islands, California, 2007–2009.

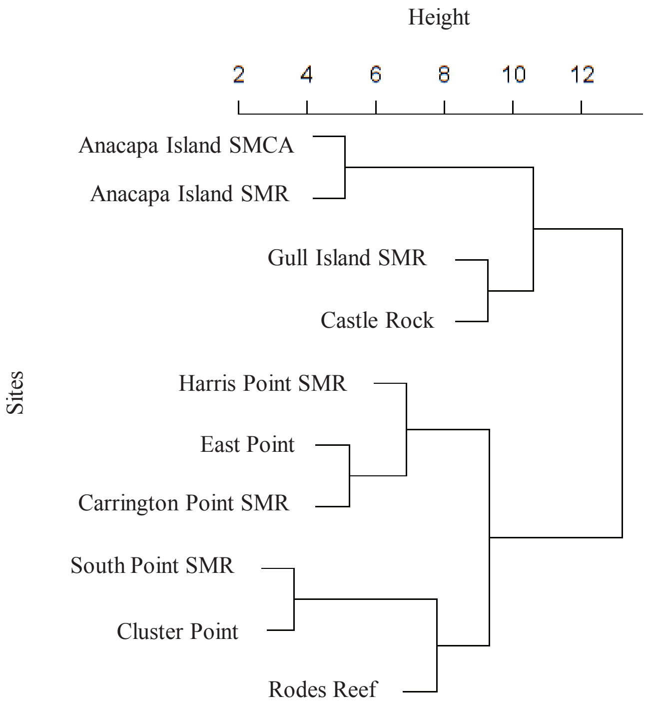

Figure 4.— Dendogram of cluster analysis results using percent occurrence by invertebrate species and complexes, 2007–2009 combined, at marine protected area (MPA) and control sites offshore of the northern Channel Islands, California. Height represents similarities or differences between the MPA and control sites. Cluster analysis was run using R method diana with metric = Manhattan; agglomerative coefficient <0.59.

Data by sites combined and depth.—We examined the effect of depth on the number of species and complexes observed with MPA and control sites combined and all years combined. The data were not separated by MPA and control due to the differences in the range of depths (Table 2). The mean depth for all sites was 39 m, with a minimum depth of 19.1 m and a maximum depth of 67.0 m (Table 2). The R^2 for the regression was <0.01 and the slope was -0.014, ($P > 0.32$, $df = 392$; Figure 5).

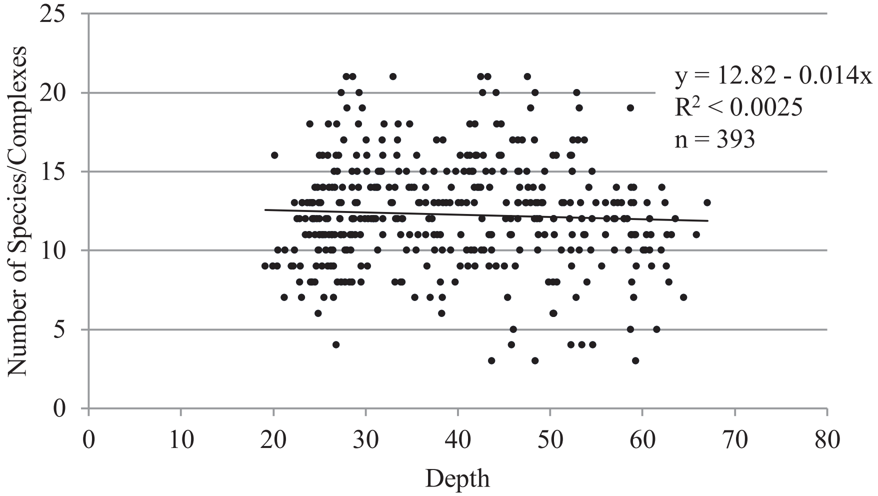

Figure 5.—The number of invertebrate species and complexes observed by depth at sites offshore of the northern Channel Islands, California, 2007–2009.

We also examined depth effects on number of species or complexes per line using ANOVA to separate depth effects from site and year effects. Sites were not differentiated by control and MPA. Only Harris Point SMR indicated a strong depth and year effect. Harris Point SMR showed depth, year, depth:year and depth:site:year effects with $P < 0.05$. However, when all sites were included there was little depth or year effect with $P > 0.5$. The adjusted R^2 was 0.5258, $df = 353$.

Data by biogeographic province.—From all survey lines that were processed, we were able to use 204 lines in the Oregonian Province, 108 in the Transition Zone, and 81 in the Californian Province (Table 1). Data were grouped by MPA, control, and sites combined within biogeographic province (Table 5).

Both *Adelogorgia phyllosclera* and *Eugorgia rubens* were found in all three provinces; however, *E. rubens* had a higher PO (91) in the Californian Province, and a lower PO in the Transition Zone and Oregonian Province (41 and 19, respectively) while *A. phyllosclera* had PO values of 30, 17, and 2, respectively in the Californian Province, Transition Zone, and Oregonian Province when reviewing combined MPA and control sites. *Muricea* spp. was absent from the Oregonian Province, and was found in the Transition Zone, and Californian Province with a greater PO (1.9 and 42.0, respectively) in combined MPA and control sites (Table 5).

Astropecten spp. was found in all three biogeographic regions, with greater PO values moving from the Oregonian Province into the Transition Zone to the Californian

Table 5.—Percent occurrence by invertebrate species and complex and biogeographic province for years combined at locations surveyed offshore of the northern Channel Islands, California, 2007–2009.

Phylum	Species and complexes	Biogeographic Province Oregonian	 Transition	 Californian
Porifera				
	Acarnus erithacus	34.3	25.0	4.9
	Craniella arb	49.5	8.3	7.4
	Geodia mesotriaena	52.9	28.7	17.3
	Halichondria panacea	3.9	1.9	0.0
	Neopetrosia zumi	0.5	0.9	0.0
	Polymastia spp.	60.3	17.6	18.5
	Red sponge	2.9	0.0	0.0
	Rhabdocalyptus spp.	1.0	9.3	3.7
	Spheciospongia confoederata	2.9	0.9	0.0
	Staurocalyptus spp.	0.0	0.0	3.7
	Tethya aurantia	79.4	34.3	27.2
	White sponge	6.9	17.6	9.9
	White sponge branching	2.5	8.3	1.2
	Xestospongia spp.	8.8	0.0	2.5
Cnidaria				
	Adelogorgia phyllosclera	2.0	16.7	25.9
	Aglaophenia struthionides	1.0	0.9	0.0
	Balanophyllia elegans	0.5	2.8	0.0
	Coenocyathus bowersi	0.5	26.9	0.0
	Corynactis californica	64.2	38.0	18.5
	Epizoanthus scotinus	0.5	0.0	0.0
	Eugorgia rubens	19.1	40.7	91.4
	Gorgonacea	2.0	0.9	3.7
	Halipteris californica	23.0	75.9	24.7
	Muricea spp.	0.0	1.9	42.0
	Pachycerianthus fimbriatus	4.4	11.1	9.9
	Parazoanthus lucificum	0.0	0.0	29.6
	Plexauridae	68.1	95.4	86.4
	Ptilosarcus gurneyi	9.8	12.0	0.0
	Stylaster californicus	4.4	0.9	0.0
	Stylatula elongata	28.4	61.1	13.6
	Urticina columbiana	70.1	61.1	33.3
	Urticina lofotensis	6.9	5.6	0.0
	Urticina mcpeaki	0.0	0.9	0.0
	Urticina piscivora	2.0	2.8	0.0
	Urticina spp.	0.5	0.9	1.2
Bryozoa				
	Diaperoforma californica	24.0	16.7	2.5
	Heteropora pacifica	52.9	29.6	0.0
	Hippoporina insculpta	30.4	7.4	1.2

Table 5.—Continued.

Mollusca			
Dorididae	9.8	5.6	0.0
Doryteuthis opalescens (eggs)	1.5	0.0	0.0
Leopecten diegensis	0.0	2.8	0.0
Megathura crenulata	0.0	1.9	23.5
Octopus spp.	0.5	0.0	0.0
Arthropoda			
Cancer productus	0.5	0.0	0.0
Cancridae	0.5	2.8	0.0
Loxorhynchus crispatus	0.5	0.0	0.0
Loxorhynchus grandis	2.9	0.9	2.5
Panulirus interruptus	0.0	0.0	1.2
Echinodermata			
Astrometis sertulifera	2.0	0.0	0.0
Astropecten spp.	4.4	7.4	12.3
Ceramaster patagonicus	1.5	0.9	0.0
Dermasterias imbricate	20.6	14.8	4.9
Henricia spp.	43.1	43.5	24.7
Luidia foliolata	18.1	48.1	4.9
Lytechinus pictus	0.0	0.0	2.5
Mediaster aequalis	81.9	73.1	50.6
Ophioderma panamensis	1.0	0.0	1.2
Ophiopsila californica	0.5	0.0	0.0
Ophiothrix spiculata	3.4	8.3	100.0
Ophiurida	19.6	7.4	1.2
Orthasterias koehleri	17.2	9.3	8.6
Parastichopus spp.	81.9	83.3	100.0
Patiria miniata	93.6	89.8	98.8
Pisaster spp.	59.3	52.8	56.8
Poraniopsis inflata	5.4	1.9	0.0
Pycnopodia helianthoides	80.9	75.0	1.2
Strongylocentrotus franciscanus	7.4	34.3	28.4
Strongylocentrotus purpuratus	0.5	0.0	0.0
Chordata			
Ascidia paratropa	0.5	0.0	0.0
Botrylloides spp.	0.0	1.9	0.0
Cystodytes lobatus	3.4	0.0	0.0
Polyclinum planum	18.1	6.5	0.0
Styela montereyensis	2.5	13.9	0.0
Number of Species/complexes	64	56	42
Number of Transect Lines[a]	204	108	81

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[a] Does not include transect lines excluded from analysis.

Province when reviewing MPA and control sites combined (4.4, 7.4, and 12.3, respectively) (Table 5). Notably, *Pycnopodia helianthoides* had a PO of 1.2 with MPA and control combined within the Californian Province, with an increase of PO in the Oregonian and Transition Zone (80.9 and 75.0, respectively).

Data by island.—One MPA and control site-pair was located offshore of San Miguel Island (Figure 1, Table 1). Thirty-four individual species were identified along with 14 complexes (Table 6). *Astropecten* spp. and *Ophiothrix spiculata* were found with a PO of 3.3 and 11.7, respectively (Table 6).

Santa Rosa Island had the most sites consisting of two MPA sites and three control sites (Figure 1, Table 1). Forty-seven invertebrates were identified to species, along with 14 complexes (Table 6). *Megathura crenulata* was identified offshore of Santa Rosa Island with a PO of 1.0. *Astropecten* spp. and *O. spiculata* were observed with a PO of 5.8 and 4.7, respectively.

Santa Cruz Island hosted one MPA site (Figure 1, Table 1). Twenty-nine species were observed, along with 14 complexes (Table 6). *Halipteris californica* and *Muricea* spp. were present at Santa Cruz Island with a PO of 100 and 3.3, respectively. *Astropecten* spp. was observed with a PO of 6.6.

One MPA and control site pair (consisting of an SMR and SMCA) was located offshore of Anacapa Island (Figure 1, Table 1). Twenty-eight invertebrates were identified to species, as well as 14 complexes (Table 6). *Muricea* spp. was identified offshore of Anacapa Island with a PO of 42.0. *M. crenulata* increased offshore of Anacapa Island with a PO of 23.5. *Astropecten* spp. and *O. spiculata* were found with PO values of 12.3 and 100, respectively. At the Anacapa Island sites the PO of all bryozoans dropped substantially and chordates were absent.

Discussion

Marine invertebrate identification from ROV video can be challenging. Often small differences in structure or characters must be closely examined to identify invertebrates to species level. Such fine details sometimes are not available from the videos due to low light conditions, camera resolution, algae cover, sand-impacted reefs, or limited underwater visibility resulting from turbidity or occasional mysid swarms. When these observational difficulties were prolonged, the line was removed from analysis to avoid unintended bias.

The loss of ambient light with water depth required the use of lights on the ROV. The use of artificial lights can cause some invertebrates to change their behavior and perhaps be less visible; however, the lights were necessary to perform the survey and accurately identify species.

Differences observed between sample years were confounded by changes to the camera system used to identify invertebrates in this study. Loss of the downward camera was a factor in 2008 and 2009. Perhaps the most critical factor, however, was the increased resolution in 2009 when the Sidus replaced the DOE camera. Calibration of the two different camera systems were not conducted offshore of the northern Channel Islands. In future analysis of the ROV data, researchers should consider evaluating the datasets from different camera systems separately when examining time-trends in abundance. Alternatively, concurrent use of new and old camera systems on the same ROV would allow for quantitative calibration across time series, critical to evaluating any MPA effects over time.

Table 6.—Percent occurrence by invertebrate species and complex, and island for years combined at locations surveyed offshore of the northern Channel Islands, California, 2007–2009.

		Island			
Phylum	Species and complex	San Miguel	Santa Rosa	Santa Cruz	Anacapa
Porifera					
	Acarnus erithacus	11.7	46.1	3.3	4.9
	Craniella arb	46.7	42.9	0.0	7.4
	Geodia mesotriaena	61.7	39.3	44.3	17.3
	Halichondria panacea	0.0	5.2	0.0	0.0
	Neopetrosia zumi	1.7	0.0	1.6	0.0
	Polymastia spp.	53.3	55.5	6.6	18.5
	Red sponge	5.0	1.6	0.0	0.0
	Rhabdocalyptus spp.	3.3	0.0	16.4	3.7
	Spheciospongia confoederata	3.3	2.6	0.0	0.0
	Staurocalyptus spp.	0.0	0.0	0.0	3.7
	Tethya aurantia	60.0	85.3	0.0	27.2
	White sponge	18.3	2.1	29.5	9.9
	White sponge branching	8.3	0.0	14.8	1.2
	Xestospongia spp.	26.7	1.0	0.0	2.5
Cnidaria					
	Adelogorgia phyllosclera	0.0	2.1	29.5	25.9
	Aglaophenia struthionides	0.0	1.6	0.0	0.0
	Balanophyllia elegans	1.7	1.6	0.0	0.0
	Coenocyathus bowersi	0.0	1.6	44.3	0.0
	Corynactis californica	56.7	70.2	6.6	18.5
	Epizoanthus scotinus	0.0	0.5	0.0	0.0
	Eugorgia rubens	16.7	16.2	68.9	91.4
	Gorgonacea	5.0	0.5	1.6	3.7
	Halipteris californica	10.0	32.5	100.0	24.7
	Muricea spp.	0.0	0.0	3.3	42.0
	Pachycerianthus fimbriatus	0.0	8.4	8.2	9.9
	Parazoanthus lucificum	0.0	0.0	0.0	29.6
	Plexauridae	68.3	74.3	96.7	86.4
	Ptilosarcus gurneyi	15.0	10.5	6.6	0.0
	Stylaster californicus	3.3	4.2	0.0	0.0
	Stylatula elongata	28.3	29.8	82.0	13.6
	Urticina columbiana	60.0	79.6	34.4	33.3
	Urticina lofotensis	3.3	9.4	0.0	0.0
	Urticina mcpeaki	0.0	0.5	0.0	0.0
	Urticina piscivora	3.3	1.0	4.9	0.0
	Urticina spp.	0.0	1.0	0.0	1.2
Bryozoa					
	Diaperoforma californica	26.7	26.2	1.6	2.5
	Heteropora pacifica	26.7	59.7	16.4	0.0
	Hippoporina insculpta	23.3	29.3	0.0	1.2

Table 6.—Continued.

Phylum	Species and complex	Island San Miguel	 Santa Rosa	 Santa Cruz	 Anacapa
Mollusca					
	Dorididae	13.3	8.9	1.6	0.0
	Doryteuthis opalescens (eggs)	0.0	1.6	0.0	0.0
	Leopecten diegensis	0.0	0.0	4.9	0.0
	Megathura crenulata	0.0	1.0	0.0	23.5
	Octopus spp.	0.0	0.5	0.0	0.0
Arthropoda					
	Cancer productus	0.0	0.5	0.0	0.0
	Cancridae	1.7	1.0	1.6	0.0
	Loxorhynchus crispatus	0.0	0.5	0.0	0.0
	Loxorhynchus grandis	1.7	2.6	1.6	2.5
	Panulirus interruptus	0.0	0.0	0.0	1.2
Echinodermata					
	Astrometis sertulifera	0.0	2.1	0.0	0.0
	Astropecten spp.	3.3	5.8	6.6	12.3
	Ceramaster patagonicus	5.0	0.0	1.6	0.0
	Dermasterias imbricata	3.3	25.1	13.1	4.9
	Henricia spp.	61.7	30.4	65.6	24.7
	Luidia foliolata	13.3	36.1	19.7	4.9
	Lytechinus pictus	0.0	0.0	0.0	2.5
	Mediaster aequalis	98.3	67.0	96.7	50.6
	Ophioderma panamensis	0.0	1.0	0.0	1.2
	Ophiopsila californica	0.0	0.5	0.0	0.0
	Ophiothrix spiculata	11.7	4.7	0.0	100.0
	Ophiurida	21.7	15.7	8.2	1.2
	Orthasterias koehleri	20.0	16.2	3.3	8.6
	Parastichopus spp.	76.7	80.1	95.1	100.0
	Patiria miniata	78.3	100.0	82.0	98.8
	Pisaster spp.	26.7	74.9	31.1	56.8
	Poraniopsis inflata	15.0	1.6	1.6	0.0
	Pycnopodia helianthoides	56.7	91.1	62.3	1.2
	Strongylocentrotus franciscanus	1.7	26.2	1.6	28.4
	Strongylocentrotus purpuratus	0.0	0.5	0.0	0.0
Chordata					
	Ascidia paratropa	1.7	0.0	0.0	0.0
	Botrylloides spp.	0.0	0.0	3.3	0.0
	Cystodytes lobatus	3.3	2.6	0.0	0.0
	Polyclinum planum	53.3	4.2	6.6	0.0
	Styela montereyensis	0.0	9.9	1.6	0.0
Number of Species/complexes		48	61	43	42
Number of Transect Lines[a]		60	191	61	81

[a] Does not include transect lines excluded from analysis.

The MPA sites were not selected by a random process; they were selected based on the targeted rocky substrate in depths ≥20 m, while the control sites were chosen based on comparable habitat, depth (if practical), and exposure to their associated MPA site. The survey lines within the MPA and control sites were selected randomly. While care was taken to adhere to the site criteria using sonar maps and ROV exploratory surveys, this task proved difficult because the targeted depth and rocky substrate was found to be limited and patchy as detailed in Karpov et al. (2012). Greater than 90% of the area at our study depths was soft substrate only (K. Karpov, personal observation).

During our study, fifty-three invertebrate species were identified, and 20 to complex level (Table 4). Invertebrates identified to complex level likely also had members identified to species level; thus, some inconsistency in identification methodology should be noted. For example, the red sponge category may also include *Acarnus erithacus.* The identifications of *Neopetrosia zumi* may not be accurate and perhaps should have been included in the white sponge branching complex. *Aglaophenia struthionides,* identified from the 2007 surveys, is questionable due to the size of that species and resolution of the camera system at the time. Some occurrences of the bryozoa, genus *Diaperoforma* and *Heteropora*, may have been misidentified for each other during conditions of low lighting or low resolution. Furthermore, the northern staghorn bryozoan (*Heteropora pacifica*) can be confused with *Celleporella* spp. Most bryozoan species are small, complex animals requiring a microscope to differentiate among them. Many molluscs tend to be cryptic and the majority of molluscs identified during this study were small, compounding observational difficulties. Echinoderms also had the potential for misidentification under conditions of low visibility, including *Luidia foliolata* with *Orthasterias koehleri* and *Patiria miniata* with *Mediaster aequalis*.

The 2007–2009 ROV surveys yielded five species and two taxonomic complexes that are subject to fishing (Table 6; C. McKnight, CDFW, personal communication). These species include *Parastichopus* spp., *Strongylocentrotus franciscanus*, and *Loxorhynchus grandis*, which we found offshore of all the northern Channel Islands. Cancridae were identified offshore of San Miguel, Santa Rosa, and Santa Cruz islands. Harvested species observed offshore of Santa Rosa Island include *C. productus* and *Strongylocentrotus purpuratus*. The commercially harvested *D. opalescens* was not found during the surveys; however, their egg cases were found offshore of Santa Rosa Island. Offshore of Anacapa Island we found the only occurrence of *P. interruptus*. A few of the harvested species observed have been identified as invertebrates likely to benefit from MPAs (CDFG 2008). Focal species or complexes for MPA deep subtidal monitoring (CDFG 2004) observed in this survey included *S. franciscanus*, *S. purpuratus*, Cancridae, and *P. interruptus*. *D. opalescens*, also a focal species (CDFG 2004), was observed only in the egg stage.

The invertebrate observations included species with structure-forming potential (Tissot et al. 2006). Tissot et al. (2007) detailed the importance of benthic macroinvertebrate congregations that, along with substrate, can influence groundfish abundance and distribution.

The purpose of this study was descriptive and the statistical analysis should be considered in broad terms. Percent occurrence was used because of the number and complexity of species encountered at the ten sites. Because the statistical methods used were for exploratory data analysis, no adjustments for multiple testing were made to the probabilities. Consequently, the effects and relationships indicated by the statistical procedures should be viewed as indicators and not as proven. To allow for comparisons between sites among individual species, other methods of enumeration such as describing colonial sponges by area of coverage, would lend themselves to greater statistical precision.

When looking at site-pairs we found the result of cluster analyses was consistent for MPA and control at two of the five site-pairs (Figure 4). However, care should be taken to attribute what factors produced these clusters. Differences in habitat composition, depth, currents, and other factors likely come into play. Despite South Point SMR yielding approximately twice as much soft habitat as its control site Cluster Point, the site-pair clustered together (Figure 4, Table 3). Also, the apparent uniqueness of the Gull Island SMR and East Point site-pair from each other could result from a number of factors. For example, East Point had approximately twice as much hard habitat as Gull Island SMR (Table 3). Consequently, differences between these two sites will be confounded. These two sites were rejected by Karpov et al. (2012) in their analysis of MPA effects on finfish as least comparable site pairs due to lack of depth and habitat relief overlap; their study found less than 12% overlap in depth between the two sites.

Both the Harris Point SMR-Castle Rock and the Carrington Point SMR-Rodes Reef site-pairs had approximately twice as much hard habitat in their control sites as their respective MPA sites (Table 3). These site-pairs did not cluster together (Figure 4). Although not a site-pair, it is interesting that the San Miguel Island Castle Rock site clustered with Santa Cruz Island Gull Island SMR site because the Castle Rock site has approximately five to six times as much hard substrate.

When reviewing cluster analysis, the Santa Rosa Island sites, four of which are within the Oregonian Province, formed their own cluster (Figure 4). The cluster also included another site within the Oregonian Province, the Harris Point SMR San Miguel Island site. Anacapa Island SMR and Anacapa Island SMCA, both with similar habitat composition and within the Californian Province, clustered together (Figure 4). The clustering of sites does suggest an island effect or, perhaps, clinal change from the Oregonian Province through the Transition Zone to the Californian Province.

Within the Oregonian Province are the site-pairs for San Miguel Island and Santa Rosa Island, areas that are commonly under the influence of cooler waters of the California Current. Assemblages of species in this zone are generally characteristic of central and northern California, Oregon, and Washington (Airame et al. 2003). In the Transition Zone, located offshore of the Santa Cruz Island and Santa Rosa Island, respectively, lie the Gull Island SMR and East Point site-pair. Within the Transition Zone, we would expect to see an overlap of both colder and warmer water species (National Centers for Coastal Ocean Science 2005). The Anacapa Island site-pair is located in the warmer Californian Province.

The majority of invertebrates observed had recorded ranges throughout the California coastline. Of the invertebrates identified to species level, literature reviews yielded only five (four cnidarians [*A. phyllosclera, E. rubens, Parazoanthus lucificum*, and *U.mcpeaki*] and one echinoderm [*Lytechinus pictus*]) with a northern range limit of Point Conception (Brusca 1980, Ricketts et al. 1985, Gotshall 2005); these invertebrates would be considered to be within the Californian Province. During the surveys *P. lucificum* and *L. pictus* were found only within the Californian Province, and *U. mcpeaki* was found only within the Transition Zone (Table 5). *A. phyllosclera* and *E. rubens* were both found in all three provinces, with greater PO in the Californian Province and lower PO in the Transition Zone and Oregonian Province (Table 5).

Considering invertebrates identified to complex level, the two gorgonians (*M. fruticosa* and *M. californica*) within *Muricea* spp. have northern ranges of Point Conception, California (Ricketts et al. 1985, Gotshall 2005). *Muricea* spp. was found in the Transition Zone with a low PO and with a greater PO in the Californian Province (Table 5).

Astropecten spp., consisting of *A. armatus* and *A. verrilli*, have a historic range from San Pedro, California to Ecuador (Ricketts et al. 1985, Gotshall 2005). *Astropecten* spp. was found in all three biogeographic regions, with greater PO moving from the Transition Zone to the Californian Province.

P. helianthoides can be found throughout California; however, it is uncommon south of Monterey Bay. *P. helianthoides* had a low PO within the Californian Province (Anacapa SMR and Anacapa SMCA) compared to the Oregonian and Transition Zone. This seems to follow a trend consistent with annual SCUBA surveys for kelp monitoring offshore of the Channel Islands (Kushner et al. 2013).

When considering species by island, some differences in occurrence are interesting. *H. californica* was found offshore of all the islands surveyed; however, PO of *H. californica* at Santa Cruz Island was 100, possibly due to Santa Cruz Island yielding a greater amount of soft substrate in which *H. californica* resides (Table 6). While *O. spiculata* was absent from the Santa Cruz Island sites and was found with relatively low PO offshore of San Miguel and Santa Rosa Islands, its PO jumped to 100 offshore of Anacapa Island (Table 6). *O. spiculata* is known to congregate in large masses and can compete with other species for food.

The mollusc *M. crenulata* had low PO offshore of Santa Rosa Island and was not found offshore of San Miguel Island and Santa Cruz Island (Table 6). However, PO of *M. crenulata* increased offshore of Anacapa Island (Table 6). Concurrently, the PO of all bryozoans dropped substantially, and none of the chordates were detected at Anacapa Island (Table 6). While many factors can come into play, it is interesting to note that *M. crenulata* is an omnivore with a varied diet that includes bryozoans and chordates (i.e., tunicates), with a preference for red algae and tunicates (Mazariegos-Villarreal et al. 2013).

Our study is descriptive at the site level. Differences between sites and site-pairs were confounded by multiple factors including geographic distribution, depth, temperature, amount of soft substrate, differential fishing pressure, and a myriad of other potential factors including competition for space or food that could not be controlled for in our analysis. We would not expect to see any MPA effect due to the short duration of the study, nor would such an interpretation be valid, given the confounding factors including camera differences across time. Future analysis of the differences between these sites will improve methods for comparing the MPA and control sites.

Conducting a study in which all species are identified increases our knowledge of species that may not be targeted during surveys that focus on a specific group, such as surveys targeting harvested species. Because of the inclusion of all invertebrates, we established new maximum depth records for three invertebrate species in the phylum Cnidaria (Table 7) when compared to published records (Verrill 1922, Gotshall 2005, Lamb and Hanby 2005). The depths were noted at the time of observation and not obtained from average transect depths. These results are likely due to the depths covered by the ROV (42–67 m), that are not typically visited by divers using SCUBA. In addition, the California hydrocoral (*Stylaster californicus*) was found offshore of both San Miguel and Santa Rosa islands during the ROV survey (Table 6). *S. californicus* previously had not been found offshore of Santa Rosa Island at SCUBA depths (J. Engle, University of California, Santa Barbara, personal communication; Kushner et al. 2013); furthermore, literature review did not find *S. californicus* offshore of Santa Rosa Island in ROV depths. The fishery is currently closed, but this slow-growing invertebrate can be damaged by anchors or divers (Love et al. 2010), and is sensitive to sedimentation and algal overgrowth (Morris et. al 1980, Whitmire and Clarke 2007).

Table 7.—New depth records for invertebrate species and location (island) based on surveys offshore of the northern Channel Islands, California, 2007–2009.

Phylum	Species	Current Depth[a] (m)	New Depth (m)	Island
Cnidaria	*Muricea californica*	30	42.8	Anacapa
	Urticina columbiana	45–55	61.8	Santa Cruz
	Urticina lofotensis	23–25	45.3	Santa Rosa

[a] Maximum depth limits based on Verrill 1922, Gotshall 2005, Lamb and Hanby 2005.

For future ROV surveys, we recommend increasing and standardizing the camera resolution and lighting across a longer time series. The initial focus of these ROV surveys was on fish associated with hard substrate, and differences between surveys for fish and invertebrates must be a consideration in future designs. For example, utilizing a high definition still camera and strobe to photograph one-meter quadrants independently of the transects would facilitate identification of both invertebrates and fishes. Additionally, when changes in sampling gear are introduced, paired surveys using both old and new technologies should be conducted to assess the efficacy of the new technology relative to the old. Further, collection of specimens to aid in accurate identification and to determine recognizable characters for video identification would be beneficial.

Night surveys could yield increased sightings of nocturnal species, such as lobsters (Gotshall 2005, CDFW 2013). While we occasionally detected lobsters, the encounters provided little information on their abundance. Night surveys might also reveal species known to inhabit the northern Channel Islands, but that we did not detect, such as abalone or *Centrostephanus coronatus* (Gotshall 2005, Kushner et al. 2013). Future surveys would benefit from enumeration of select invertebrate species to determine changes (if any) in abundance.

Any differences between MPA and control sites will likely take several years to detect, considering the many confounding factors and dynamic processes involved. We believe, however, that this descriptive analysis of invertebrates, as well as the extended range of distribution for some species, will be useful for assessing long-term changes in species composition due to influences such as fishing or pollution and, potentially responses to climate change.

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Commission (PSMFC) staff A. Lauermann, S. Ahlgren, P. Cheng-Terry, E. Jacobsen, A. Keiser, and Y. Yokozawa. We also thank the The Channel Islands National Marine Sanctuary's R/V *SHEARWATER* captains S. Dyer, C. Lara, and T. Shinn, and crew members D. Carlson, M. Davis, R.Greenwood, S. Katz, and N. Senyk. C. Pattison, D. Baldwin, and M. Prall, A. Lauermann, P. Cheng-Terry, and Y. Yokozawa, along with S. Holz and D. Rosen of Marine Applied Research and Exploration, collected the specimens of *X. edapha* and *X. diprosopia* while onboard the F/V *DONNA KATHLEEN* with captain T. Maricich and crew J. Howk, D. Maricich, K. Maricich, and T. Maricich. The specimen of *Geodia mesotriaena* was collected by C. Pattison, D. Baldwin, A. Lauermann, P. Cheng-Terry, A. Keiser, Y. Yokozawa, S. Holz, and D. Rosen. W. Lee, California Academy of Sciences, identified *X. edapha* and *X. diprosopia* specimens and facilitated the *Geodia* sponge identification. P. Cardenas, University of Bergen, identified the *G. mesotriaena* specimen. J. Watanabe, Hopkins Marine Station, Stanford University, provided bryozoan name revisions. L. Ryley and C. Miller (formerly of), PSMFC, California Department of Fish and Wildlife Marine Region GIS Lab, provided database assistance. P. Serpa, CDFW Marine Region GIS Lab, created the site map. C. McKnight provided commercial harvest information. We gratefully acknowledge CDFW staff S. Wertz and C. Valle and for their support and S. Wertz and C. Miller for manuscript review. We also thank our anoymous friend who provided valuable guidance and support. We appreciate L. Lovell, D. Richards, and an anonymous reviewer for their thoughtful comments, which improved the manuscript.

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Overview of the creation and management of California's marine protected area network

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In December 2012, with the California Department of Fish and Wildlife (CDFW) as a lead agency, the State of California completed a comprehensive network of marine protected areas (MPAs). The MPA network spans the California coastline (state waters including bays, except the San Francisco Bay, estuaries, and offshore islands) and encompasses approximately 2200 km^2 of state waters. The first of its kind in the United States, this landmark MPA network was developed through a robust public process based on sound scientific guidance and a strong legal mandate and was designed to be a biologically functioning network with each MPA contributing to its overall success. Prior to completing this effort, California had a series of individual, unrelated MPAs that often lacked clearly defined purposes (California Fish and Game Code Section 2851[a]). Three separate but complementary pieces of legislation provided the necessary guidance, mandate, and authority to ensure the successful creation of the statewide MPA network.

Legislative background.—In 1998, the Marine Life Management Act (MLMA; California Fish and Game Code Sections 90-99.5, 105, 7050-7090, 8585-8589.7, 8842, and 9001.7) created a broad scale programmatic framework for managing fisheries through a variety of conservation measures, including MPAs. In 1999, the Marine Life Protection Act (MLPA; California Fish and Game Code Sections 2850-2863) recognized that MPAs and sound fisheries management were complementary components of a comprehensive effort to sustain marine habitat and fisheries (California Fish and Game Code Section 2851[d]) and established a programmatic framework for the creation of a statewide MPA network. In 2000, the Marine Managed Areas Improvement Act (MMAIA; California Public Resources Code Sections 36600-36900) standardized and clarified a statewide classification system for marine managed areas (MMAs), of which MPAs are a subset. It was this classification system of MPAs that was used when implementing the MLPA. The combined effect of these three laws was, in large part, to shift marine resource management away from a single species approach to one that focuses on sustaining marine resources by considering ecosystem function and biodiversity in management measures.

MPA designation and management authority.—The MMAIA provides designation authority of MMAs, including MPAs, to the Fish and Game Commission, State Park and Recreation Commission (State Parks Commission) and State Water Resources Control Board (Water Board; Marine Managed Areas Improvement Act 36602[b]). The MMAIA also provides direct management authority of adopted MMAs, including MPAs, to CDFW and the Department of Parks and Recreation (State Parks; California Public Resources Code Section 36602[c]). However, neither the State Parks Commission nor the Water Board has authority to restrict the take of marine resources. Therefore, if either the State Parks Commission or the Water Board adopts any MMA or MPA designations, take (as defined in Fish and Game Code Section 86) regulations must be consistent with those found in Fish and Game Code (California Public Resources Code Section 36725[e], Fish and Game Code Section 2860).

The MLPA mandates the Fish and Game Commission adopt a marine life protection program intended to improve the design and management of the state's MPAs (Fish and Game Code Section 2853[b]. Components of the marine life protection program of which the MPA network is a product include the creation and adoption of a master plan developed by or under the direction of CDFW (Fish and Game Code Section 2855[a],[b]), a preferred MPA siting plan including alternatives designed to meet MLPA goals and design criteria (Fish and Game Code Section 2856[a][2][D]; Fish and Game Code Section 2857[c][1]), and the ability to regulate the commercial and recreational take of marine species within MPAs to the Fish and Game Commission (Fish and Game Code Section 2860). The CDFW is responsible for management of the network of MPAs along California's coast as adopted by the Fish and Game Commission pursuant to the MLPA.

There is currently one MPA within the network that was adopted by both the State Parks Commission and the Fish and Game Commission at separate times. Initially adopted as Cambria State Marine Conservation Area (SMCA) by the Fish and Game Commission in 2006 as part of MLPA implementation, the Cambria SMCA was subsequently adopted as Cambria State Marine Park (SMP) by the State Parks Commission in 2010. No changes to the Fish and Game Commission adopted regulations or boundaries were made by the State Parks Commission. Therefore, the area has dual designation as Cambria SMCA/SMP and is jointly managed by CDFW and State Parks.

Designing an MPA network.—The MLPA requires that California's system of MPAs be redesigned to increase coherence and effectiveness in protecting the state's marine life and habitats, marine ecosystems, and marine natural heritage, as well as to improve recreational, educational, and study opportunities provided by marine ecosystems subject to minimal human disturbance (Fish and Game Code Section 2853). Between 2000 and 2004 the CDFW undertook two separate attempts to implement the MLPA, both of which were unsuccessful. From 2004 to 2012, through a memorandum of understanding, a partnership known as the Marine Life Protection Act Initiative (MLPA Initiative) matched public and private resources to aid with the implementation of the MLPA. A regional approach to MPA planning was used to implement the MLPA and the state was divided into five regions, central coast (MPAs implemented 2007), north central coast (MPAs implemented 2010), south coast (MPAs implemented 2012), north coast (MPAs implemented 2012), and the San Francisco Bay (MPA planning process pending). Each regional process contributed a suite of MPAs designed at the local level that became part of the larger, cohesive statewide network.

Table 1.—Summary of allowed uses for different classifications within California's marine protected area network. SMR = state marine reserve, SMP = state marine park, SMCA = state marine conservation area, SMRMA = state marine recreational management area.

Classification	Summary of Allowed Take[a]
SMR	No take
SMP	Allows limited recreational take
SMCA	Allows limited recreational and/or commercial take
SMRMA	Provides subtidal protection while allowing for legal waterfowl hunting (additional allowances may vary)
Special Closure	Prohibits human entry to protect breeding seabird and marine mammal populations from human disturbance year-round

[a] Non-consumptive uses and permitted scientific research are allowed in all classifications, and allowances vary by location. See the California Code of Regulations Title 14, Section 632, for details.

MPA network.—The MPA network includes state marine reserves, state marine parks, state marine conservation areas, state marine recreational management areas, and special closures (Table 1). Non-consumptive uses and permitted scientific research are allowed in MPA and MMA categories. The California Code of Regulations Title 14, Section 632 (a), defines circumstances under which permission to access special closures may be granted. Comprised of 119 MPAs, 5 MMAs, and 15 special closures, each with unique boundaries and associated regulations, the MPA network currently covers approximately 2,200 km^2 (≈16%) of state waters across a variety of habitat types and depths.

Scientific guidance.—Marine protected areas can be an effective tool in an ecosystem-based approach to protecting marine life and critical habitats by complementing existing fishery regulations (Fish and Game Code Section 2851[d]), which are often limited in scope and address only temporal or spatially specific restrictions. Meeting the stated program goals of the MLPA (Fish and Game Code Section 2853), requires scientifically based design considerations for MPAs. Design considerations intended to meet the goals of the MLPA were included in a master plan framework (Fish and Game Code Sections 2855 and 2856) developed by a CDFW-convened master plan team. The master plan framework was adopted in 2005 provided scientific guidance to develop the MPA network with the guidance applied at both network and individual MPA design levels. Guidance was further refined to address regional considerations during regional planning.

Network design considerations are intended to link all MPAs and involve assessing larger ecosystem functions and socioeconomic values in recommending size and spacing, location, habitat replication, and MPA classification. Individual MPA design considerations include the size and spacing, location, arrangement, classification, and specific habitat an MPA contains. As part of the planning process, MPA proposals were evaluated by the SAT to determine effectiveness in meeting scientific design guidance (individual and network) as well as their potential to meet the goals of the MLPA.

California's redesigned MPA network largely reflects the successful integration of the scientific design guidelines set forth in the MLPA, the master plan, and regional MPA planning processes. When compared to California's MPAs in 1999, prior to the MLPA when less than 3% of state waters were incorporated into any MPA classification, there is now a dramatic increase in the number of MPAs, the proportion of state waters protected, the average MPA size, the habitats represented and replicated within MPAs, and a reduction in the distance between protected habitats.

MPA management.—With the MPA network in place along the coast, CDFW is focusing on managing it relative to legislated goals and requirements of the MLMA, MLPA, and MMAIA. Core CDFW management responsibilities for the MPA network include public outreach, enforcement, issuing scientific collecting permits, monitoring, meeting adaptive management needs, and updating the master plan. Due to the large-scale nature of the MPA network and the numerous management responsibilities associated with it, CDFW has currently formed key partnerships to assist with outreach, data collection, and monitoring efforts.

In addition to working collaboratively with the many entities involved in MPA outreach statewide, CDFW Marine Region staff has developed MPA outreach materials. These materials are designed to increase public awareness and understanding of MPAs and compliance with associated regulations. Facilitating public awareness to increase regulatory compliance should allow MPAs to function in the manner they were designed. Reducing unintentional take violations should allow data collection and monitoring efforts to factor in regulated take when assessing MPA effectiveness.

California Department of Fish and Wildlife Marine Region staff is working directly with the MPA Monitoring Enterprise, a program of the Ocean Science Trust, in developing regional MPA monitoring plans, baseline data collection, and analysis. Data collection and monitoring efforts designed to measure individual MPA and overall network effectiveness relative to stated goals and objectives are an essential component to understanding long-term impacts of the MPA network. Providing these results directly to CDFW managers may help to inform long-term and adaptive management measures while also providing an extraordinary opportunity to better understand and manage marine resources from an ecosystem-based perspective. Long-term management of the MPA network may also require that marine resource managers consider how MPAs impact traditional fisheries management measures, how the two approaches can successfully be integrated, and what ecosystem benefits MPAs may provide.

In 2013, policy direction for MPAs was assumed through legislation (Fish and Game Code Section 2850.5 [Added Stat 2013 ch 356 Section 2 {SB} 96]) by the OPC. The OPC is now working with CDFW to gather input from agencies and stakeholders to best inform future policy actions with regard to MPAs. A formalized management plan, the *"California Collaborative Approach: Marine Protected Areas Partnership Plan*" currently under development between the OPC and CDFW will provide overarching policy guidance to promote a partnership model for the management of the MPA network across multiple agencies and organizations. This plan is expected to provide guidance that contributes to the overall success of MPA management.

As MPA effects on marine ecosystems, populations, and habitats are better understood over time, changes to individual MPAs or to the statewide network may become necessary. If changes are needed, it is the role of adaptive management as identified in the MLPA (Fish and Game Code Section 2852[a]) to inform those changes. Any proposed changes to an individual MPA, or the network in general, would be provided by CDFW directly to the Fish and Game Commission, the entity with the authority to enact those changes (Fish and Game Code Section 2861). However, because measurable biological responses to MPAs, especially for long-lived and slow-growing species, may require several years to appear, any adjustments to the MPA network, if needed, are expected to occur over longer time frames. The CDFW will continue to manage the MPA network in coordination with key partners to meet legislated goals and mandates under which it was created.

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BOOKS RECEIVED AND AVAILABLE FOR REVIEW

Copies of the following books have been received, and are available for review by interested parties. Individuals interested in preparing a formal review that will be published in *California Fish and Game* should contact the editor (Vern.Bleich@wildlife.ca.gov) with their request to do so.

GOTSHALL, D. W. 2012. Pacific Coast inshore fishes. Fifth edition. Sea Challengers, Monterey, California, USA. 363 pages. $9.99 (E-Book).

KIRKWOOD, S., AND E. MEYERS. 2012. America's national parks: an insider's guide to unforgettable places and experiences. Time Home Entertainment, Inc., New York, New York, USA. 208 pages. $24.95 (hard cover).

LOVE, M. S. 2011. Certainly more than you want to know about the fishes of the Pacific coast: a postmodern experience. Really Big Press, Santa Barbara, California, USA. 650 pages. $29.95 (soft cover).

INFORMATION FOR CONTRIBUTORS

California Fish and Game is a peer-reviewed, scientific journal focused on the biology, ecology, and conservation of the flora and fauna of California or the surrounding area, and the northeastern Pacific Ocean. Authors may submit papers for consideration as an article, note, review, or comment. The most recent instructions for authors are published in Volume 97(1) of this journal (Bleich et al. 2011), and are accessible through the California Department of Fish and Wildlife web site (www.dfg.ca.gov/publications).

Planning is in progress to provide an avenue for authors to submit manuscripts directly through the web site, and to enable restricted and confidential access for reviewers. In the meantime, manuscripts should be submitted by e-mail following directions provided by Bleich et al. (2011). The journal standard for style is consistent with the Council of Science Editors (CSE) Style Manual (CSE 2006). Instructions in Bleich et al. (2011) supersede the CSE Style Manual where differences exist between formats.

Authors of manuscripts that are accepted for publication will be invoiced for charges at the rate of $50 per printed page at the time page proofs are distributed. Authors should state acceptance of page charges in their submittal letters. The corresponding author will receive a PDF file of his or her publication without additional fees, and may distribute those copies without restriction. Plans are underway to make the complete series of *California Fish and Game* available as PDF documents on the California Department of Fish and Wildlife web site.

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The Scientific Journal *California Fish and Game* celebrates its 100th Anniversary with four special collector editions.

The California Department of Fish and Wildlife (CDFW) has published the highly respected scientific journal *California Fish and Game* continuously for an entire century. To commemorate the anniversary, CDFW is publishing four special issues this year.

Promoting "Conservation Through Education," *California Fish and Game* is an internationally recognized, peer-reviewed research publication read primarily by scientists in the fields of conservation, ecology and natural resource management. It focuses on the wildlife of western North America and the eastern North Pacific Ocean, but occasionally includes material from elsewhere.

This issue (Vol. 100, Issue 2) is the second of the four special issues to be published in 2014, each of which will focus on different areas of conservation, and includes the results of research on marine organisms and marine ecology conducted largely by CDFW scientists and their collaborators in several academic institutions. Also included is an extensive history of the implementation of California's Nearshore Fishery Management Plan and an overview of the creation and management of California's marine protected area network.

"I'm proud to have been the editor of this important scientific journal for the past five years, and to guide it through publication of its centennial volume," said Dr. Vern Bleich, Editor-in-Chief. "I believe it highlights the important work that many scientists, both within CDFW and elsewhere, are doing on behalf of conservation."

The marine issue features an introduction by Michael Sutton, President of the California Fish and Game Commission, and a co-authored introduction by CDFW Director Charlton H. Bonham and Francisco Werner, Director of the NOAA Southwest Fisheries Center. The first issue of volume 100 focused on research and conservation of vegetation resources in California; the remaining 100th Anniversary issues will focus on ecology of freshwater organisms, and terrestrial wildlife. They, too, will be introduced by prominent Californians who support the conservation of the flora and fauna of western North America and the eastern Pacific Ocean.

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