# Status Review of the Southern Stock of Bocaccio (*Sebastes paucispinis*)

Alec MacCall and Xi He

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Santa Cruz Laboratory
Southwest Fisheries Science Center
National Marine Fisheries Service
Santa Cruz, CA

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**Status Review of the Southern Stock of Bocaccio (*Sebastes paucispinis*)**

## EXECUTIVE SUMMARY

This status review was conducted in response to a petition to list bocaccio under the Endangered Species Act (Natural Resources Defense Council, Center for Biological Diversity and Center for Marine Conservation to NMFS Office of Protected Resources, January 25, 2001, "A petition to list the central/southern population of bocaccio (*Sebastes paucispinis*) as a threatened species").

In determining whether a listing under the ESA is warranted, two key questions must be addressed: 1) " Is the entity in question a "species" as defined by the ESA?" and 2) If so, "Is the "species" threatened or endangered?" With regard to the first question, the ESA allows listing of "distinct population segments" (DPSs) of vertebrates as well as named species and subspecies. The bocaccio off California show genetic differences from the bocaccio off Washington. Accordingly, the bocaccio population off Mexico (about 10% of the total abundance) and California, is treated as a DPS for the purposes of ESA consideration.

Bocaccio are moderately long-lived, with maximum observed ages of 30 to 40 years. They take about five years to mature, and have a mean generation time of 12 years in the absence of fishing. Bocaccio recruitment (addition of young fish to the population) is highly variable, with successful reproduction (where production of offspring offsets natural loss of adults) has occurred in only 26% of years. A few historical recruitments have been very large, but no large recruitment events have occurred since 1978. Because of this pattern of highly variable recruitment, abundance fluctuates naturally, having ranged between 35% and 128% of average unfished reproductive potential in the period 1951 to 1970. Under the influence of intense fishing and poor recruitment, abundance declined steadily since then, reaching 5% of unfished reproductive potential in 2002. Current abundance (age 1 and older) is about 3,000 metric tons, and is 1.6 million fish.

Historical overfishing was based on an assumption that the bocaccio stock had a productivity typical of other worldwide fish stocks. Experience has now shown that productivity is unusually low. The federal laws governing fishery management have been strengthened with regard to overfishing, and bocaccio is now under rebuilding, as required by the reauthorized Magnuson-Stevens Fishery Management and Conservation Act. Allowable catch rates are very low, and rebuilding is expected to take approximately 100 years. A Population Viability Analysis shows that the stock has a low probability of declining severely in the next 25 to 100 years if the rebuilding catch rates are observed.

## INTRODUCTION

Bocaccio (*Sebastes paucispinis*) is a common rockfish occurring in coastal waters of the northeastern Pacific from Mexico to Alaska (Miller and Lea 1972). Historically, bocaccio sustained the greatest harvest of any rockfish species in California waters, but according to the most recent stock assessment (MacCall 2002, included as Appendix 1 to this document) the stock has declined to a relatively low level of abundance in recent years.

Rockfish in general have a life history that is susceptible to overharvesting: they are long-lived, and have a relatively low compensatory capacity (low steepness) in their stock-recruitment relationships (Dorn 2002). Bocaccio is one of several rockfish stocks off California, Oregon and Washington that have been formally declared as "overfished" by the Pacific Fishery Management Council (PFMC) and the National Marine Fisheries Service (NMFS). An overfished condition exists if abundance of a west coast groundfihs stock falls below 25% of the estimated unfished or virgin abundance, in which case a rebuilding analysis is conducted and a Rebuilding Plan is implemented as required by the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). A Rebuilding Analysis has been conducted for bocaccio (MacCall and He 2002, included as Appendix 2 to this document) and a Rebuilding Plan is in preparation by the PFMC.

### Scope and Intent of the Present Document

This document is the status review in response to a petition[1] to list bocaccio under the Endangered Species Act. Under the ESA, if a petition is found to present substantial scientific or commercial information that the petitioned action may be warranted, a status review shall be promptly commenced (16 U.S.C. §1533(b)(3)(A)). NMFS decided that the petition had sufficient merit for consideration and that a status review was warranted (66 Fed. Reg. 32304, June 14, 2001). The ESA stipulates that listing determinations should be made on the basis of the best scientific and commercial information available. The National Marine Fisheries Service appointed the authors of the most recent PFMC bocaccio assessment (MacCall 2002) and Rebuilding Analysis (MacCall and He 2002) to undertake a scientific review of the biology, population status and future outlook for bocaccio. This document reports this team's conclusions regarding the biological status of bocaccio as a potential candidate for listing under the ESA. These conclusions are subject to revision should important new information arise in the future.

Bocaccio abundance is low relative to the estimated unfished level, and reproductive rates have not compensated for fishery harvests in recent years. Although bocaccio is one of the best studied and data-rich species on the U.S. west coast, some aspects of bocaccio biology remain poorly understood. The primary threat to the species is harvest, both intentional and

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[1] Natural Resources Defense Council, Center for Biological Diversity and Center for Marine Conservation to NMFS Office of Protected Resources, January 25, 2001, "A petition to list the central/southern population of bocaccio (*Sebastes paucispinis*) as a threatened species"

unintentional (i.e., as bycatch). Bocaccio catches have been reduced severely by the PFMC. The 1998-2001 average annual catch (219 metric tons, mt) was 11% of the 1990-1995 average (1956 mt), and the 2002 groundfish fishery was curtailed at the beginning of July when the total bocaccio catch had reached approximately 100 mt. Further reductions in catch are planned beginning in 2003 according to the Rebuilding Plan that is in preparation. Rebuilding analyses conducted by the PFMC focus on the probability of abundance increasing to 40% of the estimated unfished level within a time frame that is not greater than the length of time needed to rebuild in the absence of fishing, plus one mean generation time (this length of time is over 100 years, details are provided elsewhere in this document). However, rebuilding analyses generally do not examine the likelihood of extinction during the course of rebuilding. It is possible that a rebuilding policy with a high probability of success may nonetheless also have a small probability of extinction; these aspects are not mutually exclusive.

Key Questions in ESA Evaluations

In determining whether a listing under the ESA is warranted, two key questions must be addressed:

1) Is the entity in question a "species" as defined by the ESA?
2) If so, is the "species" threatened or endangered?

These two questions are addressed in separate sections of this report. NMFS is required by law (ESA Sec. 4(a)(1)) to determine whether one or more of the following factors is/are responsible for the species' threatened or endangered status:

The present or threatened
(A) destruction, modification or curtailment of its habitat or range;
(B) overutilization for commercial, recreational, scientific, or educational purposes;
(C) disease or predation;
(D) inadequacy of existing regulatory mechanisms; or
(E) other natural or human factors affecting its continued existence.

*The "Species" Question*: As amended in 1978, the ESA allows listing of "distinct population segments" of vertebrates as well as named species and subspecies. After determining whether the listing identifies a species, the next issue is whether there are “distinct population segments” (DPSs) within the species. However, the ESA provides no specific guidance for determining what constitutes a distinct population, and the resulting ambiguity has led to the use of a variety of approaches for considering vertebrate populations. This led the Fish and Wildlife Service and NMFS to publish a Policy Regarding the Recognition of Distinct Vertebrate Population Segments Under the Endangered Species Act (61 FR 4722). The policy identifies two elements in a decision regarding whether it is appropriate to identify separate DPSs: discreteness and significance of the population segment to the species. A DPS may be considered discrete if it is markedly separate from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors or if it is delimited by international governmental boundaries. If a population segment is considered discrete, its biological and ecological significance will be evaluated on the basis of considerations including, but not limited to its persistence, evidence that loss of the DPS would result in a significant gap, evidence of the DPS representing the only surviving natural occurrence of a taxon, or evidence that the DPS differs markedly in its genetic characteristics. Then if the DPS is appropriate, the status of the DPS should be considered separately in relation to the standards of the ESA. A more detailed discussion of this topic appeared in the NMFS "Definition of Species" paper (Waples 1991).

*The "Extinction Risk" Question:* The ESA (section 3) defines the term "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." The term "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." NMFS considers a variety of information in evaluating the level of risk faced by an ESU in deciding whether the ESU is threatened or endangered. Important considerations include 1) absolute numbers of fish and their spatial and temporal distribution; 2) current abundance in relation to historical abundance and carrying capacity of the habitat; 3) any trends in abundance; 4) natural and human-influenced factors that cause variability in survival and abundance; 5) possible threats to genetic integrity (e.g., artificial rearing); and 6) recent events (e.g., a drought or a change in management) that have predictable short-term consequences for abundance of the species. Additional risk factors, such as disease prevalence or changes in life history traits, may also be considered in evaluating risk to populations.

According to the ESA, the determination of whether a species is threatened or endangered should be made on the basis of the best scientific and commercial information available regarding its current status, after taking into consideration conservation measures that are being made. In this review, we do not evaluate likely or possible effects of conservation measures. Therefore, we do not make recommendations as to whether the species or identified DPSs should be listed as threatened or endangered species. Rather, we have drawn scientific conclusions about the risk of extinction faced by identified ESUs under the assumption that present conditions will continue (recognizing, of course, that natural demographic and environmental variability is an inherent feature of "present conditions"). Conservation measures will be taken into account by NMFS in making its listing recommendations.

## Summary of the Bocaccio Listing Petition

A document titled “A petition of list the central/southern population of bocaccio (*Sebastes paucispinis*) as a threatened species” dated 1/25/01 was filed in the NMFS Office of Protected Resources jointly by three parties (Natural Resources Defense Council, Center for Biological Diversity, and Center for Marine Conservation, now known as the Ocean Conservancy). In response, NMFS issued a “90-day finding for a petition to list bocaccio (*Sebastes paucispinis*) as threatened” (66 Fed. Reg. 32304, June 14, 2001), and included a formal request for information. In response to that request, the NRDC submitted a letter[2] providing additional information regarding one of the factors thought to threaten bocaccio: the inadequacy of existing regulatory mechanisms.

The petition was based on the decline in bocaccio abundance reported in the 1999 stock assessment (MacCall et al. 1999), where the abundance in 1999 was estimated to be two percent of the abundance in 1969. The petition identified overutilization as the primary cause of this decline. Secondary issues raised by the petition were habitat modification (due to the effects of bottom trawling gear, pollution of nearshore juvenile habitat and shifts in oceanographic conditions) , and inadequacy of existing regulatory mechanisms (the latter issue was also addressed by the NRDC letter of 8/13/01). The petition asserts that listing of bocaccio would provide NMFS with stronger regulatory authority than presently exists with regard to both "take" and preservation of "critical habitat," and that NMFS would be obligated to prepare a detailed recovery plan.

## BOCACCIO LIFE HISTORY AND ECOLOGY

### Distribution and Habitat

Boccacio occur in coastal waters from Baja California, Mexico, to Alaska. The northern and southern segments of the population are separated by an area of scarcity off northern California and southern Oregon, a feature that is apparent from the record of Russian catches made during a period of high bocaccio abundance, 1963-1978 (Figure 1). Genetic analysis indicates that bocaccio from southern California and central California (Monterey) are a well-mixed population, but do not mix extensively with fish sampled from Washington waters (Russ Vetter, NMFS, SWFSC, personal communication). For purposes of fishery management, the Pacific Fishery Management Council (PFMC) treats the northern and southern segments of the population as separate management units, but treats bocaccio off southern and central California as a single management unit.

A portion of the bocaccio population resides in Mexican waters. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys of fish larvae extended into Mexican waters routinely until 1985 (Hewitt 1988, Moser et al. 2000). Data on bocaccio larval abundances (which are indicative of spawning adult abundances) are available for surveys conducted off California and Mexico from 1972 to 1985. During this period, Mexican waters accounted for about ten percent of the larval abundance, with the remainder split about evenly between southern and central California.

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[2] Andrew Wetzler and Drew Caputo, Natural Resources Defense Council, letter to Jim Lecky, NMFS, August 13, 2001.

Bocaccio do not show strong habitat specificity. Adults (both in schools and singly) are most frequently found in association with rocky areas, from near-surface to depths exceeding 100 fathoms. Juvenile bocaccio (age three to six months) sometimes form dense schools in the nearshore area. Bocaccio are one of most mobile rockfish species, and are capable of moving freely throughout the range of the southern stock.

## Life History

Bocaccio copulate in the late summer to early fall, and females bear their young live in the winter months. Offspring (larvae and early juveniles) are pelagic until early June, when they move toward the shore and settle to the bottom where they develop as juveniles. They grow rapidly, but typically take five years to mature. Based on the oldest fish that have been seen, bocaccio may live up to 30 or 40 years. The mean generation time (the average time required for offspring to replace the parents) is 12 years (Figure 2).

Bocaccio do not participate in any known interspecies relationships of significant magnitude or importance. They serve as prey to larger organisms, including marine mammals, and juvenile bocaccio can at times provide a significant component of seabird diets. Bocaccio are predatory fish, and consume a wide variety of smaller fishes, including adults and juveniles of many species of rockfish including bocaccio.

## Abundance and Reproduction

The most recent stock assessment (MacCall 2002) treats the bocaccio population off southern and central California as a single fully-mixed unit stock. The portion of the stock off Mexico is implicitly included in the assessed population. Treatment of the southern California and central California portions of the resource as separate assessment units was explored during the 2002 stock assessment, and some aspects of that exploration are used in this status review.

MacCall (2002) estimated historical abundance for the period 1951 to 2002 (Figure 3), whereas MacCall et al. (1999) were able to estimate abundance only for 1969 to 1999. Notably, the longer history shows that abundance fluctuated substantially before 1969, which was very near the historical peak. Thus the extent of decline from 1969 to 1999 exaggerates the depletion relative to a longer term baseline of abundance, e.g., relative to the 1951-1975 average abundance. Because bocaccio reproduction consists of rare large yearclasses, adult abundance is highly variable even in the absence of fishing.

Bocaccio recruitment (the young fish added to the population as the result of parental reproduction) is characterized by rare large events, and most of the population consists of fish from a very small number of years (Figure 4). The past 25 years has produced only three large recruitments (in 1977, 1984 and 1988). The 1999 and 2002 yearclasses appear to be large, but it is too soon to obtain a reliable quantitative estimate of their strengths. In contrast, the decade between 1969 and 1979 produced four large yearclasses. Long-term ocean climate patterns appear to have a strong influence on the frequency of large recruitments. Although this relationship cannot yet be quantified, the cooler ocean since 1998 is similar to the cool conditions of the 1960s and early 70s, and may be associated with better bocaccio reproduction. The protracted and extremely warm conditions of the 1990s was associated with poor reproduction of most rockfish species, including bocaccio, and undoubtedly contributed to the decline in abundance.

The historical relationship between estimated parental abundance and subsequent recruitment shows little or no evidence of increased reproductive rate at low abundances (Figure 5). The long-term average reproductive success only slightly exceeds the level needed to replace natural losses of parents (replacement), so that future abundances resemble the mathematical process of a "random walk" (a process characterized by lack of consistent trend and increasing variability over time).

A somewhat different pattern emerges when southern California is considered separately (MacCall 2002). The southern California segment shows much more productivity than the central California segment of the population, which is nearly neutral in net productivity (Figure 6). The combined stock assessment (MacCall 2002) is heavily influenced by the central California condition, and was favored by the STAR Panel peer-review for purposes of fishery management. However, for purposes of evaluating the long-term existence of the resource, the viability of the portion of the stock in southern California may be an appropriate alternative measure of status.

## HISTORICAL AND PRESENT STATUS OF FISHERY MANAGEMENT

### Summary of MSFCMA Requirements

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) imposes regulatory requirements with regard to continuing existence of fishery resources that in many respects are more stringent than would be imposed by the ESA. The following summary highlights those MSFCMA aspects that relate to ESA considerations.

The National Standards established by the MSFCMA (16 U.S.C. 1851, § 301(a), "National Standards for Fishery Conservation and Management") require, among other things, that:

> (1) Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery;

(3) To the extent practicable, an individual stock of fish shall be managed as a unit throughout its range; and

(6) Conservation and management measures shall take into account and allow for variations among, and contingencies in, fisheries, fishery resources and catches.

Fishery management under the MSFCMA requires development of fishery management plans (16 U.S.C. 1853, § 303(a), "Contents of Fishery Management Plans") with required provisions including:

(1)(A) measures necessary and appropriate for the conservation and management of the fishery to prevent overfishing and rebuild overfished stocks, and to protect, restore and promote the long-term health and stability of the fishery;

(3) assessment and specification of the present and probable future condition of, and the maximum sustainable yield and optimum yield from, the fishery;

(10) specific objectives and measurable criteria for identifying when the fishery to which the plan applies is overfished, and in the case of a fishery which the Council or the Secretary has determined is approaching an overfished condition or is overfished, the FMP must contain conservation and management measures to prevent overfishing or end overfishing and rebuild the fishery.

The MSFCMA imposes further requirements on management of fish stocks that have been identified as "overfished" (16 U.S.C. 1854, § 304(e), "Action by the Secretary"). The Council, through its fishery management plan must:

(3)(A) Within one year, prepare a fishery management plan, plan amendment, or proposed regulations to end overfishing and rebuild affected stocks;

(4) In its fishery management plan, amendment or proposed regulations, specify a time period for ending overfishing and rebuilding the fishery that shall be as short as possible and not exceed 10 years except where biology of the stock or other environmental conditions dictate otherwise.

Appropriate actions under the latter exception are described by the Magnuson-Stevens Act Provisions; National Standard Guidelines; Final Rule issued by NMFS in 1998 (50 CFR part 600). Regarding §600.310 National Standard 1 – Optimum Yield, (e) Ending overfishing and rebuilding overfished stocks, (4) Constraints on Council action, (ii) Council action must specify a time period for rebuilding the stock that satisfies the requirements of section 304(e)(4)(A) of the Magnuson-Stevens Act. This continues, (B)(3) If the lower limit [of the time period for rebuilding] is 10 years or greater, then the specified time period for rebuilding may be adjusted upward ... except that no such upward adjustment can exceed the rebuilding period calculated in the absence of fishing mortality, plus one mean generation time or equivalent period based on the species life-history characteristics. For example, suppose a stock could be rebuilt within 12 years in the absence of any fishing mortality, and has a mean generation time of 8 years. The rebuilding period, in this case, could be as long as 20 years.

Bocaccio has been identified as a species that cannot be rebuilt within 10 years (MacCall and He 2002), and is therefore subject to the above National Standards Guidelines requirement that the time period for rebuilding not exceed the length of time it would take in the absence of fishing (97 years), plus one generation time (12 years). This time period is assumed to begin in the year following designation of the stock as overfished, i.e., the first year of rebuilding is 2000.

## History of Bocaccio Fishery Management

Until recently, fishing pressure on bocaccio has been higher than levels now believed to be optimal for rockfish exploitation (Figure 7). Until the mid-1990s, the resource was believed to be capable of withstanding an exploitation rate that is commonly applied in fisheries throughout the U.S. and worldwide, F35%. This is a fishing rate that reduces the expected average lifetime reproductive output of a fish to 35% of the output it would achieve in an unfished condition (note that this criterion naturally scales the fishing rate to the life history properties of the species, see Clark 1991). In the late 1990s, the PFMC recognized that rockfish stocks were continuing to decline and concluded that this fishing intensity was too high for rockfish species. The PFMC subsequently modified the rockfish harvest policy to F40% in 1998 and again to F50% in 2001 (Ralston 2002). The current policy of F50% is an extraordinarily low rate of fishery exploitation by worldwide standards.

In 1999 the bocaccio resource was formally declared “overfished” in accordance with the newly-passed reauthorization of the MSFCMA, which had strengthened national policies intended to reduce and eliminate overfishing (see summary above). Following the declaration, a rebuilding analysis (MacCall 1999) was conducted based on the results of the1999 stock assessment (MacCall et al 1999), and the PFMC implemented a rebuilding policy beginning in 2000. Formal establishment of rebuilding policies as PFMC fishery management plan amendments has gone slowly, but all required regulatory actions associated with rebuilding have been implemented in a timely manner nonetheless. The bocaccio rebuilding policy initiated in 2000 established a rebuilding time of 37 years (calendar year 2037). The total target catch was to be held at a constant value of 100 metric tons (mt) for the years 2000 through 2002, and in 2003 the intent was to switch to a corresponding constant harvest rate that would set annual catches according to resource abundance. The target 100mt catch was exceeded in 2000 and 2001, as the PFMC is in the process of “learning” how to track within-year catches and to reduce harvests of a single species within a complicated mix of fishing modes and biological co-occurrences. Since 2000 the PFMC has implemented progressive restrictions not only on allowable catches of bocaccio, but on allowable catches of other species that tend to co-occur with bocaccio (e.g., chilipepper, *Sebastes goodei*), and also established closed seasons designed to reduce the overall level of fishing activity likely to encounter bocaccio. Recent exploitation rates have dropped substantially (Figure 7). In response to indications that the 2002 target catch is being achieved too early in the season, the PFMC enacted unprecedented gear, season and area fishing restrictions beginning in July, 2002 in order to minimize further catch of bocaccio.

The 2002 bocaccio assessment (MacCall 2002) and rebuilding analysis (MacCall and He 2002) were completed in June 2002. The new assessment provides an extended 50-year view of bocaccio fluctuations, and also incorporates an expanded set of resource observations from both southern and central California. Although the new assessment showed the relative depletion to be not quite as severe as previously thought, the estimated average rate of fish production was lower than in the previous assessment. Consequently, the new rebuilding analysis indicated that rebuilding would be slower and more erratic, requiring 97 years even in the absence of fishing. The new rebuilding target date is 2108, and the rebuilding OY for 2003 is approximately 6 mt.

## CONSIDERATION OF THE “SPECIES” QUESTION

### Criteria for Identification of Distinct Population Segments

The joint policy of the US Fish and Wildlife Service (USFWS) and NMFS provides guidelines for defining distinct population segments (DPSs) below the taxonomic level of species (USFWS-NMFS, 1996):

*Discreteness:* The first of two elements to be considered is the discreteness of a population segment with respect to the rest of the populations within the species. Genetic differences between the population segments being considered may be used to evaluate discreteness. The policy also states that international boundaries within the geographical range of the species may be used to delimit a distinct population segment in the United States. This criterion is applicable if differences in the control of exploitation of the species, that management of the species' habitat, the conservation status of the species, or regulatory mechanisms differ between countries that would influence the conservation status of the population segment in the United States.

*Significance:* The second element in defining distinct population segments is that the segment must be biologically or ecologically significant. Significance is evaluated in terms of the importance of the population segment to the overall welfare of the species. Some of the considerations that can be used to determine a discrete population segment's significance to the taxon as a whole include:

1) Persistence of the population segment in an unusual or unique ecological setting;

2) Evidence that loss of the population segment would result in a significant gap in the range of the taxon; and

3) Evidence that the population segment differs markedly from other populations of the species in its genetic characteristics.

Distinct Population Segments of Bocaccio

*Northern vs. Southern Stock:* The northern and southern bocaccio stocks meet both the discreteness and significance criteria for treatment as separate DPSs. Genetic differences have been identified (Vetter, NMFS, SWFSC, Pers. Comm.), and there is a gap in the geographic distribution in the area of northern California and southern Oregon (Figure 1). The remainder of this review will address only the southern stock as a DPS, that population segment having been the subject of the listing petition that generated this biological review.

*Southern California vs. Central California:* Genetic similarity of bocaccio from southern California and central California indicates that these two segments are not isolated. The southern and central California segments of the southern bocaccio stock have been combined for fishery assessment and management purposes under the Pacific Fishery Management Council. The primary implication is that catches taken from either segment are considered to have an equivalent impact on the stock. As a gap in bocaccio abundance already exists north of central California (Figure 1), hypothetical loss of bocaccio in central California would only widen a geographic gap between the two DPSs that already exists. Both the strong 1999 and 2002 yearclasses “spilled over” from southern California into central California as juveniles, indicating that the central California segment is easily repopulated from southern California. Thus there is no reason to treat southern and central California segments of the bocaccio stock as DPSs, or as otherwise significant geographic areas for purposes of the ESA.

*Transboundary and International Issues:* The southern bocaccio stock extends into Mexican waters. The current Mexican portion of the total stock abundance is not known, but historical (1972-1985) larval abundances indicate a value of about ten percent. Bocaccio larval abundances declined at all locations during the 1972 to 1985 period, and the relative decline in Mexican waters was similar to that in U.S. waters. Due to the relative inaccessibility of northern Baja California waters to fishermen, historical fishing pressure on bocaccio has probably been lighter than in U.S. waters, and the current portion of the bocaccio stock residing in Mexican waters may be somewhat above ten percent, but is probably not large. Although it can be argued that regulatory mechanisms differ between the U.S. and Mexico and that bocaccio catches in Mexico would potentially influence the conservation status of bocaccio in the U.S. to some degree (the discreteness criterion), that influence is presumably small given the relative sizes of the stock segments. Treatment of the Mexican segment of the bocaccio stock as a separate DPS is not warranted.

In conclusion, the DPS treated in this review consists of the bocaccio off California and Mexico (extending to approximately 200 miles south of the U.S.-Mexican border). The portion in Mexican waters is approximately ten percent of the total southern stock DPS.

## CONSIDERATION OF THE "EXTINCTION RISK" QUESTION

### Evaluation of Risk Factors

As listed in the Introduction, a number of factors must be considered in evaluating the status of the petitioned species.

*Absolute numbers:* Absolute numbers of bocaccio in the southern stock is 1.6 million fish (age 1 and older) in 2002 (MacCall 2002). About 1.0 million of these fish are south of Pt Conception, where recent recruitments have been relatively stronger. Fish are older and average size is larger north of Pt. Conception. Absolute numbers corresponding to "extinction" is not known, but current abundance is far higher than conventional "extinction" values (usually hundreds or thousands of individuals) used for other species.

*Relative abundance:* Current abundance (2002) of the southern stock is 3000 mt, with 1300 mt occurring south of Pt. Conception (MacCall 2002). Current reproductive potential is 720 billion eggs (243 billion eggs south of Pt. Conception). Estimated unfished reproductive potential of the southern stock is 14857 billion eggs (MacCall 2002). The current reproductive potential is 5% of the estimated average unfished level, and is low by conventional standards.

*Trends in abundance:* Historical abundance (measured as spawning potential) has been estimated since 1951 (MacCall 2002). Between 1951 and 1969, abundance fluctuated between 35% (in 1960-61) and 128% (1969) of the estimated average unfished level (Figure 3), demonstrating the natural tendency of bocaccio abundance to fluctuate strongly over time. After 1969, relative abundance declined steadily to its current relative value of 5% of estimated unfished abundance.

*Natural and human-influenced factors* that cause variability in survival and abundance: Environmental conditions providing for successful reproduction (i.e., producing more offspring than are needed to replace the current year's natural losses) are not understood, but such events are infrequent, and have occurred in 13 of the last 50 years (26%), and only 4 of those events were large enough to replace more than the average 3.8 years (1/0.26) between successful reproductions. Importantly, none of those large events have happened since 1978, contributing to the decline in abundance. The U.S. west coast experiences a 60-year cycle of conditions that alternate between favorable (ca. 1941 to 1975) and unfavorable (1976 to 1998) for many coastal species of fish (MacCall 1996). It is likely that the higher frequency of poor bocaccio reproductive successes since 1978 has been associated with the unfavorable phase of the long-term ocean climate cycle. Evidence is accumulating that a new favorable period began in 1999, and bocaccio have recently achieved two successful reproductions, in 1999 and in 2002. This also demonstrates that the stock has not been reduced to a "depensatory" level where reproductive rate decreases due to such phenomena as inability to find mates.

The primary cause of the current low abundance is excessive harvesting, particularly during the 1980s and early 1990s when the stock was believed to be capable of sustaining an F35% harvest rate. Recent bocaccio management associated with the MSFCMA requirement for ending overfishing and rebuilding the stock has reduced fishing pressure to levels that assure long-term population growth. The risk of further bocaccio decline under a rebuilding program is evaluated quantitatively in the following section on Population Viability Analysis.

Both natural conditions and fishery management policy now provide for a much more optimistic outlook than was the case during the most of the bocaccio decline. The ocean climate cycle appears to be in a more favorable phase for bocaccio reproduction, and fishery management has formally embraced stock rebuilding policies. Because of these changes, the most important natural and human factors associated with the historical decline in bocaccio are no longer operative.

*Threats to genetic integrity:* There are no known threats to the genetic integrity of bocaccio.

*Recent events:* The most important recent events that influence the status of bocaccio are the apparent shift to a more favorable ocean climate beginning in 1999, and the strengthening of the MSFCMA with regard to rebuilding overfished stocks.

*Additional risk factors*: The optimistic outlook for fishery management is based on the PFMC's continuing adherence to the rebuilding requirements specified in the MSFCMA. However, if the bocaccio rebuilding program is weakened or abandoned (for example, if the PFMC invokes the "mixed stock exception"[3] to allow increased harvest of bocaccio), the risk of further decline in the species will be higher, and the following Population Viability Analysis would require revision.

Population Viability Analysis (PVA)

The PFMC's rebuilding policy is designed to achieve population growth over the long term, but the irregular recruitment pattern exhibited by bocaccio results in a risk of further decline despite the rebuilding policy. The bocaccio rebuilding analyses provided to the PFMC (MacCall and He 2002) utilized the standard rebuilding software package developed by Andre

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[3] The Magnuson-Stevens Act Provisions; National Standard Guidelines; Final Rule issued by NMFS in 1998 (50 CFR part 600). Regarding §600.310 National Standard 1 – Optimum Yield, (d) Overfishing, (6) Exceptions. There are certain limited exceptions to the requirement to prevent overfishing. Harvesting one species of a mixed-stock complex at its optimum level may result in the overfishing of another stock component in the complex. A Council may decide to permit this type of overfishing only if all of the following conditions are satisfied: ... (iii) The resulting rate or level of fishing mortality will not cause any species or evolutionarily significant unit thereof to require protection under the ESA.

Punt of the PFMC's Scientific and Statistical Committee (SSC). Here, the SSC rebuilding software was also used to investigate the risk of further decline in bocaccio abundance under alternative fishery management scenarios. The simulation involves simulating the next 100 years of bocccio abundance by random resampling of recruitment successes (recruits per spawner) from the historical series 1953 to 1999, which are treated as equally likely values of what will happen in the future. Alternative constant fishing rates are considered, and are scaled according to what the catch would be in 2003–from 0 to 50 mt. (The PFMC has not yet specified the OY for 2003, but it will most likely be at the low end of this range). A total of 10,000 simulations were run for each case in order to achieve good precision despite the underlying recruitment variability. Abundances at the end of 25 and 100 years are expressed as spawning outputs (billion eggs) or as spawning output relative to the present estimate of 720 billion eggs. The median value (50 percentile) is given as a likely result of long-term fishing at the given rate. Risk is expressed as the lowest 5 percentile of abundance, a fairly unlikely outcome, but useful as a "worst-case" scenario. The 5 percentile abundances are reported for 25 years and 100 years in the future (calendar years 2027 and 2102).

Table 1 shows the results for the combined southern and central California model used in the stock assessment (MacCall 2002). Table 2 shows an alternative scenario that is based on southern California only (results are still expressed relative to the current combined spawning potential of 720 billion eggs), where current abundance is somewhat higher and reproductive successes tend to be better, relative to central California. The combined central and southern California stock projection shows 100-year median abundance that are higher than the present abundance except for the highest fishing rate; all southern California stock projections show strong population growth. The 5 percentile "worst-case" abundances for the combined model range from 15 to 22% of the present abundance at the end of 25 years, and from 2 to 11% of present abundance at the end of 100 years. The southern California model gives higher estimates of future abundances, suggesting that the risk may be less than given by the combined model.

Abundance levels corresponding to "extinction" have not been defined in this PVA, as no exploited marine fish is known to have gone extinct–there is no precedent on which to base such a value. The lowest 5 percentile abundance given in the tables is 1.9% of the present abundance, which is roughly equivalent to 57 mt, or 30,000 individual fish.

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Table 1. Population Viability Analysis for the combined southern and central California bocaccio stock.

| Catch in 2003 (mt) | Constant Fishing rate | Future Spawning Outputs | | | | |
|---|---|---|---|---|---|---|
| | | Median (50%) in 2102 (billion eggs) | Lowest 5% | | | |
| | | | in 2027 (billion eggs) | in 2102 (billion eggs) | in 2027 (percentage of 2002) | in 2102 (percentage of 2002) |
| 0 | 0 | 3650 | 160.5 | 81.4 | 22.3% | 11.3% |
| 10 | 0.0115 | 2248 | 145.6 | 52.3 | 20.2% | 7.3% |
| 20 | 0.0228 | 1399 | 132.5 | 33.3 | 18.4% | 4.6% |
| 30 | 0.0343 | 865 | 120.0 | 21.4 | 16.7% | 3.0% |
| 40 | 0.0459 | 536 | 108.8 | 13.7 | 15.1% | 1.9% |

Table 2. Population Viability Analysis for the bocaccio stock in southern California only.

| Catch in 2003 (mt) | Constant Fishing | Future Spawning Outputs | | | | |
|---|---|---|---|---|---|---|
| | | Median (50%) in 2102 (billion eggs) | Lowest 5% | | | |
| | | | in 2027 (billion eggs) | in 2102 (billion eggs) | in 2027 (percentage of 2002) | in 2102 (percentage of 2002) |
| 0 | 0 | 140207 | 405.5 | 3161.2 | 56.3% | 353.0% |
| 10 | 0.0171 | 64573 | 341.1 | 1506.8 | 47.4% | 209.3% |
| 20 | 0.0344 | 29679 | 288.6 | 717.7 | 40.1% | 99.7% |
| 30 | 0.0519 | 13592 | 244.3 | 342.9 | 33.9% | 47.6% |
| 40 | 0.0697 | 6212 | 206.3 | 164.7 | 28.6% | 22.9% |

## Bocaccio

Locations of Russian trawls where Bocaccio were caught (left panel) versus tow locations where no Bocaccio were found, 1963-1978. Stars are proportional to the square root of the total number caught per tow.

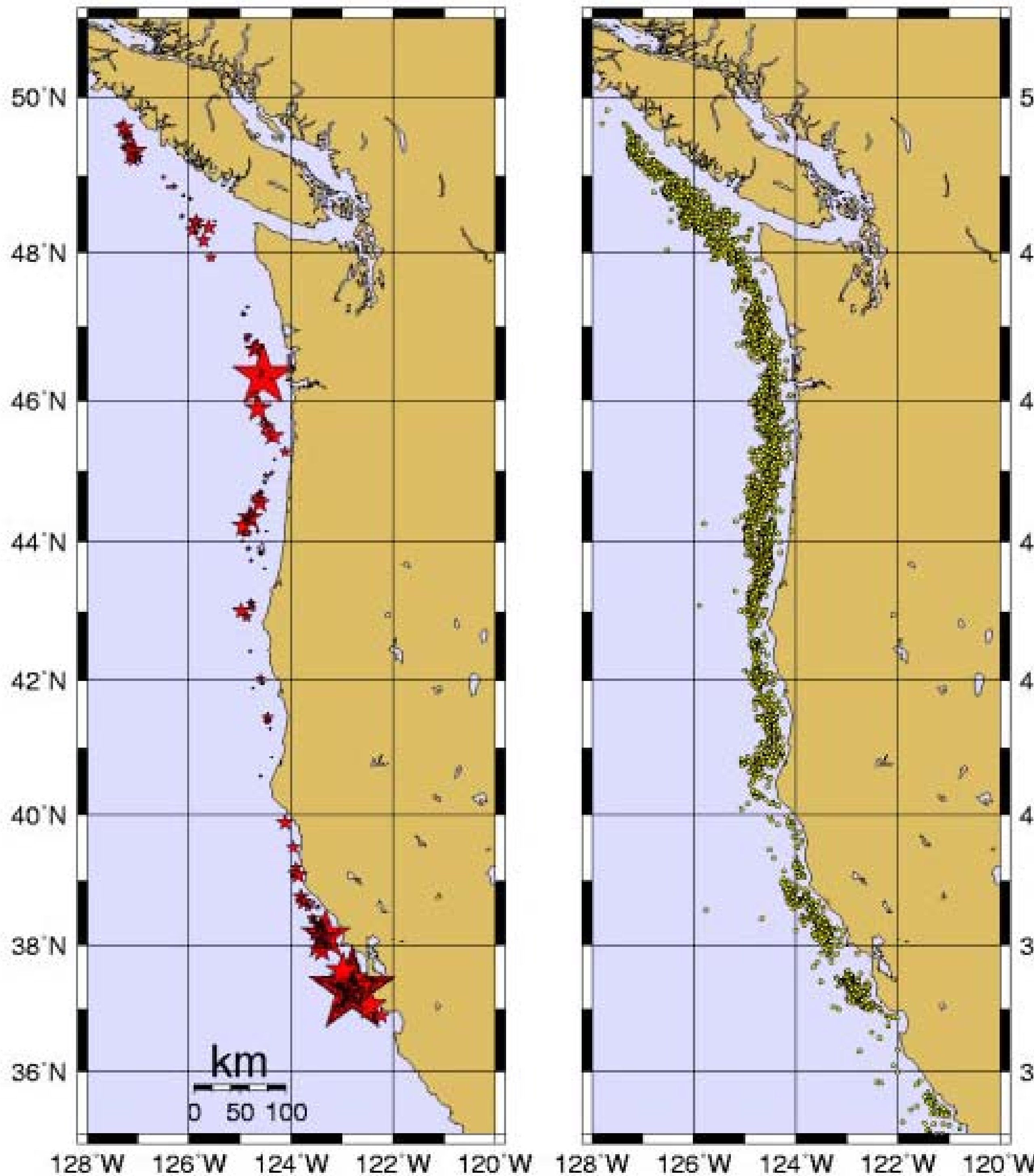



Figure 1. Catch locations of bocaccio in the Russian fishery.

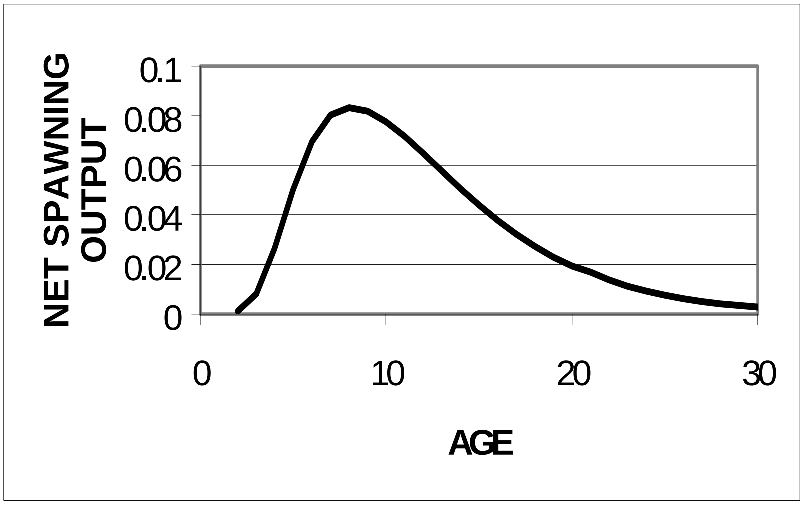



**Figure 2**. Net maternity function (product of survivorship and fecundity) for bocaccio, normalized to unit area. Mean generation time is 12 yr.

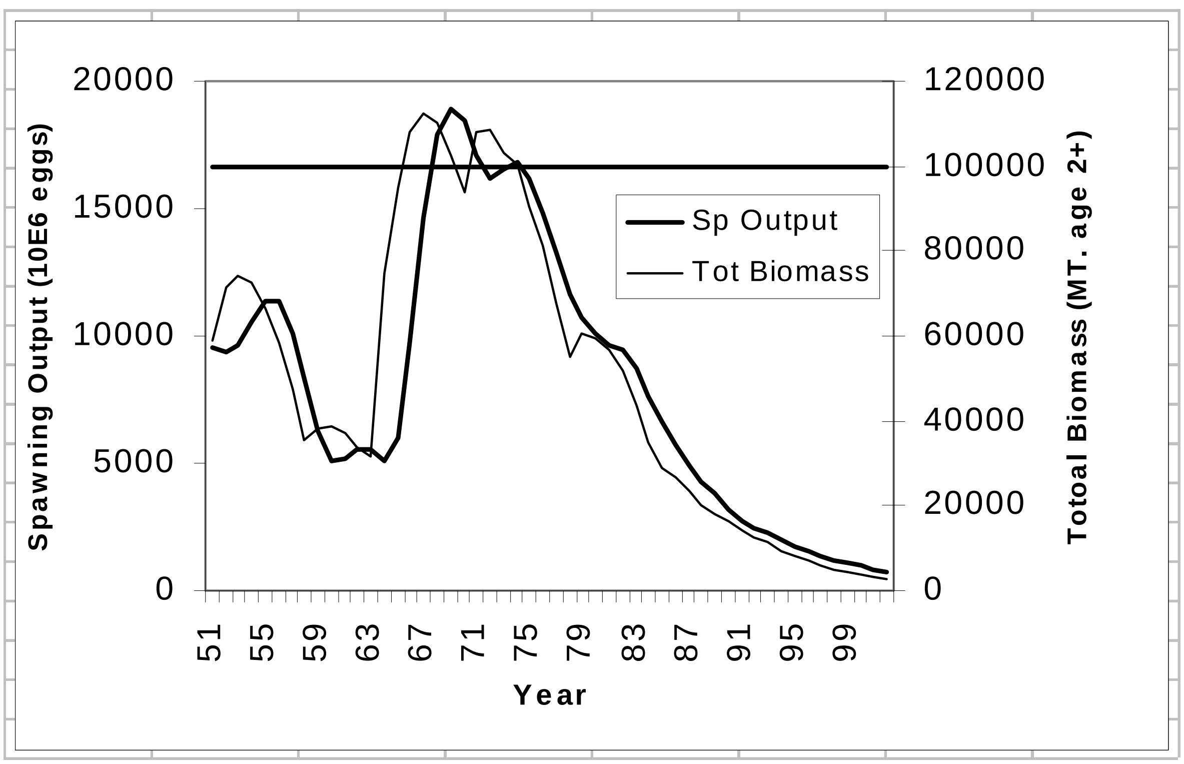
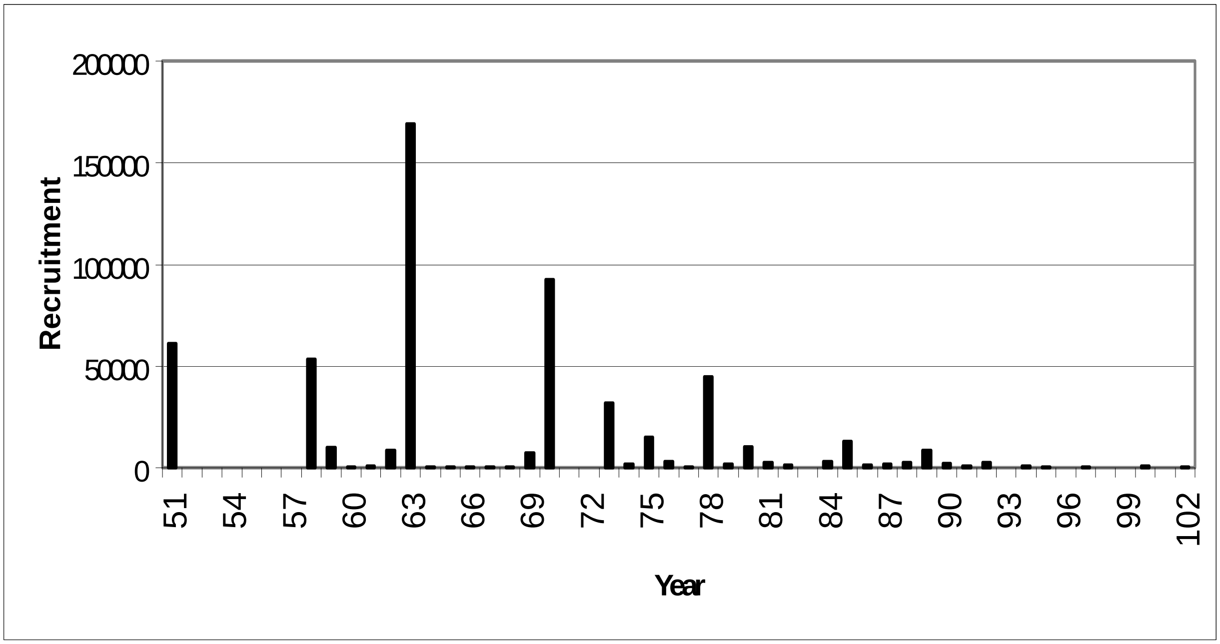



**Figure 3.** Estimated historical bocaccio abundances. Horizontal line is estimated unfished spawning output (14,857 billion eggs).



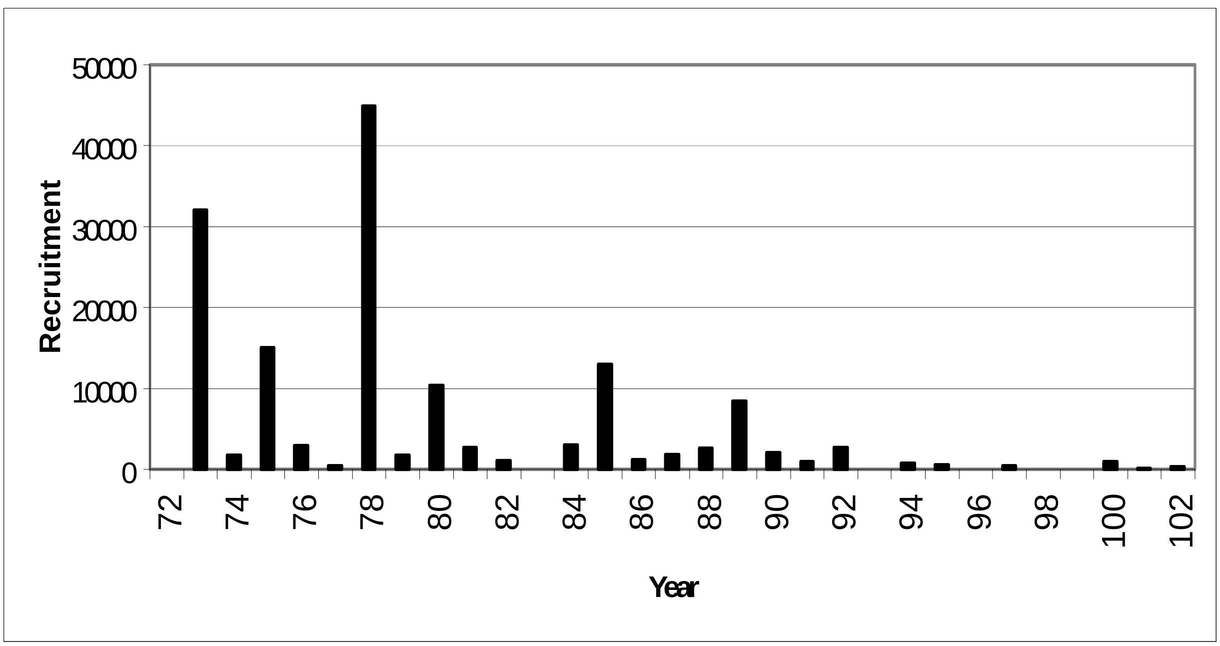




**Figure 4.** Estimated bocaccio recruitment strengths. Lower panel shows detail of recent years.

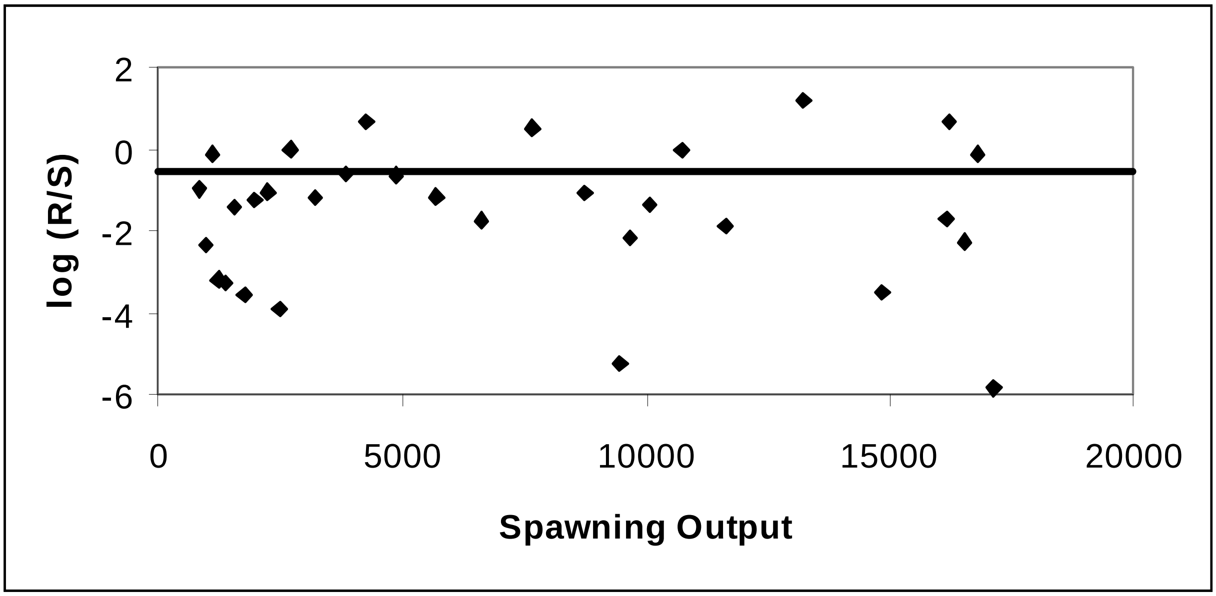



**Figure 5.** Historical reproductive success related to parental abundance. Horizontal line is replacement level in the absence of fishing.

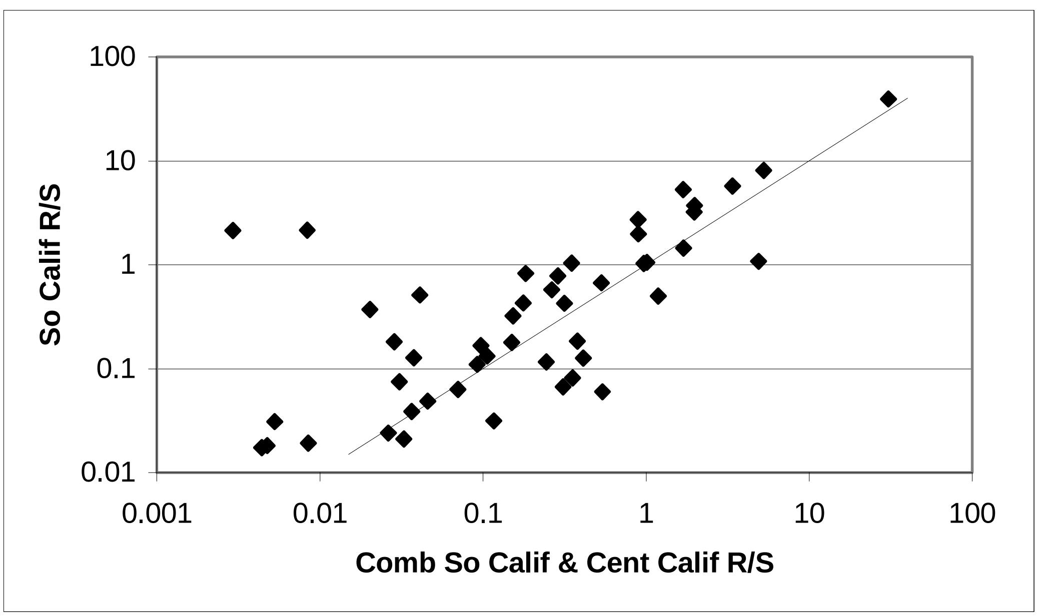



**Figure 6.** Comparison of estimated reproductive successes (recruits per spawning output) showing tendency for better reproductive successes in southern California. Diagonal line is equality.

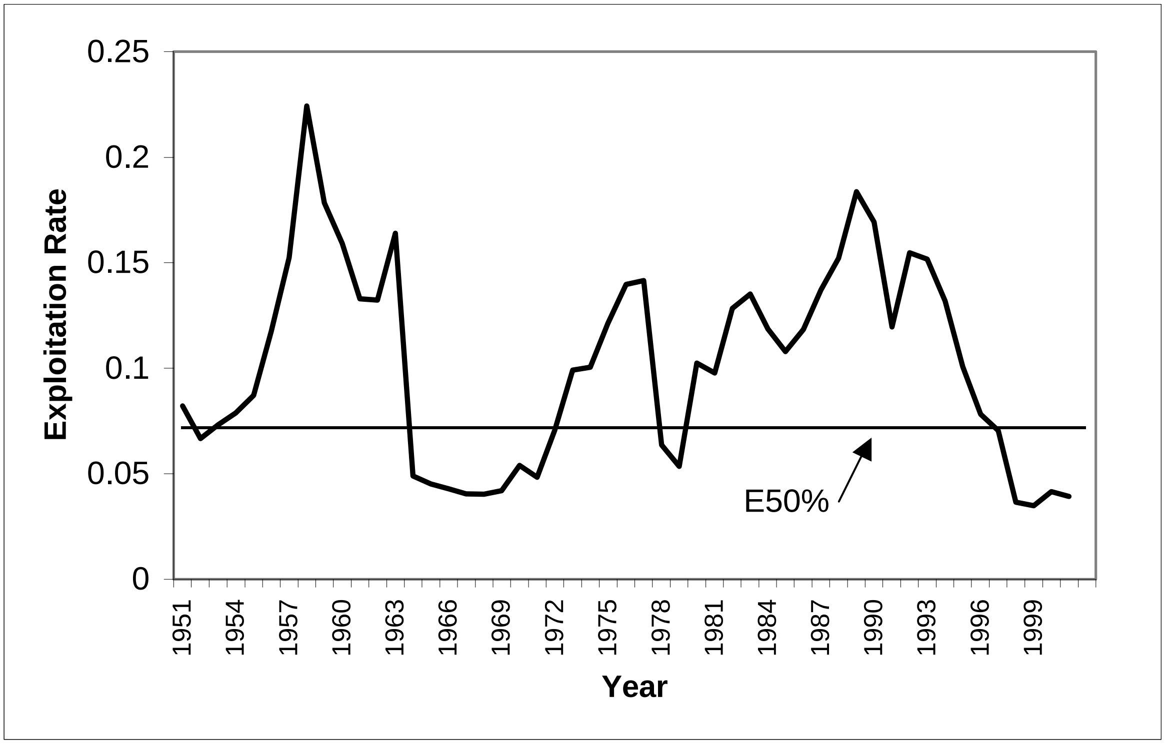



**Figure 7.** History of bocaccio exploitation rates (catch as fraction of age 2+ biomass). Horizontal line is exploitation rate corresponding to fishing intensity at maximum sustainable yield.

# STATUS OF BOCACCIO OFF CALIFORNIA IN 2002

by

Alec D. MacCall

Santa Cruz Laboratory
Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
110 Shaffer Road., Santa Cruz CA 95060

June 2002

EXECUTIVE SUMMARY

SPECIES/AREA: Bocaccio rockfish (*Sebastes paucispinis*) occurring in waters off the state of California. For management purposes, the stock may be considered to reside in U.S. waters south of Cape Mendocino. This stock assessment treats the resource in Southern and Central California as a combined unit (see unresolved problems below).

| YEAR | 1951 | 1961 | 1971 | 1976 | 1981 | 1986 | 1991 | 1996 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BIOMASS (MT, 2+) | 58,754 | 36,856 | 108,159 | 81,031 | 56,986 | 26,981 | 14,112 | 6,874 | 4,373 | 3,738 | 3,364 | 2,914 |
| CATCH (MT) | 5,119 | 5,079 | 5,478 | 11,825 | 5,742 | 3,172 | 1,757 | 599 | 213 | 233 | 215 | |
| EXPLOITATION RATE | 0.087 | 0.138 | 0.051 | 0.146 | 0.101 | 0.118 | 0.125 | 0.087 | 0.049 | 0.062 | 0.064 | |

CATCHES: Catches have been in severe decline for the last two decades, reflecting both a long-term decline in abundance and progressive restrictions on harvest of bocaccio. Values of catches in recent years are imprecise, for example because of undocumented discarding. In the base model of this assessment, recreational catches may have been slightly overestimated and commercial catches underestimated. Some alternative values were explored. All interpretations of total catch indicate that the 100 MT OY established by the PFMC for 2000 and 2001 has been exceeded.

DATA AND ASSESSMENT: The last assessment was conducted in 1999. Like the previous assessment, this assessment uses a length-based stock synthesis model. Whereas the previous assessment extended back to 1969, this assessment extends back to 1951. Data included catches from seven fisheries segments reflecting four gears and two areas (trawl, setnet, hook&line, and recreational; the latter three segments were divided into Southern and Central California areas), length compositions from eight sources (all seven fisheries segments, and the Triennial Survey), three indexes of abundance in Central California (trawl logbook CPUE, recreational CPUE, and the Triennial Survey), two indexes of abundance in Southern California (CalCOFI index of spawning abundance and recreational CPUE), and two indexes of recruitment (Central California Juvenile Rockfish Survey, and Southern California Power Plant Impingement Index).

UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES: The relationship between stock segments in Southern and Central California is unclear, and the status and productivity in those two areas may differ. Results of area-specific models indicates that Southern California is relatively less depleted (ca. 10% of unfished abundance), and may have greater capacity for rebuilding. Central California, which appears to be more severely depleted, has a higher unfished biomass, but a lower productivity rate, suggesting a tendency to large natural fluctuations in abundance, with consequent difficulty in rebuilding the stock. Even in the combined model, the historical variability in recruitment produces a very imprecise estimate of unfished abundance (see reference points below), with similar imprecision in the rebuilding target.

REFERENCE POINTS: Population reproductive potential is measured as spawning output (units of billion eggs). Unfished abundance cannot be estimated reliably from the stock and recruitment due to lack of curvature in the relationship. An imprecise estimate of unfished spawning output of 14857 (CV=31%) was obtained by multiplying the average recruitment (1953 to 1998) by SPR(F=0). The PFMC proxy of 50% SPR is supported by the average recruitment success (recruits/spawning output), which indicates that a 49% SPR is sustainable (however, the CV is 51%).

STOCK BIOMASS: Estimated spawning output in 2002 is 720 billion eggs, or 4.8% of the estimated unfished level. The estimated 2002 total biomass (age 2+) is 2958 MT.

RECRUITMENT: The last significant recruitment appeared as age 1 fish in 1989. The following decade was remarkable for consistent recruitment failure. Although the 1999 year class is the strongest in several years, it now appears to be weak relative to the range of possibilities considered in the 1999 assessment.

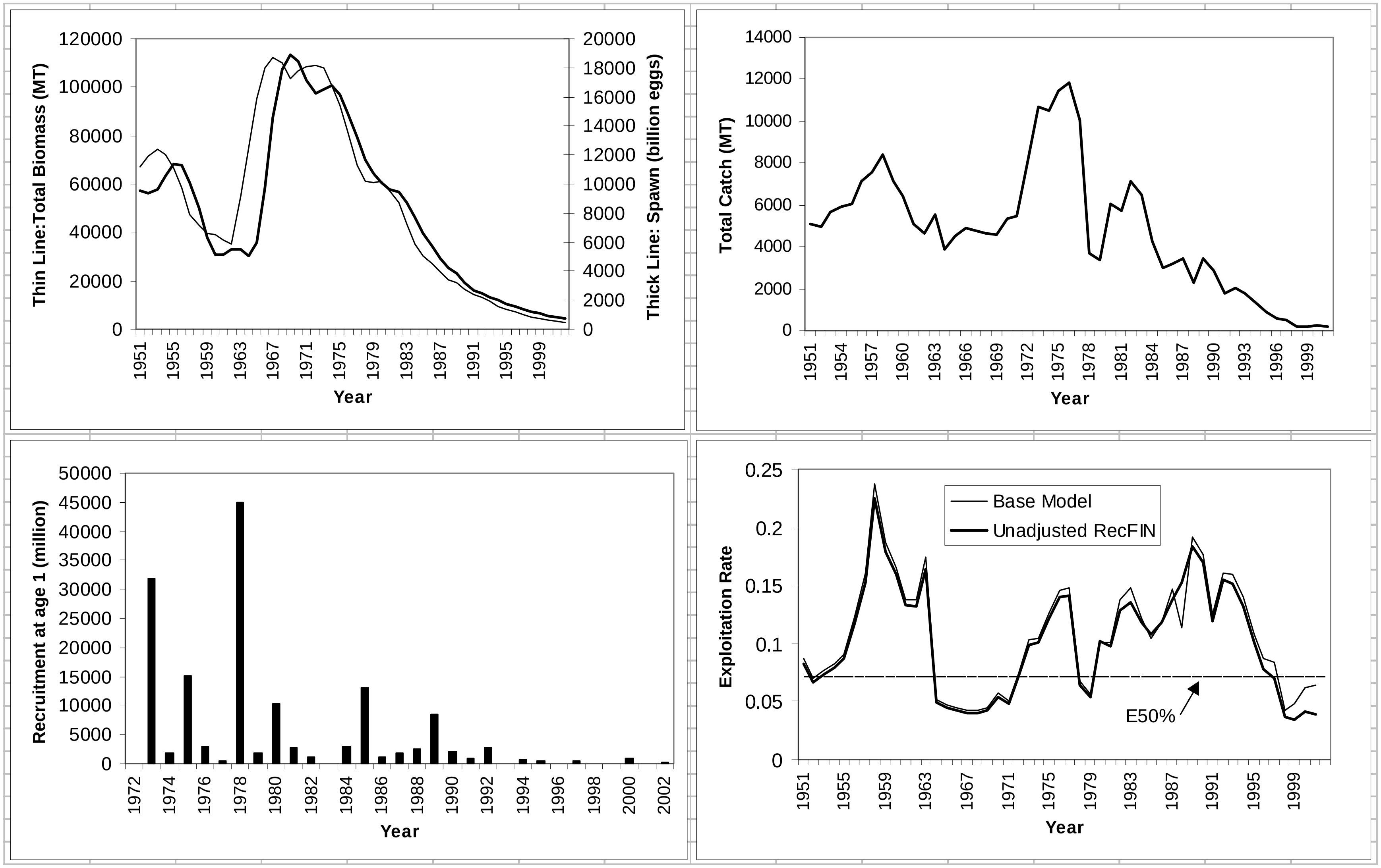
EXPLOITATION STATUS: Estimated exploitation rate (catch/total biomass age 2+) in 2001 depends on the values of catch taken by recreational and commercial fisheries (see CATCHES above). Exploitation rate in the base model was 6.4%, which is slightly below the 50%SPR level of 0.0717 used as a proxy MSY rate by the PFMC. If catches have been overestimated, the exploitation rate would be correspondingly lower.

MANAGEMENT PERFORMANCE: In hindsight, the stock has been heavily overfished during the entire period of PFMC management. Stock assessments have identified biomass as being below 25% of the unfished level since 1991, but due to mistaken confidence in the correctness of the F35% proxy, insufficient effort was made to slow the decline in abundance (note that the decline could not have been halted because of weak recruitments). Recent catches have exceeded the 100 MT rebuilding target set for 2000-2002, indicating need for re-evaluation of management measures, especially in view of the drastically reduced catch levels that are now estimated to be required for rebuilding.

FORECASTS: Spawning output will continue to decline for several years due to past recruitment failures, with no improvement being likely in the next five to ten years. Stock projections were conducted using stock synthesis and the SSC rebuilding simulation developed by Andre Punt. The projections indicate that the median time to rebuild to 40% of Bunfished is approximately 97 years in the absence of fishing. The 1999 assessment was overly optimistic due to erroneous assumptions regarding the strength of the 1999 yearclass. According to this new assessment, the 38-year rebuilding timeframe based on medium yearclass strength scenario of the 1999 assessment is not feasible even if all fishing mortality is eliminated.

RECOMMENDATIONS: A revised rebuilding analysis will be prepared. Annual catches of bocaccio must be reduced to a near-zero level. An abbreviated assessment and review in 2003 would address some data problems and help resolve the strength of the 1999 yearclass.

REFERENCES: STAR Panel Report.




Long-term patterns of bocaccio abundance, catch, recruitment and exploitation rate.

# STATUS OF BOCACCIO OFF CALIFORNIA IN 2002

## Introduction

Previous stock assessments (Bence and Hightower 1990, Bence and Rogers 1992, Ralston et al. 1996, MacCall et al. 1999) demonstrated that the bocaccio (*Sebastes paucispinis*) resource off California has been declining since 1969, the earliest year for which abundances could be estimated reliably. On the basis of the 1996 assessment by Ralston et al., the stock was declared formally as overfished. A rebuilding plan was implemented beginning in 2000, but formal adoption as a Groundfish Plan Amendment has been delayed. The rebuilding plan and associated Plan Amendment is expected to be revised according to the updated view of the resource developed in this assessment. Also, in January 2001 the National Marine Fisheries Service received a petition to consider listing of bocaccio under the Endangered Species Act. This stock assessment is intended to serve as one of the documents supporting the required Biological Review in response to that petition.

Two aspects of this assessment are of special significance:

*1999 Year Class.* The rebuilding policy adopted by the Pacific Fishery management Council (PFMC) beginning in 2000 was strongly influenced by the assumed strength of the 1999 year class which had been observed in unusual abundance at the San Onofre power plants. This year class is the first significant year class in several years, and became available to the Southern California recreational fishery in 2000 and 2001. However, the 1999 year class still has not made a significant showing in Central California north of Avila/Port San Luis. Determination of the strength of the 1999 year class will help formulate the rebuilding policy.

*Southern California Information.* Previous bocaccio assessments were based mainly on data from Central California (especially the Triennial Survey). This assessment utilizes new information relevant to Southern California. It examines both combined assessment models and individual models for each area, and contributes to an understanding of the relationship between those two segments of the population.

## History of Management

Bocaccio have long been a dominant species in groundfish catches taken off California. In 1962 and 1963, bocaccio comprised over 40% of the rockfish taken by trawling off California, and comprised well over 50% of the rockfish taken by trawl south of San Francisco (Nitsos 1965). There were few restrictions on harvest other than area closures and minimum mesh size requirements prior to federal management of the fishery.

The Pacific Fishery Management Council (PFMC) assumed management responsibility for west coast groundfish when the Groundfish Fisheries Management Plan (FMP) became effective in September 1982.  For all practical purposes, full-time groundfish management by the PFMC began in 1983.  The history of bocaccio management is summarized in Table 1.

The PFMC routinely adopted an acceptable biological catch (ABC) for bocaccio of 4,100 MT for the Monterey INPFC area and 2,000 MT for the Conception area from 1983 through 1990.  Landings in other areas were considered too small to warrant a separate ABC.  These ABC's were based solely on historical landings during selected periods.

In response to concerns about bocaccio stock conditions, an assessment was conducted in 1990 (Bence and Hightower, 1990).  The results of that assessment were used by the PFMC to establish an 800 MT ABC for the combined Conception-Monterey-Eureka INPFC areas for 1991.  The PFMC, after hearing public testimony, established a harvest guideline of 1,100 MT for those INPFC areas. The ABC and harvest guideline applied to all gears and include the recreational fishery.  The same ABC and harvest guideline were in effect through 1992.  During those two years, actual harvest exceeded the harvest guideline by 300-500 tons.

In 1992,  the PFMC reviewed a new assessment for bocaccio (Bence and Rogers, 1992).  That assessment stated, "...under current harvesting rates, although fishing mortality is estimated to be below F35%, the expected stock biomass and spawning capacity is projected to decline further, and possibly fall to less than 20% of the levels seen in 1980....we recommend harvesting at the current harvest guideline [1100 MT]."  Nonetheless, the PFMC adhered strictly to its F35% policy and recommended that the 1993 ABC be increased to 1,540 MT and that the harvest guideline be set equal to the ABC in the same INPFC areas.  The new assessment accommodated some expected discard in the trawl and set net fisheries that often fished to the trip limits.  By 1994 the Council had determined that few trips were being impacted by trip limits and the reduction to account for discard was unnecessary.  Therefore, the 1,540 MT ABC and harvest guideline, in effect since 1993, were adjusted to 1,700 MT for 1995 and was extended through 1996.  Actual landings fell short of these ABC levels and declined so rapidly that even an 1100 MT harvest guideline would have had little effect.

A stock assessment conducted in 1996 (Ralston et al., 1996) showed the resource to be in severe decline, and the PFMC drastically reduced the ABC to 265 MT in 1997, and to 230 MT with adoption of an F40% policy in 1998 and 1999.  Moreover, the long string of recruitment failures during the 1990's continued.  In 1999, the stock was formally designated as "overfished" according to the requirements of the newly amended MSFCMA and the Overfished/Rebuilding Threshold for groundfish adopted by the PFMC in Groundfish FMP Amendment 11.  The incoming 1999 year class appeared to be relatively strong, helping to buffer the catch restrictions needed to accomplish rebuilding.  The rebuilding policy adopted by the PFMC held the rebuilding  OY constant at 100 MT for the years 2000-2002, with the intention of switching to a constant fishing rate policy beginning in 2003.

During the 1983-1990 period bocaccio were managed in combination with other rockfish in the Sebastes complex.  Trip and frequency limits were used to constrain total complex landings only. After 1990, various bocaccio trip limits were used to keep total commercial landings within established harvest guidelines. These limits have been specific to the area south of Cape Mendocino and remain nested within overall Sebastes complex limits. Constraints on the recreational take of bocaccio were limited to daily bag limits for combined rockfish. Beginning in 2001, a two-fish daily bag limit was imposed for bocaccio, and time-area closures were implemented in 2002 to reduce the recreational catch of bocaccio.

## Life History

In most respects bocaccio is typical of other rockfishes. It displays a primitive form of viviparity (Wourms, 1991), with 50% of females maturing by 48 cm FL (Gunderson *et al*., 1980). Fish copulate early in the fall (Moser, 1967), although fertilization is delayed (Wyllie Echeverria, 1987). Embryonic development takes at least a month to complete and the larvae hatch internally (Moser, 1967). The total fecundity of bocaccio ranges from 250,000-2,500,000 larvae, resulting in weight-specific fecundities of 250-400 larvae/gm (Phillips, 1964). Parturition occurs during the winter months (Wyllie Echeverria, 1987) and larvae eventually metamorphose into pelagic juveniles (Moser and Boehlert, 1991), a stage that takes months to complete (Woodbury and Ralston, 1991). Settlement to littoral and demersal habitats begins in late spring and extends throughout the summer months. Even though subadult growth can be very rapid in absolute terms (24 cm at age I), adults grow slowly (Wilkins, 1980). Moreover, growth is sexually dimorphic, with females reaching larger sizes than males (ca. 90 versus 75 cm). The diet of bocaccio is primarily fish.

## New Aspects of this Assessment

The following list highlights the major changes that have been implemented here relative to the last assessment that was conducted on bocaccio (MacCall et al., 1999):

– Separate stock assessments are considered for waters north and south of Pt. Conception (but the final model combines the two areas).

– The beginning of the estimated time series of abundances is 18 years earlier than in previous assessments (previously 1969, now 1951).

– Commercial landings have been re-estimated from port sampling data, and the years 1978 and 1979 have been added.

– Recreational landings have been re-estimated from the MRFSS database, replacing blank strata (formerly treated as zero catch) with estimated catches. Northern California partyboat landings and length compositions are from the CDF&G sampling program, and also fill in recreational fishing information for years 1990-92 in which MRFSS did not conduct sampling.

– Many of the indexes were produced by a delta-lognormal general linear model (GLM), avoiding the potential distortions caused by adding an arbitrary constant before taking logarithms of values. Precision of indexes was estimated by a grouped jacknife approach.

– The Triennial Survey index of abundance and length compositions have been recalculated with off-bottom "water hauls" omitted. This affects abundance estimates and size compositions for the earlier years. The index is based on a GLM.

– New indexes of spawning biomass are based on GLMs of revised CalCOFI larval abundances for Southern California and Central California, from 1951 to 2000 in Southern California, and from 1955 to 2000 in Central California.

– A new Central California partyboat recreational CPUE index (GLM based on CDF&G observers) from 1987 to 1998 is introduced.

– A Southern California recreational CPUE index (GLM, based on MRFSS) from 1980 to 2001 is introduced.

– A recruitment index based on a GLM of impingement rates at five Southern California power plants from 1972 to 2000 is introduced.

## Stock Structure

Previous assessments of bocaccio included the Conception, Monterey and Eureka INPFC areas, mainly as a matter of convenience. Although catches of bocaccio occur regularly to the north, especially off Cape Flattery and in Canadian waters, very little northern information is available for purposes of stock assessment. At the time of the 1999 assessment, genetic information indicated lack of intermixing between the fish off the Pacific Northwest and the fish off California. More recent work indicates a somewhat higher possibility of intermixing (Vetter, pers. comm., SWFSC, La Jolla). Historical surveys reported in the 1999 assessment indicated a consistent lack of bocaccio off Northern California and Southern Oregon, which is interpreted as a discontinuity between the Pacific Northwest fish and those off California. For management purposes, the stock off California is considered to be separate and independent of the stock off the Pacific Northwest. Bocaccio off Northern Baja California are presumably associated with the California stock, but no information on catches is available. CalCOFI larval abundances are available for some years during the 1970's and 1980's, but were not worked up for this assessment.

An important unresolved question is the relationship between the Southern California and Central California segments of the resource (the nominal dividing line is Pt. Conception). Current management treats these two areas as a single well-mixed unit. Although a fully developed migration model is not available, this stock assessment uses available tools to examine consequences of partial stock separation.

## Sources of Data and Model Setup

### Landings Statistics

Landings by major fishery segments are summarized in Table 1. The total landings are taken from standard sources, or are estimated from available limited information (especially pre-1980). In some cases, such as recent recreational estimates, landings estimates may be subject to controversy, and alternative values can be obtained by various estimation methods and from alternative data sources. The recreational landings used here are not identical to the official RecFIN estimates (some blanks were filled with estimates if catch in number of fish was available, and some zero catch estimates were replaced with positive estimates). A sensitivity analysis using the unaltered RecFIN landings is included later in the document.

*Early landings:* Estimated landings for the pre-monitoring period follows the estimates developed in the 1996 assessment, except that this assessment requires historical catches for Southern and Central California separately. The estimated statewide bocaccio commercial landings were apportioned north and south of Pt. Conception according to the corresponding fractions of the recorded rockfish landings reported in CDF&G Fish Bulletins. In Central California, catch by gear was apportioned as in the 1996 assessment. Southern California trawl landing prior to 1978 were assumed to be negligible, and the commercial catch was assumed to be from the hook and line fishery. Pre-monitoring recreational catches were similarly apportioned to Southern and Central California in proportion to the partyboat landings for those two areas reported in CDF&G Fish Bulletins.

*Post-1978 monitoring:* In previous assessments, statistics of monitored landings began in 1980, but the database now includes commercial landings for 1978 and partial data for 1979. California's port sampling methodology is based on the statistical methodology of Sen (1986). The expansions of the sampled landings and length frequencies to the estimated statewide landings are described by Pearson and Erwin (1997), and reside in the COMCAL database maintained at the Santa Cruz Laboratory. The expansions have been recalculated since the previous assessment, resulting in a somewhat different time series of landings. Use of nominal landings categories, i.e., "bocaccio-chilipepper" received greater emphasis in the new expansions.

Changes in the recreational catch estimates from the MRFSS database mainly reflect the replacement of blank values (treated as zero in conventional queries) with approximate values. If a catch in numbers is available for the wave, region and fishing mode, the numbers are multiplied by the average weights in the preceding and following wave. If only estimated trips are available, the angler trips is multiplied by the average catch per trip in the preceding and following wave. Estimates for the 1993-95 Central California partyboat catch are not available from MRFSS; values were provided by Deb Wilson-Vandenberg (CDF&G, Pers. Comm.) based on the CDF&G partyboat monitoring program.  Catches for the unsampled recreational segments in the1993-95 period were estimated as a linear trend between adjacent known values.

The combined effect on the estimated statewide landings (MT) by individual fishery segments is summarized for the period 1980 to 1998 in the following table:

| | Differences from 1999 Assessment | | | | | | | Revised |
|---|---|---|---|---|---|---|---|---|
| Years | Trawl | SetNet | H&L | Rec'l | Com'l | Total | % Change | Total Landings |
| 1980-84 | -15 | 541 | -59 | -275 | 468 | 193 | 0.7% | 29628 |
| 1985-89 | 121 | 2801 | -359 | 112 | 2563 | 2674 | 21.1% | 15341 |
| 1990-94 | -81 | 840 | 198 | 377 | 957 | 1334 | 15.8% | 9781 |
| 1995-98 | 5 | 93 | -4 | 65 | 94 | 159 | 7.9% | 2166 |
| Total | 30 | 4276 | -225 | 279 | 4081 | 4360 | 8.3% | 56916 |

**Surveys and Abundance Indexes**

Methodological Note on Delta-Lognormal GLMs and Jacknife Procedures: The previous assessment used GLMs based on log-transformed observations ln(OBS + c) where c is a small constant.  This approach has the drawback that the resulting indexes are influenced by the value of c, the value of which is arbitrary.  Several of the following indexes were developed from a delta-lognormal GLM, which allows estimation of a multiplicative effects (log-additive) model without use of the arbitrary added constant.

The probability of observing a positive value in a cell is given by a GLM with marginal (i.e., year, location, month) probabilities,

$P(\text{positive})_{ijk} = PYEAR_i * PMONTH_j * PLOCATION_k * \text{error}.$

The marginal probabilities are fit under logit transform.  A separate GLM is applied to logarithms of the positive observations only, generating another set of marginal effects:

$\ln(\text{CELL VALUE})_{ijk} = LYEAR_i + LMONTH_j + LLOCATION_k + \text{error}.$

The year indexes from the delta-lognormal GLM are the product of the two back-transformed marginal year effects.   Back-transformation from the logit model is

$PYEAR_i = \exp(y_i+y_o)/(1+\exp(y_i+y_o))$

where $y_i$ is the year effect and $y_o$ is the fitted constant under logit transformation.  The back-transform of estimated marginal year effects ($x_i$) from the second GLM for positive values is simply its exponentiated value, so the year index is given by

$\text{Year Index}_i = PYEAR_i*\exp(LYEAR_i)$ .

The fitted constant from the second (logarithmic) model component and the traditional bias correction are omitted because they have no effect on the utility of the output as an index.

Estimation of standard errors of the year indexes utilizes resampling methodology. Erik Williams (pers. comm. SEFSC, Beaufort) has designed a bootstrapping procedure, but that approach seems to encounter estimation problems if the data contain a high proportion of zero values. A simple alternative is to use a grouped jackknife procedure (Efron and Gong 1983), where the variance is estimated by

$$s^2(\theta) = ((N_{groups}-1)/N_{groups})\Sigma w_i(\theta_i-\theta\bullet)^2$$

where $N_{groups}$ is the number of sets of observations to be deleted, $w_i$ is a weighting factor based on group sample size given to each subset (the values of $w_i$ have unit mean), $\theta_i$ is the estimate of parameter $\theta$ with the ith subset of observations deleted, and $\theta\bullet$ is the mean of the $N_{groups}$ different values of $\theta_i$. The estimated standard error (SE) is the square root of this estimated variance, and the estimated coefficient of variation (CV) is the ratio of the SE to the estimated parameter value.

***CalCOFI Indexes of Spawning Biomass:*** Abundances of larval bocaccio observed on CalCOFI surveys from 1951 to 2000 (Moser et al. 2000) provide indexes of historical spawning biomass for Southern California and Central California. Development of these two indexes is described separately. In both indexes, jacknifing used five groups of deleted stations, chosen to be widely distributed geographically.

Southern California CalCOFI Index: Years with very limited coverage (less than 50 samples) were deleted, leaving 37 years with sufficient data to calculate annual indexes of abundance. Observations from December through April were used, based on consistency of station occupations and positive occurrences. CalCOFI Lines 80 (off Pt. Conception) to 93 (off San Diego) were included in the Southern California index. Offshore stations with rare occurrences of bocaccio larvae were deleted, leaving a total of 39 standard stations. Of the 7215 (37 years x 39 stations x 5 months) cells in this design, there were 3726 observations, 907 of which were positive for bocaccio larvae. These data were fit by a delta-lognormal GLM, estimating year effects (Figure 1), station (location) effects, and month effects. Five jackknife groups were formed from groups of stations chosen to cover the north-south and inshore-offshore range, with approximately equal numbers of observations, and so that no station contained all zero observations within a group. CVs ranged from 20-30% in the early years to 50-80% in recent years due to the progressively rarer occurrence of bocaccio larvae (Figure 1).

Central California CalCOFI Index: Bocaccio larvae from CalCOFI Lines 60 (off San Francisco) to 73 (off Piedras Blancas) Conception have only been identified thoroughly since 1972, and were rarely occupied after 1984. However, Line 77 (off Avila) has been identified since 1954, and continued to be occupied through 2000. Year effects from GLMs using Line 77 only and using Lines 60 to 73 are similar for the years 1972-1984, indicating that Line 77 is sufficiently representative of Central California to extend the time series from 1954 to 2000. Numbers of positive stations are so few (especially in more recent years) that years were combined into nominal years to produce estimates that could be jackknifed for estimation of standard errors. The combined years (and corresponding nominal years) are

1962=61+62
1959=58+59
1966=65+66
1979=1978+1979
1981=1980+1981+1982
1984=1983+1984+1985
1987=1986+1987+1988
1990=1989+1990+1991
1995=1992+1993+1994+1995+1996+1997+1998
2000=1999+2000.

Only the three peak reproductive months of January, February and March, and 26 CalCOFI stations were used. The final design comprised 1404 cells (18 years * 26 stations * 3 months) in which there were 568 observations and 154 positive observations.

As was done for Southern California, these data were fit by a delta-lognormal GLM, estimating year, station (location), and month effects. Five jackknife groups were formed from groups of stations chosen to cover the north-south and inshore-offshore range, with approximately equal numbers of observations, and so that no station contained all zero observations within a group. CVs for the Central California Index are much larger than for Southern California and average well over 100%. The most precise estimates are from 1960 to 1972 (average CV approximately 50%), a period during which bocaccio appear to have been significantly less abundant than in the following decade (Figure 2).

The Central California CalCOFI Index was used only in the exploratory Central California model, and was not used in the final combined model.

<u>CalCOFI Index Selectivity:</u> Although the Stock Synthesis program computes spawning biomass (or spawning output), it does not include an option for fitting a spawning biomass index directly. An approximate selectivity curve was derived by fitting a logistic model to the relationship of weight specific fecundity (proportion mature * eggs/weight) and length (Figure 3). This selectivity curve was applied to the female abundances to obtain predicted values of the CalCOFI indexes.

***Triennial Survey Index*** **(<u>Central California</u>):** The Alaska Fisheries Science Center has conducted bottom trawl surveys every three years off the west coast since 1977, with the most recent survey in 2001. The Monterey INPFC area was sampled on every survey, but the Conception area was not sampled on the 1980, 1983 and 1986 surveys. The 1977 survey did not sample the 55-91m depth range, but Ralston et al (1996) showed that very few bocaccio tend to be encountered in this range, so no attempt is made in this assessment to adjust the 1977 index for this small difference. Recent analysis of historical Triennial Survey trawl performance identified a problem with the extent of bottom contact by the net during the early years of the survey (Zimmerman et al. 2001). The questionable trawl samples have been deleted from the Triennial Survey data used in this analysis (pers. comm., Mark Wilkins, AFSC).

I used a simple log-transformed GLM to obtain bocaccio abundance indexes from the triennial survey stratum means; the GLM treatment provided a means of estimating the index despite the Conception region not having been surveyed in some years. Factors were survey year, area (Conception vs. Monterey), and depth stratum ( nearshore, 55-183m, vs. and offshore, 184-366m). Values from the Eureka INPFC area were not included, as bocaccio were too rare in the catches to be informative. The coefficient of variation of the GLM index was assumed to be the same as the directly-calculated CV for the combined strata. The resulting index was imprecise, with CVs ranging from 30% to 80% (Figure 4).

***Recreational Fishery CPUE:*** Two separate indexes of abundance were developed from GLM treatment of catch rates of bocaccio in recreational fisheries.

<u>Central California Partyboat CPUE:</u> The California Department of Fish and Game has conducted intensive sampling of partyboat catches in Central California (Deb Wilson-Vandenberg, Pers. Comm.), providing a basis for a CPUE index. The GLM was based on year (1987 through 1998), quarter (4) and boat (29) effects. Boat effects were a surrogate for location effects, and boats with low catch rates or short-term participation were deleted. The database contained 3632 observations, of which 1336 were positive for bocaccio. Quarters were used as groups for deletion in the jackknife procedure. Except for the1987 index, precision was good, with CVs ranging from about 10% to 25% (Figure 5).

<u>Southern California Recreational CPUE:</u> The MRFSS database provides a basis for estimating a Southern California partyboat CPUE. The GLM was based on bimonthly mean catch per angler according to year (1980-1989, 1993-2001), season (4 bimonthly sampling waves excluding the summer season, i.e., November through June), and fishing mode (partyboat vs. private). Sampling waves were used as groups for deletion in the jackknife procedure. Most of the CVs were in the 30%-50% range, with a few larger or smaller values (Figure 6).

***Trawl Fishery CPUE*** **(<u>Central California</u>):** Ralston (1999) developed a CPUE index of bocaccio abundance based on California trawl logbooks (Figure 7). Because the logbooks do not identify most individual species such as bocaccio, Ralston applied species compositions from local port sampling to the overall catch rates of rockfish from the trawl logbooks. This assessment uses Ralston's "area-weighted" index of bocaccio CPUE, and the associated standard errors (average CV is 29%).

***Recruitment Indexes*:** Two separate recruitment indexes were developed, for Central and Southern California respectively.

Trawl Survey Recruitment Index (Central California): Midwater trawl surveys for juvenile rockfish have been conducted by the Santa Cruz Laboratory in May-June of each year since 1983. The survey region from Monterey to Pt. Reyes is divided into seven geographic strata, with three to five standard trawl locations within each stratum. The geographic area is surveyed three times (“sweeps”). In each year, the two sweeps that encountered the largest number of juvenile bocaccio in all areas combined were retained for use in the GLM (in a few cases of approximately equal catch rates, all three sweeps were retained). All trawls conducted in the same region and year were considered to be equivalent iid observations, yielding 745 observations, of which 171 were positive for bocaccio juveniles. The GLM was based on year and region effects (Figure 8). Three groups of individual trawl stations within the geographic strata were used for deletion in the jacknife procedure. Estimated CVs were quite variable with individual year effects ranging from very precise (ca. 10%) to very imprecise (over 100%).

Power Plant Recruitment Index (Southern California): Annual impingement rates (bocaccio per volume of intake water) at five Southern California electrical generating stations (Kevin Herbinson, pers. comm., Southern California Edison) from 1972 to 2000 form the basis of a recruitment index. These data were fit by a delta-lognormal GLM, estimating year (recruitment index) and station (location) effects. Observations from the three separate units at San Onofre were given fractional weightings summing to unity at that location for each year. Standard errors for the year effects were estimated by a grouped jacknife, deleting individual power plants (Ngroups=5). The only years in which no bocaccio were impinged at any location were the two El Niño years of 1983 and 1998. In three other years (1982, 1993 and 1994) bocaccio were impinged at only one location, preventing jackknife estimates of precision of those years; approximate standard errors for these five recruitment index values were inferred from the approximately linear relationship between standard error and corresponding year index near the origin (Figure 9). The coefficients of variation average about 2, indicating extreme imprecision in this index.

The strength of the1999 year class has been of particular interest since it was first observed in the power plant entrainments at San Onofre. This database shows that the 1999 year class was observed at only two of the five locations, and was abundant only at San Onofre. The corresponding 1999 index value is extremely imprecise (CV=600%), but is more similar to the “low” (1991 year class equivalent strength) than to the “medium” (1988 year class equivalent strength) case considered in the 1999 assessment and rebuilding analysis.

## Age Determinations

The break-and-burn method of age determination from otolith circuli is considered to be more reliable than surface readings, and tends to result in older age determinations (Don Pearson, SCL, SWFSC, Pers. Comm.). However, Ralston et al. (1996) and Ralston and Ianelli (1998) found that use of the age composition information for bocaccio conflicted with length composition information, and caused peculiar shifts in the years associated with major bocaccio recruitments. The true year of recruitment is clearly established by known length of young-of-the-year fish and clear modal patterns in the length compositions (Figure 10). The results of the previous assessment indicate that an unknown but probably systematic pattern of errors in the age determinations is present, and the age composition information provides misleading information. Age compositions are not used in this assessment, but break-and-burn age determinations are assumed to be approximately correct for purposes of estimating length-at-age and maximum longevity.

## Sample Sizes

Determination of appropriate sample sizes has been a recurring problem in maximum likelihood models such as stock synthesis. Catch and survey samples are taken as clusters of fish, and several mechanisms can cause within-cluster variance to be severely reduced relative to an equivalent number of iid samples. An empirical estimate of "effective" sample size ($N_{eff}$)is provided by the synthesis model, based on the ratio of the variance of the expected proportion (p) from a multinomial distribution to the mean squared error of the observed proportion (p'), i.e., $N_{eff}$ = sum[p(1-p)]/sum[(p-p')$^2$]. Rather than direct use of $N_{eff}$ (e.g., McAllister and Ianelli, 1997), this assessment follows the iterative regression "smoothing" approach developed in the 1999 bocaccio assessment: actual sample sizes are replaced by nominal sample sizes based on the predicted effective sample sizes from a regression of $N_{eff}$ on actual number of fish measured (actual sample size is used if it is a smaller number than is predicted by the regression). After the first iteration the effective sample size values from the regression predictions tend to be stable. The relationships between actual and effective sample sizes are shown for various sources in Figure 11. The ratios of nominal to actual and effective (based on the final model) to actual sample sizes is given in Table 4. The nominal sample sizes used in this assessment are higher than final effective sample sizes because the nominal sizes were derived from separate Southern and Central California models in which length compositions could be fit more precisely than in the combined model. Because the fits in the separate models were better, the quantity sum[(p-p')$^2$] was lower, producing higher estimated effective sample sizes than are given by the combined model.

## Natural Mortality Rate

Previous estimates of the natural mortality rate (M) have decreased over the history of bocaccio stock assessments, partially due to improvements in age determination methods and resulting increases in maximum observed ages: Bence and Hightower (1990) used 0.25, Bence and Rogers (1992) used 0.20, and in 1996, Ralston et al. used 0.15 (the units $yr^{-1}$ are omitted). In 1999, MacCall et al. returned to use of 0.20. This assessment assumes M=0.2, but examines implications of the alternative values of 0.15 and 0.25.

**Growth**

This assessment is based on length compositions rather than age compositions, and the growth curve has nearly as large an influence as the natural mortality rate in determining the stock dynamics. The influence of abundant small fish in some years of the Triennial Survey length compositions tended to “trap” the estimated length at age 1.5 at an unrealistically small value (abundance, length and selectivity were confounded), so the initial (age 1.5) length was fixed at 27cm for both sexes, and the asymptotic length was fixed at 75.89cm for females and at 65.56cm for males. The growth rate parameter was estimated freely for each sex.

## Model Results

The calculations utilize the length-based version of the Stock Synthesis model (Methot 1990). During model development, separate models were constructed for Southern and Central California. However, the STAR Panel preferred a final assessment model using combined data for both areas. The results presented here are for the combined model (Table 4 and Appendix 1). The projections are based on either the stock synthesis program with separate selectivity patterns for each fishery or Andre Punt’s rebuilding simulation model, using the composite selectivity pattern given in Appendix 1 (see section on Stock Projections for more details).

*Selectivity*: Length-based selectivity patterns were examined in the 1996 and 1999 assessments. Because of potential interactions with isolated strong year classes, time-varying selectivity was not considered. As in the previous assessments, most selectivity patterns have a strong descending limb. In previous assessments, male-female differences were seen only in the trawl selectivities; this assessment found no sex-related difference in the Central California trawl selectivities. Trawl size compositions from the Southern California fishery were available only for two years, and produced highly questionable selectivity curves with a very narrow peak. Consequently, the Southern California trawl length compositions were deleted from the likelihood function, and selectivity of the Central California trawl fishery was also applied to trawl catches from Southern California. The is no clear systematic relationship between selectivity curves of equivalent gears in Central and Southern California (Figure 12).

*Fits to abundance indexes:* The fit to the Triennial Survey (Figure 13) reflects the high error variability shown in Figure 4; a precise fit should not be expected. In addition, the model had difficulty identifying an appropriate selectivity curve for the length composition information from the Triennial Survey; the final selectivity curve favors smaller fish (Figure 12). Fits to the trawl CPUE (Figure 14) and Central and Southern California recreational CPUE (Figures 15 and 16) are good. The fit to the CalCOFI index (Figure 17) is also quite good.

The fit to the Central California recruitment index is similar to that seen in the previous assessment (Figure 18). The survey identifies some, but not all of the stronger year classes. The fit to the Southern California recruitment index similarly shows general agreement (Figure 19), but with some strong differences for individual years. This is expected, given the imprecision of the Southern California recruitment index.

### Recruitment

Minimum recruitment was set at 50,000 fish. Recruitment estimates for several of the weakest years, especially El Niño years, were constrained by this bound. The model did not include a likelihood component for the fit to a stock-recruitment relationship. Recruitment estimates for the 1950's and 1960's are not based on length compositions, so are not reliable for date, but only for magnitude when averaged over decadal time scales. As has been seen in previous assessments, recruitment is irregular (Figure 20). The stock-recruitment relationship (Figure 21) suggest that larger recruitments have been associated with higher abundances, but shows no curvature. The relative reproductive success (measured by the logarithm of recruits per spawning output) is level over the range of spawning abundances (Figure 22), indicating that the recent history of bocaccio reproduction shows no evidence of density dependent compensation. In the 30 year history shown in Figure 22, recruitment exceeded the replacement level in only eight years. The most recent successful reproduction was in 1999, which is the leftmost point above the horizontal replacement line. The CV on the estimated strength of the 1999 yearclass is estimated to be approximately 78% based on treating estimates obtained by omitting individual likelihood components (see the sensitivity analysis of component emphasis, documented below) as a grouped jacknife.

The history of recruitments and parental abundances provides the basis for estimating an approximate sustainable fishing rate. The 41-year average recruitment per spawning output was 1.466. The spawning output per recruit (SPR) at F=0 is 1.379. A fishing rate that reduces SPR to 1/1.466 = 0.682 or 49% of the unfished level should be sustainable. Thus, the F50% proxy being used by the PFMC to manage rockfish stocks is sustainable for bocaccio. This calculation does not indicate whether F50% would produce MSY, however.

### Abundance

The trend of abundances after 1969 (the initial year in the previous assessment) resembles those from previous stock assessments except that the size of the resource is now estimated to have been about 50% larger (Figure 23). Extension of the assessment back to 1951 reveals that abundances were lower in the two decades preceding the 1969 peak, and shows the fluctuating pattern that would be expected from dynamics based on rare large recruitments. The spawning output lags the total biomass by a few years, reflecting the time to maturity. The unfished abundance (Bunfished) is estimated based on the average recruitment from 1955 to 1995 multiplied by the spawning output per recruit in the absence of fishing, giving an estimated unfished spawning output of 14850 billion eggs (shown as a horizontal line in Figure 23). This estimate is very imprecise (CV=31%) due to the extreme variability of recruitment. The current

(2002) spawning output is estimated to be 720 billion eggs, or 4.8% of the estimated unfished level, and the estimated current total (age 2+) biomass is 2958MT.

*Fishing rate time series:* Figure 24 shows the history of exploitation rate (catch as a fraction of total (age 2+) biomass. Exploitation rates have exceeded F50% in most years since 1951.

**Sensitivity Analysis**

*Random restarts:* Convergence properties of the base model are demonstrated by varying the starting parameters by plus-or-minus 30%, and re-estimating the maximum likelihood fit. The result of this procedure (Figure 25) indicates good convergence of the model.

*Retrospective analysis:* Some forms of bias can be detected by simulating a time series of model estimates with progressively earlier final years of the analysis (note that the GLM indexes of abundance were not recomputed). The retrospective pattern of the bocaccio assessment shows no bias, but does show an irregular effect due to the Triennial Survey data that contributes a new data point only every third year (Figure 26).

*Effect of alternative catch data:* The estimates of bocaccio catch used as data in this assessment are a major source of uncertainty. Catches for the pre-1978 years are approximations based on very limited information. Catches in the most recent years pose a different problem. Commercial landings do not include the portion of the catch that was discarded at sea, and anecdotal information suggests that discards have been increased substantially in 2000 and 2001 due to the restrictive limit on landings. Recreational catch have become imprecise, with an increasing number of two-month waves in which no bocaccio are estimated to have been landed by recreational fishery segments. This seems questionable in view of frequent complaints by recreational fishermen and partyboat operators that bocaccio are abundant and impossible to avoid.

Results of some alternative catch scenarios relative to the base model are examined in the following table. Following the base model, the first case represents a pre-1978 catch history where Southern California catches are half the values used in the base model (recreational and Central California commercial catches are considered to be more reliable). The second case uses the RecFIN data from 1980 to present without adjustment for unsampled waves or zero catch estimates. The third case assumes that commercial catches in 2000 and 2001 have been twice the reported landings due to at-sea discards.

| Case | Base Model | 50% Early SoCal Commercial | Unadjusted RecFIN Catch | 200% Commercial in 2000, 2001 |
|---|---|---|---|---|
| TotBiomass2002(MT age2+) | 2958 | 2896 | 3367 | 2907 |
| SpOut2002/Bunfished | 4.8% | 4.1% | 5.3% | 4.8% |
| SPRsustainable | 49% | 51% | 51% | 49% |
| Exploitation rate 2001 | 6.4% | 6.5% | 3.9% | 7.1% |
| Years to Rebuild@F=0 | 97 | 103 | 99 | 97 |
| Rebuilding OY2003 (MT) | 5.8 | 4.9 | 6.4 | 5.3 |

The alternative catch scenarios do not alter the model results substantially. Use of the alternative recent catches result in similar estimates of current relative abundance, and do not indicate substantially different rebuilding scenarios. The smaller historical Southern California catch results in a lower estimate of Bunfished, but that is offset by a slightly lower productivity rate. The RecFIN catches indicate a lower current exploitation rate (consistent with lower current catch), but the 2001 data were incomplete (lacking wave 6) at the time of model development. It is likely that the base model overestimates recent recreational catches and underestimates recent commercial catches; however, the results are influenced mainly by the magnitude of combined removals, irrespective of fishery segment.

*Effect of alternative natural mortality rates:* The natural mortality rate of bocaccio is not known, and use of M=0.20 in the base model is based on convention rather than on knowledge of the true rate. To examine this source of uncertainty, the population model was run at two alternative natural mortality rates, M=0.15 and 0.25, which are thought to bracket the likely range of true values. Results are shown in the following table.

| Case | M=0.15 | M=0.20 | M=0.25 |
|---|---|---|---|
| TotBiomass2002(MT age2+) | 2820 | 2958 | 4397 |
| SpOut2002/Bunfished | 4.5% | 4.8% | 6.9% |
| SPRsustainable | 39% | 49% | 61% |
| Exploitation rate 2001 | 6.8% | 6.4% | 4.9% |
| Years to Rebuild@F=0 | 64 | 97 | 257 |
| Rebuilding OY2003 (MT) | 9.8 | 5.8 | 1.5 |

Models based on the three alternative natural mortality rates roughly agree on the present level of depletion relative to estimated unfished conditions. Use of a higher natural mortality rate results in generally higher estimated biomasses and recruitments throughout the time series, but the relative decline indicates lower per capita productivity. Use of M=0.15 yields an average recruit per spawner ratio that implies sustainability at a higher fishing rate, whereas use of M=0.25 would indicate a sustainable fishing rate that is lower than the current proxy of F50%. The differences in productivity are most noticeable in the projected median rebuilding times: Whereas the M=0.15 case indicates a somewhat more rapid rebuilding trajectory and a sightly higher rebuilding OY, the M=0.25 case shows extremely slow rebuilding.

*Effect of alternative emphasis values:* Emphasis was set at 1.0 for all likelihood components in the base model so that the likelihood function and model properties can be given standard statistical interpretation. In this sensitivity analysis, emphasis factors for likelihood component groups were set individually at 0.1 or 10.0 to determine how the interactions among the components influence the final model (Table 5). Model results are unusually stable with regard to changes in emphasis, perhaps partially as a result of having a wide variety of separate data sources. The main pattern in Table 5 is that the Southern California components tend to raise the ending biomass estimate (and the status relative to the unfished level), suggesting that the resource may less depressed in Southern California relative to the condition in Central California.

Alternative emphases on groups of components are alsi informative. The difference between relative condition of the resource in Central and Southern California is clear in the results of the respective group emphases. Also, the Southern California components indicate a potential for more rapid attainment of the rebuilding target. [IMPORTANT NOTE: This does not mean that a separate Southern California rebuilding OY of 39.1 MT is a viable management option–these results are based on combined catch data for both areas and cannot be separated in this model.]

| Group Emphasis (x10) | Base Model | Central Calif | Southern Calif |
|---|---|---|---|
| TotBiomass2002(MT,2+) | 2958 | 1695 | 5015 |
| SpOut2002/Bunfished | 4.8% | 3.8% | 7.0% |
| SPRsustainable | 49% | 47% | 46% |
| Exploitation rate 2001 | 6.4% | 10.6% | 4.0% |
| Years to Rebuild@F=0 | 97 | 106 | 47 |
| Rebuilding OY2003 (MT) | 5.8 | 2.5 | 39.1 |

There is similar contrast between the model results emphasizing surveys and abundance indexes vs. the model emphasizing length compositions, with the length compositions tending to indicate a more depleted resource. However, in this case the difference in current status does not result in a difference in median rebuilding time.

| Group Emphasis (x10) | Base Model | Length Comp | Abundance Indexes |
|---|---|---|---|
| TotBiomass2002(MT,2+) | 2958 | 2126 | 4146 |
| SpOut2002/Bunfished | 4.8% | 3.2% | 9.5% |
| SPRsustainable | 49% | 47% | 48% |
| Exploitation rate 2001 | 6.4% | 9.0% | 4.5% |
| Years to Rebuild@F=0 | 97 | 94 | 77 |
| Rebuilding OY2003 (MT) | 5.8 | 5.2 | 7.9 |

**Stock Projections**

The stock projections presented in this analysis utilize both stock synthesis (sample size = 100 simulations) and the rebuilding simulation developed by Andre Punt for the SSC (V1.5, sample size = 10,000 simulations). Strength of future model recruitments is based on randomly resampling the historical reproductive success( recruits per spawning output, R/S) from recruitment (age 1) years 1954 to 2000, and multiplying by the parental spawning output for the year being simulated. As shown in Figure 22, the mean and distribution of R/S values have been invariant with stock abundance, justifying this approach. The resulting projections are very imprecise. Spawning success has exceeded replacement level (the condition necessary for population growth) in relatively few historical years (Figure 22).

*Long-term projections:* In the absence of fishing, the median time to reach the rebuilding target spawning output of 5943 billion eggs is 97 (SE = 1) years. The rebuilding target of 0.4*Bunfished is imprecisely estimated, with a 50% probability that the true value lies between 4700 and 7200 billion eggs. Based on stock synthesis projections, this range of rebuilding targets translates to an uncertainty in rebuilding times of ±5 years. The distribution of projected abundances after 100 years without fishing is shown in Figure 27 (this projection is from stock synthesis).

If the rebuilding time frame is extended by one mean generation time (12 yr), less the 3 years already elapsed, the new rebuilding horizon is 106 yr. The allowable catch under rebuilding is very small, approximately 6 MT. These results indicate that the previously adopted 38 yr rebuilding time frame is not feasible, and the draft rebuilding plan will need to be revised. It is worth noting that these results are consistent with the "low-1999" projections in the previous stock assessment and rebuilding analysis (which indicated a minimum rebuilding time of 76 years and allowable catches of about 10MT).

*Near-term projections:* In Figure 28, stock abundance is projected (using stock synthesis) to the year 2025 for a condition of no fishing. Median abundance declines slightly at the beginning and rises slightly toward the end, but is level overall. Because of the effect of a few strong year classes in the simulations, the average projected abundance begins to rise slowly after about 10 years. Given the present assessment, it is unlikely that the resource condition will change significantly in the coming decade.

There are many sources of error and imprecision both inside and outside the model. Within the model, alternative assumptions of the natural mortality rate and emphasis on Southern and Central California data give different results (see sensitivity analyses), but do not radically change the outlook. The ocean climate was extraordinarily bad during the 1990s, and if the climate has changed to a more favorable state, the probability of strong year classes in the near future may be higher than in this analysis. If strong yearclasses appear during the coming decade, they will not only contribute to an increase in abundance, but will also contribute to a higher frequency of good reproductive successes in future stock projections, giving some hope for more liberal fishing opportunities. However, such strong year classes must first be documented quantitatively, e.g., in recruitment surveys and power plant impingements.

## STAT Team Comment on Southern vs. Central California

During development of the assessment model, the STAT Team examined separate models for Southern and Central California, but the STAR Panel preferred a single combined model. The two independent models were statistically well-behaved (lacking internal conflicts among data elements), and provided an alternative view of resource dynamics. Estimated yearclass strengths were highly correlated for the strong recruitments, but were independent for the weaker recruitments. This could result from migration of fish between the two regions, or from parallel responses to widespread oceanic conditions (or both). Abundances and recruitment strengths averaged two to three times higher in Central California than in Southern California, but exploitation reduced the abundance in the Central California segment to a greater extent than that in the Southern California segment, indicating a condition of localized depletion that cannot be modeled under the STAR Panel's preferred combined model. Reproductive successes were somewhat higher in the Southern California model, and were lower but more variable in the Central California model. This leads to the inference that the Southern California segment may be more resilient, while the Central California segment, although historically larger, may have lower resilience, and may be subject to wide fluctuations in a natural condition. This kind of differential variability in geographically separated segments of a single population is a well-known phenomenon (MacCall 1990), would provide a justifiable basis for area-specific management, including area-specific rebuilding goals and programs. Ideally, a model with explicit diffusion (larvae) and migration (adults) components would allow exploration of geographic structure and implications for bocaccio management. However, the necessary model does not currently exist in a form that is compatible with the length-based bocaccio data.

## Recommendations for Next Assessment

A minimal bocaccio reassessment, utilizing the new expedited stock assessment review process, is recommended in 2003. The strength of the 1999 year class continues to have a strong influence on stock status and rebuilding projections. This year class will be more evident in the length compositions, and new information on discard rates may be available for the observer program. Under consultation with knowledgeable fishery scientists, it may be worthwhile to reconsider the value of the assumed natural mortality rate (presently 0.20). Use of M=0.15 results in slightly higher estimated productivity, but must be justified objectively.

The next full assessment should attempt to explore the geographic relationships of the Southern and Central California segments of the stock. This will require development of new modeling tools.

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Table 1. Historical summary of bocaccio management.

| YEAR | ABC | HG | ACTUAL | RELEVANT QUOTES AND (NOTES) |
|---|---|---|---|---|
| 1983 | 6100 | | 6486 | (4100 MT Monterey, 2000mt Conception, managed as "other rockfish") |
| to | | | | |
| 1987 | 6100 | | 3461 | |
| 1988 | 6100 | | 2287 | "ABC may be too high [will be revised pending new assessment]" |
| 1989 | 6100 | | 3429 | "ABC may be too high [GMT hopes a new assessment will be available]" |
| 1990 | 6100 | | 2836 | "no new analysis has been conducted" |
| 1991 | 800 | 1100 | 1757 | "The spawning biomass in 1991 is probably less than 25% of the average, unfished level" |
| 1992 | 800 | 1100 | 2054 | "The spawning biomass in 1991 is probably less than 25% of the average, unfished level" |
| 1993 | 1540 | 1540 | 1811 | "catch in 1991[1700MT]…was near the target catch level now indicated by application of the F35% harvest policy" |
| 1994 | 1540 | 1540 | 1333 | "biomass has declined substantially since 1980 and is approaching 20 percent of its estimated unfished level"<br>"there is some risk in maintaining harvests at this level" |
| 1995 | 1700 | 1700 | 865 | "weak recruitments since 1979 will cause the stock to decline unless total harvest is kept closer to 1100MT, However, reported commercial catch in 1994 totaled only 1,260MT." |
| 1996 | 1700 | 1700 | 600 | "weak recruitments since 1979 will cause the stock to decline unless total harvest is kept closer to 1100MT, However, reported commercial catch in 1994 totaled only 1,025MT." |
| 1997 | 265 | | 488 | "unlikely that the current stock is greater than 17 to 20 percent of the 1970 level" |
| 1998 | 230 | | 215 | (Fmsy proxy changed to F40%)<br>"a one-fish daily bag limit would be necessary to accomplish a reduction in recreational catch" |
| 1999 | 230 | | 213 | "OY account[s] for unavoidable bycatch…under existing management of other rockfish species" |
| 2000 | 100 | | 233 | Rebuilding initiated assuming “medium” 1999 year class strength |
| 2001 | 100 | | 214 | |
| 2002 | 100 | | | |

Table 2.  Recent bocaccio fishing regulations.

January 2001
Recreational
- Bag limit: 10 rockfish, only 2 bocaccio, 10" minimum size
- North of Cape Mendocino: open year round
- Cape Mendocino-Pt Conception: Closed March-June except inside 20 fathoms - open May-June
- Pt Conception South: Closed January-February except inside 20 fathoms (open all year)

Commercial
- Limited Entry (fixed and trawl):
- Southern Area: 300 lbs/month Jan-April and Nov-Dec,  otherwise 500 lbs/month
- Open Access:  200 lbs/month, year round

January 2002
Recreational
- Bag limit: 10 rockfish, no more than 2 bocaccio if not prohibited
  - Inside 20 fathoms, central area: recreational fishing allowed May-June and Sept-Oct, but bocaccio may not be retained
  - Outside 20 fathoms, central area: open January-February and July-August
- All southern waters: open March-October

Commercial
- Limited Entry Trawl: Jan-April 600 lbs/2 months, May-Oct. 1,000 lbs/2 months, Nov-Dec 600lbs/2 months
- Limited Entry Fixed Gear:
  - North of Cape Mendocino:  200lbs/month
  - Cape Mendocino - Pt Arguello: 200 lbs/month Jan-Feb and July-Aug, closed otherwise
  - South of Pt. Arguello:  200 lbs/month March-Oct, closed otherwise
- Open Access:
  - North of Cape Mendocino:  200lbs/month
  - Cape Mendocino - Pt. Arguello: 200 lbs/month Jan-Feb and July-Aug, closed otherwise
  - South of Pt. Arguello:  200 lbs/month March-Oct, closed otherwise

Table 3. Estimated historical bocaccio landings (MT) in California (for assessment use only).

| | Southern California | | | | | Northern California | | | | | Statewide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trawl | H&L | Setnet | Rec'l | Total | Trawl | H&L | Setnet | Rec'l | Total | Total |
| 1950 | 0 | 428 | 0 | 39 | 468 | 2816 | 438 | 0 | 86 | 3339 | 3807 |
| 1951 | 0 | 471 | 0 | 35 | 506 | 3895 | 620 | 0 | 98 | 4613 | 5119 |
| 1952 | 0 | 366 | 0 | 45 | 411 | 3866 | 630 | 0 | 86 | 4582 | 4993 |
| 1953 | 0 | 298 | 0 | 56 | 355 | 4494 | 750 | 0 | 72 | 5316 | 5671 |
| 1954 | 36 | 547 | 0 | 122 | 705 | 4401 | 750 | 0 | 91 | 5242 | 5946 |
| 1955 | 1305 | 504 | 0 | 213 | 2023 | 3451 | 492 | 0 | 108 | 4051 | 6074 |
| 1956 | 942 | 540 | 0 | 256 | 1738 | 4608 | 689 | 0 | 121 | 5418 | 7155 |
| 1957 | 1296 | 522 | 0 | 138 | 1956 | 4803 | 678 | 0 | 120 | 5601 | 7557 |
| 1958 | 1199 | 604 | 0 | 95 | 1899 | 5041 | 1249 | 0 | 193 | 6483 | 8382 |
| 1959 | 444 | 611 | 0 | 57 | 1113 | 4691 | 1185 | 0 | 160 | 6036 | 7149 |
| 1960 | 1054 | 609 | 0 | 63 | 1725 | 3922 | 636 | 0 | 125 | 4683 | 6408 |
| 1961 | 826 | 654 | 0 | 72 | 1552 | 2821 | 612 | 0 | 94 | 3527 | 5079 |
| 1962 | 690 | 670 | 0 | 68 | 1427 | 2460 | 642 | 0 | 109 | 3210 | 4637 |
| 1963 | 953 | 657 | 0 | 67 | 1677 | 3102 | 617 | 0 | 111 | 3830 | 5507 |
| 1964 | 492 | 555 | 0 | 94 | 1140 | 2177 | 459 | 0 | 85 | 2721 | 3861 |
| 1965 | 559 | 654 | 0 | 117 | 1330 | 2508 | 540 | 0 | 132 | 3179 | 4509 |
| 1966 | 800 | 630 | 0 | 170 | 1600 | 2571 | 564 | 0 | 142 | 3277 | 4877 |
| 1967 | 1086 | 713 | 0 | 210 | 2010 | 2162 | 483 | 0 | 140 | 2785 | 4795 |
| 1968 | 961 | 655 | 0 | 223 | 1838 | 2173 | 495 | 0 | 166 | 2834 | 4673 |
| 1969 | 906 | 611 | 0 | 212 | 1728 | 2190 | 479 | 0 | 154 | 2823 | 4551 |
| 1970 | 888 | 529 | 0 | 289 | 1706 | 2908 | 523 | 0 | 204 | 3634 | 5340 |
| 1971 | 642 | 603 | 0 | 244 | 1489 | 3031 | 791 | 0 | 167 | 3988 | 5477 |
| 1972 | 1266 | 814 | 0 | 339 | 2419 | 4302 | 1066 | 0 | 226 | 5595 | 8013 |
| 1973 | 1532 | 875 | 0 | 401 | 2808 | 6043 | 1553 | 0 | 260 | 7855 | 10663 |
| 1974 | 376 | 2262 | 0 | 459 | 3097 | 5673 | 1441 | 0 | 289 | 7403 | 10500 |
| 1975 | 1941 | 1058 | 0 | 450 | 3449 | 6132 | 1586 | 0 | 276 | 7993 | 11442 |
| 1976 | 2424 | 1015 | 0 | 417 | 3856 | 6113 | 1608 | 0 | 248 | 7969 | 11825 |
| 1977 | 2286 | 895 | 0 | 377 | 3558 | 4969 | 1330 | 0 | 218 | 6517 | 10075 |
| 1978 | 587 | 145 | 83 | 350 | 1165 | 2243 | 35 | 47 | 196 | 2522 | 3686 |
| 1979 | 2423 | 1507 | 0 | 445 | 4375 | 1479 | 228 | 3 | 242 | 1952 | 6327 |
| 1980 | 39 | 84 | 121 | 1691 | 1936 | 3607 | 215 | 77 | 190 | 4090 | 6026 |
| 1981 | 84 | 161 | 213 | 844 | 1302 | 3904 | 76 | 227 | 233 | 4439 | 5741 |
| 1982 | 217 | 301 | 176 | 1010 | 1703 | 4123 | 559 | 423 | 329 | 5433 | 7136 |
| 1983 | 356 | 156 | 135 | 261 | 907 | 3941 | 138 | 1227 | 272 | 5578 | 6486 |
| 1984 | 63 | 75 | 242 | 170 | 550 | 3125 | 131 | 385 | 47 | 3688 | 4238 |
| 1985 | 18 | 81 | 305 | 309 | 714 | 1205 | 36 | 973 | 67 | 2281 | 2995 |
| 1986 | 13 | 147 | 327 | 395 | 882 | 1033 | 20 | 1065 | 172 | 2290 | 3172 |
| 1987 | 52 | 73 | 253 | 104 | 482 | 1101 | 181 | 1585 | 113 | 2979 | 3461 |
| 1988 | 0 | 144 | 76 | 111 | 332 | 1226 | 172 | 505 | 52 | 1955 | 2287 |
| 1989 | 0 | 112 | 193 | 266 | 572 | 1120 | 172 | 1476 | 88 | 2857 | 3429 |
| 1990 | 0 | 198 | 8 | 233 | 439 | 1102 | 143 | 1061 | 91 | 2397 | 2836 |
| 1991 | 1 | 26 | 174 | 200 | 401 | 703 | 157 | 404 | 92 | 1356 | 1757 |
| 1992 | 6 | 335 | 98 | 167 | 606 | 484 | 212 | 659 | 92 | 1448 | 2054 |
| 1993 | 1 | 270 | 160 | 135 | 565 | 558 | 222 | 366 | 99 | 1245 | 1811 |
| 1994 | 13 | 151 | 53 | 195 | 412 | 514 | 86 | 268 | 43 | 911 | 1323 |
| 1995 | 1 | 21 | 62 | 43 | 127 | 376 | 50 | 281 | 30 | 738 | 865 |
| 1996 | 1 | 36 | 27 | 78 | 142 | 287 | 64 | 76 | 30 | 457 | 600 |
| 1997 | 1 | 24 | 7 | 66 | 97 | 229 | 34 | 31 | 97 | 391 | 488 |
| 1998 | 1 | 12 | 4 | 30 | 47 | 72 | 29 | 37 | 29 | 168 | 215 |
| 1999 | 0 | 3 | 2 | 60 | 66 | 45 | 18 | 5 | 80 | 148 | 213 |
| 2000 | 0 | 2 | 0 | 59 | 61 | 19 | 5 | 1 | 147 | 172 | 233 |
| 2001 | 0 | 3 | 0 | 105 | 108 | 13 | 5 | 1 | 87 | 107 | 214 |

Table 4. Summary of historical estimates from bocaccio base model. Recruits are at age 1.

| Year | Bage2+ (MT) | SpOut($10^9$eggs) | Recruits($10^3$) | Catch | ExploitRate |
|---|---|---|---|---|---|
| pre-51 | 58754 | 9521 | 12168 | 3807 | 6.5% |
| 1951 | 58754 | 9522 | 61065 | 5119 | 8.7% |
| 1952 | 71522 | 9374 | 175 | 4993 | 7.0% |
| 1953 | 74110 | 9609 | 90 | 5670 | 7.7% |
| 1954 | 72372 | 10537 | 50 | 5947 | 8.2% |
| 1955 | 66730 | 11402 | 50 | 6074 | 9.1% |
| 1956 | 58322 | 11324 | 50 | 7155 | 12.3% |
| 1957 | 47224 | 10133 | 96 | 7557 | 16.0% |
| 1958 | 35294 | 8365 | 53201 | 8382 | 23.7% |
| 1959 | 38311 | 6296 | 9922 | 7149 | 18.7% |
| 1960 | 38779 | 5135 | 580 | 6409 | 16.5% |
| 1961 | 36856 | 5166 | 769 | 5079 | 13.8% |
| 1962 | 33771 | 5538 | 8713 | 4638 | 13.7% |
| 1963 | 31600 | 5526 | 169111 | 5508 | 17.4% |
| 1964 | 74859 | 5066 | 388 | 3861 | 5.2% |
| 1965 | 95179 | 6006 | 232 | 4510 | 4.7% |
| 1966 | 108008 | 9753 | 219 | 4877 | 4.5% |
| 1967 | 112425 | 14630 | 256 | 4794 | 4.3% |
| 1968 | 110057 | 17909 | 478 | 4673 | 4.2% |
| 1969 | 102533 | 18927 | 7360 | 4551 | 4.4% |
| 1970 | 93780 | 18429 | 92424 | 5341 | 5.7% |
| 1971 | 108159 | 17121 | 154 | 5478 | 5.1% |
| 1972 | 108763 | 16216 | 50 | 8013 | 7.4% |
| 1973 | 103319 | 16526 | 31983 | 10664 | 10.3% |
| 1974 | 100394 | 16808 | 1752 | 10500 | 10.5% |
| 1975 | 90591 | 16150 | 15045 | 11443 | 12.6% |
| 1976 | 81031 | 14840 | 2955 | 11825 | 14.6% |

| Year | Bage2+ (MT) | SpOut($10^9$eggs) | Recruits($10^3$) | Catch | ExploitRate |
|---|---|---|---|---|---|
| 1976 | 81031 | 14840 | 2955 | 11825 | 14.6% |
| 1977 | 67893 | 13233 | 455 | 10075 | 14.8% |
| 1978 | 54849 | 11621 | 44923 | 3686 | 6.7% |
| 1979 | 60297 | 10731 | 1779 | 3401 | 5.6% |
| 1980 | 59619 | 10065 | 10397 | 6024 | 10.1% |
| 1981 | 56986 | 9678 | 2660 | 5742 | 10.1% |
| 1982 | 51931 | 9459 | 1127 | 7138 | 13.7% |
| 1983 | 43686 | 8735 | 50 | 6486 | 14.8% |
| 1984 | 34817 | 7666 | 3053 | 4238 | 12.2% |
| 1985 | 28647 | 6629 | 12986 | 2994 | 10.5% |
| 1986 | 26981 | 5699 | 1170 | 3172 | 11.8% |
| 1987 | 23673 | 4867 | 1801 | 3462 | 14.6% |
| 1988 | 20169 | 4249 | 2587 | 2286 | 11.3% |
| 1989 | 17865 | 3846 | 8436 | 3427 | 19.2% |
| 1990 | 16110 | 3222 | 2078 | 2836 | 17.6% |
| 1991 | 14112 | 2703 | 998 | 1757 | 12.5% |
| 1992 | 12791 | 2466 | 2732 | 2053 | 16.1% |
| 1993 | 11382 | 2239 | 50 | 1811 | 15.9% |
| 1994 | 9474 | 1976 | 795 | 1324 | 14.0% |
| 1995 | 7993 | 1749 | 569 | 864 | 10.8% |
| 1996 | 6874 | 1556 | 50 | 599 | 8.7% |
| 1997 | 5863 | 1383 | 379 | 489 | 8.3% |
| 1998 | 5006 | 1217 | 52 | 214 | 4.3% |
| 1999 | 4373 | 1089 | 50 | 213 | 4.9% |
| 2000 | 3738 | 961 | 971 | 233 | 6.2% |
| 2001 | 3364 | 832 | 93 | 215 | 6.4% |
| 2002 | 2914 | 720 | 316 | | |

Table 5. Effects of varying emphasis on individual likelihood components.

| | TotBiomass2002(MT, 2+) | | SpOut2002/Bunfished | | SPRsustainable | |
|---|---|---|---|---|---|---|
| Base Model Value | 2914 | | 4.83% | | 49.5% | |
| GROUP | EMPH=10 | EMPH=0.1 | EMPH=10 | EMPH=0.1 | EMPH=10 | EMPH=0.1 |
| Length Comps | | | | | | |
| TrawlCenCal | 2036 | 3234 | 3.68% | 5.33% | 46.9% | 49.4% |
| H&L CenCal | 2197 | 3047 | 3.42% | 5.24% | 49.0% | 49.4% |
| SetNetCenCal | 2629 | 3079 | 3.98% | 5.22% | 36.6% | 50.9% |
| Rec'lCenCal | 3485 | 2848 | 5.97% | 4.79% | 50.5% | 49.3% |
| TriennialSurvCenCal | 4791 | 2747 | 6.66% | 4.82% | 56.6% | 48.1% |
| H&LSoCal | 2175 | 2974 | 3.43% | 5.09% | 46.8% | 49.4% |
| SetNetSoCal | 1953 | 3048 | 3.47% | 5.13% | 42.0% | 50.3% |
| Rec'lSoCal | 2647 | 3421 | 4.37% | 5.70% | 51.5% | 49.2% |
| Abundance Indexes | | | | | | |
| Rec'lCPUECenCal | 2971 | 2914 | 5.03% | 4.95% | 49.5% | 49.5% |
| TrawlCPUECenCal | 2574 | 2994 | 4.52% | 5.06% | 49.5% | 49.4% |
| TriennialSurvCenCal | 1998 | 3214 | 3.70% | 5.34% | 48.2% | 49.4% |
| Rec'lCPUESoCal | 5609 | 1759 | 7.73% | 3.43% | 49.2% | 48.6% |
| CalCOFISoCal | 5563 | 2167 | 8.81% | 3.67% | 46.6% | 47.6% |
| Recruitment Indexes | | | | | | |
| JuvenileSurvCenCal | 2685 | 3563 | 4.93% | 5.47% | 51.5% | 48.9% |
| PowerPlantsSoCal | 2841 | 3109 | 4.90% | 5.20% | 53.1% | 49.2% |

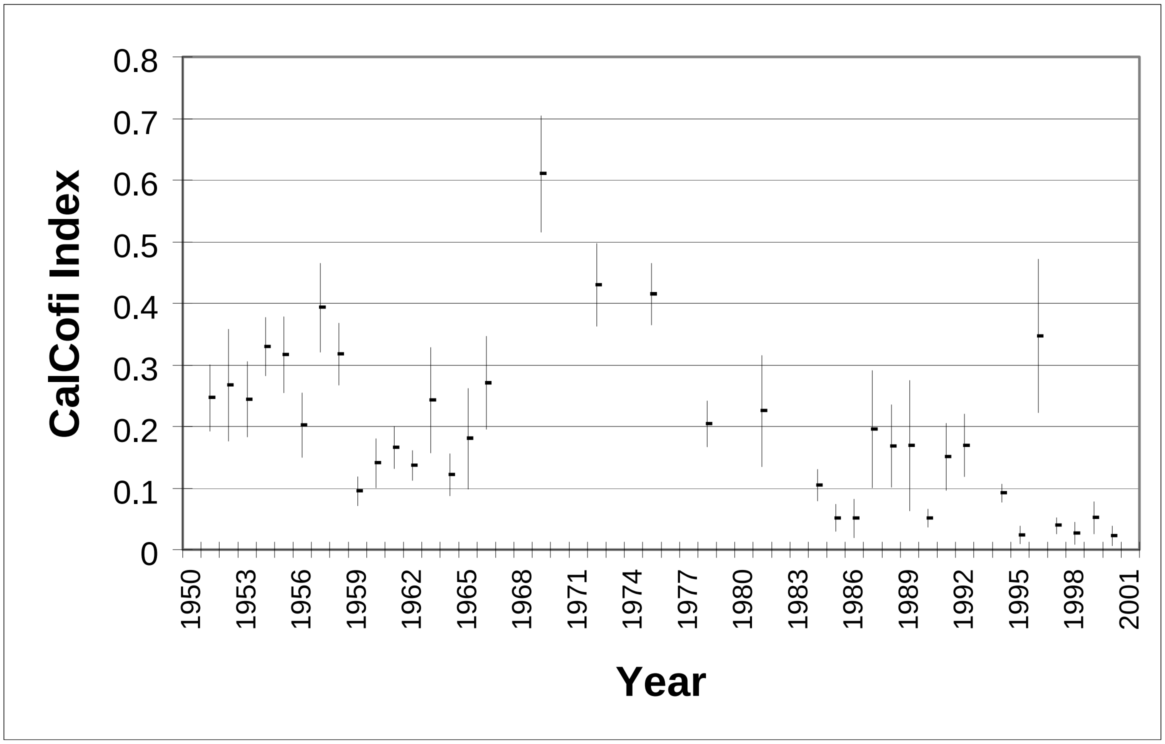


**Figure 1**. Index of bocaccio spawning abundance from GLM of larval densities from CalCOFI Surveys in Southern California. Error bars are ±1SE.

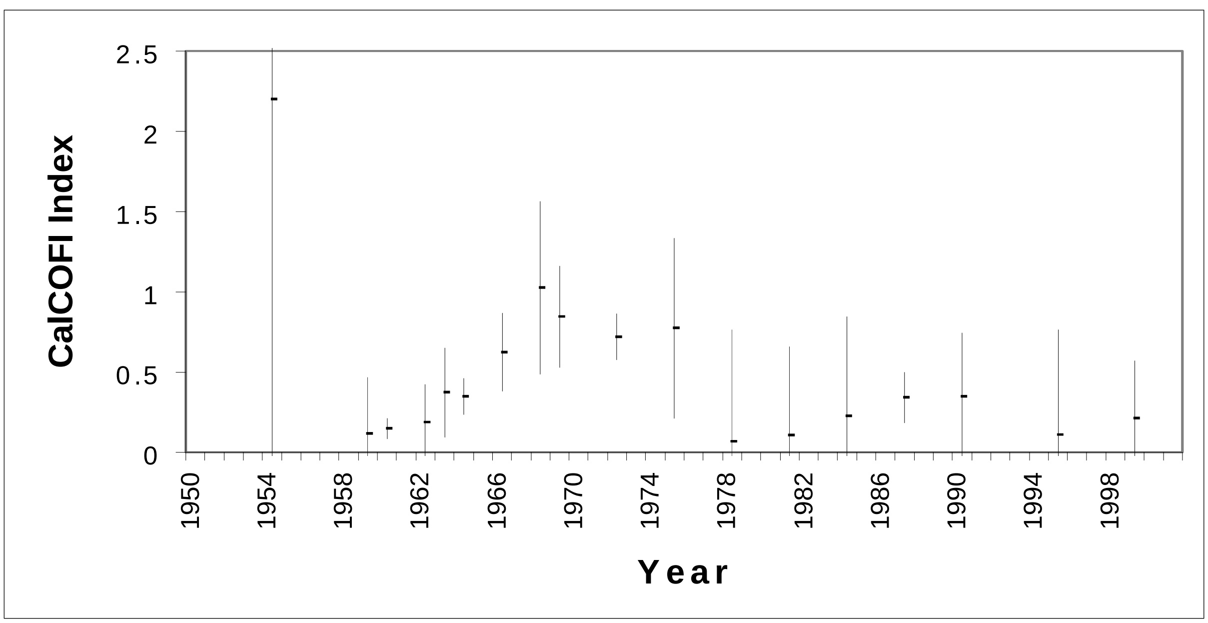


**Figure 2**. Index of bocaccio spawning abundance from GLM of larval densities from CalCOFI Surveys in Central California. Error bars are ±1SE.

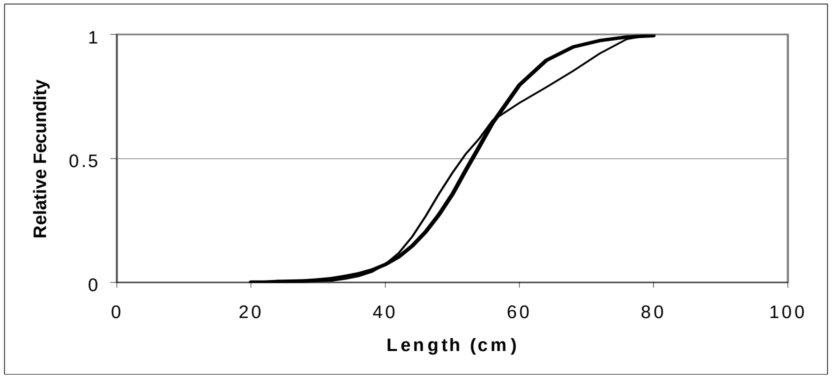


**Figure 3**. Bocaccio fecundity per weight, relative to maximum. Thin line is best estimate, thick line is logistic approximation used as selectivity curve.

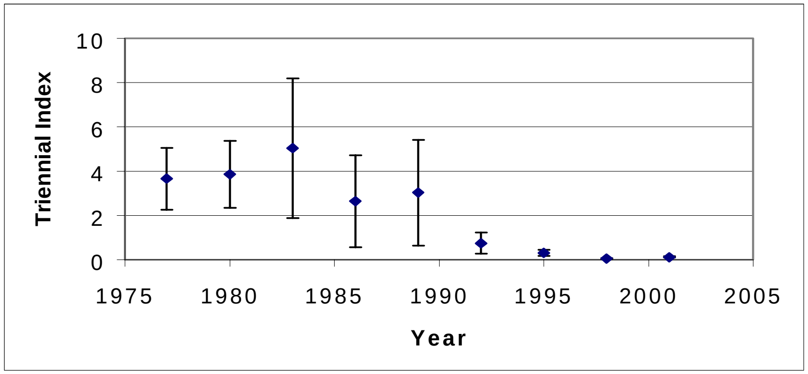


**Figure 4**. Triennial Trawl Survey GLM index of abundance for Central California (Monterey and Conception INPFC areas). Error bars are ±1SE.

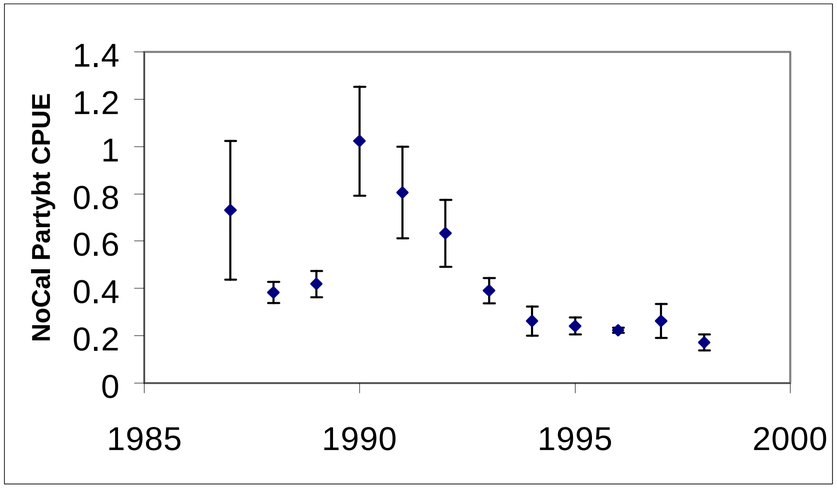


**Figure 5**. CPUE index of Central California bocaccio abundance from GLM of CDF&G observed partyboat catches. Error bars are ±1SE.

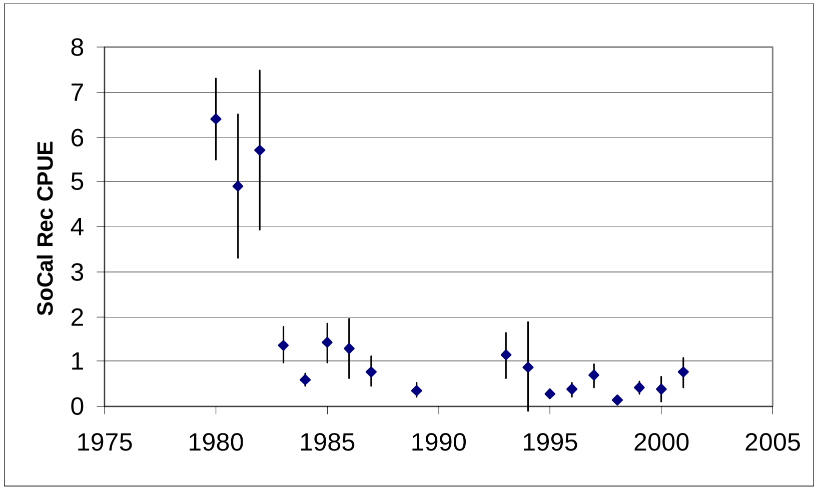


**Figure 6**. CPUE index of Southern California bocaccio abundance from GLM of MRFSS observed private and partyboat catches. Error bars are ±1SE.

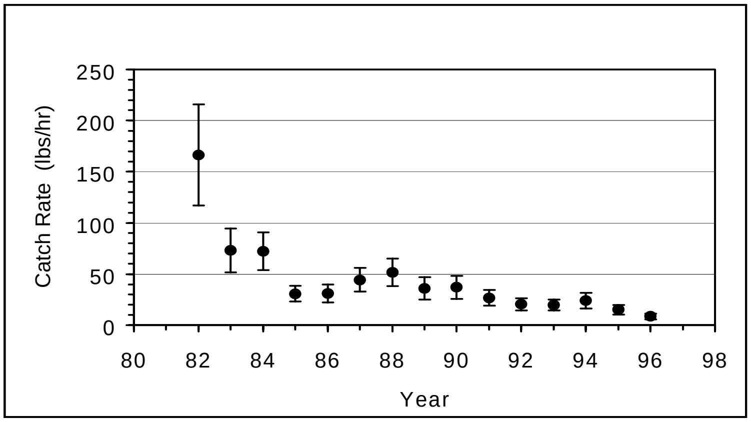


**Figure 7**. CPUE index of Central California bocaccio abundance from California trawl fishery logbooks (Ralston 1999). Error bars are ±1SE.

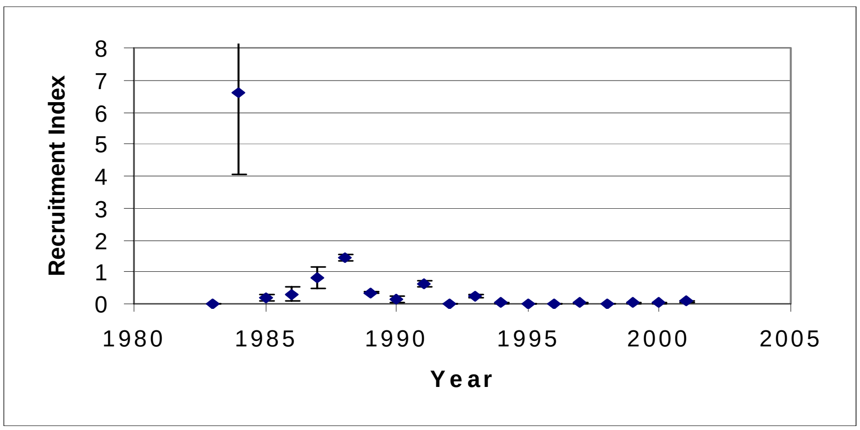


**Figure 8**. Central California bocaccio recruitment index (at age 0) from GLM of juvenile boccacio catch rates on Santa Cruz Laboratory midwater trawl surveys. Error bars are ±1SE.

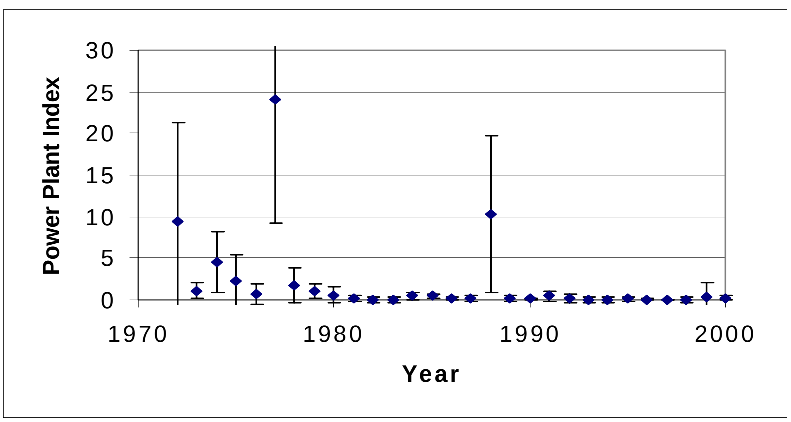


**Figure 9**. Southern California bocaccio recruitment index from GLM of impingement rates at five electrical power plants. Error bars are ±1SE.

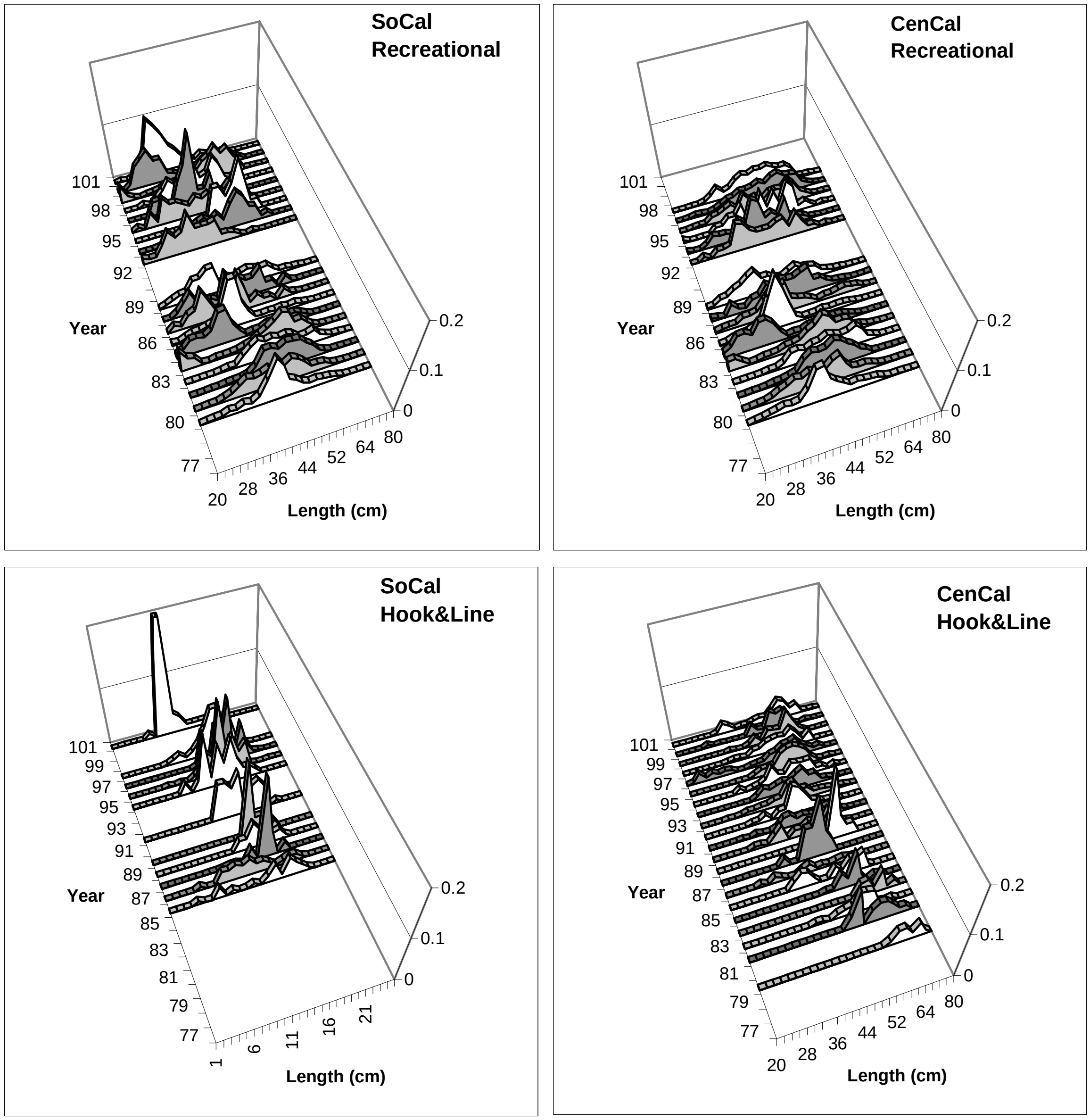


**Figure 10.** Length frequencies of female bocaccio used in the assessment.

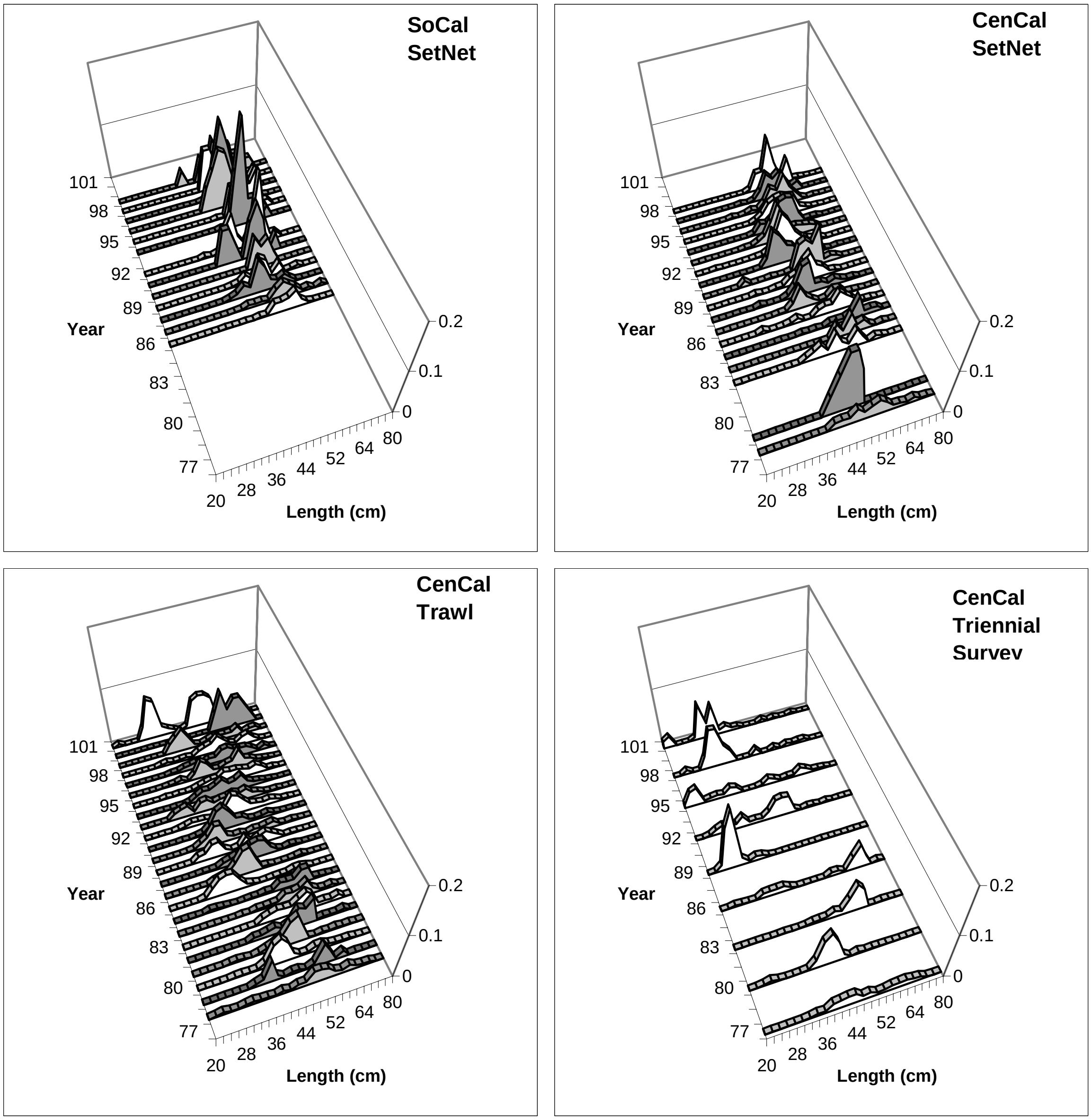


**Figure 10 cont.** Length frequencies of female bocaccio used in the assessment.

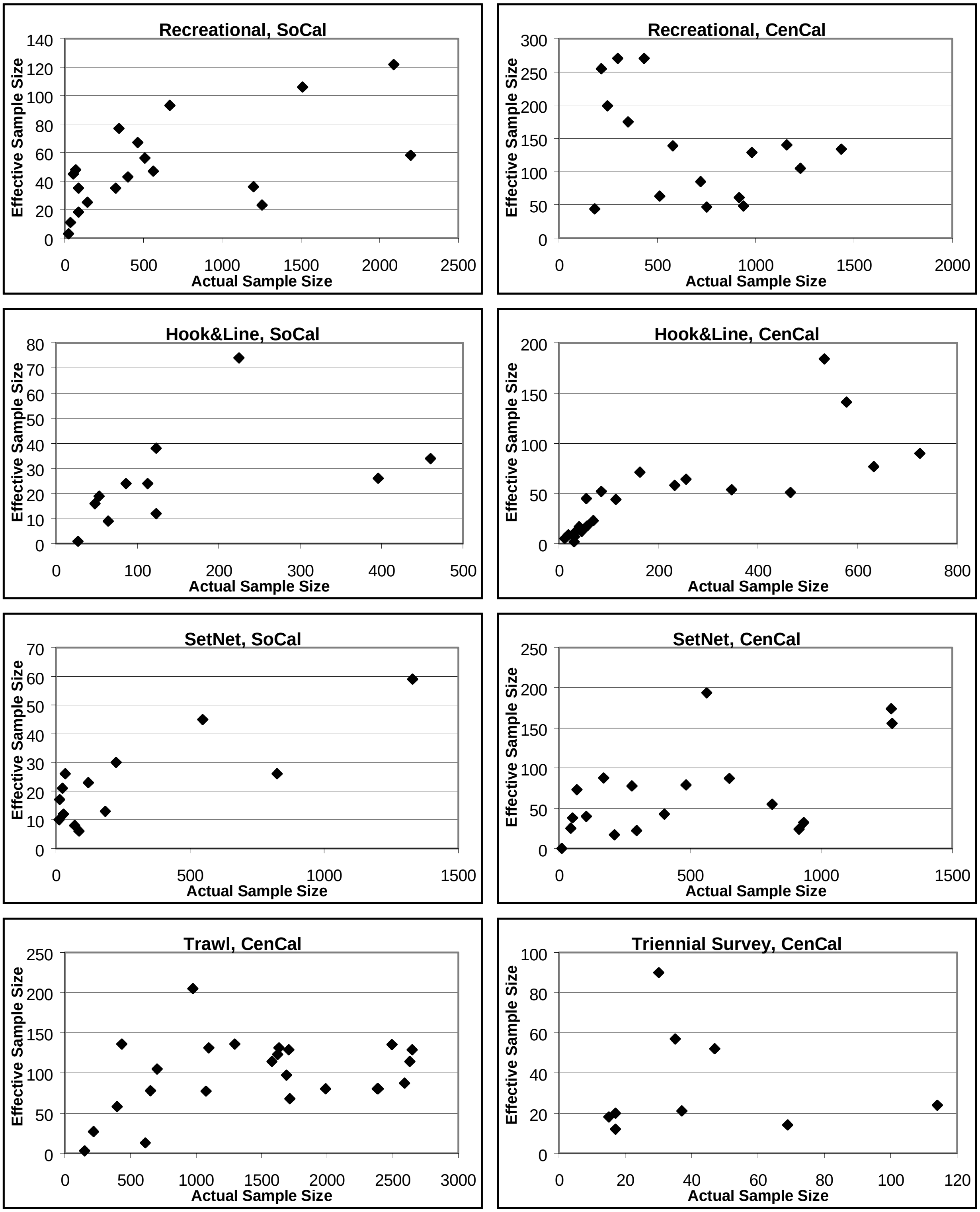


**Figure 11.** Relationships between effective sample size and number of fish examined for various data sources.

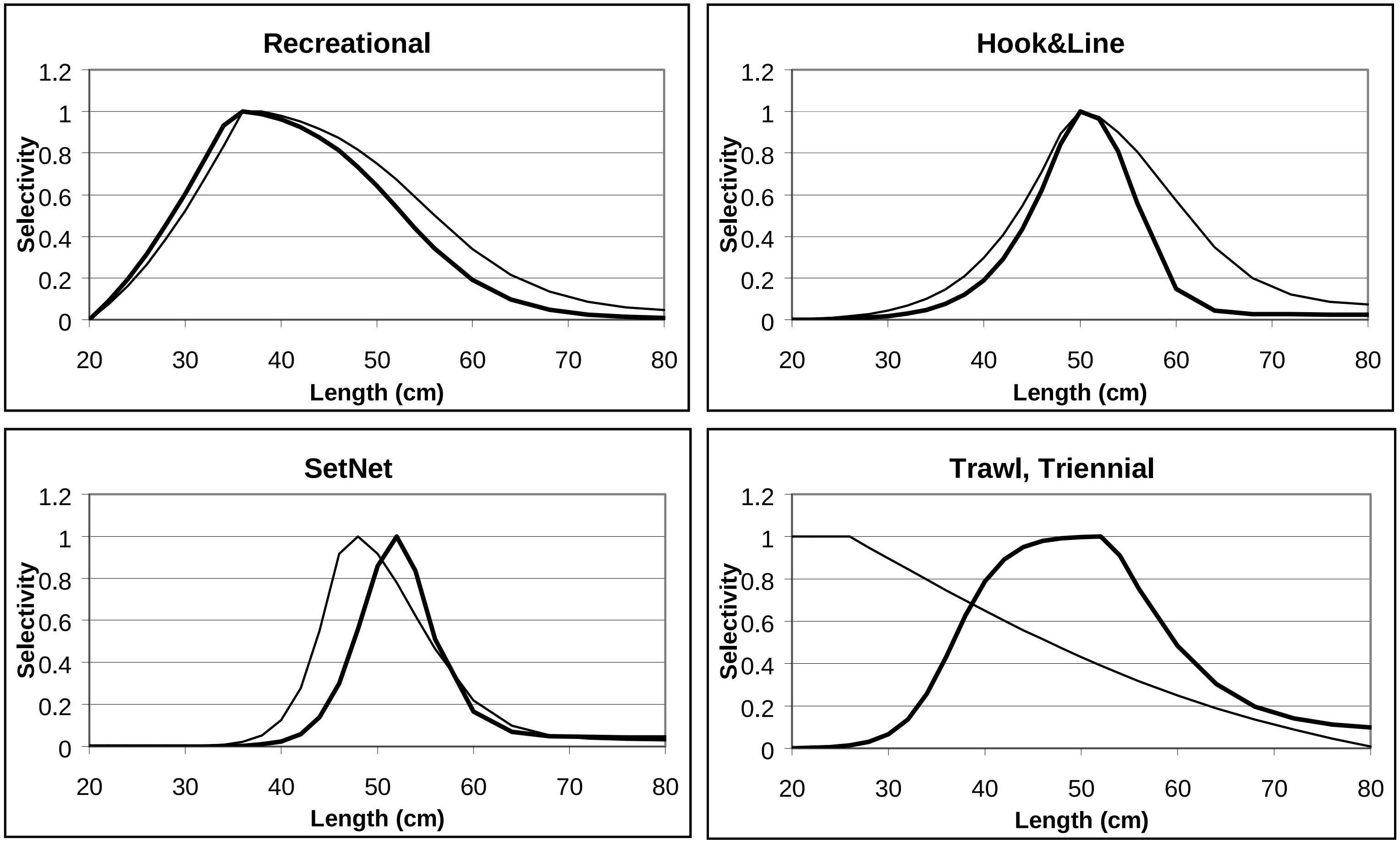


**Figure 12.** Fitted selectivity curves for size compositions in the bocaccio model. Thick line is Southern California, thin line is Central California. Lower right pane: Thick line is Central California trawl, thin line is Triennial Survey.

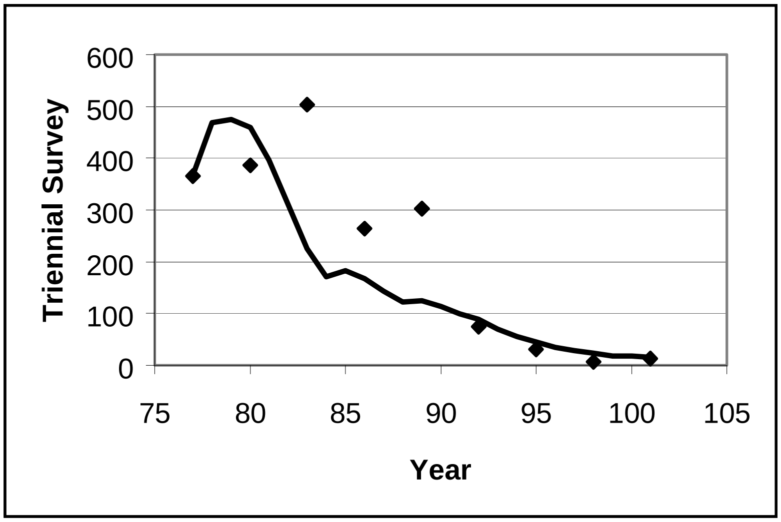


**Figure 13.** Fit to Triennial Survey abundances.

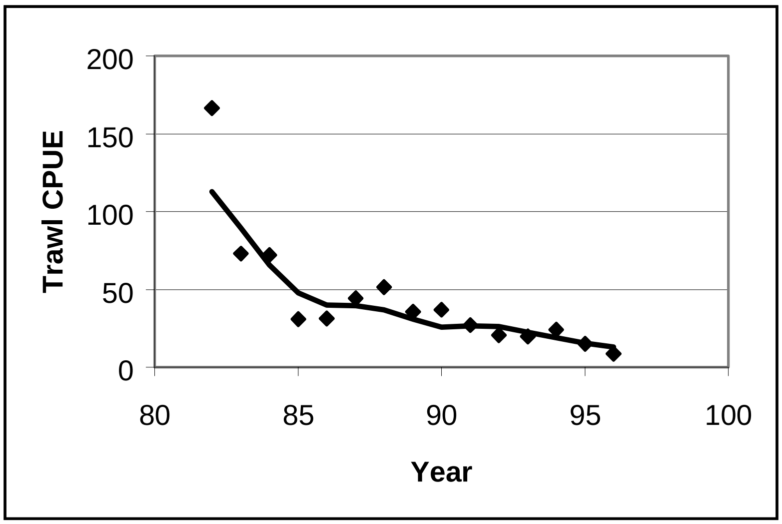


**Figure 14.** Fit to Central California Trawl CPUE.

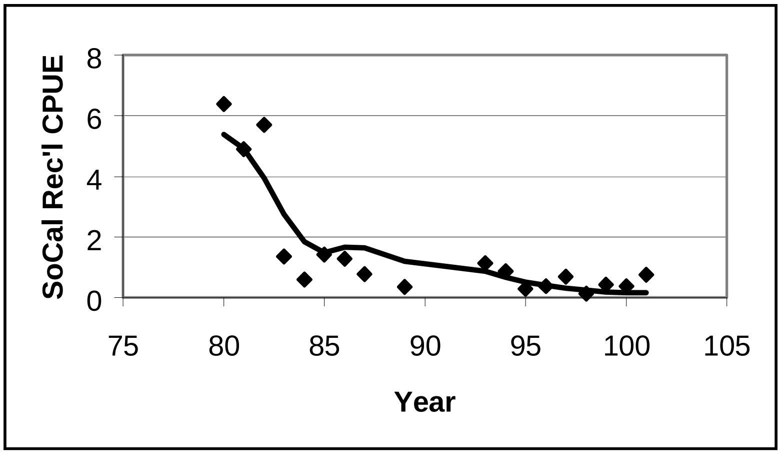


**Figure 15.** Fit to Southern California recreational CPUE.

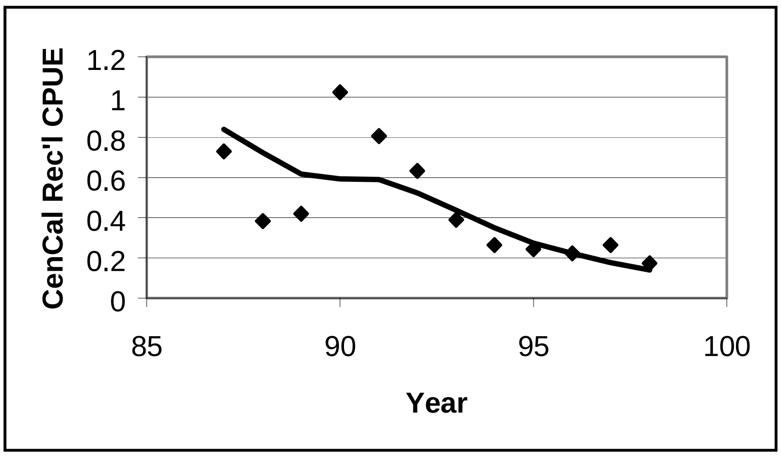


**Figure 16.** Fit to Central California recreational CPUE.

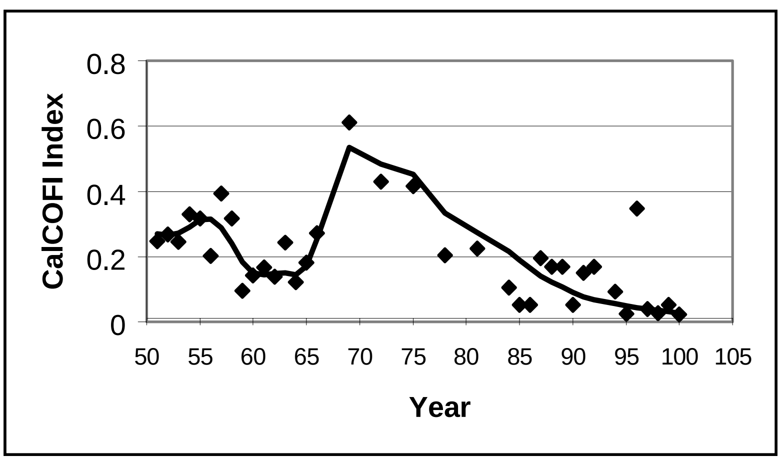


**Figure 17.** Fit to CalCOFI larval abundance index.

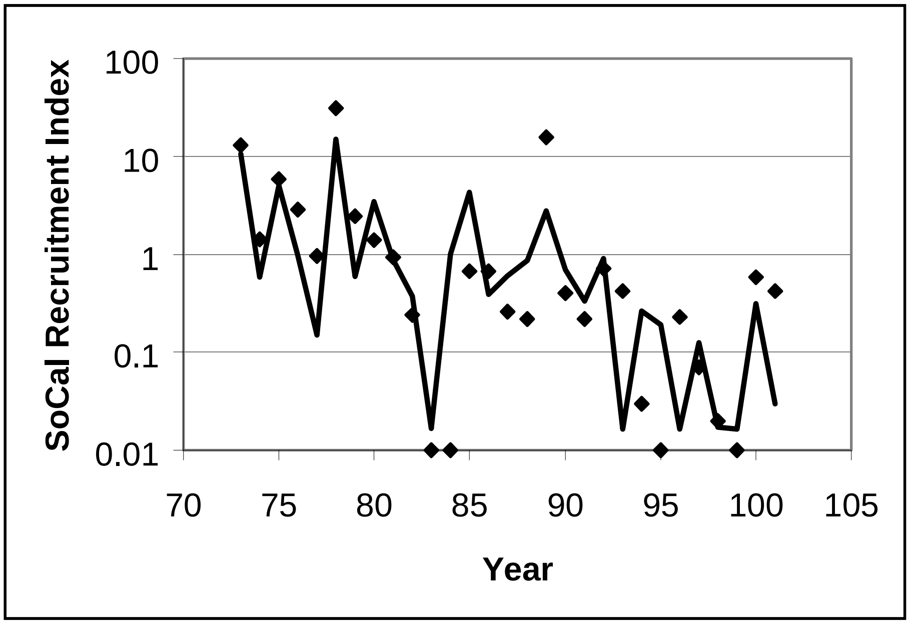


**Figure 18.** Fit to Southern California (power plant) recruitment index.

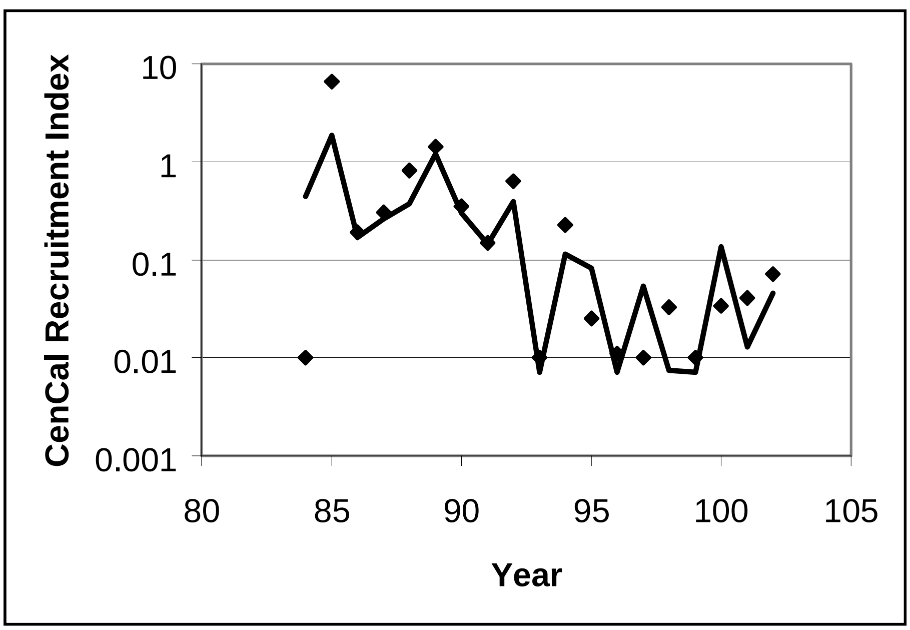


**Figure 19.** Fit to Central California (midwater trawl survey) recruitment index.

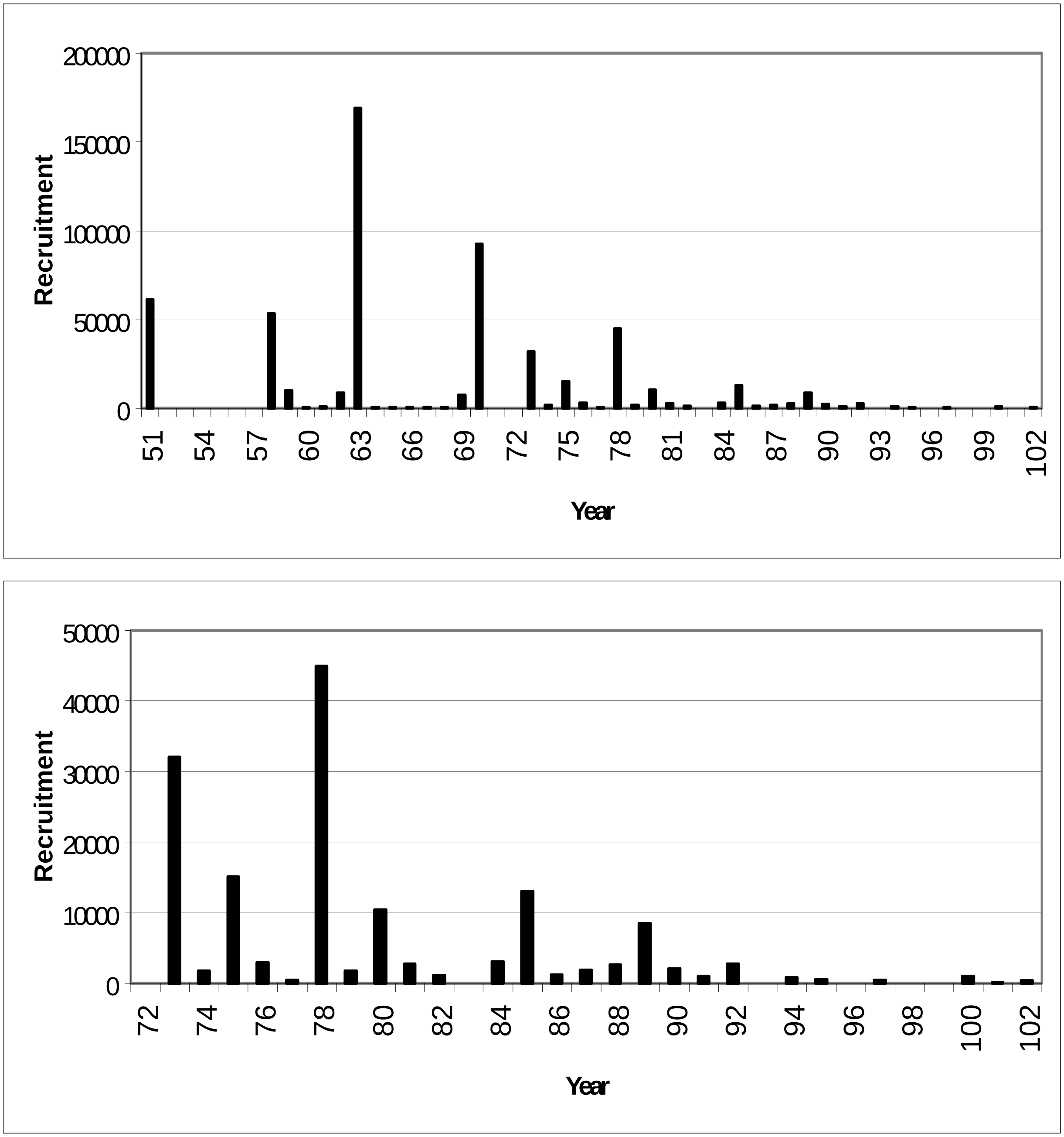


**Figure 20.** Estimated bocaccio recruitment strengths. Lower panel shows detail of recent years.

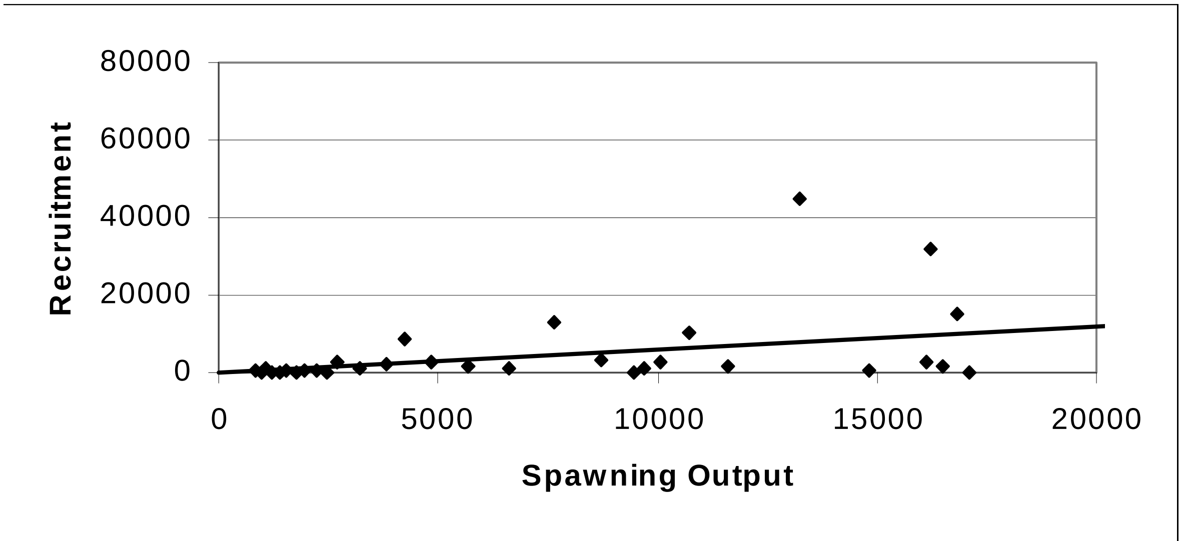


**Figure 21.** Bocaccio stock and recruitment relationship. Diagonal line is replacement level in the absence of fishing.

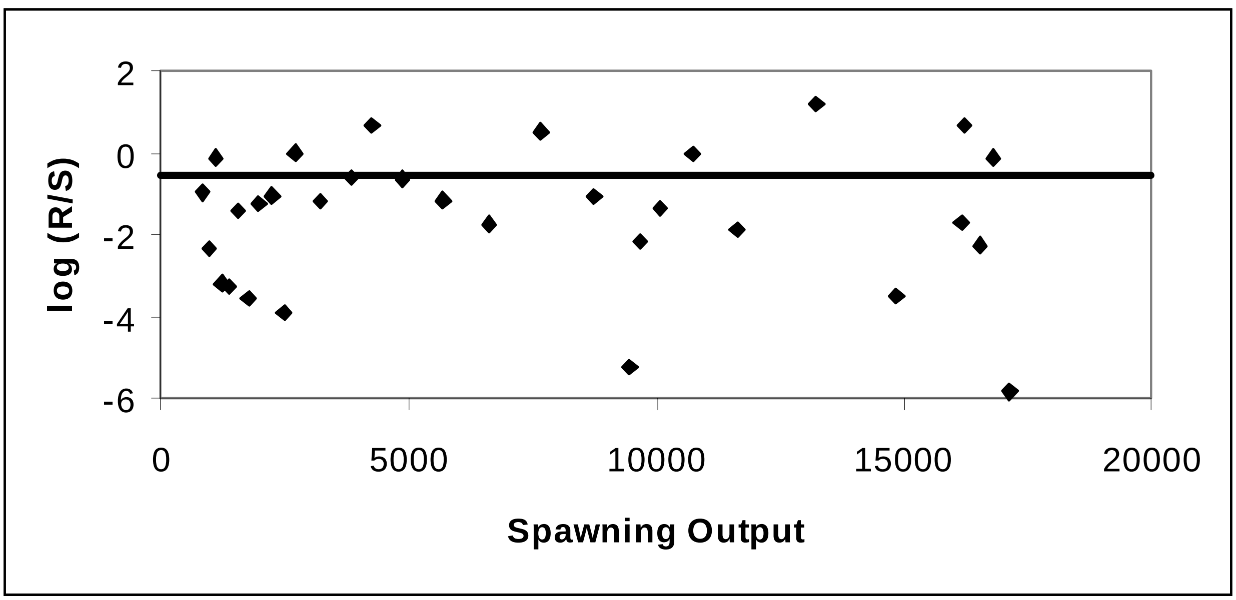


**Figure 22.** Historical reproductive success related to parental abundance. Horizontal line is replacement level in the absence of fishing.

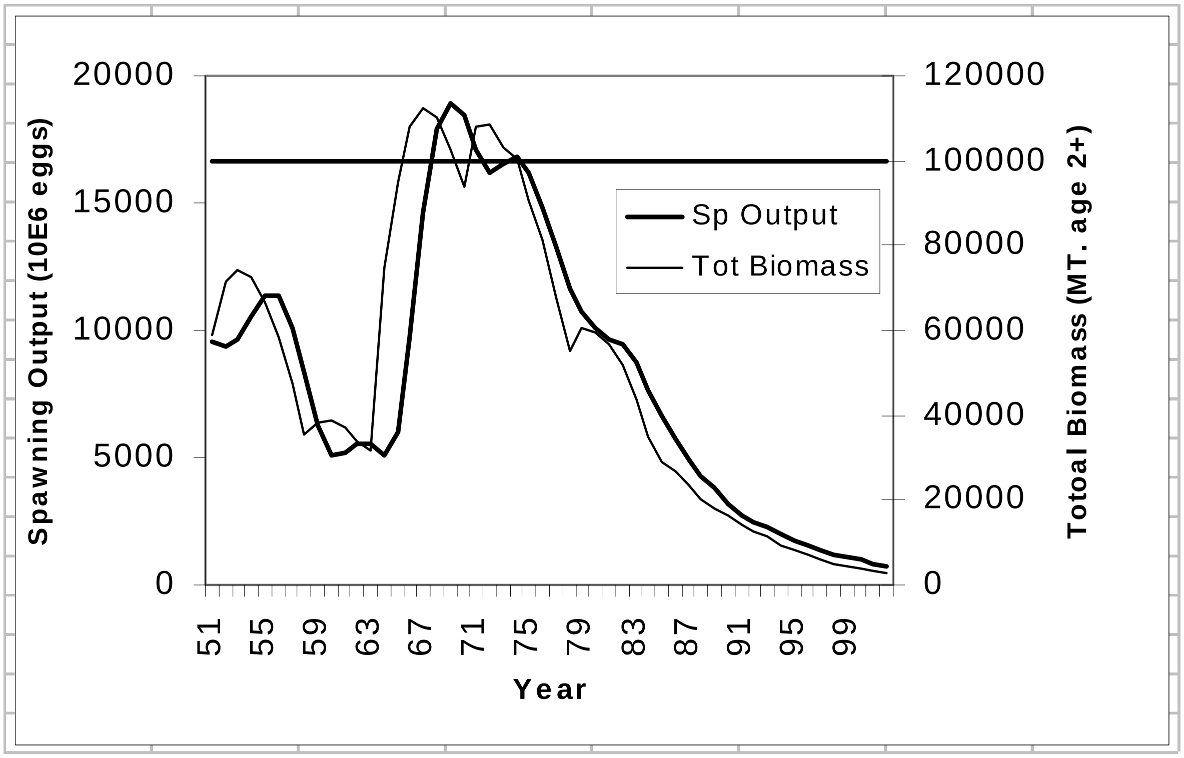


**Figure 23.** Estimated historical bocaccio abundances. Horizontal line is estimated unfished spawning output (Bunfished).

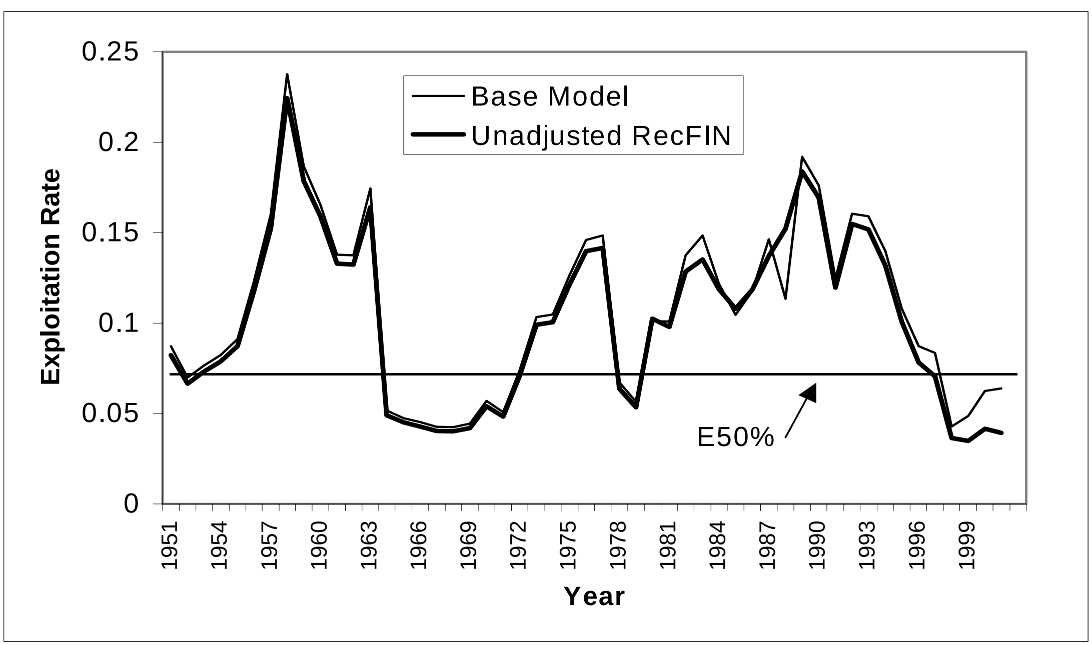


**Figure 24.** History of estimated bocaccio exploitation rates. Results based on use of unadjusted RecFIN catches are shown for comparison.

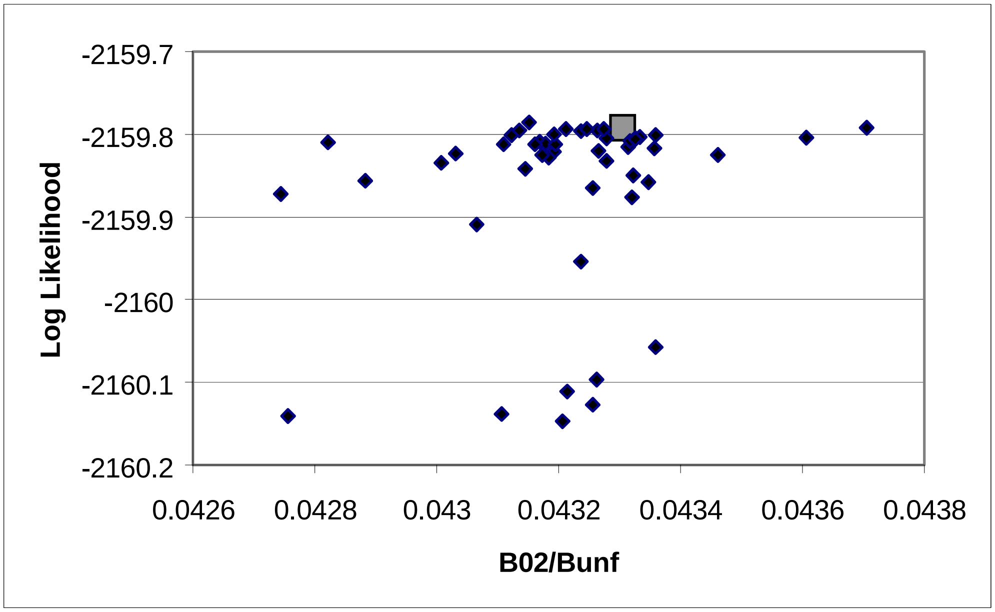


**Figure 25.** Convergence test of bocaccio model.

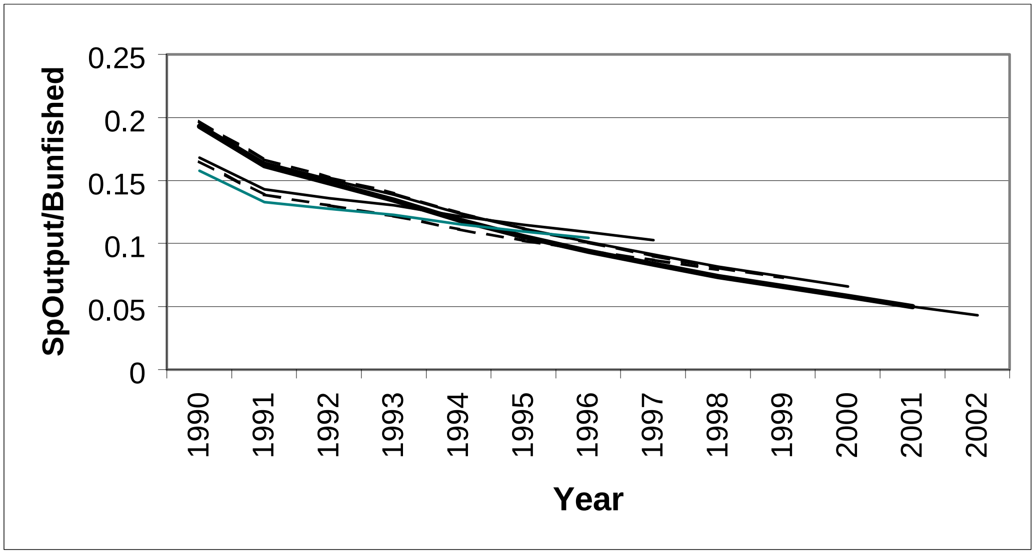


**Figure 26.** Retrospective pattern of relative abundance estimates.

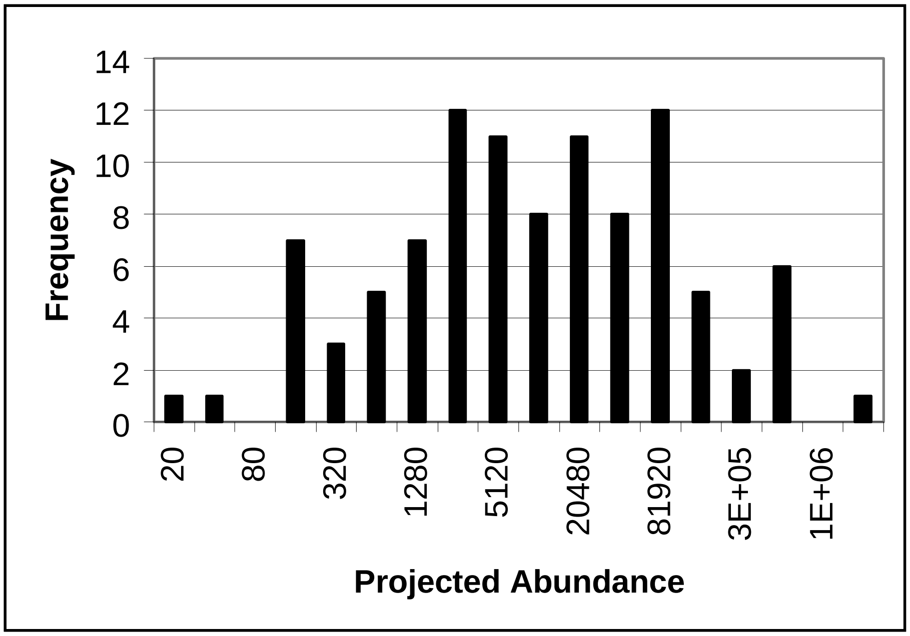


**Figure 27.** Distribution of projected bocaccio abundances (log scale) after 100 yr with no fishing.

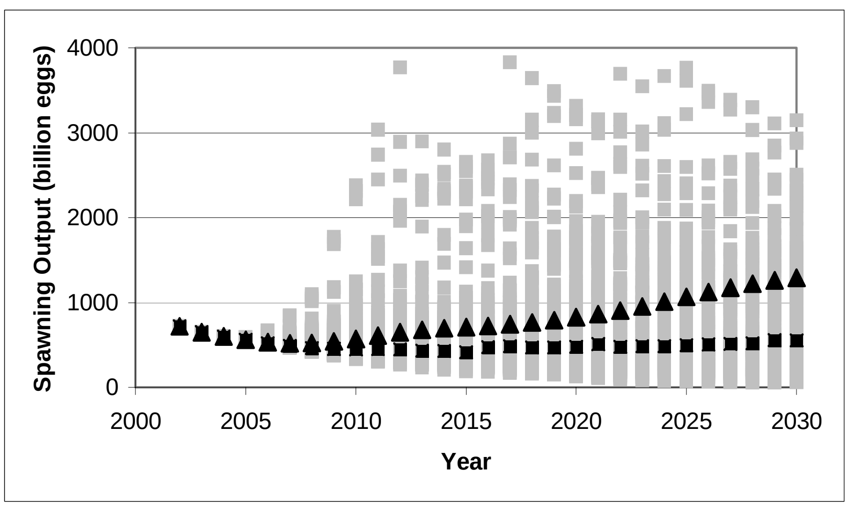


**Figure 28.** Near-term projections of bocaccio abundance in the absence of fishing. Light symbols are individual outcomes, lower dark square symbols are median value, upper dark triangles are average value.

Appendix 1. Results of the bocaccio base model.

| Year | Bage2+ (MT) | SpOut($10^9$eggs) | Recruits($10^3$) | Catch | ExploitRate |
|---|---|---|---|---|---|
| pre-51 | 58754 | 9521 | 12168 | 3807 | 6.5% |
| 1951 | 58754 | 9522 | 61065 | 5119 | 8.7% |
| 1952 | 71522 | 9374 | 175 | 4993 | 7.0% |
| 1953 | 74110 | 9609 | 90 | 5670 | 7.7% |
| 1954 | 72372 | 10537 | 50 | 5947 | 8.2% |
| 1955 | 66730 | 11402 | 50 | 6074 | 9.1% |
| 1956 | 58322 | 11324 | 50 | 7155 | 12.3% |
| 1957 | 47224 | 10133 | 96 | 7557 | 16.0% |
| 1958 | 35294 | 8365 | 53201 | 8382 | 23.7% |
| 1959 | 38311 | 6296 | 9922 | 7149 | 18.7% |
| 1960 | 38779 | 5135 | 580 | 6409 | 16.5% |
| 1961 | 36856 | 5166 | 769 | 5079 | 13.8% |
| 1962 | 33771 | 5538 | 8713 | 4638 | 13.7% |
| 1963 | 31600 | 5526 | 169111 | 5508 | 17.4% |
| 1964 | 74859 | 5066 | 388 | 3861 | 5.2% |
| 1965 | 95179 | 6006 | 232 | 4510 | 4.7% |
| 1966 | 108008 | 9753 | 219 | 4877 | 4.5% |
| 1967 | 112425 | 14630 | 256 | 4794 | 4.3% |
| 1968 | 110057 | 17909 | 478 | 4673 | 4.2% |
| 1969 | 102533 | 18927 | 7360 | 4551 | 4.4% |
| 1970 | 93780 | 18429 | 92424 | 5341 | 5.7% |
| 1971 | 108159 | 17121 | 154 | 5478 | 5.1% |
| 1972 | 108763 | 16216 | 50 | 8013 | 7.4% |
| 1973 | 103319 | 16526 | 31983 | 10664 | 10.3% |
| 1974 | 100394 | 16808 | 1752 | 10500 | 10.5% |
| 1975 | 90591 | 16150 | 15045 | 11443 | 12.6% |
| 1976 | 81031 | 14840 | 2955 | 11825 | 14.6% |
| 1977 | 67893 | 13233 | 455 | 10075 | 14.8% |
| 1978 | 54849 | 11621 | 44923 | 3686 | 6.7% |
| 1979 | 60297 | 10731 | 1779 | 3401 | 5.6% |
| 1980 | 59619 | 10065 | 10397 | 6024 | 10.1% |
| 1981 | 56986 | 9678 | 2660 | 5742 | 10.1% |
| 1982 | 51931 | 9459 | 1127 | 7138 | 13.7% |
| 1983 | 43686 | 8735 | 50 | 6486 | 14.8% |
| 1984 | 34817 | 7666 | 3053 | 4238 | 12.2% |
| 1985 | 28647 | 6629 | 12986 | 2994 | 10.5% |
| 1986 | 26981 | 5699 | 1170 | 3172 | 11.8% |
| 1987 | 23673 | 4867 | 1801 | 3462 | 14.6% |
| 1988 | 20169 | 4249 | 2587 | 2286 | 11.3% |
| 1989 | 17865 | 3846 | 8436 | 3427 | 19.2% |
| 1990 | 16110 | 3222 | 2078 | 2836 | 17.6% |
| 1991 | 14112 | 2703 | 998 | 1757 | 12.5% |
| 1992 | 12791 | 2466 | 2732 | 2053 | 16.1% |
| 1993 | 11382 | 2239 | 50 | 1811 | 15.9% |
| 1994 | 9474 | 1976 | 795 | 1324 | 14.0% |
| 1995 | 7993 | 1749 | 569 | 864 | 10.8% |
| 1996 | 6874 | 1556 | 50 | 599 | 8.7% |
| 1997 | 5863 | 1383 | 379 | 489 | 8.3% |
| 1998 | 5006 | 1217 | 52 | 214 | 4.3% |
| 1999 | 4373 | 1089 | 50 | 213 | 4.9% |
| 2000 | 3738 | 961 | 971 | 233 | 6.2% |
| 2001 | 3364 | 832 | 93 | 215 | 6.4% |
| 2002 | 2914 | 720 | 316 | | |

Appendix 1, cont. Results of the bocaccio base model.

| AGE | FEMALES BEGWT | MIDWT | RELATIVE F | N 102 | SPAWN | MALES BEGWT | MIDWT | RELATIVE F | N 102 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.136 | 0.214 | 0.297 | 61.6 | 0.000 | 0.145 | 0.215 | 0.300 | 61.6 |
| 2 | 0.364 | 0.492 | 0.845 | 34.5 | 0.002 | 0.341 | 0.445 | 0.782 | 34.5 |
| 3 | 0.698 | 0.860 | 1.000 | 249.9 | 0.024 | 0.605 | 0.728 | 1.000 | 253.4 |
| 4 | 1.103 | 1.284 | 0.901 | 8.8 | 0.123 | 0.905 | 1.035 | 0.974 | 8.9 |
| 5 | 1.547 | 1.739 | 0.731 | 6.5 | 0.310 | 1.216 | 1.345 | 0.882 | 6.5 |
| 6 | 2.009 | 2.197 | 0.560 | 38.5 | 0.536 | 1.523 | 1.647 | 0.767 | 36.9 |
| 7 | 2.450 | 2.624 | 0.420 | 4 | 0.754 | 1.815 | 1.931 | 0.654 | 3.7 |
| 8 | 2.858 | 3.019 | 0.313 | 34.6 | 0.955 | 2.085 | 2.187 | 0.559 | 32 |
| 9 | 3.234 | 3.381 | 0.235 | 36.7 | 1.144 | 2.319 | 2.405 | 0.484 | 33.2 |
| 10 | 3.576 | 3.707 | 0.182 | 1.7 | 1.321 | 2.517 | 2.591 | 0.424 | 1.5 |
| 11 | 3.880 | 3.996 | 0.146 | 63.6 | 1.484 | 2.687 | 2.751 | 0.376 | 55.3 |
| 12 | 4.148 | 4.249 | 0.121 | 15.6 | 1.632 | 2.834 | 2.889 | 0.337 | 12.9 |
| 13 | 4.381 | 4.468 | 0.104 | 23.6 | 1.764 | 2.959 | 3.006 | 0.306 | 18.5 |
| 14 | 4.581 | 4.656 | 0.092 | 63.8 | 1.880 | 3.065 | 3.105 | 0.282 | 46.7 |
| 15 | 4.754 | 4.818 | 0.083 | 13 | 1.981 | 3.155 | 3.187 | 0.263 | 8.7 |
| 16 | 4.901 | 4.955 | 0.076 | 6.2 | 2.068 | 3.229 | 3.257 | 0.248 | 3.7 |
| 17 | 5.025 | 5.071 | 0.071 | 2.9 | 2.143 | 3.292 | 3.314 | 0.236 | 1.5 |
| 18 | 5.131 | 5.169 | 0.067 | 25.6 | 2.206 | 3.344 | 3.363 | 0.227 | 11.1 |
| 19 | 5.219 | 5.252 | 0.064 | 4.6 | 2.259 | 3.387 | 3.402 | 0.220 | 1.8 |
| 20 | 5.293 | 5.321 | 0.062 | 0.1 | 2.304 | 3.422 | 3.435 | 0.214 | 0.0 |
| 21+ | 5.536 | 5.536 | 0.056 | 88 | 2.451 | 3.534 | 3.534 | 0.199 | 20.5 |

2002 Relative fishing intensity by gear and area

| Southern California | Relative Fmax | Central California | Relative Fmax |
|---|---|---|---|
| Recreational | 1.000 | Recreational | 0.601 |
| Hook & Line | 0.038 | Hook & Line | 0.030 |
| Set Net | 0.000 | Set Net | 0.012 |
| | | Trawl | 0.082 |

Appendix 2.  Stock Synthesis parameter file.

```
fincomb.dat      **** UNKNOWN CONVERGENCE STATUS
fincom.run
fincomb.par
final 2002 bocaccio assessment, combined so&cent calif
     100.000000        .010000     BEGIN AND END DELTA F PER LOOP1
   2   .99                 FIRST LOOP1 FOR LAMBDA & VALUE
   1.100                   MAX VALUE FOR CROSS DERIVATIVE
   0 READ HESSIAN
fincomb.hes
   1 WRITE HESSIAN
fincomb.hes
    .001                   MIN SAMPLE FRAC. PER AGE
   1  21   2  21           MINAGE, MAXAGE,  SUMMARY AGE RANGE
  51 102                   BEGIN YEAR, END YEAR
  1       12  0  0  0      NPER, MON/PER
  1.00                     SPAWNMONTH
  7  8 NFISHERY, NSURVEY
  2 N SEXES
   50000.  REF RECR LEVEL
  0 MORTOPT
     .200000     .010000     .250000 'M                '   0   1  0     .000000   .0000 !   1 NO PICK    .000      -1.      .0000000
 -999.000000     .010000    1.000000 'M SAME FOR M+F  '   0   1  0     .000000   .0000 !   2 NO PICK    .000      -1.      .0000000
 TRAWL      TYPE:  1
  7 SELECTIVITY PATTERN
   0   0   0   2   0   0   0  AGE TYPES USED
     1.00000       .10 ' TWL CATCH BIOMASS  '  ! # =  1 VALUE:         .00000
     1.00000       .30 ' TWL  SIZE COMPS    '  ! # =  2 VALUE:     -440.53364
  1  1  0  0  0  0  SEL. COMPONENTS
     .543698     .001000    1.000000 'Trawl:transition'   2   1  0     .000000   .0000 !   3 OK          .000  -69245.    -1.0000000
     .000001     .000001    1.000000 'Trawl:InitSelect'   0   1  0     .000000   .0000 !   4 NO PICK     .000      -1.      .0000000
     .540193     .001000    1.000000 'Trawl:SmlInflect'   2   1  0     .000000   .0000 !   5 OK          .000  -21733.    -1.0000000
     .393077     .001000    3.000000 'Trawl:SmlSlope  '   2   1  0     .000000   .0000 !   6 OK          .000   -2876.    -1.0000000
     .097800     .001000    1.000000 'Trawl:femfinal  '   2   1  0     .000000   .0000 !   7 OK          .000   -4623.    -1.0000000
     .001000     .001000    1.000000 'Trawl:feminflct '   2   1  0     .000000   .0000 !   8 BOUND       .000      -1.    -1.0000000
     .180806     .001000    5.000000 'Trawl:femSlope  '   2   1  0     .000000   .0000 !   9 OK          .000  -11727.    -1.0000000
 &Lso   T   TYPE:  2
  7 SELECTIVITY PATTERN
   0   0   0   4   0   0   0  AGE TYPES USED
     1.00000       .10 ' H&Lso CATCH BIOMASS'  ! # =  3 VALUE:         .00000
     1.00000       .30 ' H&Lso SIZE COMPS   '  ! # =  4 VALUE:     -139.95620
  1  1  0  0  0  0  SEL. COMPONENTS
     .514679     .001000    1.000000 'H&Lso:transition'   2   1  0     .000000   .0000 !  10 OK          .000  -39191.    -1.0000000
     .000001     .000001    1.000000 'H&Lso:InitSelect'   0   1  0     .000000   .0000 !  11 NO PICK     .000      -1.      .0000000
    1.000000     .001000    1.000000 'H&Lso:YngInflect'   2   1  0     .000000   .0000 !  12 BOUND       .000      -1.    -1.0000000
     .241380     .001000    3.000000 'H&Lso:YngSlope  '   2   1  0     .000000   .0000 !  13 OK          .000   -7023.    -1.0000000
     .025479     .001000    1.000000 'H&Lso:femfinal  '   2   1  0     .000000   .0000 !  14 OK          .000   -8792.    -1.0000000
     .163889     .001000    1.000000 'H&Lso:feminflct '   2   1  0     .000000   .0000 !  15 OK          .000   -3174.    -1.0000000
     .509347     .001000    5.000000 'H&Lso:femSlope  '   2   1  0     .000000   .0000 !  16 OK          .000    -229.    -1.0000000
 &Lcen      TYPE:  3
  7 SELECTIVITY PATTERN
   0   0   0   6   0   0   0  AGE TYPES USED
```

```
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    1.00000       .30 ' H&Lcen SIZE COMPS  '  ! # =  6 VALUE:     -219.93826
 1  1  0  0  0  0  SEL. COMPONENTS
    .511224     .001000    1.000000 'HLcen:transition'   2   1  0     .000000   .0000 !  17 OK          .000  -15006.    -1.0000000
    .000001     .000001    1.000000 'HLcen:InitSelect'   0   1  0     .000000   .0000 !  18 NO PICK     .000      -1.      .0000000
   1.000000     .001000    1.000000 'HLcen:YngInflect'   2   1  0     .000000   .0000 !  19 BOUND       .000      -1.    -1.0000000
    .189829     .001000    3.000000 'HLcen:YngSlope  '   2   1  0     .000000   .0000 !  20 OK          .000   -6948.    -1.0000000
    .072025     .001000    1.000000 'HLcen:femfinal  '   2   1  0     .000000   .0000 !  21 OK          .000   -1027.    -1.0000000
    .292344     .001000    1.000000 'HLcen:feminflct '   2   1  0     .000000   .0000 !  22 OK          .000    -551.    -1.0000000
    .227318     .001000    5.000000 'HLcen:femSlope  '   2   1  0     .000000   .0000 !  23 OK          .000    -721.    -1.0000000
ETNso      TYPE:  4
 7 SELECTIVITY PATTERN
  0   0   0   8   0   0   0  AGE TYPES USED
    1.00000       .10 'SetNsoCATCHBIOM     '  ! # =  7 VALUE:         .00000
    1.00000       .30 'SetNsoSizeComps     '  ! # =  8 VALUE:     -104.70210
 1  1  0  0  0  0  SEL. COMPONENTS
    .547453     .001000    1.000000 'StNso:transition'   2   1  0     .000000   .0000 !  24 OK          .000  -58700.    -1.0000000
    .000001     .000001    1.000000 'StNso:InitSelect'   0   1  0     .000000   .0000 !  25 NO PICK     .000      -1.      .0000000
    .922931     .001000     .990000 'StNso:YngInflect'   2   1  0     .000000   .0000 !  26 OK          .000   -3333.    -1.0000000
    .457047     .001000    3.000000 'StNso:YngSlope  '   2   1  0     .000000   .0000 !  27 OK          .000   -1301.    -1.0000000
    .043270     .001000    1.000000 'StNso:femfinal  '   2   1  0     .000000   .0000 !  28 OK          .000   -6437.    -1.0000000
    .001000     .001000    1.000000 'StNso:feminflct '   2   1  0     .000000   .0000 !  29 BOUND       .000      -1.    -1.0000000
    .391704     .001000    5.000000 'StNso:femSlope  '   2   1  0     .000000   .0000 !  30 OK          .000    -695.    -1.0000000
SETcen     TYPE:  5
 7 SELECTIVITY PATTERN
  0   0   0  10   0   0   0  AGE TYPES USED
    1.00000       .10 'SetNcenCATCHBIOM    '  ! # =  9 VALUE:         .00000
    1.00000       .30 'SetNcenSizeComps    '  ! # = 10 VALUE:     -276.54877
 1  1  0  0  0  0  SEL. COMPONENTS
    .462606     .001000    1.000000 'StNcn:transition'   2   1  0     .000000   .0000 !  31 OK          .000 -131223.    -1.0000000
    .000001     .000001    1.000000 'StNcn:InitSelect'   0   1  0     .000000   .0000 !  32 NO PICK     .000      -1.      .0000000
    .968272     .001000     .990000 'StNcn:YngInflect'   2   1  0     .000000   .0000 !  33 OK          .000   -4309.    -1.0000000
    .450869     .001000    3.000000 'StNcn:YngSlope  '   2   1  0     .000000   .0000 !  34 OK          .000   -3766.    -1.0000000
    .029396     .001000    1.000000 'StNcn:femfinal  '   2   1  0     .000000   .0000 !  35 OK          .000  -12757.    -1.0000000
    .178693     .001000    1.000000 'StNcn:feminflct '   2   1  0     .000000   .0000 !  36 OK          .000   -3185.    -1.0000000
    .276661     .001000    5.000000 'StNcn:femSlope  '   2   1  0     .000000   .0000 !  37 OK          .000   -3121.    -1.0000000
RECLso     TYPE:  6
 7 SELECTIVITY PATTERN
  0   0   0  12   0   0   0  AGE TYPES USED
    1.00000       .10 'RECLsoCATCHBIOM     '  ! # = 11 VALUE:         .00000
    1.00000       .30 'RECLsoSIZECOMPS     '  ! # = 12 VALUE:     -340.66430
 1  1  0  0  0  0  SEL. COMPONENTS
    .250736     .101000    1.000000 'RCLso:transition'   2   1  0     .000000   .0000 !  38 OK          .000  -12886.    -1.0000000
    .000001     .000001    1.000000 'RCLso:InitSelect'   0   1  0     .000000   .0000 !  39 NO PICK     .000      -1.      .0000000
   1.000000     .001000    1.000000 'RCLso:SmlInflect'   2   1  0     .000000   .0000 !  40 BOUND       .000      -1.    -1.0000000
    .122279     .001000    5.000000 'RCLso:SmlSlope  '   2   1  0     .000000   .0000 !  41 OK          .000   -1106.    -1.0000000
    .008163     .001000    1.000000 'RCLso:femfinal  '   2   1  0     .000000   .0000 !  42 OK          .000  -10141.    -1.0000000
    .359000     .001000    1.000000 'RCLso:feminflct '   2   1  0     .000000   .0000 !  43 OK          .000   -3973.    -1.0000000
    .197017     .001000    5.000000 'RCLso:femSlope  '   2   1  0     .000000   .0000 !  44 OK          .000   -3996.    -1.0000000
 RECLcen   TYPE:  7
 7 SELECTIVITY PATTERN
  0   0   0  14   0   0   0  AGE TYPES USED
    1.00000       .10 'RECLcenCATCHBIOM    '  ! # = 13 VALUE:         .00000
    1.00000       .30 'RECLcenSIZECOMPS    '  ! # = 14 VALUE:     -310.77890
```

```
 1  1  0  0  0  0  SEL. COMPONENTS
    .272747     .101000    1.000000 'RCLcn:transition'   2   1  0     .000000   .0000 !  45 OK          .000 -133629.    -1.0000000
    .000001     .000001    1.000000 'RCLcn:InitSelect'   0   1  0     .000000   .0000 !  46 NO PICK     .000      -1.      .0000000
   1.000000     .001000    1.000000 'RCLcn:SmlInflect'   2   1  0     .000000   .0000 !  47 BOUND       .000      -1.    -1.0000000
    .129618     .001000    5.000000 'RCLcn:SmlSlope  '   2   1  0     .000000   .0000 !  48 OK          .000   -2647.    -1.0000000
    .045887     .001000    1.000000 'RCLcn:femfinal  '   2   1  0     .000000   .0000 !  49 OK          .000   -3872.    -1.0000000
    .406861     .001000    1.000000 'RCLcn:feminflct '   2   1  0     .000000   .0000 !  50 OK          .000   -2884.    -1.0000000
    .169538     .001000    5.000000 'RCLcn:femSlope  '   2   1  0     .000000   .0000 !  51 OK          .000   -3632.    -1.0000000
SoRect     TYPE:  8
 3 SELECTIVITY PATTERN
  0   0   0   0   0   0   0  AGE TYPES USED
    .000369  0  1  2 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
    1.00000       .50 'SoCalRectIndex      '  ! # = 15 VALUE:      -56.42015
   1.000000     .000000    1.000000 'SoCalAge1Nos    '   0  73  0     .000000   .0000 !  52 NO PICK     .000      -1.      .0000000
   1.000000     .000000    1.000000 'SoCalAge1Nos    '   0  73  0     .000000   .0000 !  53 NO PICK     .000      -1.      .0000000
SoMRFS     TYPE:  9
 2 SELECTIVITY PATTERN
  0   0   0   0   0   0   0  AGE TYPES USED
    .000202  0  1  1 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
    1.00000       .20 'MRFFSINDEX          '  ! # = 16 VALUE:      -23.10905
   6.000000    -.200000    1.000000 'SoCalReclSeltype'   0 -80  0     .000000   .0000 !  54 NO PICK     .000      -1.      .0000000
  20.000000     .010000   20.000000 'SoCalRecl:minsiz'   0 -80  0     .000000   .0000 !  55 NO PICK     .000      -1.      .0000000
  84.000000     .001000   84.000000 'SoCalRecl:maxsiz'   0 -80  0     .000000   .0000 !  56 NO PICK     .000      -1.      .0000000
CALCOFI    TYPE: 10
14 SELECTIVITY PATTERN
  0   0   0   0   0   0   0  AGE TYPES USED
    .000013  0  1  1 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
    1.00000       .10 ' CALCOFI INDEX      '  ! # = 17 VALUE:      -14.18740
    .000001     .001000    1.000000 'CALCOFI:Initsele'   0  51  0     .000000   .0000 !  57 NO PICK     .000      -1.      .0000000
  53.000000     .001000    1.000000 'CALCOFI:YngInfle'   0  51  0     .000000   .0000 !  58 NO PICK     .000      -1.      .0000000
    .195700     .001000    3.000000 'CALCOFI:YngSlope'   0  51  0     .000000   .0000 !  59 NO PICK     .000      -1.      .0000000
    .999999     .001000    1.000000 'CALCOFI:Transtn '   0  51  0     .000000   .0000 !  60 NO PICK     .000      -1.      .0000000
   1.000000     .001000    1.000000 'CALCOFI:FemFinal'   0  51  0     .000000   .0000 !  61 NO PICK     .000      -1.      .0000000
    .700000     .001000    5.000000 'CALCOFI:FemInflc'   0  51  0     .000000   .0000 !  62 NO PICK     .000      -1.      .0000000
    .100000     .001000    5.000000 'CALCOFI:Femslope'   0  51  0     .000000   .0000 !  63 NO PICK     .000      -1.      .0000000
    .000001     .001000    2.000000 'CALCOFI:MalStart'   0  51  0     .000000   .0000 !  64 NO PICK     .000      -1.      .0000000
    .000001     .100000   10.000000 'CALCOFI:MalShape'   0  51  0     .000000   .0000 !  65 NO PICK     .000      -1.      .0000000
    .000001     .000001    1.000000 'CALCOFI:MalFinal'   0  51  0     .000000   .0000 !  66 NO PICK     .000      -1.      .0000000
TRITRAWL   TYPE: 11
 7 SELECTIVITY PATTERN
  0   0   0  19   0   0   0  AGE TYPES USED
    .020355  0  1  1 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
    1.00000       .16 'TRI SURVEY BIO      '  ! # = 18 VALUE:         .71092
    1.00000       .30 'TRI SIZE COMPS      '  ! # = 19 VALUE:     -209.12397
 1  1  0  0  0  0  SEL. COMPONENTS
    .054545     .010000    1.000000 'TriSv:transition'   2  77  0     .000000   .0000 !  67 OK         -.001   -9080.    -1.0000000
   1.000000     .001000    1.000000 'TriSv:InitSelect'   0  77  0     .000000   .0000 !  68 NO PICK     .000      -1.      .0000000
    .083549     .001000    1.000000 'TriSv:YngInflect'  -2  77  0     .000000   .0000 !  69 NO PICK     .000      -1.    -1.0000000
    .701782     .001000    3.000000 'TriSv:YngSlope  '  -2  77  0     .000000   .0000 !  70 NO PICK     .000      -1.    -1.0000000
    .009068     .001000    1.000000 'TriSv:femfinal  '   2  77  0     .000000   .0000 !  71 OK          .000    -885.    -1.0000000
    .001000     .001000    1.000000 'TriSv:feminflct '   2  77  0     .000000   .0000 !  72 BOUND       .000      -1.    -1.0000000
    .042465     .001000    5.000000 'TriSv:femSlope  '   2  77  0     .000000   .0000 !  73 OK          .000  -12324.    -1.0000000
CenRect    TYPE: 12
 3 SELECTIVITY PATTERN
```

```
  0   0   0   0   0   0   0  AGE TYPES USED
    .000160  0  1  2 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
   1.00000       .50 'CenCalRectIndex     '  ! # = 20 VALUE:       -35.14511
   1.000000     .000000    1.000000 'CenCalAge1Nos   '   0  84  0     .000000   .0000 !  74 NO PICK    .000      -1.       .0000000
   1.000000     .000000    1.000000 'CenCalAge1Nos   '   0  84  0     .000000   .0000 !  75 NO PICK    .000      -1.       .0000000
TwlCPUE    TYPE: 13
 2 SELECTIVITY PATTERN
  0   0   0   0   0   0   0  AGE TYPES USED
    .003894  0  1  1 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
   1.00000       .20 'TrawlCPUE           '  ! # = 21 VALUE:        12.60428
   1.000000    -.200000    1.000000 'TrawlSeltype    '   0 -82  0     .000000   .0000 !  76 NO PICK    .000      -1.       .0000000
  20.000000     .010000   20.000000 'TrawlCPUE:minsiz'   0 -82  0     .000000   .0000 !  77 NO PICK    .000      -1.       .0000000
  84.000000     .001000   84.000000 'TrawlCPUE:maxsiz'   0 -82  0     .000000   .0000 !  78 NO PICK    .000      -1.       .0000000
CenMRFS    TYPE: 14
 2 SELECTIVITY PATTERN
  0   0   0   0   0   0   0  AGE TYPES USED
    .000086  0  1  1 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
   1.00000       .20 ' CenCalMRFS         '  ! # = 22 VALUE:        -1.84971
   7.000000    -.200000    1.000000 'CenCalReclSeltyp'   0 -87  0     .000000   .0000 !  79 NO PICK    .000      -1.       .0000000
  20.000000     .010000   20.000000 'CenCalRecl:minsi'   0 -87  0     .000000   .0000 !  80 NO PICK    .000      -1.       .0000000
  84.000000     .001000   84.000000 'CenCalRecl:maxsi'   0 -87  0     .000000   .0000 !  81 NO PICK    .000      -1.       .0000000
ROF-BIO    TYPE: 15
 1 SELECTIVITY PATTERN
  0   0   0   0   0   0   0  AGE TYPES USED
  10.351493  0  1  1 Q, QUANT, LOGERROR=1, BIO=1 or NUM=2
    .00000       .01 ' PROF-BIO ABUND     '  ! # = 23 VALUE:         3.91212
   4.000000    -.200000    1.000000 'PROFBIO MINAGE  '   0   1  0     .000000   .0000 !  82 NO PICK    .000      -1.       .0000000
  21.000000     .010000   55.000000 'PROFBIO MAXAGE  '   0   1  0     .000000   .0000 !  83 NO PICK    .000      -1.       .0000000
   1.000000     .001000    4.000000 'PROFBIO MULT    '   0   1  0     .000000   .0000 !  84 NO PICK    .000      -1.       .0000000
 1 AGEERR: 1: MULTINOMIAL,  0: S(LOG(P))=CONSTANT,  -1: S=P*Q/N
500.000 : MAX N FOR MULTINOMIAL
 3 1=%CORRECT, 2=C.V., 3=%AGREE, 4=READ %AGREE @AGE
    .800000     .300000     .950000 'p AGREE. @1     '   0  80  0     .000000   .0000 !  85 NO PICK    .000      -1.       .0000000
    .050000     .000000     .900000 'p agree @21     '   0  80  0     .000000   .0000 !  86 NO PICK    .000      -1.       .0000000
   1.000000     .001000    2.000000 'POWER           '   0  80  0     .000000   .0000 !  87 NO PICK    .000      -1.       .0000000
    .150000     .010000     .300000 'OLD DISCOUNT    '   0  80  0     .000000   .0000 !  88 NO PICK    .000      -1.       .0000000
    .000001     .001000     .100000 '%MIS-SEXED      '   0  80  0     .000000   .0000 !  89 NO PICK    .000      -1.       .0000000
 0 END OF EFFORT
 0 FIX n FMORTs
 0  CANNIBALISM
 1  GROWTH: 1=CONSTANT, 2=MORT. INFLUENCE
 1.5000 99.0000  AGE AT WHICH L1 AND L2 OCCUR
 1 1=NORMAL, 2=LOGNORMAL
  27.000000   20.000000   60.000000 'FEMALE L1       '   0   1  0     .000000   .0000 !  90 NO PICK    .000      -1.       .0000000
  75.892728   60.000000   90.000000 'FEMALE LINF     '   0   1  0     .000000   .0000 !  91 NO PICK    .000      -1.       .0000000
    .180233     .050000     .400000 'FEMALE K        '   2   1  0     .000000   .0000 !  92 OK         .000 -396064.     -1.0000000
    .107000     .010000     .990000 'FEMALE CV1      '   0   1  0     .000000   .0000 !  93 NO PICK    .000      -1.       .0000000
    .033000     .010000     .990000 'FEMALE CV21     '   0   1  0     .000000   .0000 !  94 NO PICK    .000      -1.       .0000000
-999.000000   20.000000   40.000000 'MALE L1         '   0   1  0     .000000   .0000 !  95 NO PICK    .000      -1.       .0000000
  65.555310   50.000000   80.000000 'MALE LINF       '   0   1  0     .000000   .0000 !  96 NO PICK    .000      -1.       .0000000
    .198393     .100000     .400000 'MALE K          '   2   1  0     .000000   .0000 !  97 OK         .000 -337895.     -1.0000000
-999.000000     .010000     .990000 'MALE CV1        '   0   1  0     .000000   .0000 !  98 NO PICK    .000      -1.       .0000000
-999.000000     .010000     .990000 'MALE CV21       '   0   1  0     .000000   .0000 !  99 NO PICK    .000      -1.       .0000000
          0  DEFINE MARKET CATEGORIES
```

```
 0 ENVIRONMENTAL FXN:    [-INDEX]  [FXN TYPE(1-4)]  [ENVVAR USED]
 0 ESTIMATE N ENVIRON VALUES
 0 PENALTIES
 0 ENVIRONMENT EFFECT ON EXP(RECR)
24  STOCK-RECR
 1 1=B-H, 2=RICKER, 3=new B-H
 0 0=USE S-R CURVE, 1=SCALE CURVE
     .00001     -1.00 'SPAWN RECR.         '  ! # = 24 VALUE:     -365.38087
     .00001      -.30 'S-R means           '  ! # = 25 VALUE:   -14594.02356
   1.000000     .001000   10.000000 'VIR. RECR. MULT.'  -2   1  0      .000000   .0000 ! 100 NO PICK    .000       -1.    -1.0000000
    .889568     .100000     .990000 'B-H S/R PAR.    '  -2   1  0      .000000   .0000 ! 101 NO PICK    .000       -1.    -1.0000000
    .243361     .001000   10.000000 'BACK RECR.      '   2   1  0      .000000   .0000 ! 102 OK         .000    -6984.    -1.0000000
   1.000000     .010000    2.000000 'S/R STD.        '  -2   1  0      .000000   .0000 ! 103 NO PICK    .000       -1.    -1.0000000
    .000000    -.100000     .100000 'RECR. TREND     '   0   1  0      .000000   .0000 ! 104 NO PICK    .000       -1.      .0000000
   1.000000     .000000    2.000000 'RECR. MULT.     '   0   1  0      .000000   .0000 ! 105 NO PICK    .000       -1.      .0000000
-2 INIT AGE COMP
   1.221301     .001000   30.000000 'Recruit 51      '   2  51  0      .000000   .0000 ! 106 OK         .000      -70.    -1.0000000
    .003504     .001000   30.000000 'Recruit 52      '   2  52  0      .000000   .0000 ! 107 OK         .000     -281.    -1.0000000
    .001807     .001000   30.000000 'Recruit 53      '   2  53  0      .000000   .0000 ! 108 OK         .000     -914.    -1.0000000
    .001000     .001000   30.000000 'Recruit 54      '   2  54  0      .000000   .0000 ! 109 OK         .000    -3002.    -1.0000000
    .001000     .001000   30.000000 'Recruit 55      '   2  55  0      .000000   .0000 ! 110 BOUND      .000       -1.    -1.0000000
    .001000     .001000   30.000000 'Recruit 56      '   2  56  0      .000000   .0000 ! 111 BOUND      .000       -1.    -1.0000000
    .001925     .001000   30.000000 'Recruit 57      '   2  57  0      .000000   .0000 ! 112 OK         .000     -792.    -1.0000000
   1.064012     .001000   30.000000 'Recruit 58      '   2  58  0      .000000   .0000 ! 113 OK         .000      -38.    -1.0000000
    .198434     .001000   30.000000 'Recruit 59      '   2  59  0      .000000   .0000 ! 114 OK        -.001      -29.    -1.0000000
    .011604     .001000   30.000000 'Recruit 60      '   2  60  0      .000000   .0000 ! 115 OK         .000      -40.    -1.0000000
    .015380     .001000   30.000000 'Recruit 61      '   2  61  0      .000000   .0000 ! 116 OK         .000      -33.    -1.0000000
    .174266     .001000   30.000000 'Recruit 62      '   2  62  0      .000000   .0000 ! 117 OK         .000      -29.    -1.0000000
   3.382221     .001000   30.000000 'Recruit 63      '   2  63  0      .000000   .0000 ! 118 OK        -.002      -37.    -1.0000000
    .007769     .001000   30.000000 'Recruit 64      '   2  64  0      .000000   .0000 ! 119 OK         .000      -86.    -1.0000000
    .004632     .001000   30.000000 'Recruit 65      '   2  65  0      .000000   .0000 ! 120 OK         .000     -177.    -1.0000000
    .004381     .001000   30.000000 'Recruit 66      '   2  66  0      .000000   .0000 ! 121 OK         .000     -217.    -1.0000000
    .005110     .001000   30.000000 'Recruit 67      '   2  67  0      .000000   .0000 ! 122 OK         .000     -218.    -1.0000000
    .009554     .001000   30.000000 'Recruit 68      '   2  68  0      .000000   .0000 ! 123 OK         .000     -192.    -1.0000000
    .147198     .001000   30.000000 'Recruit 69      '   2  69  0      .000000   .0000 ! 124 OK         .000     -222.    -1.0000000
   1.848470     .001000   30.000000 'Recruit 70      '   2  70  0      .000000   .0000 ! 125 OK         .000     -291.    -1.0000000
    .003089     .001000   30.000000 'Recruit 71      '   2  71  0      .000000   .0000 ! 126 OK         .000     -659.    -1.0000000
    .001000     .001000   30.000000 'Recruit 72      '   2  72  0      .000000   .0000 ! 127 BOUND      .000       -1.    -1.0000000
    .639650     .001000   30.000000 'Recruit 73      '   2  73  0      .000000   .0000 ! 128 OK         .000     -716.    -1.0000000
    .035030     .001000   30.000000 'Recruit 74      '   2  74  0      .000000   .0000 ! 129 OK         .000    -2057.    -1.0000000
    .300902     .001000   30.000000 'Recruit 75      '   2  75  0      .000000   .0000 ! 130 OK         .000    -1725.    -1.0000000
    .059102     .001000   30.000000 'Recruit 76      '   2  76  0      .000000   .0000 ! 131 OK         .000    -4660.    -1.0000000
    .009104     .001000   30.000000 'Recruit 77      '   2  77  0      .000000   .0000 ! 132 OK         .000   -26373.    -1.0000000
    .898468     .001000   30.000000 'Recruit 78      '   2  78  0      .000000   .0000 ! 133 OK         .000    -2969.    -1.0000000
    .035590     .001000   30.000000 'Recruit 79      '   2  79  0      .000000   .0000 ! 134 OK         .000    -8317.    -1.0000000
    .207930     .001000   30.000000 'RECRUIT 80      '   2  80  0      .000000   .0000 ! 135 OK         .000    -7813.    -1.0000000
    .053193     .001000   30.000000 'RECRUIT 81      '   2  81  0      .000000   .0000 ! 136 OK         .000   -19026.    -1.0000000
    .022538     .001000   30.000000 'RECRUIT 82      '   2  82  0      .000000   .0000 ! 137 OK         .000   -59335.    -1.0000000
    .001000     .001000   30.000000 'RECRUIT 83      '   2  83  0      .000000   .0000 ! 138 BOUND      .000       -1.    -1.0000000
    .061052     .001000   30.000000 'RECRUIT 84      '   2  84  0      .000000   .0000 ! 139 OK         .000   -35217.    -1.0000000
    .259723     .001000   30.000000 'RECRUIT 85      '   2  85  0      .000000   .0000 ! 140 OK         .000   -15837.    -1.0000000
    .023397     .001000   30.000000 'RECRUIT 86      '   2  86  0      .000000   .0000 ! 141 OK         .000   -42396.    -1.0000000
    .036014     .001000   30.000000 'RECRUIT 87      '   2  87  0      .000000   .0000 ! 142 OK         .000   -50043.    -1.0000000
    .051744     .001000   30.000000 'RECRUIT 88      '   2  88  0      .000000   .0000 ! 143 OK         .000   -39453.    -1.0000000
```

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .168729 | .001000 | 30.000000 | 'RECRUIT 89 | ' | 2 | 89 | 0 | .000000 | .0000 | ! 144 | OK | .000 | -29708. | -1.0000000 |
| .041559 | .001000 | 30.000000 | 'RECRUIT 90 | ' | 2 | 90 | 0 | .000000 | .0000 | ! 145 | OK | .000 | -120307. | -1.0000000 |
| .019951 | .001000 | 30.000000 | 'RECRUIT 91 | ' | 2 | 91 | 0 | .000000 | .0000 | ! 146 | OK | .000 | -67755. | -1.0000000 |
| .054646 | .001000 | 30.000000 | 'RECRUIT 92 | ' | 2 | 92 | 0 | .000000 | .0000 | ! 147 | OK | .000 | -104905. | -1.0000000 |
| .001000 | .001000 | 30.000000 | 'RECRUIT 93 | ' | 2 | 93 | 0 | .000000 | .0000 | ! 148 | BOUND | .000 | -1. | -1.0000000 |
| .015899 | .001000 | 30.000000 | 'RECRUIT 94 | ' | 2 | 94 | 0 | .000000 | .0000 | ! 149 | OK | .000 | -444138. | -1.0000000 |
| .011388 | .001000 | 30.000000 | 'RECRUIT 95 | ' | 2 | 95 | 0 | .000000 | .0000 | ! 150 | OK | .000 | -636224. | -1.0000000 |
| .001000 | .001000 | 30.000000 | 'RECRUIT 96 | ' | 2 | 96 | 0 | .000000 | .0000 | ! 151 | BOUND | .000 | -1. | -1.0000000 |
| .007573 | .001000 | 30.000000 | 'RECRUIT 97 | ' | 2 | 97 | 0 | .000000 | .0000 | ! 152 | OK | .000 | -1213547. | -1.0000000 |
| .001032 | .001000 | 30.000000 | 'RECRUIT 98 | ' | 2 | 98 | 0 | .000000 | .0000 | ! 153 | OK | .000 | -9818191. | -1.0000000 |
| .001000 | .001000 | 30.000000 | 'RECRUIT 99 | ' | 2 | 99 | 0 | .000000 | .0000 | ! 154 | BOUND | .000 | -1. | -1.0000000 |
| .019410 | .001000 | 30.000000 | 'RECRUIT 100 | ' | 2 | 100 | 0 | .000000 | .0000 | ! 155 | OK | .000 | -126144. | -1.0000000 |
| .001853 | .001000 | 30.000000 | 'RECRUIT 101 | ' | 2 | 101 | 0 | .000000 | .0000 | ! 156 | OK | .000 | -3099014. | -1.0000000 |
| .006326 | .001000 | 30.000000 | 'RECRUIT 102 | ' | 2 | 102 | 0 | .000000 | .0000 | ! 157 | OK | .000 | -333911. | -1.0000000 |

Appendix 3.  Stock Synthesis data file (truncated at right and bottom).

```
Alec's2002CombinedBocacciodataforCalifornia
3807    1       trawl   H&Lso   H&Lcen  setnetSO        setnetCEN       recSO   recCEN
50      1       2816    428     438     0       0       39      86
51      1       3895    471     620     0       0       35      98
52      1       3866    366     630     0       0       45      86
53      1       4494    298     750     0       0       56      72
54      1       4401    583     750     0       0       122     91
55      1       3451    1810    492     0       0       213     108
56      1       4608    1481    689     0       0       256     121
57      1       4803    1818    678     0       0       138     120
58      1       5041    1804    1249    0       0       95      193
59      1       4691    1056    1185    0       0       57      160
60      1       3922    1663    636     0       0       63      125
61      1       2821    1480    612     0       0       72      94
62      1       2460    1359    642     0       0       68      109
63      1       3102    1611    617     0       0       67      111
64      1       2177    1046    459     0       0       94      85
65      1       2508    1213    540     0       0       117     132
66      1       2571    1430    564     0       0       170     142
67      1       2162    1799    483     0       0       210     140
68      1       2173    1616    495     0       0       223     166
69      1       2190    1516    479     0       0       212     154
70      1       2908    1417    523     0       0       289     204
71      1       3031    1245    791     0       0       244     167
72      1       4302    2080    1066    0       0       339     226
73      1       6043    2407    1553    0       0       401     260
74      1       5673    2638    1441    0       0       459     289
75      1       6132    2999    1586    0       0       450     276
76      1       6113    3439    1608    0       0       417     248
77      1       4969    3181    1330    0       0       377     218
78      1       2830    145     35      83      47      350     196
79      1       1792    115     228     0       3       1021    242
80      1       3646    84      215     121     77      1691    190
81      1       3988    161     76      213     227     844     233
82      1       4340    301     559     176     423     1010    329
83      1       4297    156     138     135     1227    261     272
84      1       3188    75      131     242     385     170     47
85      1       1223    81      36      305     973     309     67
86      1       1046    147     20      327     1065    395     172
87      1       1153    73      181     253     1585    104     113
88      1       1226    144     172     76      505     111     52
89      1       1120    112     172     193     1476    266     88
90      1       1102    198     143     8       1061    233     91
91      1       704     26      157     174     404     200     92
92      1       490     335     212     98      659     167     92
93      1       559     270     222     160     366     135     99
94      1       528     151     86      53      268     195     43
95      1       377     21      50      62      281     43      30
96      1       288     36      64      27      76      78      30
97      1       230     24      34      7       31      66      97
98      1       73      12      29      4       37      30      29
```

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99 | 1 | 45 | 3 | 18 | 2 | 5 | 60 | 80 | | | | |
| 100 | 1 | 19 | 2 | 5 | 0 | 1 | 59 | 147 | | | | |
| 101 | 1 | 14 | 3 | 5 | 0 | 1 | 105 | 87 | | | | |
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| 95 | 1 | 8 | 11 | 31 | 14 | 1995 | TRIENNIAL | INDEX |

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0.22475         0.03657         eggs/kginterceptandslopeReinterpretedfromPhillipsbyRalston1996


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Beginning       OF      SIZEANDAGECOMPOSITION

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Remainder of file (332 lines) omitted

**Bocaccio Rebuilding Analysis for 2002**

Alec D. MacCall and Xi He (June 2002)
NMFS Santa Cruz Laboratory
110 Shaffer Rd.
Santa Cruz, CA 95060
email: Alec.MacCall@noaa.gov, Xi.He@noaa.gov

## Introduction

In 1998, the PFMC adopted Amendment 11 of the Groundfish Management Plan, which established a minimum stock size threshold of 25% of unfished biomass. Based on the stock assessment by Ralston et al. (1996), bocaccio was declared formally to be overfished, thereby requiring development of a rebuilding plan for consideration by the Council in the fall of 1999. A new stock assessment (MacCall et al. 1999) found that under continuing recruitment failure, the index of bocaccio spawning output was about half the the estimate made in 1996, but at that time preliminary indications of a strong 1999 year class allowed some optimism.

The most recent stock assessment (MacCall 2002) is based on a wide variety of information from both Central and Southern California. The new estimate of the strength of the 1999 year class is at or below the low end of the range considered in the1999 analyses. The following rebuilding analysis utilizes the SSC Rebuilding Analysis (V1.5) developed by Andre Punt of the PFMC-SSC, and incorporates the information developed in the 2002 bocaccio stock assessment.

## Management Reference Points

**$B_{unfished}$.** Unfished biomass is estimated by multiplying average recruitment by the spawning output per recruit achieved when the fishing mortality rate is zero ($SPR_{F=0}$ = 1.3806, spawning output in billion eggs, recruitment in thousand fish at age 1). The estimated unfished spawning output is 14857 billion eggs, based on the average recruitment between 1953 and 1998. Because recruitment is highly variable, this calculation is imprecise (CV = 31%) as can be seen in Figure 1.

**$B_{msy}$.** The rebuilding target is the spawning abundance level that produces MSY. This value cannot be determined directly for bocaccio, so we use the proxy value of 40% of estimated unfished spawning abundance. Estimated $B_{msy}$ is 5943 billion eggs.

**Mean generation time.** Mean generation time of bocaccio can be estimated from the net maternity function, and is estimated to be 12 years.

**Simulation Model**

The rebuilding model tracks male and female abundances at age, with an accumulator at age 21+. Values of weights at age, composite selectivity and fecundity are taken from MacCall (2002), and are given in Appendix 1. Population simulations begin with the 2002 age composition. Subsequent recruitments are generated by a random draw of one of the historical values of R/S (from 1953 to 1999), which is multiplied by current spawning output (S) to obtain the following year's recruitment. Resampling R/S is supported by the nearly constant pattern of historical R/S values (Figure 2), whereas the strong historical decline in recruitment strengths argues against resampling recruitments directly (Figure 3). Simulations extend to a maximum of 500 years, and the maximum number of simulations allowed by the program (N=10000) was used to minimize the imprecision in the analysis.

Rebuilding is assumed to have begun in 2000, and three years of rebuilding have elapsed as of the beginning of 2003. The model accounts for further removals that occurred following the beginning of 2002; the catch in 2002 is still unknown but is assumed to be 100MT in the base model. Sensitivity analyses address the consequences of alternative catch scenarios.

The distribution of simulated times (number of years) to reach the rebuilding target at F=0 ($T_{min}$) is wide, ranging from about 20 years to over 500 years (Figure 4). The mode (most frequent) rebuilding time is about 60 years. The median (50% probability) rebuilding time is 97 yr (SE = 1 yr). The maximum length of time to rebuild is this value plus one generation time (12 yr), less the time already elapsed since the start of rebuilding (3 yr), or 106 years. The maximum allowable fishing mortality rate is that which allows the stock to achieve the target abundance in 106 years (i.e., calendar year 2108), with a probability of 50%. The constant fishing rate that achieves a 50% rebuilding success by year 2108 translates to a catch of 5.8 MT (SE = 0.6MT) in 2003. In most rebuilding plans, options with a higher probability of success (e.g., 60%) are considered. In the case of bocaccio, the maximum probability of rebuilding by year 2108 is 54% under no catch, so options for higher probabilities do not exist at the present time.

Simulated individual rebuilding trajectories are erratic (Figure 5). The time series of percentiles of simulated trajectories (Figure 6) is more informative. A peculiar feature of the boccacio simulations is that the median abundance (dark line in Figure 6) does not reach the target level after 106 years ($T_{max}$). Although 50% of the simulations achieved the target level at some time on or before 97 years (thus qualifying as having been rebuilt), many of those trajectories subsequently declined so that only about 30% are currently at or above the target after 97 years. This property is consistent with the behavior of individual simulations (Figure 5).

The rebuilding consequences of some of the uncertainties described in the bocaccio stock assessment are examined in Table 1. Most sources of uncertainty have little effect on rebuilding OYs. Note that cases emphasizing Central or Southern California information are for comparison only, and are not properly specified for use as management options.

**References**


MacCall, A. 2002. Status of bocaccio off California in 2002. Prepared for the PFMC.

MacCall, A., S. Ralston, D. Pearson and E. Williams. 1999. Status of bocaccio off California in 1999, and outlook for the next millennium. Pacific Fishery Management Council.

Ralston,S., J. Ianelli, R. Miller, D. Pearson, D. Thomas, and M. Wilkins. 1996. Status of bocaccio in the Conception/Monterey/Eureka INPFC areas in 1996 and recommendations for management in 1997. Pacific Fishery Management Council.


Table 1. Results of sensitivity analyses.

| Model | Tmin | OY | Generation Time |
|---|---|---|---|
| Base Model (100t catch in 2002) | 97 | 5.8 | 12 |
| M = 0.15 | 64 | 9.8 | 14 |
| M = 0.25 | 257 | 1.5 | 11 |
| Emphasis on Southern California information | 47 | 39.1 | 12 |
| Emphasis on Central California information | 106 | 2.5 | 12 |
| Emphasis on abundance data | 77 | 7.9 | 12 |
| Emphasis on composition data | 94 | 5.2 | 12 |
| Use unaltered RecFin data | 99 | 6.4 | 12 |
| Early SoCalif commercial catch at 50% | 103 | 4.9 | 12 |
| Recent commercial catch at 2x landings | 97 | 5.3 | 12 |
| Assume 200t catch in 2002 | 99 | 5.6 | 12 |

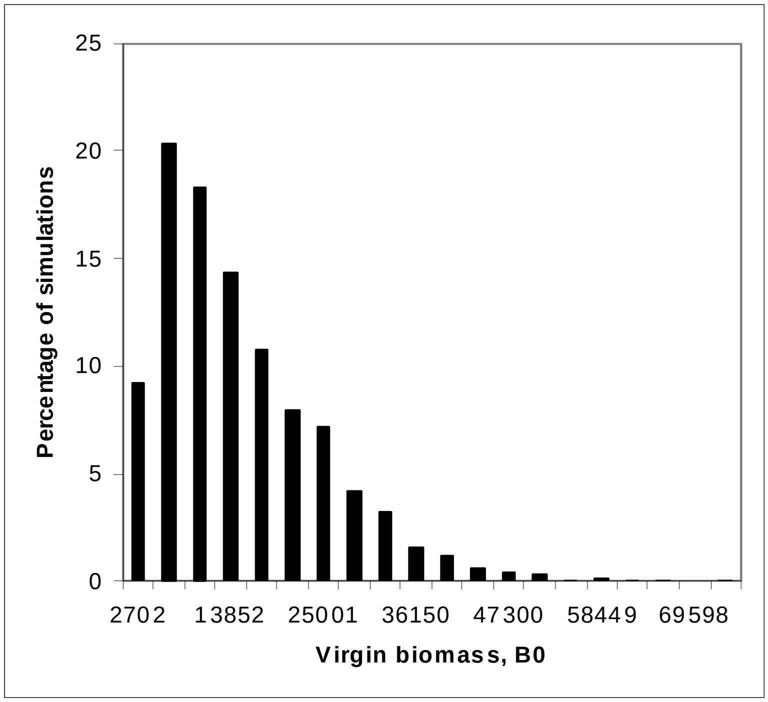


**Figure 1**. Distribution of simulated unfished abundances (measured as spawning output in billion eggs)

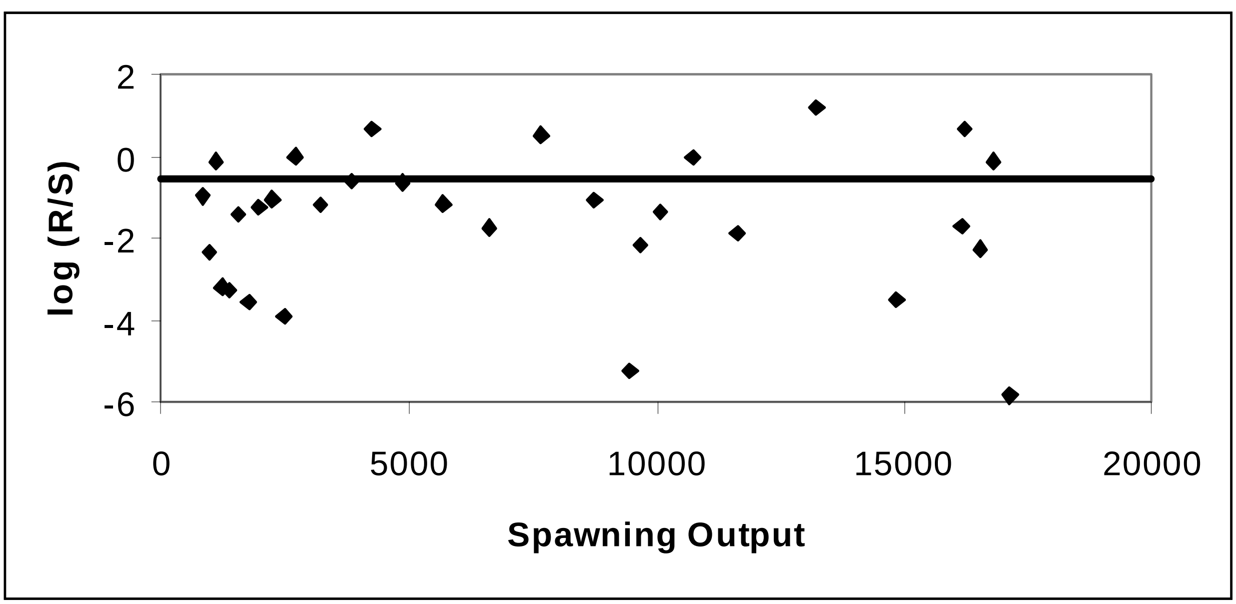


**Figure 2.** Historical bocaccio reproductive success related to parental abundance. Horizontal line is replacement level in the absence of fishing.

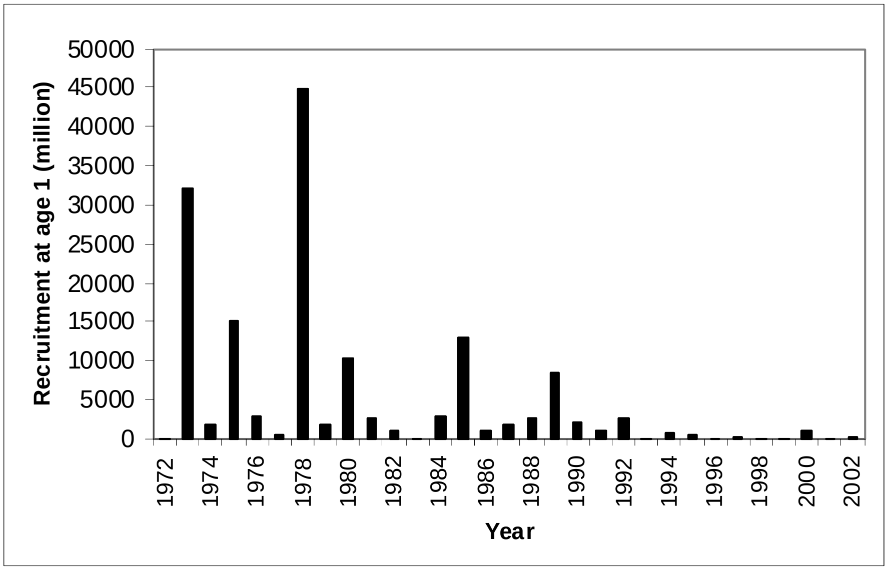


**Figure 3**. Historical series of bocaccio recruitments.

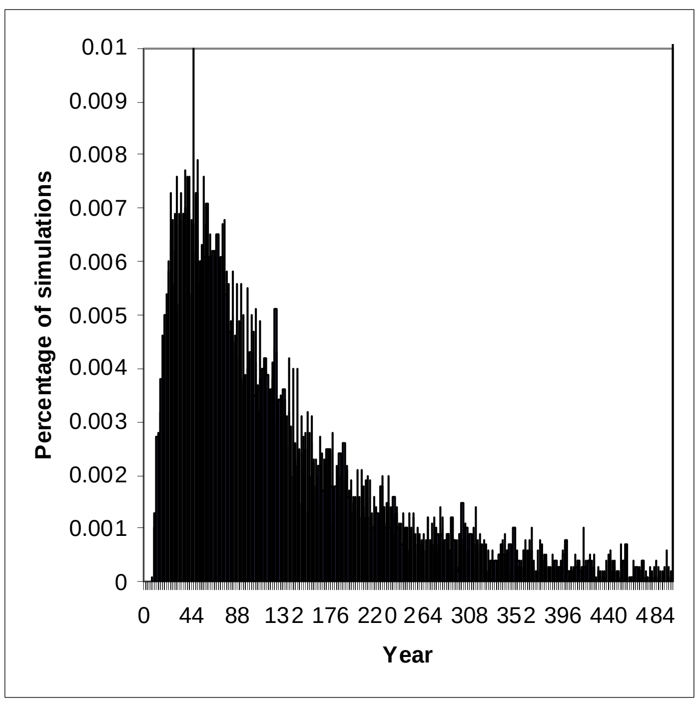


**Figure 4**. Distribution of simulated bocaccio rebuilding times in the absence of fishing.

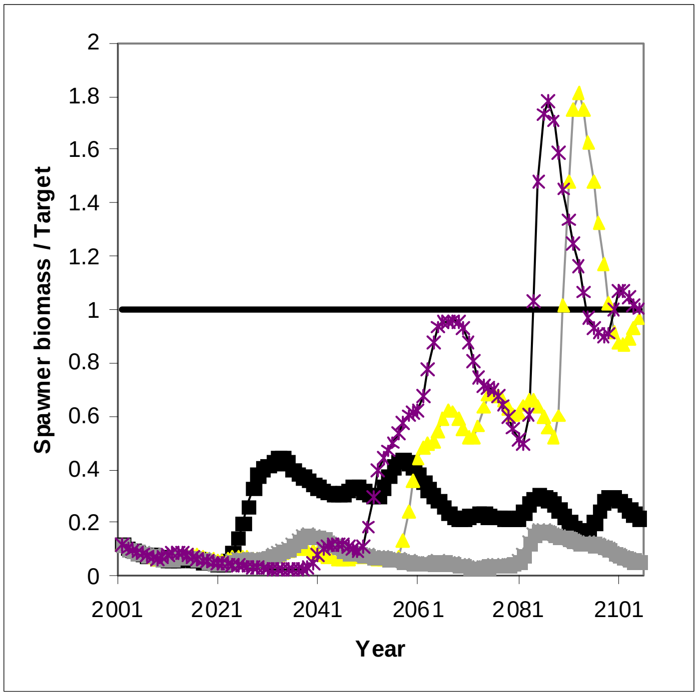


**Figure 5**. Simulated bocaccio rebuilding trajectories.

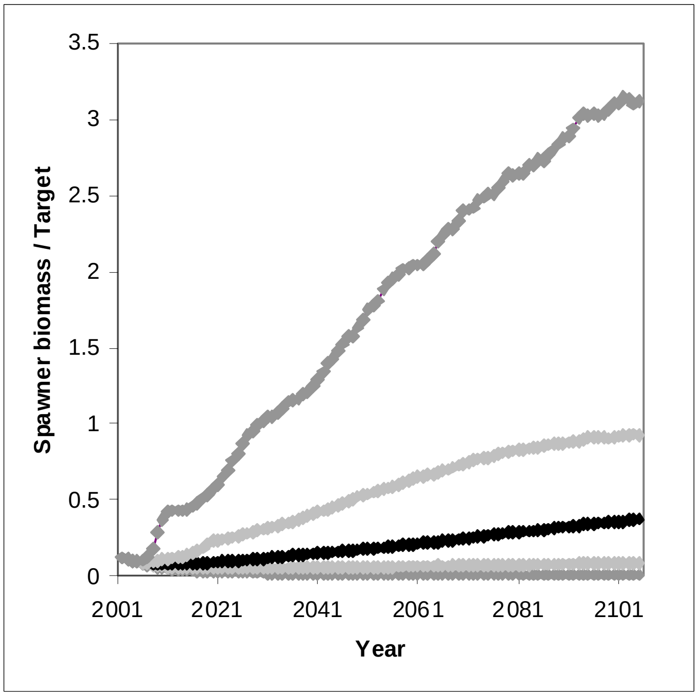


**Figure 6**. Time series of relative abundance expressed as percentiles (5, 25, 50, 75 and 95) of simulations.

Appendix: Input file for SSC rebuilding analysis.

#Title
Bocaccio - default assumptions
# Number of sexes
2
# Age range to consider (minimum age; maximum age)
1 21
# First year of projection
2002
# Year declared overfished
1999
# Is the maximum age a plus-group (1=Yes;2=No)
1
# Generate future recruitments using historical recruitments (1), historical recruits/spawner (2), or a stock-recruitment (3)
2
# Constant fishing mortality (1) or constant Catch (2) projections
1
# Pre-specify the year of recovery (or -1) to ignore
-1
# Fecundity-at-age
#  3  4  5  6  7  8  9 10
0.0000 0.0018 0.0242 0.1224 0.3104 0.5362 0.7541 0.9552 1.1442 1.3211 1.4838 1.6315 1.7634 1.8796 1.9808 2.0683 2.1428 2.2060 2.2594 2.3042 2.4610
# Age specific information (Females then males), M, weight, selectivity and numbers
# Females
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2142 0.4922 0.8601 1.2841 1.7392 2.1965 2.6236 3.0185 3.3812 3.7072 3.9958 4.2487 4.4677 4.6563 4.8176 4.9551 5.0713 5.1692 5.2516 5.3206 5.5526
0.297077 0.843938 0.999140 0.899828 0.730868 0.559329 0.420034 0.312984 0.235168

0.181857 0.145744 0.121238 0.103611 0.091574 0.082545 0.075666 0.070937
0.067068 0.064058 0.061479 0.055460
158.2 35.4 251.7 8.8 6.7 38.8 4.0 34.8 36.7 1.7 63.3 16.2 23.2 63.5 13.1 6.2 2.9 25.6
4.6 0.1 87.8
# Males
0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2154 0.4451 0.7275 1.0347 1.3451 1.6467 1.9313 2.1867 2.4054 2.5913 2.7515 2.8888 3.0058 3.1046 3.1874 3.2567 3.3144 3.3625
3.4021 3.4348 3.5419
0.300086 0.782029 1.000000 0.974205 0.881771 0.767412 0.654342 0.558899 0.483663
0.424334 0.376182 0.337059 0.306105 0.281599 0.262683 0.248065 0.236457
0.226999 0.219690 0.213672 0.198624
158.2 35.4 255.2 8.9 6.6 37.2 3.8 32.3 33.2 1.5 55.1 13.4 18.2 46.4 8.7 3.7 1.5 11.1
1.8 0 20.4
# Number of simulations
10000
# Recruitment and Spanwer biomasses
# Number of historical assessment years
49
# Historical data: Year, Recruitment, Spawner biomass, Used to compute B0, Used to project based
# on R, Used to project based on R/S

| | | | | | |
|---|---|---|---|---|---|
| 1954 | 50 | 10537 | 1 | 0 | 0 |
| 1955 | 50 | 11402 | 1 | 0 | 0 |
| 1956 | 50 | 11324 | 1 | 0 | 1 |
| 1957 | 96 | 10133 | 1 | 0 | 1 |
| 1958 | 53201 | 8365 | 1 | 0 | 1 |
| 1959 | 9922 | 6296 | 1 | 0 | 1 |
| 1960 | 580 | 5135 | 1 | 0 | 1 |
| 1961 | 769 | 5166 | 1 | 0 | 1 |
| 1962 | 8713 | 5538 | 1 | 0 | 1 |
| 1963 | 169111 | 5526 | 1 | 0 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| 1964 | 388 | 5066 | 1 | 0 | 1 |
| 1965 | 232 | 6006 | 1 | 0 | 1 |
| 1966 | 219 | 9753 | 1 | 0 | 1 |
| 1967 | 256 | 14630 | 1 | 0 | 1 |
| 1968 | 478 | 17909 | 1 | 0 | 1 |
| 1969 | 7360 | 18927 | 1 | 0 | 1 |
| 1970 | 92424 | 18429 | 1 | 0 | 1 |
| 1971 | 154 | 17121 | 1 | 0 | 1 |
| 1972 | 50 | 16216 | 1 | 0 | 1 |
| 1973 | 31983 | 16526 | 1 | 0 | 1 |
| 1974 | 1752 | 16808 | 1 | 0 | 1 |
| 1975 | 15045 | 16150 | 1 | 0 | 1 |
| 1976 | 2955 | 14840 | 1 | 0 | 1 |
| 1977 | 455 | 13233 | 1 | 0 | 1 |
| 1978 | 44923 | 11621 | 1 | 0 | 1 |
| 1979 | 1779 | 10731 | 1 | 0 | 1 |
| 1980 | 10397 | 10065 | 1 | 0 | 1 |
| 1981 | 2660 | 9678 | 1 | 0 | 1 |
| 1982 | 1127 | 9459 | 1 | 0 | 1 |
| 1983 | 50 | 8735 | 1 | 0 | 1 |
| 1984 | 3053 | 7666 | 1 | 0 | 1 |
| 1985 | 12986 | 6629 | 1 | 0 | 1 |
| 1986 | 1170 | 5699 | 1 | 0 | 1 |
| 1987 | 1801 | 4867 | 1 | 0 | 1 |
| 1988 | 2587 | 4249 | 1 | 0 | 1 |
| 1989 | 8436 | 3846 | 1 | 0 | 1 |
| 1990 | 2078 | 3222 | 1 | 0 | 1 |
| 1991 | 998 | 2703 | 1 | 0 | 1 |
| 1992 | 2732 | 2466 | 1 | 0 | 1 |
| 1993 | 50 | 2239 | 1 | 0 | 1 |
| 1994 | 795 | 1976 | 1 | 0 | 1 |
| 1995 | 569 | 1749 | 1 | 0 | 1 |
| 1996 | 50 | 1556 | 1 | 0 | 1 |
| 1997 | 379 | 1383 | 1 | 0 | 1 |
| 1998 | 52 | 1217 | 1 | 0 | 1 |
| 1999 | 50 | 1089 | 1 | 0 | 1 |
| 2000 | 971 | 961 | 0 | 0 | 1 |
| 2001 | 93 | 832 | 0 | 0 | 0 |
| 2002 | 316 | 720 | 0 | 0 | 0 |

# Number of years with pre-specified catches
1
# catches for years with pre-specified catches
2002 100.0

```
# Number of future recruitments to override
0
# Process for overiding (-1 for average otherwise index in data list)
# Which probability to product detailed results for (1=1.5,2=0.6,etc.)
1
# Steepness and sigma-R
0.5 0.5
# Target SPR rate (FMSY Proxy)
0.5
# Target SPR information: Use (1=Yes) and power
0 20
# Discount rate (for cumulative catch)
0.1
# Truncate the series when 0.4B0 is reached (1=Yes)
0
# Set F to FMSY once 0.4B0 is reached (1=Yes)
1
# Percentage of FMSY which defines Ftarget
0.9
# Conduct MacCall transition policy (1=Yes)
0
# Defintion of recovery (1=now only;2=now or before)
2
# Produce the risk-reward plots (1=Yes)
0
# Calculate coefficients of variation (1=Yes)
0
# Number of replicates to use
10
# First Random number seed
-89102
```