TECHNICAL REPORT
TO THE
CALIFORNIA COASTAL COMMISSION

D. Adult-Equivalent Loss

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October 1989

TABLE OF CONTENTS

APPENDICES

i

TABLE OF CONTENTS - APPENDICES

APPENDIX E: Estimating Duration At Rick For Planktonic Stages

iv

SUMMARY

In this report we estimate the loss of adult-equivalent fish due to entrapment by SONGS' Units 2 and 3. We define an adult equivalent as a fish that would have recruited to the adult stock had it not been entrapped as an egg, larva, or juvenile. We estimate adult-equivalent loss in terms of 1) percent of new recruits and 2) numbers and biomass of the standing stock. The first estimate, percent of new recruits, is an annual rate. This we estimate for 21 taxa. The second, loss to the standing stock, is for all year classes combined and requires the accumulated effect of plant operation over the number of years equal to the oldest fish in the stock.

Percent of New Recruits

The percent of new recruits lost is highest for those taxa with the highest proportions of planktonic and juvenile stages found in waters near the depth of SONGS' intake risers. Of the 21 taxa studied, three have estimated losses in excess of 5%, 11 have estimated losses between 1% and 5%, and seven have estimated losses less than 1%. Queenfish, white croaker and giant kelp fish have the highest estimated losses, 12.7%, 7.5% and 6.5%, respectively. Northern anchovy, Pacific mackerel and California halibut, whose planktonic and juvenile stages are not at great risk to entrapment, have the lowest estimated loss, all less than 0.2%.

Numbers and Biomass

We estimate loss to the standing stocks of adults for three taxa, those for which we could estimate adult abundance. Losses are 551 MT (18,000,000 fish) and 394 MT (4,100,000 fish) for queenfish and white croaker, respectively. Estimated loss of northern

anchovy is 1,340 MT (89,000,000 fish). These three taxa account for approximately 70% of all entrained larvae and together sum to total loss of over 2,290 MT.

1.0 INTRODUCTION

SONGS' Units 2 and 3 draw in approximately 6.8 million cubic meters of water per day. This equals the volume of a seawater tank with a base the size of a football field and a height of over one-half mile. Entrapped with these waters are adult and juvenile fish, larvae, and eggs. Some entrapped adults and juveniles (sexually immature fish) are impinged or otherwise killed. The fish return system may allow a significant portion of older juveniles and adults to survive (DeMartini *et al.* 1987; Love *et al.* 1987). All entrapped larvae and eggs are killed (Barnett 1987).

In this report we evaluate the potential effects of SONGS' entrapment of eggs, larvae, and juveniles on stocks of adult fish living in the California Bight, the body of water extending from Cabo Colnet, Baja California, Mexico to Point Conception. We call this estimate "relative adult-equivalent loss," or simply "adult-equivalent loss." We define an adult-equivalent as a fish that would have recruited to the adult stock, had it not been entrapped and killed as an egg, larva, or juvenile. We estimate adult-equivalent loss for 21 taxa: those with the highest risk to entrapment and/or those of sport/commercial interest. We do not estimate losses for taxa where only the juvenile stage is entrapped because of insufficient data. However, we do discuss the relative magnitude of loss of these taxa.

We report adult-equivalent loss in two ways. First, we report adult-equivalent loss as a percent of new recruits to the adult stock (annual cohort). This estimate is an annual rate. Second, for select taxa, we estimate the numbers and biomass of adult equivalents lost to the standing stock.

1

To compute relative loss, our primary task, we use procedures developed by MacCall *et al*. (1983). While we discuss these procedures in METHODS, we mention at this point the main advantage of using this technique: estimates of natural mortality for eggs, larvae, and juveniles are not required. This is fortunate, since the natural mortality rates of these lifestages are unknown. (In fact, natural mortality rates for the adults of most entrapped taxa have never been estimated.) Other methods make a less direct comparison. Goodyear (1978) extended a method proposed by Horst (1975) for treating entrained larvae in terms of adult-equivalent losses. Additional methods of assessment include more complex models using Leslie matrices (Vaughan and Saila 1976; Horst 1977; Vaughan 1981), differential equations (Hackney *et al*. 1980), or stock-progeny-recruit models (Christensen *et al*. 1977). All of these methods, including those used in the Hudson River Study (see Barnthouse *et al*. 1984), require life history parameters (i.e., fecundity, survivorship) which are unknown for the taxa analyzed in this report. The procedures of MacCall *et al*. require only 1) estimates of the ratio of numbers entrapped to numbers in the source water (the Bight), and 2) duration of risk to entrapment.

We estimate the potential loss in numbers and biomass of adult fish by multiplying relative adult-equivalent loss (an annual rate) times the abundance of adults (all year classes) in the Bight. In effect, we compute loss by reducing each year class in the adult stock by the relative loss it would have experienced during its first year (as an egg, larvae or juvenile) due to SONGS' operation. Thus, we essentially accumulate loss over the number of years represented in the adult stock. We estimate adult abundance and, consequently, losses in numbers and biomass for only three taxa (queenfish, white croaker, and northern anchovy). These three taxa together account for approximately 70% of all entrapped eggs and larvae.

We use common names when discussing taxa. Table 1 lists common and corresponding scientific names.

2.0 METHODS

Estimation of Reduced Recruitment of New Adults due to Entrainment of Immature Stages

SONGS' intake risers sit at approximately the 9 m depth contour and rise 4 to 5 meters from the bottom. SONGS entraps immature fish (juveniles, larvae, and eggs) which live near this depth. The higher the proportion of a taxon's populations of immatures found in waters at this depth, the greater the relative risk to entrapment. Thus for taxa like queenfish, where the older larvae and juveniles are found almost exclusively in waters at this depth, the risk is high. For taxa like northern anchovy, where these planktonic stages are also abundant offshore, the relative risk to the population is less, despite the fact that SONGS entraps greater numbers of the eggs, larvae, and juveniles of anchovies than queenfish.

The design of the MRC's (1988a) ichthyoplankton sampling program provides a useful means for illustrating relative risk. The MRC sampled the density of ichthyoplankton in five cross-shelf blocks (A, B, C, D, and E, Figure 1). The intake risers sit at approximately the boundary of A- and B-Blocks, 1.1 km from shore. SONGS entraps waters from both these blocks (ECOsystems 1988). Data (presented in RESULTS) indicate that for most taxa considered in this report, the populations of eggs and larvae are not found beyond E-Block. (Northern anchovy is an exception.) Thus, the higher the proportion of A- through E-Block immatures found in A- and B-Blocks, the higher the relative risk to entrapment. Additionally, longer-lived stages have longer exposure to entrapment and are at higher risk. Following MacCall *et al.*, we use this basic idea of risk being a function of (1) cross-shelf distribution, and (2) time at risk, to estimate adult-equivalent loss (following).

4

2.1 Basic Method for Estimating Adult Equivalent Losses

The basis of our projections of adult equivalent losses is the following calculations, given by McCall *et al.* (1983).

Suppose that, without SONGS, the probability of surviving the ith immature stage is p_i. This is the ratio of the number entering stage i to the number entering stage i+1. If there are k immature stages (including eggs), the probability of a new-born egg surviving to adulthood is the product, $p_1 p_2 ... p_k$.

With SONGS in operation, surviving the ith stage requires avoiding both natural mortality and entrapment. If the natural rates are unchanged, and the probability of avoiding entrapment in the ith immature stage is q_i, the probability of surviving the ith stage is the product, $p_i q_i$. The probability of a new-born egg surviving to adulthood is now $p_1 q_1 p_2 q_2 ... p_k q_k$.

The new rate of recruitment, expressed as a fraction of the old rate, is the ratio of the post-SONGS to the pre-SONGS probability. This is the product of the probabilities of avoiding entrapment,

$$R_c = q_1 q_2 ... q_k, = (1 - E_1)(1 - E_2)...(1 - E_k),$$

where E_i is the probability of an entering stage i fish being entrapped before reaching stage i + 1. The fractional loss in recruitment is then $1 - R_c$.

2.1.1 Compensation Ignored

These calculations assume that natural survival rates (p_1, p_2, ..., p_k in the description above) do not change: that there is no compensation as the density of immatures declines. This is deliberate. Our <u>aim</u> is to determine the reductions in recruitment rates of new adults implied by the <u>uncompensated</u> killing of immature stages by SONGS. These overall rate reductions combine the effects on the different life stages, to summarize the direct effect of SONGS on the populations.

In addition, the calculation of these reductions will later become an intermediate step toward the calculation of the change in fish stocks, when compensation <u>is</u> considered (see Technical Report M). When the new equilibrium population is reached, at which SONGS losses are matched by the increased growth, fecundity or survival of the individuals not killed by SONGS, rates of adult recruitment and of adult mortality must again be equal. Except for any compensation via adult survival, this implies that, when the new equilibrium is reached, the rate of recruitment to the adult population is again what it was before SONGS began.

2.1.2 Loss to the Adult Standing Stock

To give a feeling for the amount of loss implied by the fractional loss, we estimate the loss to the adult standing stock to be

Adult Loss = (Fractional loss) × (Current Standing Stock)

$$= (1 - R_c) \times \text{(Current Standing Stock)}.$$

This calculation assumes that the total number of eggs produced per year remains constant. Since the number of adults has been reduced, this assumption is one of compensation: the number of eggs produced per adult must increase when the adult population declines. Some such assumption is needed: without compensation, the standing stock would decrease each year, and the adult loss would decrease with it, eventually to zero.

The adult loss described here is not the loss in new recruits each year. This loss is

$$\text{Recruits Lost} = (1 - R_c) \times (\text{Pre-SONGS number of recruits}).$$

The adult standing stock is composed of more than one year class, so it contains not only the most recent set of recruits, but also the survivors from the recruits of earlier years. Thus our calculation assumes that SONGS has been operating since before the birth of the oldest fish in the stock, so that all year classes have been affected. All rates other than egg production are assumed to be unchanged.

2.2 Estimation of Entrapment Probabilities

We now turn to the problem of estimating the probabilities of avoiding entrapment, $q_1, q_2, ..., q_k$.

First we define the "instantaneous" probability of entrapment for a fish in stage i to be

7

e_i = (fraction of stage i fish entrapped in time t)/t,

when t is very small.

It can be shown that, if e_i is constant throughout the ith stage, the probability of avoiding entrapment for T time units is exp(-e_iT). In particular, if the duration of the ith stage is d_i time units, the probability of avoiding entrapment through the entire stage is

$$E_i = \exp(-e_i d_i).$$

If e_i is not constant through the stage, the same formula still holds for E_i, except that "e_i" must now be interpreted as the average entrapment. Technically, if the entrapment rate for immatures of age t is e(t), then

$$e_i = I\ e(t)dt/d_i$$

the integral being from t = t_i, the beginning of the stage, to t = t_i + d_i, the end.

Thus, E_i can be estimated by substituting estimates of e_i, the entrapment rate, and d_i, the stage duration, in this relationship.

2.3 Estimation of Entrapment Rates

The instantaneous probability of entrapment, per day, for any stage is estimated as

$$^* \qquad e_i = L/S$$

where

8

L = estimated number of stage i entrapped per day

and

S = estimated total number of stage i in the population.

The "population" is taken to be the population of the Southern California Bight, defined as extending from Cabo Colnet, Baja California, Mexico to Point Conception, about 500 km (after Jones 1971). While eggs, larvae, juveniles, and adults for many taxa considered in this report extend both north and south of the Bight, we use the Bight because it represents a natural ecological and economic unit. The immatures killed by SONGS will almost all have been born inside the Bight, and the losses are unlikely to be significant outside it.

2.3.1 Entrapment Rate for Plankton

In this section we describe the estimation of L and S for plankton of a given stage (referred to as "plankton"). The stages are (1) eggs (when they are planktonic), (2) yolksac and preflexion larvae, (3) flexion larvae, and (4) postflexion larvae.

Since plankton appear to move passively with the water, the number killed per day can be estimated by

$$L = D_S W_S,$$

where

W_S = amount of water withdrawn by SONGS per day

and

D_S = density of plankton in the water withdrawn by SONGS.

9

An estimate of the standing stock, the total number of plankton in the population, is given by

$$S = D_B W_B$$

where

W_B = amount of water in the Bight

and

D_B = average density of plankton in the Bight.

For W_S, we need the average daily intake volume for Units 2 and 3: Unit 1 is not covered in this Report, and it is the actual average flow that determines the number of plankton entrapped, not the flow at full operation. Since 1984, this average daily intake volume has been 6.8×10^6 m³/day (MRC 1988b). Thus we take

$$W_S = 6.8 \times 10^6 \text{ (m}^3\text{/day)}.$$

To estimate D_S and D_B, we use data collected by Marine Ecological Consultants (MEC) at an Impact site near SONGS (1-3 km south of the intakes) and at a Control site (18 km south). These were analyzed for 21 taxa, chosen either for their sport/commercial importance or because they are highly at risk (have high proportions of their populations living in entrapped waters).

In 1978 MEC collected abundance data at the Impact site only. From 1979 through 1986, abundance data were collected at both the Impact and Control sites. Each site was divided into 15 strata: five cross-shelf blocks (A, B, C, D, and E) and three depth zones (neuston, midwater, and epibenthos). MEC defined neuston as the top 0.16 m and epibenthos as the bottom 0.5 m. On each cross-shelf survey,

each of the 15 strata was sampled. From 1983 through 1986, samples from E-Block were not analyzed in the laboratory. The MRC's (1988a) report on ichthyoplankton describes sampling and data analysis procedures.

SONGS' Units 2 and 3 draw in waters from both A- and B-Blocks. Thus we estimate the density of plankton in the water withdrawn by SONGS as

$$D_S = \text{number per } m^3 \text{ in A and B Blocks.}$$

This number per m^3 is obtained by multplying the densities per m^3 in the three regions (neuston, midwater and epibenthos) by the relative volumes these regions represent, i.e., (volume of region)/(total volume of A and B Blocks), and adding these products.

Since most of the taxa considered in this report are not found beyond E-Block (Table 2), we estimate the Bight-wide density by the numbers contained in a meter-wide strip running from the shore to the outer edge of E-Block, about 7 km offshore. Thus

$$D_B = \text{number per meter-wide strip through Blocks A-E.}$$

Since D_B is given in terms of meter-wide strips, W_B is the number of such strips in the Southern California Bight. The Bight is about 500 km long, so

$$W_B = 500,000.$$

The estimates given here make several assumptions, the most important appearing to be: planktonic eggs and larvae move passively with the water, so the number killed is the density in the water multiplied by the amount of water withdrawn; plankton in neuston, midwater and epibenthos are equally at risk; the density over A-B Blocks is approximately the same as in the water withdrawn by SONGS (which is near the boundary between A and B Blocks); and a meter-wide strip near SONGS is "typical" of the Bight, i.e., it contains about the same number of plankton as the average of such strips over the entire Bight.

A further assumption is that plankton in A-B Blocks and plankton in C-E Blocks are equally catchable. We do not need perfect catchability: as long as catchability is the same, so that both D_S and D_B are underestimated by the same proportion, the ratio L/S is unaffected.

In some cases, final estimates required some assumptions due to gaps in the data.

Eggs cannot be identified to taxon, except for northern anchovy and a few other species not on the target list. But the egg stage is short, both absolutely (2.5 days) and relative to the other stages, so we assume that the distribution (i.e., D_S/D_B) is the same for eggs as for yolksac and preflexion larvae.

For all stages, the estimates of both the A-B density and the A-E density used both pre- and post- operational data from both Impact and Control areas. SONGS operation may have affected the abundance of four taxa at the Impact site. For

12

these taxa, we adjust for the SONGS effect using estimates of relative change presented in the MRC's (1988a) report on ichthyoplankton.

E-Block samples were analyzed in the laboratory for the pre-operational period, but not for the operational period. We assume that the fraction in E Block of the plankton in A-E Blocks was the same in the post-operational period as in the pre-operational period. Thus we take

$$\text{Post-op A-E} = \text{Post-op A-D} \times [(\text{Pre-op A-E})/(\text{Pre-op A-D})].$$

Further discussion and details of assumptions and sampling methods are given in Appendix A.

2.3.2 Entrapment Rate for Juveniles

We define juvenile as the stage from metamorphosis (end of the post-flexion stage) to first sexual maturity. Metamorphosis occurs when fin rays and scales are fully developed. For most taxa, juveniles mature at the end of the first year.

The methods used to estimate plankton entrapment rates are not suitable for estimating juvenile rates for two reasons. First, juveniles do not move passively with the water: they can resist entrainment, and this ability increases during the stage, as the fish gets bigger. Second, we have no data on juvenile densities: quantitative methods have not been developed to sample early juvenile stages.

For some taxa, e.g., cryptic reef dwellers and some benthic fish such as blennies, juvenile stages do not inhabit water near the intake openings, so are rarely, or never, entrapped. There is significant juvenile entrapment for only 9 of our 21 taxa.

For three of the taxa whose juveniles are entrapped (northern anchovy, queenfish and white croaker), we are able to provide approximate estimates of entrapment rate, using information on post-flexion larvae and young adults. These estimates assume that density near SONGS ("availability") and probability of being unable to escape from water that is being drawn into SONGS ("vulnerability") change during the juvenile stage, as a function of length, from those of the postflexion stage to those of young adults.

Unfortunately, how these functions change is almost completely unknown. This is only of minor importance for availability, since distributions of postflexion larvae are not very different from those of young adults in these cases. But the function is of major importance for vulnerability, which changes greatly between postflexion larvae (vulnerability = 1) and young adults (vulnerability $\approx$ 0, although the high availability of some species results large absolute numbers of entrapped individuals). Whether the bulk of the change from postflexion vulnerability to young adult vulnerability occurs early or late in the juvenile stage has a very large effect on the juvenile entrapment rate. Also, since the juvenile stage is much longer than all the other stages, changes in the juvenile entrapment rate lead to very large changes in the overall adult equivalent loss.

In Appendix D, we give high, middle and low estimates of juvenile entrapment rates, based on different guesses at the vulnerability function. These guesses are guided mainly by the velocity of water at the intakes and by the known relations between body length and "burst speed", the maximum swimming speed of the fish.

For the remaining six taxa whose juveniles are entrapped, these approximate methods are not possible: we cannot estimate the entrapment rates of young adults because we cannot estimate the standing stock. For these taxa, we estimate adult equivalent loss through the postflexion stage only. This clearly underestimates adult equivalent loss.

2.3.3 Duration of the Stages

Duration (d_i) is the length of time (in days) a given life stage i is at risk to entrapment.

For all eggs we use a duration of 2.5 days, the average embryonic period of small, pelagic marine fish eggs at about 16 C° (W. Watson *pers. comm.*).

For all other planktonic stages, we estimate duration in days by dividing the range in length at stage by daily growth rate.

We estimate ranges in length at stage by subtracting modal lengths of successive stages:

range of length for stage $_i$ = (modal length)$_{i+1}$ - (modal length)$_i$.

We feel that differences in modal lengths give us estimates similar to differences in initial lengths, since modal lengths at stage, i and i+1 both overestimate initial length.

We obtain estimates of daily growth rate, as well as estimates of length at hatching and metamorphosis (the beginning and end point of the larval stage) from published literature.

Appendix E gives further details on the estimation of the durations of planktonic stages.

3.0 RESULTS

We discuss those taxa whose juvenile stages are entrapped (Section 3.1) and those whose are not (Section 3.2) separately. Of the nine taxa whose juvenile stages are entrapped, only for three (anchovy, queenfish, and white croaker) were we able to estimate adult equivalent loss for the juvenile stage. For the remaining six of these nine taxa (black croaker, California corbina, California grunion, jacksmelt, kelp and barred sand bass, and salema), we estimate loss through the post-flexion stage only. Since juveniles are entrapped, we know that we underestimate adult-equivalent loss for these six taxa.

For 12 taxa, juveniles return to the adult habitat (usually the benthos or kelp beds) following metamorphosis and are no longer susceptible to entrapment (Section 3.2). For these taxa, we estimate adult-equivalent loss through the post-flexion stage only.

In the following, most information on natural history comes from A Field Guide to Pacific Coast Fishes (Eschmeyer *et al.* 1983). In Table 3 we present estimates of adult-equivalent loss by stage, accumulated to that stage. Thus, the tabulated estimates of adult-equivalent loss for the flexion stage of white croaker, for example, include the losses for preflexion, yolksac, and eggs.

In the following, Baja refers to Baja California, Mexico.

17

3.1 Taxa Whose Juvenile Stages Are Entrapped

Due to lack of data on entrapment rate for juveniles, adult-equivalent loss is not estimated for the juvenile stage of six taxa (see Appendix D) which have juveniles that are entrapped. These are black croaker, California corbina, California grunion, jacksmelt, kelp and barred sand bass, and salema. Consequently, the estimated lost adult-equivalents shown in Table 3 reflect loss through the post-flexion stage only and are underestimates.

Black Croaker

Black croaker (*Cheilotrema saturnum*) range from Pt. Conception to southern Baja. Most adults live close to shore, between depths of 3-15 m. Their pelagic eggs are entrapped.

Most larvae are found close to shore, nearly 100% inshore of E-Block (Table 2). Larvae may move onshore as they mature, since the proportion in A- and B-Blocks increases with age (Table 2). All post-flexion larvae are found within A- and B-Blocks.

A high entrapment rate and relatively long duration for the post-flexion stage yield an estimated adult-equivalent loss of 3.9% (Table 3). Entrapment rate of the post-flexion stage is high, relative to that for flexion and preflexion, but note that this stage is of low abundance (Table 2), and is found on only five cross-shelf transects. The high entrapment rate for post-flexion is, however, consistent with the inshore habitat of adults.

We cannot estimate adult-equivalent loss for the juvenile stage because we do not have estimates of the bight-wide standing stock of juveniles and adults (see Appendixes C and D).

California Corbina

California corbina (*Menticirrhus undulatus*) range from Pt. Conception to southern Baja, usually in shallow water along sand beaches. Their planktonic eggs are entrapped.

Most larvae are found close to shore, nearly 100% inshore of E-Block (Table 2). Larvae probably move onshore as they mature, since the proportion in A- and B-Blocks increases with age, and almost all post-flexion larvae are found within A- and B-Blocks (Table 2).

Entrapment rate is high, but durations of stages are relatively short. Still, estimated adult-equivalent loss through the post-flexion stage is relatively high (3.6%; Table 3). Entrapment rate is high for the post-flexion stage relative to flexion and preflexion, but note that it is based on only four cross-shelf transects (Table 2). The high entrapment rate for post-flexion is, however, consistent with the inshore habitat of juveniles and adults.

We cannot estimate adult-equivalent loss for the juvenile stage because we do not have estimates of the bight-wide standing stock of adults (see Appendixes C and D).

California Grunion

California grunion (*Leuresthes tenuis*) range from San Francisco to southern Baja, inshore to a depth of 18 m. Eggs are buried in intertidal sand and are, therefore, not entrapped.

Most larvae (approximately 80%) are found inshore of E-Block (Table 2).

SONGS may have increased the abundance of grunion larvae at the Impact site by 170% (Table A.1). We increase entrapment rate to account for this increase in density (see Appendix A, Sections A.2.2 and A.3.2). Through the post-flexion stage, the estimated adult equivalent loss is 4.6% (Table 3). [If we do not adjust for SONGS' effect, adult-equivalent loss through post-flexion is 1.7% (using methods of Appendix A, Sections A.2.1 and A.3.1).]

We cannot estimate adult-equivalent loss for the juvenile stage because we do not have estimates of the bight-wide standing stock of adults (see Appendixes C and D).

Jacksmelt

Jacksmelt (*Atherinopsis californiensis*) range from Oregon to southern Baja. Eggs are attached to benthic algae and are not entrapped. Approximately 95% of the larvae are found inshore of E-Block (Table 2). Moderate entrapment rates and durations of planktonic stages yield an estimated adult-equivalent loss through the post-flexion stage of 2.5% (Table 3).

We cannot estimate adult-equivalent loss for the juvenile stage because we do not have estimates of the bight-wide standing stock of adults (see Appendixes C and D).

Kelp and Barred Sand Bass

These two taxa are combined because their larvae are indistinguishable.

Kelp bass (*Paralabrax clathratus*) range from Oregon to southern Baja and are usually found in or near kelp beds and rocky reefs. Barred sand bass (*Paralabrax nebulifer*) range from central California to southern Baja, usually on sandy bottom among or near rocks. Their planktonic eggs are entrapped.

Only a small fraction of larvae are found in A- and B-Blocks (Table 2). Consequently, larvae of these basses are at relatively low risk to entrapment compared to other taxa. Estimated adult-equivalent loss is relatively low through the post-flexion stage (0.08%; Table 3). Even 0.08% may be an overestimate because the population of larvae probably extends beyond E-Block. If this is true, we have underestimated the denominator of entrapment rate, and overestimated adult-equivalent loss.

We cannot estimate adult-equivalent loss for the juvenile stage because we do not have estimates of the bight-wide standing stock of adults (see Appendixes C and D).

Northern Anchovy

Northern anchovy (*Engraulis mordax*) are pelagic fish that range from southern Canada to southern Baja. Their planktonic eggs are entrapped.

Only a small fraction of larvae are found in A- and B- Blocks (Table 2). Larvae extend well beyond E-Block, although there is some indication that larvae move towards shore as they mature, since the fraction in A- and B-Blocks increase from preflexion to post-flexion stages.

SONGS may have reduced the abundance of northern anchovy larvae at the Impact site by 27% (Table A.1) and we adjusted entrapment rate for this reduction in density (see Appendix A, Sections A.2.2 and A.3.2). Through the juvenile stage, the estimated adult equivalent loss is less than 0.10% (Table 3). [If we do not adjust for the reduced density near SONGS, adult-equivalent loss through the juvenile stage is still less than 0.10% (using methods of Appendix A, Sections A.2.1 and A.3.1).]

Queenfish

Queenfish (*Seriphus politus*) range from Oregon to southern Baja and live inshore and occur abundantly to depths of 21 m. Their planktonic eggs are entrapped. Larvae probably move onshore as they mature, since the proportion in A- and B-Blocks increases with age (Table 2). 95% of post-flexion larvae are found in A- and B-Blocks. Estimated adult-equivalent loss is 5.4% through the post-flexion stage. High, middle and low estimates of entrapment rate through the juvenile stage

22

are estimated in Appendix D. An average estimate of adult-equivalent loss through the juvenile stage (based on an average of loss for critical lengths of 4 and 5 -- Appendix D) is 12.7%. This relatively large estimate of adult-equivalent loss is due to both high entrapment rates and long durations for post-flexion and juvenile stages (Table 3).

Salema

Salema (*Xenistius califoriensis*) range from central California to Peru, and are found in kelp beds and other rocky reefs. Their planktonic eggs are entrapped.

Only a small fraction of larvae are found in A- and B-Blocks (Table 2). Consequently, salema larvae are at relatively low risk of entrapment compared to other taxa. Estimated adult-equivalent loss is relatively low through the post-flexion stage (0.36%; Table 3).

Even 0.36% is an overestimate, as the population of larvae probably extends beyond E-Block. Thus we probably have underestimated the population at risk, the denominator of entrapment rate, and overestimated adult equivalent loss.

We cannot estimate adult-equivalent loss for the juvenile stage because we do not have estimates of the bight-wide standing stock of adults (see Appendixes C and D).

23

White Croaker

White croaker (*Genyonemus lineatus*) range from Canada to southern Baja and are found inshore, usually shallower than 30 m. Their planktonic eggs are entrapped.

While relatively high proportions are found inshore of E-Block, the proportion in A- and B-Blocks is lower than that for queenfish (Table 2).

SONGS may have increased the density of white croaker at the Impact site by 67% (Table A.1). We increase entrapment rate for this increase in density (see Appendix A, Sections A.2.2 and A.3.2). Through the post-flexion stage, estimated adult-equivalent loss is 3.8% (Table 3). [If we do not adjust for the increased density near SONGS, adult-equivalent loss through the post-flexion stage is 3.2% (using methods of Appendix A, Sections A.2.1 and A.3.1).]

High, middle and low estimates of entrapment rate are estimated in Appendix D for the juvenile stage. An average estimate of adult-equivalent loss through the juvenile stage (based on an average of loss for critical lengths of 4 and 5 -- Appendix D) is 7.5%.

3.2 Taxa Whose Juvenile Stages Are Not Entrapped

Juveniles, of the following taxa, move to the bottom of kelp beds or otherwise become unavailable to entrapment after metamorphosis.

24

Arrow Goby

Adult arrow goby (*Clevelandia ios*) range from Canada to southern Baja and inhabit estuaries, lagoons, and tidal sloughs. Their benthic eggs are not entrapped. Most larvae are found close to shore; all larvae are found inshore of E-Block, with a high proportion in A- and B-blocks (Table 2).

SONGS may have reduced the abundance of arrow goby at the Impact site by 40% (Table A.1). We adjusted entrapment rate for this reduction in density (see Appendix A, Sections A.2.2 and A.3.2). The estimated adult-equivalent loss is 2.6% through the post-flexion stage, (Table 3). This relatively high loss results from a combination of high entrapment rate and the relatively long duration of the post-flexion stage (29.6 days). [If we do not adjust for SONGS' effect, the adult-equivalent loss through post-flexion is 4.3%, (using methods of Appendix A, Sections A.2.1 and A.3.1).]

Blennies

Blennies (*Hypsoblennius* spp.) are found from central California to southern Baja. They occur in the shallow waters of the rocky intertidal zone, among oyster and clam beds, and in other inshore habitats. Their benthic eggs are not entrapped.

Only a small fraction of larvae are found in A- and B-Blocks (Table 2). Consequently, the risk of entrapment is relatively low and estimated adult equivalent loss is low through the post-flexion stage (0.14%; Table 3).

25

0.14% may be an overestimate because the population of larvae probably extends beyond E-Block. Thus, we have underestimated the population at risk (the denominator of entrapment rate) and overestimated adult-equivalent loss.

California Clingfish

California clingfish (*Gobiesox rhessodon*) range from Pismo Beach south to central Baja, and are found from the intertidal to a depth of approximately 11 m. Their benthic eggs are not entrapped. Almost all larvae are found inshore of E-Block (Table 2). Through post-flexion, estimated adult-equivalent loss is 1.4%, largely because the duration of planktonic stages is relatively short (Table 3).

California Halibut

California halibut (*Paralichthys californicus*) range from the state of Washington to southern Baja. Their planktonic eggs are entrapped.

Only a small fraction of larvae are found in A- and B-Blocks (Table 2). Consequently, halibut larvae are at relatively low risk to entrapment compared to other taxa. Estimated adult-equivalent loss is relatively low through the post-flexion stage (0.11%; Table 3).

Since about 80% of the A- through E-Block abundance was found in A- through D-Blocks (Table 1), the larval population probably does not extend much beyond E-Block. To the extent that larvae extend beyond E-Block, the estimated adult- equivalent loss of halibut will be even less.

Cheekspot Goby

Cheekspot goby (*Ilypnus gilberti*) range from northern California to southern Baja. Like the arrow goby, the cheekspot goby inhabit bays, estuaries, and tidal sloughs. Their benthic eggs are not entrapped.

Most larvae are found close to shore. Approximately 95% of all planktonic stages are found inside of E-Block (Table 2). A high proportion of larvae (approximately 80%) are found in A- and B-Blocks. Through the post-flexion stage, the estimated adult-equivalent loss is 3.04% (Table 3).

Pacific Mackerel

Pacific mackerel (*Scomber japonicus*) are found worldwide in temperate and tropical seas. In North America, the Pacific mackerel ranges from Alaska to Mexico. Their planktonic eggs are entrapped.

Only a small fraction of larvae are found in A- and B-Blocks (Table 2). Consequently, Pacific mackerel larvae are at relatively low risk to entrapment. Estimated adult-equivalent loss is relatively low through the post-flexion stage (0.08%; Table 3).

Note that 0.08% is an overestimate because the population of larvae probably extends beyond E-Block. Thus we have underestimated the population at risk (the denominator of entrapment rate) and overestimated adult-equivalent loss.

Diamond Turbot

Diamond turbot (*Hypsopsetta guttulata*) range from northern California to southern Baja and are found on mud and sand bottoms, often in bays and sloughs. Their planktonic eggs are entrapped.

Most larvae, approximately 85%, are found inshore of E-Block (Table 2). Larvae may move onshore as they mature, since the proportion of larvae in A- and B-Blocks increases with age; 100% of post-flexion larvae are found inshore of E-Block (Table 2).

Although durations of planktonic stages are relatively short, estimated adult-equivalent loss through the post-flexion stage is 2.1% (Table 3).

Giant Kelpfish

Giant kelpfish (*Heterostichus rostratus*) range along the U.S. west coast to southern Baja and are found among rocks with kelp and other algae, to a depth of 40 m. Their eggs are attached to vegetation and are not entrapped.

Most larvae, almost 100%, are found inshore of E-Block (Table 2). 95% of post-flexion larvae are found in A- and B-Blocks.

Estimated adult-equivalent loss is relatively high (6.9%; Table 3). This results from high entrapment rate and the long duration of the post-flexion stage (Table 3).

Hornyhead Turbot

Hornyhead turbot (*Pleuronichthys verticalis*) range from northern California to southern Baja, on soft-bottoms from 9 to 200 m. Their planktonic eggs are entrapped.

Only a small fraction of larvae are found in A- and B-Blocks (Table 2). Consequently, the risk to entrapment for hornyhead turbot larvae is relatively low compared to other taxa and estimated adult-equivalent loss is relatively low through the post-flexion stage (0.12%; Table 3).

Again, 0.12% is an overestimate of adult-equivalent loss because the population of larvae surely extends beyond E-Block. Thus we have underestimated the population at risk and therefore, overestimated adult-equivalent loss.

Kelpfish (Unidentified)

Kelpfish (most likely *Gibbonsia elegans*) range from Canada to central Baja. They live in subtidal rocky areas to a depth of 56 m. Their benthic eggs are not entrapped. All larvae are found inshore of E-Block (Table 2). Estimated adult-equivalent loss through the post-flexion stage is relatively high (5.0%; Table 3) because of the high entrapment rate and the relatively long post-flexion stage.

queenfish and white croaker. However, we can approximate the loss of northern anchovy, at least for planktonic stages, from losses due to planktonic stages of queenfish. We use queenfish for this purpose rather than white croaker for two reasons. First, the density of white croaker was affected by SONGS' operation while the density of queenfish was not. Second, the data set for queenfish (especially for the post-flexion stage) was more complete over the period of sampling, 1978 through 1986, and more appropriate for estimating loss of northern anchovy.

In A- and B-Blocks, post-flexion northern anchovy is 10 times as dense and has 1.5 times the duration of post-flexion queenfish. Thus, approximately 15 (= 10 x 1.5) times more northern anchovy post-flexion larvae will be entrapped than queenfish post-flexion larvae. Consequently, northern anchovy will lose approximately 15 times more adult equivalents than queenfish, assuming the mortality rates of post-flexion larvae of both taxa are equal. Post-flexion queenfish account for approximately 30% of all adult-equivalent queenfish lost (Table 3), or 5,400,000 adult fish. Thus, the adult-equivalent loss of northern anchovy due to entrapment of the post-flexion stage is about 81,000,000 (= 15 x 5,400,000) adult fish. At 15 g/fish this equals 1,215 MT of northern anchovy. Again, this calculation assumes, equal mortality for the post-flexion stage of northern anchovy and queenfish in A- and B-Blocks. While we do not have data to test this assumption, it is reasonable that post-flexion larvae of similar size and found in the same habitat should have similar mortality rates.

Earlier stages (flexion, preflexion, and yolksac) of queenfish account for approximately 10% of all queenfish losses. In A- and B-Blocks, earlier stages of northern anchovy are 3.5 times as dense and have 1.3 times the duration of post-

32

flexion queenfish. Earlier stage queenfish account for approximately 1,800,000 lost adult-equivalent queenfish. Thus, the adult-equivalent loss of northern anchovy due to entrapment of these earlier stages is about 8,100,000 (= 4.5 x 1,800,000) adult fish or 120 MT. This calculation, like that in the previous paragraph, assumes equal mortality for the earlier planktonic stages of northern anchovy and queenfish in A- and B-Blocks. Again, we do not have data to test this assumption, although it too is reasonable for the reasons discussed in the previous paragraph.

Because of their short duration and relatively low abundance in A- and B-Blocks, loss due to entrapment of northern anchovy eggs is trivial in comparison to the loss of larval stages.

Thus we estimate loss of adult northern anchovy due to entrapment of planktonic stages is approximately 89,000,000 fish or 1,340 MT. This is equivalent to about 0.3% of the average adult stock (3.7×10^{10}) weighing 534,000 MT (Appendix B, Table B.5)

We do not estimate the loss of juvenile northern anchovy based on the loss of juvenile queenfish. This would be inappropriate since we cannot assume that entrapment rates remain the same as the two taxa mature into adult fish. The MRC (Technical Report C, 1989) estimated an 87% intake survival of later-stage juvenile northern anchovy. Thus, losses to the adult stock due to entrapment of older juveniles may be relatively small. However, entrapment losses of earlier juveniles would add to losses for planktonic stages.

4.0 DISCUSSION

4.1 Magnitude of Effects

SONGS' Units 2 and 3 draw in approximately 6.8×10^6 m^3/day of water (when six out of eight circulating pumps are operating). This equals 528 meter-wide strips of A- and B-Blocks per day (approximately 190 km per year). Taxa with high proportions of planktonic and juvenile stocks in A- and B-Blocks are at highest risk to entrapment, and therefore have the highest estimated adult-equivalent loss.

In the following discussion, it may help the reader to understand the magnitude of loss by converting percent adult-equivalent loss into a geographic context. This is accomplished by multiplying the percent adult-equivalent loss times the length of the Bight, 500 km. As an example, the 12.7% loss in queenfish is equivalent to killing all the age 1 queenfish of a given cohort that would be found in 64 km (= 10.9% times 500 km) of shoreline. Note, we expect the effect of SONGS entrapment on planktonic and juvenile stages to be more widespread (hence, thinner) than this. Further, this shoreline equivalent assumes no compensation in preadult stages; compensation in preadult stages would decrease this estimate of shoreline equivalent. We suggest this geographic context simply as an alternate means of interpreting the magnitude of adult-equivalent loss. We show the shoreline equivalents to adult-equivalent loss in Table 6.

34

4.1.1 Taxa Whose Juveniles Are Entrapped

We estimate adult-equivalent loss for nine taxa whose juveniles are entrapped. Of these nine, queenfish and white croaker have relatively high estimates of adult loss, 12.7% and 7.5% (Table 3). For each taxon, total losses are essentially equally divided between planktonic and juvenile stages. Total adult-equivalent loss is high for queenfish because of the relatively large fraction of the post-flexion stage found in waters entrapped by SONGS' A- and B-Blocks.

For six of these nine, entrapment rates for the juvenile stage are not estimable, and we estimate adult-equivalent loss through the post-flexion stage only. Three of the six have relatively low proportions of planktonic stocks living in A- and B-Blocks and consequently have trivial estimates of adult-equivalent loss: northern anchovy (less than 0.1%), kelp and barred sand bass (0.08%), and salema (0.36%). Even these relatively low estimates of loss are probably overestimates, since planktonic stages probably extend beyond E-Block for both these taxa; adding in juveniles will make little difference. Four of the six have relatively high estimates of adult-equivalent loss: California grunion (4.6%), black croaker (3.9%), California corbina (3.6%), and jacksmelt (2.5%). Since SONGS also entraps juveniles for these taxa, these are underestimates.

However, we believe that adult-equivalent loss of the juvenile stage of these six taxa is less than that estimated through the planktonic stages, because as juveniles mature they move out of the area of high risk to entrapment. Consequently we expect that the total adult-equivalent loss (for eggs, larvae and juveniles) must be less than twice that through post-flexion for these taxa. We

35

believe this for the following reason. For both queenfish and white croaker, whose planktonic, juveniles and adult stages all live in the inner-nearshore midwater zone, estimated adult-equivalent losses through post-flexion and for juveniles are approximately equal (Table 3). Therefore, we expect the maximum total adult-equivalent loss to be approximately twice that through post-flexion. For these other taxa with entrapped juveniles, this is not the case: planktonic stages found in the inner-nearshore midwater depths are at greater risk than juveniles, since juveniles move out of the inner-nearshore midwater to adult habitats. Thus for these taxa, we expect adult-equivalent loss for the juvenile to be less than that for the planktonic stages.

Our estimate of relative adult-equivalent loss is less than 0.1% for northern anchovy. Most northern anchovy larvae (and presumably juveniles) are found offshore of E-Block and are at low risk to entrapment.

SONGS also entrains the juvenile stage of viviparous perch (barred surfperch, kelp perch, pile perch, rainbow seaperch, rubberlip seaperch, shiner perch, walleye surfperch, white seaperch). As with the juvenile stage of other taxa, we do not have sufficient data on estimates of either field abundance or numbers entrapped to estimate adult-equivalent loss. Further, we can not estimate adult-equivalent loss for the juvenile stage of perches as we did for northern anchovy, queenfish and white croaker (Appendixes B, C and D) since planktonic stages do not exist. However, we believe that adult-equivalent loss of these perches is probably small since juveniles are born into adult habitats and are at low risk to intake withdrawal.

4.1.2 Taxa Whose Juveniles Are Not Entrapped

For eight of the twelve taxa whose juvenile stages are not entrapped, proportions of planktonic stocks living in A- and B-Blocks are high enough and durations of planktonic stages are long enough to result in an estimated adult-equivalent loss greater than 1%: giant kelpfish (6.9%), unidentified kelpfish (5.0%), cheekspot goby (3.0%), reef finspot (2.9%), arrow goby (2.6%), shadow goby (2.1%), diamond turbot (2.1%), and California clingfish (1.4%). The other four taxa have relatively low proportions of planktonic stocks living in A- and B-Blocks, and consequently have very low estimates of adult-equivalent loss: blennies (0.13%), hornyhead turbot (0.12%), California halibut (0.11%), and Pacific mackerel (0.08). Even these relatively low estimates of adult-equivalent loss are probably overestimates, since planktonic stages likely extend beyond E-Block for these taxa. Thus, we have underestimated larval populations at risk and overestimated their entrapment rates.

4.2 Potential Losses to the Adult Standing Stock

We estimate potential loss to the standing stocks of adults to be 551 MT (18,000,000 fish) and 394 MT (4,100,000 fish) for queenfish and white croaker, respectively. While estimated less directly than for queenfish and white croaker, we estimate the loss for planktonic stages of northern anchovy to be approximately 1,340 MT (89,000,000 fish). These losses are for all year classes combined and require the accumulated effects of plant operation over the number of years equal to the oldest fish in the stock. These estimates of loss may be likened to fishery catches where the catch does not result in a long-term reduction equal to the catch.

37

Total estimated potential loss in biomass for northern anchovy, queenfish, and white croaker sums to over 2,290 MT. This estimate does not include either the juvenile stage of northern anchovy or the adult equivalents of all other entrapped taxa. Northern anchovy, queenfish and white croaker account for approximately 70% of all entrapped larval stages. We do not approximate a loss in biomass for the taxa which make up the additional 30% because, in general, their larval and juvenile stages differ in habitat, and probably mortality rates, from those of northern anchovy, queenfish and white croaker.

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6.0 TABLES and FIGURES

Table 1

Common and scientific names.

Common Name	Scientific Name
Arrow goby	*Clevelandia ios*
Black croaker	*Cheilotrema saturnum*
Blenny (unid.)	*Hypsoblennius* spp.
Calif. clingfish	*Gobiesox rhessodon*
Calif. corbina	*Menticirrhus undulatus*
Calif. grunion	*Leuresthes tenuis*
Calif. halibut	*Paralichthys californicus*
Cheekspot goby	*Ilypnus gilberti*
Pacific mackerel	*Scomber japonicus*
Diamond turbot	*Hypsopsetta guttulata*
Giant kelpfish	*Heterostichus rostratus*
Hornyhead turbot	*Pleuronichthys verticalis*
Jacksmelt	*Atherinopsis californiensis*
Kelp and barred sand bass	*Paralabrax* spp.
Kelpfish (unid.)	*Gibbonsia* type a
Northern anchovy	*Engraulis mordax*
Queenfish	*Seriphus politus*
Reef finspot	*Paraclinus integripinnis*
Salema	*Xenistius californiensis*
Shadow goby	*Quietula y-cauda*
White croaker	*Genyonemus lineatus*

Table 2

Ratios of mean densities for combinations of Blocks (AB/ABCD and ABCD/ABCDE) and the number (n) of cross-shelf surveys with occurrences. (Note the ratio of means does not change if surveys with occurrences are included.) Yolksac and preflexion stages have been combined (ys/preflexion).

		JUVENILES ENTRAPPED			
		AB/ ABCD	n	ABCD/ ABCDE	n
Black croaker	eggs	0.068	-	0.834	-
	ys/preflexion	0.068	51	0.834	38
	flexion	0.068	7	0.834	3
	post-flexion	0.408	5	1.000	2
Calif. corbina	eggs	0.119	-	0.931	-
	ys/preflexion	0.119	47	0.931	27
	flexion	0.191	19	1.000	13
	post-flexion	0.996	4	1.000	3
Calif. grunion	ys/preflexion	0.436	98	0.704	66
	flexion	0.340	91	0.719	64
	post-flexion	0.640	88	0.867	63
Jacksmelt	ys/preflexion	0.446	88	0.915	58
	flexion	0.600	69	0.972	45
	post-flexion	0.494	49	0.990	34
Kelp & barred sand bass	eggs	0.025	-	0.720	-
	ys/preflexion	0.025	67	0.720	40
	flexion	0.003	32	0.510	23
	post-flexion	0.065	31	0.515	22
N. anchovy	eggs	0.082	-	0.584	-
	ys/preflexion	0.082	141	0.584	87
	flexion	0.097	148	0.687	94
	post-flexion	0.175	151	0.823	97
Queenfish	eggs	0.159	-	0.786	-
	ys/preflexion	0.159	136	0.786	90
	flexion	0.793	109	0.983	78
	post-flexion	0.953	102	1.000	70
Salema	eggs	0.063	-	0.708	-
	ys/preflexion	0.063	32	0.708	14
	flexion	0.011	19	0.736	9
	post-flexion	0.158	14	0.489	6
White croaker	eggs	0.134	-	0.748	-
	ys/preflexion	0.134	123	0.748	82
	flexion	0.348	96	0.996	68
	post-flexion	0.296	86	1.000	64

45

Table 2. (Continued)

		JUVENILES NOT ENTRAPPED			
		AB/ ABCD	n	ABCD/ ABCDE	n
Arrow goby	ys/preflexion	0.580	65	1.000	45
	flexion	0.982	90	1.000	54
	post-flexion	0.916	133	1.000	84
Blenny (unid.)	ys/preflexion	0.093	141	0.686	93
	flexion	0.023	70	0.660	51
	post-flexion	0.015	59	0.641	46
Calif. clingfish	ys/preflexion	0.545	96	0.999	63
	flexion	0.758	57	1.000	38
	post-flexion	0.253	33	1.000	18
Calif. halibut	eggs	0.059	-	0.774	-
	ys/preflexion	0.059	123	0.774	81
	flexion	0.013	45	0.676	30
	post-flexion	0.061	72	0.835	52
Cheekspot goby	ys/preflexion	0.729	121	0.888	70
	flexion	0.878	105	1.000	55
	post-flexion	0.746	122	1.000	71
Pacific mackerel	eggs	0.125	-	0.753	-
	ys/preflexion	0.125	61	0.753	38
	flexion	0.005	30	0.594	23
	post-flexion	0.002	23	0.725	18
Diamond turbot	eggs	0.383	-	0.846	-
	ys/preflexion	0.383	57	0.846	38
	flexion	0.414	23	0.661	20
	post-flexion	0.650	13	1.000	12
Giant kelpfish	ys/preflexion	0.707	69	1.000	50
	flexion	0.545	47	1.000	29
	post-flexion	0.949	22	0.981	14
Hornyhead turbot	eggs	0.029	-	0.614	-
	ys/preflexion	0.029	112	0.614	73
	flexion	0.006	29	0.241	24
	post-flexion	0.037	28	0.258	23
Kelpfish (unid.)	ys/preflexion	0.711	87	1.000	53
	flexion	0.678	40	1.000	24
	post-flexion	0.665	23	1.000	16

Table 2. (Continued)

| | | JUVENILES NOT ENTRAPPED | | | |
		AB/ ABCD	n	ABCD/ ABCDE	n
Reef finspot	ys/preflexion	0.717	47	1.000	23
	flexion	0.697	28	1.000	12
	post-flexion	0.485	19	1.000	8
Shadow goby	ys/preflexion	0.856	86	1.000	46
	flexion	0.974	65	1.000	26
	post-flexion	0.851	69	1.000	28

Table 3

Relative adult-equivalent loss (AEL), $1 - R_c$ through stage, accumulated to that stage. Estimated daily entrapment rate (from Table A3) is the number entrapped per day divided by the standing stock. Yolksac and preflexion stages have been combined (ys/preflexion). We equate entrapment rates for eggs to those for ys/preflexion.

		JUVENILES ENTRAPPED		
		Entrapment Rate	Duration t	AEL $1-R_c$
Black croaker[1]	eggs	6.02E-05	2.5	0.015%
	ys/preflexion	6.02E-05	15.2	0.106%
	flexion	4.31E-04	6.0	0.364%
	post-flexion	1.06E-03	34.0	3.891%
Calif. corbina[1]	eggs	1.17E-04	2.5	0.029%
	ys/preflexion	1.17E-04	9.2	0.137%
	flexion	2.02E-04	8.0	0.298%
	post-flexion	1.05E-03	31.6	3.552%
Calif. grunion[1,2]	ys/preflexion	8.75E-04	11.3	0.984%
	flexion	6.95E-04	11.7	1.786%
	post-flexion	1.58E-03	18.3	4.585%
Jacksmelt[1]	ys/preflexion	4.31E-04	20.0	0.858%
	flexion	6.15E-04	18.0	1.950%
	post-flexion	5.16E-04	10.0	2.454%
Kelp & barred[1] sand bass	eggs	1.90E-05	2.5	0.005%
	ys/preflexion	1.90E-05	7.7	0.019%
	flexion	2.11E-06	5.0	0.020%
	post-flexion	3.48E-05	18.3	0.084%
N. anchovy[2]	eggs	2.45E-07	2.5	< 0.01%
	ys/preflexion	2.45E-07	24.1	< 0.01%
	flexion	3.42E-07	16.7	< 0.01%
	post-flexion	5.82E-07	66.7	< 0.10%
	juvenile	1.20E-07	255.0	< 0.10%
Queenfish	eggs	1.32E-04	2.5	0.033%
	ys/preflexion	1.32E-04	18.0	0.270%
	flexion	8.23E-04	12.0	1.250%
	post-flexion	1.01E-03	44.0	5.543%
	juvenile	2.73E-04	288.5	12.695%
Salema[1]	eggs	4.75E-05	2.5	0.012%
	ys/preflexion	4.75E-05	10.0	0.059%
	flexion	8.44E-06	8.0	0.066%
	post-flexion	8.13E-05	36.0	0.358%

Table 3. (Continued)

		JUVENILES ENTRAPPED		
		Entrapment Rate	Duration t	AEL 1-R_c
White croaker[2]	eggs	1.76E-04	2.5	0.044%
	ys/preflexion	1.76E-04	22.0	0.430%
	flexion	6.12E-04	10.0	1.038%
	post-flexion	5.22E-04	55.0	3.839%
	juvenile	1.41E-04	275.5	7.500%

		JUVENILES NOT ENTRAPPED		
		Entrapment Rate	Duration t	AEL 1-R_c
Arrow goby[2]	ys/preflexion	3.64E-04	8.0	0.291%
	flexion	6.22E-04	10.0	0.909%
	post-flexion	5.80E-04	29.6	2.596%
Blenny (unid.)	ys/preflexion	6.75E-05	8.6	0.058%
	flexion	1.58E-05	29.3	0.104%
	post-flexion	1.06E-05	29.7	0.136%
Calif. clingfish	ys/preflexion	5.74E-04	12.0	0.686%
	flexion	8.00E-04	8.0	1.320%
	post-flexion	2.67E-04	4.0	1.425%
Calif. halibut	eggs	4.85E-05	2.5	0.012%
	ys/preflexion	4.85E-05	14.6	0.083%
	flexion	9.50E-06	8.3	0.091%
	post-flexion	5.38E-05	4.2	0.113%
Cheekspot goby	ys/preflexion	6.83E-04	8.0	0.545%
	flexion	9.27E-04	4.0	0.913%
	post-flexion	7.87E-04	27.6	3.042%
Pacific mackerel	eggs	9.92E-05	2.5	0.025%
	ys/preflexion	9.92E-05	4.9	0.073%
	flexion	3.17E-06	4.4	0.075%
	post-flexion	1.06E-06	21.2	0.077%
Diamond turbot	eggs	3.42E-04	2.5	0.085%
	ys/preflexion	3.42E-04	9.2	0.399%
	flexion	2.89E-04	6.0	0.572%
	post-flexion	6.86E-04	22.0	2.061%

Table 3. (Continued)

		JUVENILES NOT ENTRAPPED		
		Entrapment Rate	Duration t	AEL 1-R_c
Giant kelpfish	ys/preflexion	7.46E-04	4.1	0.305%
	flexion	5.75E-04	5.4	0.614%
	post-flexion	9.83E-04	66.2	6.876%
Hornyhead turbot	eggs	1.90E-05	2.5	0.005%
	ys/preflexion	1.90E-05	35.0	0.071%
	flexion	1.06E-06	25.0	0.074%
	post-flexion	1.06E-05	45.0	0.122%
Kelpfish (unid.)	ys/preflexion	7.50E-04	8.0	0.598%
	flexion	7.16E-04	6.0	1.024%
	post-flexion	7.02E-04	58.0	4.973%
Reef finspot	ys/preflexion	7.57E-04	6.0	0.453%
	flexion	7.36E-04	4.0	0.746%
	post-flexion	5.12E-04	42.0	2.857%
Shadow goby	ys/preflexion	9.03E-04	8.0	0.720%
	flexion	1.03E-03	0.0	0.720%
	post-flexion	8.98E-04	16.0	2.136%

[1] Juvenile stage inestimable due to lack of data on adult stock size. See DISCUSSION, section 4.1.1, paragraph 3.

[2] Adjusted for SONGS' effect (see Table A.1).

50

Table 4

Estimated adult-equivalent loss through last stage entrapped.

TAXA WHOSE JUVENILES ARE ENTRAPPED

Common name	Adult-Equivalent Loss
Black croaker[1]	(3.89%)
Calif. corbina[1]	(3.55%)
Calif. grunion[1,2]	(4.59%)
Jacksmelt[1]	(2.45%)
Kelp and barred sand bass[1]	(0.08%)
Northern anchovy[2,3]	<0.10%
Queenfish[3,]	12.70%
Salema[1]	(0.36%)
White croaker[2,3]	7.50%

TAXA WHOSE JUVENILES ARE NOT ENTRAPPED

Common name	Adult-Equivalent Loss
Arrow goby[2]	2.60%
Blenny (unid.)	0.14%
Calif. clingfish	1.43%
Calif. halibut	0.11%
Cheekspot goby	3.04%
Pacific mackerel	0.08%
Diamond turbot	2.06%
Giant kelpfish	6.88%
Hornyhead turbot	0.12%
Kelpfish (unid.)	4.97%
Reef finspot	2.86%
Shadow goby	2.14%

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[1] Relative loss through juvenile stage inestimable. Loss is estimated only through post-flexion. See DISCUSSION, section 4.1.1, paragraph 3.

[2] Entrapment rate adjusted for SONGS' effect on density. Changes in density: arrow goby (-40%), California grunion (+170%), northern anchovy (-27%), and white croaker (+67%).

[3] Loss estimated through the juvenile stage.

51

Table 5

Potential losses to the adult standing stock in biomass and number for queenfish and white croaker. Adult standing stock estimated in Appendix B, Tables B.6 and B.7. Adult-equivalent loss (AEL) presented in Table 4. High, middle and low estimates are based on high, middle and low estimates of juvenile entrapment rate given in Appendix D.

| | ESTIMATED ADULT STANDING STOCK | |
	Biomass (MT)	Numbers of Fish
Queenfish	4,341	1.40E+08
White croaker	5,263	5.50E+07

| | | LOSS TO STANDING STOCK | |
	AEL	Biomass (MT)	Numbers of Fish
Queenfish	12.7%	551	1.8E+07
White croaker	7.5%	394	4.1E+06

Table 6

The number of 1-year-old equivalents killed by SONGS' entrapment of eggs, larvae and juveniles equals the number of 1-year olds that recruit to the length of the "shoreline equivalent" (see section 4.1) in kilometers. We expect SONGS' effect to be more widespread that this. Values assume no compensation for preadults.

TAXA WHOSE JUVENILES ARE ENTRAPPED

Common name	Kilometers
Black croaker	>19
Calif. corbina	>18
Calif. grunion	>23
Jacksmelt	>12
Kelp and barred sand bass	<1
Northern anchovy	<1
Queenfish	64
Salema	>2
White croaker	38

TAXA WHOSE JUVENILES ARE NOT ENTRAPPED

Common name	Kilometers
Arrow goby	13
Blenny (unid.)	<1
Calif. clingfish	7
Calif. halibut	<1
Cheekspot goby	15
Pacific mackerel	<1
Diamond turbot	10
Giant kelpfish	34
Hornyhead turbot	<1
Kelpfish (unid.)	25
Reef finspot	14
Shadow goby	11

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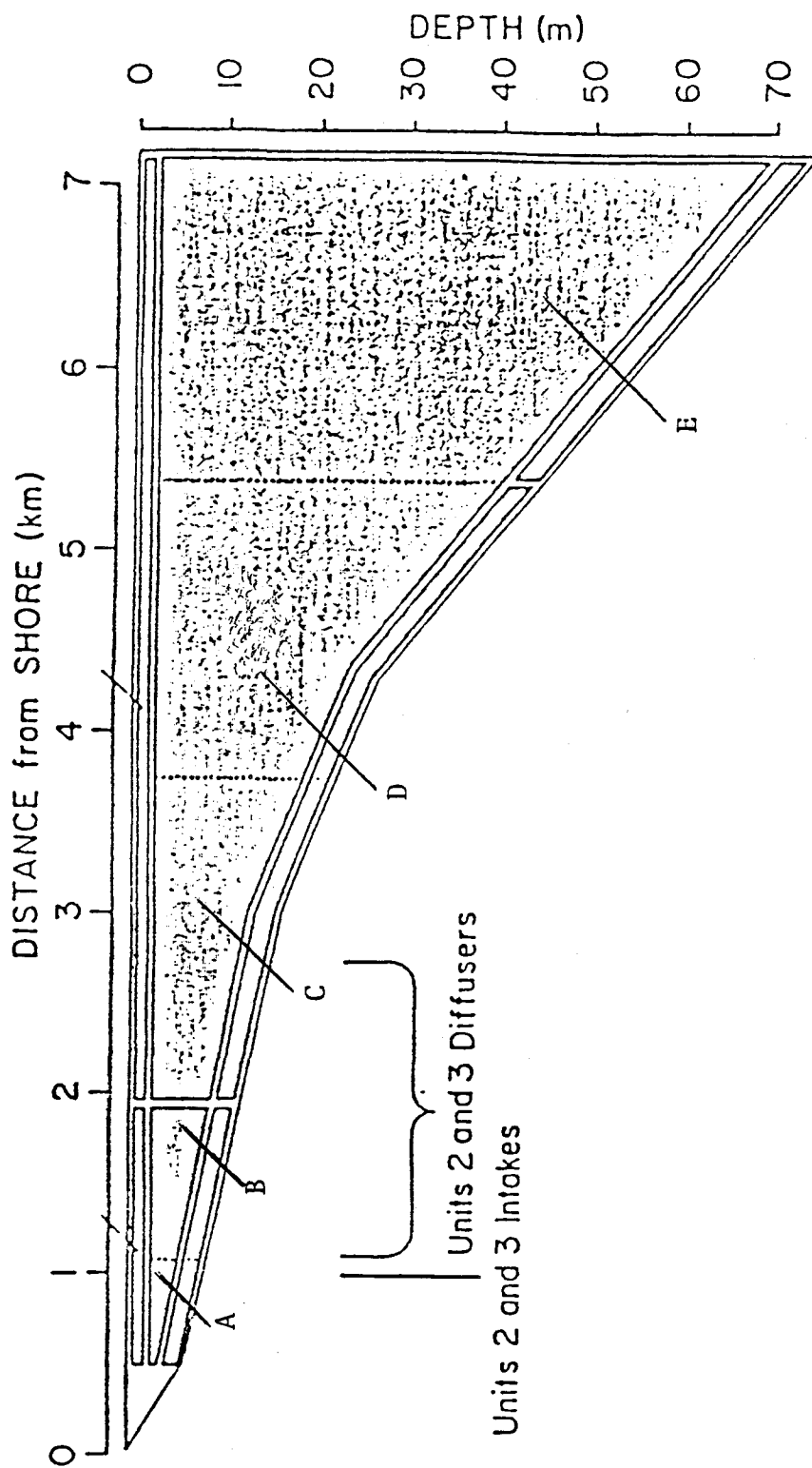
Figure 1: Cross-shelf blocks at Impact and Control sites, and their relationship to intakes and diffusers.

55

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APPENDICES

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APPENDIX A

ESTIMATING ENTRAPMENT RATE FOR PLANKTONIC STAGES

We estimate entrapment rate by stage by dividing (1) intake loss (the number entrapped per day) by (2) the standing stock in the southern California Bight. In Sections A.1 through A.4 we discuss procedures for collecting data, and for estimating intake loss (L), bight-wide standing stock (S), and entrapment rate (E). We discuss the major assumptions underlying these methods in Section A.5.

A.1 Data Collection

From 1978 through 1986, Marine Ecological Consultants Inc. (MEC) collected data on the density of eggs and larvae of fish at two sites in the vicinity of SONGS. The two sites lie approximately 1 - 3 km (Impact) and 18.5 km (Control) downcoast from SONGS. Each site was divided into five cross-shelf blocks (A-, B-, C-, D-, and E-Blocks), and each block into three depth zones (neuston, midwater, and epibenthos), resulting in 15 block/stratum combinations (see Figure 1 in main report). MEC defined neuston as the top 0.16 cm of the water column and epibenthos as the bottom 0.5 m. See the MRC (1988a) study on ichthyoplankton for a detailed description of sampling locations and methods.

In 1978, only the Impact site was sampled. From 1979 through 1986 both sites were sampled, usually on consecutive days. In the following we refer to all cross-shelf transects taken previous to July 1983 as preoperational, and all taken after June 1983 as operational. Thus the preoperational period includes samples

taken at Impact only in 1978. We divide sampling dates into preoperational and operational periods because SONGS' operation may have affected the abundance of some taxa at the Impact site in the operational period.

A.2 Intake Loss

We use the densities in A- and B-Blocks (which we refer to as the "AB density") to estimate intake loss, since the intake risers sit at approximately the boundary of A- and B-Blocks. SONGS draws in water from both these blocks (ECOsystems 1985).

SONGS' operation may have affected the density of some taxa at the Impact site. We use the relative percent change (between Impact and Control from preoperational to operational periods), as estimated by the MRC (1988a), to estimate intake loss for affected taxa. We discuss the implications of adjusting intake loss by relative percent change in Section A.5, Major Assumptions in Estimating Entrapment Rate.

A.2.1 Intake Loss for Taxa Not Affected by SONGS

We estimate intake loss (L) by multiplying the mean density in A- and B-Blocks times the mean intake volume:

$$L = AB * Vol_{intake}.$$

AB is the average density over sites and periods:

$$AB = (1/N) \Sigma (ab)_{ijk},$$

where ab_{ijk} is an average density, weighted by cross-sectional area of strata, for each i survey, at j sites (Impact and Control) for k periods (preoperational and operational). This gives an average density in A- and B-Blocks. N is the total number of cross-shelf transects sampled in the preoperational and operational periods.

During the operational period (mid-1983 through 1986) SONGS' Units 2 and 3 averaged 75% pumping capacity, or six out of eight circulating pumps per day (MRC 1988b). Each pump takes in approximately 1.13 10^6 m³/day. Hence, for an average of six pumps, Vol_{intake} computes to 6.8 10^6 m³/day. We assume that SONGS will continue to intake water at this rate.

A.2.2 Intake Loss for Taxa Affected by SONGS

SONGS' operation may have changed the density of some taxa at the Impact site relative to the Control site (MRC 1988a). Significant changes in four taxa (type I error $\leq$ 0.05) were found. Shadow goby (*Clevelandia ios*) and northern anchovy (*Engraulis mordax*) decreased at Impact relative to Control. White croaker (*Genyonemus lineatus*) and California grunion (*Leuresthes tenuis*) increased. We present significance levels and estimates of percent relative change in Table A.1.

We adjust the density at the Impact site, which is used to estimate intake loss, according to the estimated percent changes given in Table A.1. To estimate intake loss we adjust the AB density (excluding the operational period) to what it would have been had it been affected by SONGS' operation, according to the following procedure:

A - 3

$$AB' = W_1 * AB'' + F*(1-W_1)*AB'''$$

W_1 is the number of cross-shelf transects at Impact in the operational period divided by the number of cross-shelf transects for both sites and both periods (N). AB'' is the mean density at Impact during the operational period only. F is the adjustment factor for relative percent change. $F = 1 + P$, where P is the decimal equivalent of percent change in Table A.1. AB''' is the mean density when Impact is excluded during the operational period. F effectively adjusts the AB''' density to what it would have been had it been affected by SONGS' operation. [Note we achieved similar estimates of AB' by merely adjusting the mean density for all cross-shelf transects excluding Impact in the operational period, $F*AB'''$.]

Intake loss is then

$$L' = AB' * Vol_{intake}.$$

A.3 Standing Stock in the Bight

We estimate planktonic standing stock in the Bight by multiplying the number of propagules in a meter-wide strip of A- through E-Block times the number of meter-wide strips in the Bight (500,000). Again, we define the Bight as extending from Cabo Colnet, Baja California, to Point Conception. Examination of A- through E-Block densities, as presented in RESULTS, suggests that the eggs and larvae of most taxa under study do not extend beyond E-Block.

Because SONGS may have affected A- through E-Block densities for the same taxa considered in Section A.2.2, we compute standing stock for taxa not

affected and taxa affected separately. Because most eggs and larvae of northern anchovy are found offshore of the nearshore zone sampled by the MRC, we estimate standing stock for this taxon separately in Section A.3.3.

In the following section, all densities are in numbers per meter-wide strip of the various cross-shelf blocks.

A.3.1 Standing Stock for Taxa Not Affected by SONGS

E-Block samples from the operational period were not analyzed in the laboratory. Consequently, we have only A- through D-Block samples for both preoperational and operational periods. We estimate A- through E-Block densities (ABCDE) as follows:

$$ABCDE = ABCD * (ABCDE_{preop}/ABCD_{preop}),$$

where ABCD is the mean density in A- through D-Blocks for all cross-shelf transects and $(ABCDE_{preop}/ABCD_{preop})$ is the estimated ratio of mean densities in the preoperational period only.

$ABCD = (1/N) \Sigma (abcd)_{ijk}$, where abcd is the density for each i survey, at j sites (Impact and Control) for k periods (preoperational and operational), and N is the total number of cross-shelf transects.

Where ABCDE is the number per meter-wide cross-shelf strip, standing stock (S) is

$$S = ABCDE * 500,000$$

since there are 500,000 meter-wide strips in the Bight.

A.3.2 Standing Stock for Taxa Affected by SONGS

SONGS may have affected the ABCDE density of the four taxa listed in Table A.1. Thus, ABCDE densities as computed in Section A.3.1 yield underestimates of standing stock (and overestimates of entrapment rate and adult-equivalent loss) for taxa which decreased in density at Impact in the operational period (arrow goby and northern anchovy). Conversely, underestimates of entrapment rate and adult-equivalent loss would result for taxa which increased in density (California grunion and white croaker).

For taxa that may have been affected by SONGS' operation, we adjust for SONGS' effect at Impact in the operational period as follows:

$$ABCDE' = G*W_1*ABCDE'' + (1-W_1)*ABCDE'''$$

G is the factor that adjusts ABCDE density (in number per meter-wide strip) to what it would have been at Impact in the operational period, had it not been affected by SONGS. $G = 1/(1+P)$, where P is the decimal equivalent of percent change in Table A.1. W_1 is the number of cross-shelf transects at Impact in the operational period divided by the number of cross-shelf transects at both sites and both periods (N). $ABCDE''$ is the mean cross-shelf density for Impact in the operational period. $ABCDE'''$ is the mean density at all cross-shelf transects except Impact in the operational period.

Where ABCDE' Standing stock (S') is

$$S' = ABCDE' * 500,000$$

since there are 500,000 meter-wide strips in the Bight.

A - 6

A.3.3 Standing Stock of Northern Anchovy

Since most eggs and larvae of northern anchovy are found offshore of E-Block, we cannot estimate standing stocks of planktonic stages from the MRC's data.

We use published data (Picquelle and Stauffer 1985) on daily egg production and instantaneous mortality rates (Smith 1985) to estimate an average standing stock of planktonic stages. Using these mortality rates, we compute the number of propagules surviving on successive days from the number of eggs spawned; we add the number of propagules over the duration (days) of each planktonic stage to estimate standing stock. These estimates are presented in Table A2.

We find that our estimates of standing stock by stage are very sensitive to mortality rates. Changes of 25% in mortality rates result in an order of magnitude change in estimates of standing stock. We use these estimates of standing stock only to approximate entrapment rate (and ultimately adult-equivalent loss).

A.4 Entrapment Rate

For taxa not affected by SONGS, entrapment rate (E) is

$$E = L / S.$$

For taxa affected by SONGS, entrapment rate (E) is

$$E' = L' / S'.$$

Table A.3 shows estimates of entrapment rates. Note that for some taxa, eggs are not entrapped.

A.5 Major Assumptions in Estimating Entrapment Rate

A.5.1 Using Impact and Control Data for Taxa Not Affected by SONGS

Intake loss: For computing intake loss (A.2.1), we assume 1) density at the Impact site equals the density withdrawn, and 2) average contemporaneous densities at Impact and Control sites are equal.

Since the intake risers sit near the boundary of A- and B-Blocks and since intake waters come from both A- and B-Blocks, the first assumption is probably safely made. However, it should be noted that the proportion of water withdrawn from either A- or B-block may vary with oceanographic conditions. Furthermore, some B-Block samples are taken as much as 3 km south of the intake risers.

Evidence indicates that the second assumption, equal mean densities at Impact and Control, is also safe. We reviewed MEC's data for the preoperational period. We find no consistent differences in A- and B-Block densities at Impact and Control sites. (Note, the MRC's (1988a) published statistical comparisons, BACIP, are made on cross-shelf estimates of density and not just A- and B- Blocks.) We did not look at the data taken in the operational period, because we wanted to rule out any possible influence of SONGS in our analysis.

Standing stock: Estimates of standing stock (A.3.1) assume that the average density at Impact and Control equals the average density in the Bight. Review of data collected by the Los Angeles County Museum (made available to us through Southern California Edison) at 20 locations in the Bight shows that average densities at Impact and Control are within the limits of densities found elsewhere in the Bight. The Museum data are not precise enough to quantitatively relate densities near SONGS to the rest of the Bight for the purpose of computing bight-wide standing stock.

Using the Museum data, Lavenberg *et al.* (1986) show some evidence for consistent differences in the mean densities of some taxa between locations in the Bight; they show that densities of planktonic stages may be higher near habitats of spawning adults. But again, we find no appropriate way to quantitatively relate densities at SONGS to densities in other areas of the Bight.

A.5.2 Interpreting and Estimating SONGS' Effect

As documented in the Technical Appendix on Ichthyoplankton, SONGS' operation could have brought about changes in density of planktonic stages for the following reasons: Decreases could have resulted from 1) intake loss from transiting SONGS (that is, larvae were removed by SONGS and the plankton free discharge waters diluted the density at the Impact site), 2) avoidance of the Impact area, 3) higher mortality rates in the area of SONGS due to increased turbidity, turbulence from diffuser jets, or increased abundance of planktivorous fish and/or zooplankton, and 4) distributional shifts in density due to movements of water caused by SONGS' intakes and diffusers. Increases could have resulted from 1) increased survival, 2)

attraction due to increased food availability, and 3) as with decreases, distributional shifts in density due to movements of water caused by SONGS' intakes and diffusers. The MRC (1988a) was unable to determine a way which could explain the magnitude of such decreases and increases. Further, how SONGS' effect could be taxon-specific (causing both increases in some taxa and decreases in others) is problematic.

There are three ways to interpret these changes at Impact (relative to Control).

First interpretation: Decreases and increases, while statistically significant, result from natural changes in density and not from SONGS' operation; the relative changes in abundance between Impact and Control are within the range of changes expected over time. This hypothesis is supported by two arguments: (1) The majority of preoperational samples were taken in 1980. This brief period may not provide an adequate baseline (i.e., without SONGS) of Impact and Control densities. We effectively have only one sample (one spawning season) for the preoperational period. (2) The affected taxa may not be appropriate for testing SONGS' effects. The larvae of three taxa come from eggs not produced near SONGS: the eggs of arrow goby and California grunion are demersal, and eggs of the goby are spawned in bays. Northern anchovy spawn planktonic eggs primarily offshore of E-Block. These then are not ideal taxa for before-after-control-impact-pairs (BACIP) analysis (the testing and estimation procedure), since differences in larval transport mechanisms offer as likely a cause for observed changes in density as SONGS' operation. The significant increase for white croaker is troublesome. White croaker larvae virtually disappeared from the middle of the preoperational

period (May 1980) to the last year of the operational period (1986). Consequently, the data used for analysis may not represent "average" conditions for white croaker. The BACIP test results for white croaker are somewhat ambiguous. While evidence indicates white croaker larvae increased at the Impact site, we point out that, because of the nature of white croaker data, the interpretation of the results for white croaker are disputable. (See Barnett 1987).

If these changes are not a result of SONGS' operation, and probably not long-term, then in computing intake loss we need to incorporate data from both periods (preoperational and operational) and both sites (Impact and Control) equally.

Second interpretation: Decreased density in larvae results from mortality due to turbulence of diffuser jets (and/or other reasons like increased density of planktivores). Lower AB densities at the Impact site decrease estimates of intake loss (and adult-equivalent loss). Increased density resulting from increased survival (perhaps from increased availability of food) near SONGS yields a similarly false result. High AB density increases estimates of intake loss (and adult-equivalent loss).

In order to accurately estimate the total effect of SONGS' operation under this second interpretation, we would need to quantify increases and decreases over the spatial extent of SONGS' effect. We lack sufficient data to do this.

Third interpretation: Decreased density near SONGS results from dilution (larvae are filtered out of the Impact area by the plant) and/or redistribution of

different plankton densities (perhaps from induced cross-shelf shifts in densities) due to water movements caused by intakes and diffusers. Thus, SONGS decreases the AB density, and intake loss is less. Increased density near SONGS results from redistribution of plankton by water movements caused by the intakes, and/or attraction due to increased food availability. Thus SONGS increases the density of larvae near the intakes and intake loss increases.

With these interpretations in mind we make the following two decisions: 1) Observed statistical changes result from SONGS' operation. This decision is consistent with other MRC reports in which we assume that all statistically significant BACIP changes are caused by SONGS, unless there is strong evidence to the contrary. 2) We adjust intake loss according to the relative reductions reported (MRC 1988a). Thus, according to the second interpretation, we could be falsely 1) underestimating adult-equivalent loss for taxa which decrease at Impact (arrow goby and northern anchovy) and 2) overestimating adult-equivalent loss for taxa which increase at Impact (California grunion and white croaker). [Note in RESULTS we also present estimates of adult-equivalent loss computed under the assumption that relative changes at Impact in the operational period are random and not caused by SONGS, the first interpretation. In this case, factors F and G (A.2.2 and A.3.2) equal one.]

A.5.3 Using Impact Data for Affected Taxa

Intake loss: We assume that larval densities at Impact, as affected by SONGS' operation, equal that at intakes (A.2.2). Since we assume that SONGS'

operations altered density near the intakes, we use the data taken at the Impact site to estimate loss since this was the closest MRC sampling station.

Intakes are rarely under the direct influence of the plume. Therefore, acceptance of this assumption further implies that SONGS' effect is persistent and is associated with neither the immediately discharged plume nor direction of current. We have no data on which to evaluate these implications.

Standing stock: In estimating the standing stock of affected taxa (A.3.2), we assume SONGS affects densities equally in the cross-shelf (A- through E-Blocks). The relative percent changes shown in Table A.1 were for A- through D-Blocks. We do not know if SONGS' effect extends to E-Block, since E-Block samples were not analyzed for the operational period. We discuss the implications of this in A.5.5.

As a check on an equal SONGS' effect in the cross-shelf, we computed standing stock estimates of affected taxa by using the mean density over all cross-shelf transects, except Impact for the operational period. From A.3.2, ABCDE$'$ = ABCDE$'''$. Here, we effectively eliminate the need to adjust operational surveys taken at the Impact site by not considering them. Estimated entrapment rates computed in these two ways are similar (within plus or minus 15%).

A.5.4 Means Over Time

In computing intake loss and standing stock, we estimate mean densities over time (A.2 and A.3). That is, we compute a ratio of means [(mean entrapped) / (mean standing stock)] rather than mean of ratios by survey [mean (entrapped /

standing stock)]. This ratio of means statistically weights by abundance, surveys with greater abundance count more in estimating entrapment rate and adult-equivalent loss. Since SONGS kills more larvae during times of high abundance (and consequently has its greatest effect on adult equivalents), we feel this assumption is appropriate. Sampling dates are shown in MRC (1988a).

A.5.5 No Standing Stock Beyond E-Block

In estimating standing stock (A.3), we assume that planktonic stages do not extend beyond E-Block (approximately 7 km offshore). For some taxa (most notably northern anchovy), we know this assumption is incorrect. For other taxa we had no direct way to check this assumption, since MEC did not sample beyond E-Block. However, based on the magnitude of AB/ABCDE and ABCD/ABCDE ratios of mean densities, we believe we are able to identify taxa whose planktonic stages extended beyond E-Block to trivial and non-trivial extents: generally, ratios close to one indicate that larvae probably do not extend beyond E-Block; ratios much less than one show that many larvae are found in E-Block, and probably beyond. Known habitats of adults and juveniles help to evaluate results based on the magnitude of these ratios. We discuss ratios of mean densities, habitats of juveniles and adults, and their effect on estimating standing stock (and ultimately adult-equivalent loss) in RESULTS.

For taxa that do occur in non-trivial numbers beyond E-Block our estimate of stock size is too low and we overestimate entrapment rate and adult-equivalent loss. Our analyses demonstrate that taxa whose planktonic stages extend beyond E-Block have low estimates of adult-equivalent loss, even when we (wrongly and knowingly)

assume zero density beyond E-Block. In RESULTS we discuss, for each taxon, the effect of the assumption of zero density beyond E-Block by taxa.

A.5.6 Loss Is Proportionate Across All Depth Strata

In estimating intake loss, we assume that SONGS' samples vertically zoned organisms (those with relatively high densities in the neuston and epibenthos) in the same proportions as the waters they live in.

ECOsystems (1985) concludes that Units 2 and 3 intakes will exclude thin layers near the surface and seabed only on rare occasions.

Some taxa stratify vertically, especially in the flexion and post-flexion stages. The means by which these later stages accomplish natural stratification may depend on buoyancy and swimming speed, as well as other factors for maintaining vertical position in the water column. These factors, plus response time, may determine a propagule's ability to remain in the top and bottom 1/4- to 1/2- meter of the water column, and thus avoid being entrapped by SONGS.

The highest densities of flexion and post-flexion stages of some taxa are found near the surface and bottom. For instance, Jahn and Lavenberg (1986) found most post-flexion queenfish larvae within 0.5 m of the bottom. Using MRC data, we find the same result, that approximately 80% of post-flexion queenfish occur within the epibenthos. If individuals living in the (relatively thin) top and bottom layers are not entrapped by SONGS, we will overestimate intake loss (and ultimately adult-equivalent loss). Hence, our estimates present a worst case scenario.

We discuss the effect of swimming speed on entrapment in Appendix D.

A.5.7 Equal Effect Across All Stages

Estimated percent changes caused by SONGS shown in Table A.1 are for all larval stages combined. We apply this percent change for each stage separately, and therefore assume that the percent relative change for each stage equals that for all stages combined.

Because of high variance in density estimates (due in part to frequent zero occurrences), percent relative change is difficult to test and estimate separately by stage. From examining survey-by-survey data, we conclude that percent change cannot be estimated with sufficient precision by stage for the purpose of estimating intake loss for affected taxa.

A.5.8 Precision of Adult-Equivalent Loss

Estimating the precision of entrapment rate and ultimately adult-equivalent loss is not feasible because many of the estimates on which entrapment rate is estimated are based on a single observation, natural history, and/or judgment. Precision is very likely low.

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TABLE A.1.

BACIP test results for the relative change between Impact and Control sites from preoperational to operational periods, and estimated percent relative change for taxa with type I error \ 0.05 (from the Interim Technical Report 5. Fish larve and eggs, MRC 1988).

TAXA	P>T	% CHANGE
Arrow goby	0.006	-40%
Calif. grunion	0.001	+170%
Northern anchovy[1]	<0.050	-27%
White croaker	0.049	+67%

[1] Northern anchovy was tested separately for surveys of high and low abundance. Percent change listed is for all surveys combined.

TABLE A.2.

Estimated standing stock of planktonic stages of northern anchovy based on a mean daily egg production of 1.5×10^{13} eggs/day, and instantaneous daily mortality rates of 0.25, 0.16, and 0.05 for ages 0-7, 8-19, and greater than 20 days, respectively. Daily egg production is the mean from 1980 to 1984 (Picquelle and Stauffer 1985). Mortality rates are from Smith (1985). Durations of stages given in Table E.2.

STAGE	DAY BEGINNING	DAY ENDING	STANDING STOCK
ys/preflexion	2.5	26.6	3.8E+13
flexion	26.6	43.3	2.8E+12
post-flexion	43.3	110.0	2.4E+12

TABLE A.3.

Estimated entrapment rate (number entrapped per day divided by standing stock) by stage. Yolksac and preflexion stages have been combined (ys/preflexion). We equate entrapment rates of eggs to those of ys/preflexion.

TAXA WHOSE JUVENILES ARE ENTRAPPED

		ENTRAPMENT RATE
Black croaker	eggs	6.02E-05
	ys/preflexion	6.02E-05
	flexion	4.31E-04
	post-flexion	1.06E-03
Calif. corbina	eggs	1.17E-04
	ys/preflexion	1.17E-04
	flexion	2.02E-04
	post-flexion	1.05E-03
Calif. grunion[1]	ys/preflexion	8.75E-04
	flexion	6.95E-04
	post-flexion	1.58E-03
Jacksmelt	ys/preflexion	4.31E-04
	flexion	6.15E-04
	post-flexion	5.16E-04
Kelp & barred sand bass	eggs	1.90E-05
	ys/preflexion	1.90E-05
	flexion	2.11E-06
	post-flexion	3.48E-05
N. anchovy[1]	eggs	2.45E-07
	ys/preflexion	2.45E-07
	flexion	3.42E-07
	post-flexion	5.82E-07
Queenfish	eggs	1.32E-04
	ys/preflexion	1.32E-04
	flexion	8.23E-04
	post-flexion	1.01E-03
Salema	eggs	4.75E-05
	ys/preflexion	4.75E-05
	flexion	8.44E-06
	post-flexion	8.13E-05
White croaker[1]	eggs	1.76E-04
	ys/preflexion	1.76E-04
	flexion	6.12E-04
	post-flexion	5.22E-04

A - 21

Table A.3. (Continued)

TAXA WHOSE JUVENILES ARE NOT ENTRAPPED

		ENTRAPMENT RATE
Arrow goby[1]	ys/preflexion	3.67E-04
	flexion	6.22E-04
	post-flexion	5.80E-04
Blenny (unid.)	ys/preflexion	6.75E-05
	flexion	1.58E-05
	post-flexion	1.06E-05
Calif. clingfish	ys/preflexion	5.74E-04
	flexion	8.00E-04
	post-flexion	2.67E-04
Calif. halibut	eggs	4.85E-05
	ys/preflexion	4.85E-05
	flexion	9.50E-06
	post-flexion	5.38E-05
Cheekspot goby	ys/preflexion	6.83E-04
	flexion	9.27E-04
	post-flexion	7.87E-04
Pacific mackerel	eggs	9.92E-05
	ys/preflexion	9.92E-05
	flexion	3.17E-06
	post-flexion	1.06E-06
Diamond turbot	eggs	3.42E-04
	ys/preflexion	3.42E-04
	flexion	2.89E-04
	post-flexion	6.86E-04
Giant kelpfish	ys/preflexion	7.46E-04
	flexion	5.75E-04
	post-flexion	9.83E-04
Hornyhead turbot	eggs	1.90E-05
	ys/preflexion	1.90E-05
	flexion	1.06E-06
	post-flexion	1.06E-05
Kelpfish (unid.)	ys/preflexion	7.50E-04
	flexion	7.16E-04
	post-flexion	7.02E-04
Reef finspot	ys/preflexion	7.57E-04
	flexion	7.36E-04
	post-flexion	5.12E-04

TAXA WHOSE JUVENILES ARE NOT ENTRAPPED		ENTRAPMENT RATE
Shadow goby	ys/preflexion	9.03E-04
	flexion	1.03E-03
	post-flexion	8.98E-04

[1] Adjusted for SONGS' effect on density (see Table A.1): arrow goby (-40%), California grunion (+170%), northern anchovy (-27%), and white croaker (+67%).

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APPENDIX B

ESTIMATING ADULT STOCK SIZE

We cannot estimate daily entrapment rates for juveniles because we do not have data on density of juveniles. Consequently, we estimate an average juvenile entrapment rate according to an exponential rate of decrease from the entrapment rate of post-flexion larvae to the entrapment rate of early adults (Appendix D). We estimate the entrapment rate of early adults by dividing the estimated daily inplant loss of early adults by the estimated bight-wide standing stock of early adults. In this appendix, we estimate the standing stock of adults. In Appendix C, we 1) partition standing stock and daily inplant loss into their early adult components and 2) estimate daily entrapment rates of early adults by taking the quotient of these two.

Adult stock sizes estimated in this appendix are also used to estimate potential losses in numbers and biomass (section 3.3).

B.1 Introduction

We obtain estimates of the sizes of adult stocks for three taxa, queenfish, white croaker and northern anchovy. We use a modification of the "Egg Production Method" (EPM) (Parker 1980, 1985; Picquelle and Stauffer 1985) to estimate bight-wide abundance of queenfish and white croaker. Published estimates of stock size, mostly based on the EPM, are used for the northern anchovy.

Estimates of adult abundance have two important uses: (1) the fraction of total adults that fall into the young adult category is necessary as the denominator (S) used in calculating the entrapment ratio (E) of young adults (Appendix C). (2) Adult stock size is necessary to convert relative losses $(1 - R_c)$ to numbers of adult equivalents lost.

The EPM provides estimates of the size of adult populations based on measures of the production of spawned eggs and the fecundity of adult female fish. Egg production is calculated from standing stock abundance of eggs in plankton samples. Female fecundity is characterized in terms of seasonal egg output per average female (i.e., this is batch fecundity times the number of spawnings per season for taxa that spawn more than once a year). Using EPM we estimate stock size by taking the ratio of daily egg production to the expected number of eggs per individual in the stock. To calculate this expected number we need to estimate the fraction of the stock that are females, the fraction of these females which will spawn per day, and the average batch fecundity of these spawning females. These calculations can be expressed as follows:

$$A = P/F*f*R \text{ (Parker 1980)}, \qquad \text{EQU (1)}$$

where A = adult standing stock abundance

P = daily egg production of the stock,

F = average batch fecundity,

f = female spawning fraction (daily),

and R = adult female fraction of stock (females/ adults) on a weight basis.

To estimate the biomass of the adult stock (B), F is expressed as mean weight-specific fecundity (number of eggs/g) (Picquelle and Stauffer 1985), and R is the fraction that adult females contribute to total adult biomass. For a numerical stock estimate (N), F is expressed as the number of eggs per batch produced by a female of average body weight, and R is the fraction that adult females contribute to the total numbers of spawning fish of both sexes.

B.2 Queenfish and White Croaker: Egg Abundance and Production

B.2.1 Egg Abundance

Since queenfish and white croaker eggs cannot be identified, we estimate egg abundance indirectly using the numbers of unidentified, small pelagic eggs present in samples. This is different than the regression method used when eggs of the target taxa are identifiable, e.g., the approach used by NMFS personnel for the northern anchovy (Lo 1985). (Only the anchovy, among local taxa, has readily identifiable eggs.) We estimate the standing stock of queenfish eggs as follows: Total unidentified (i.e., non-anchovy) eggs present on MEC cruises made off San Onofre during the queenfish spawning season are multiplied by the fraction that queenfish yolksac and preflexion larvae contributed to total (including unidentified) yolksac and preflexion larvae present on these cruises. That is, assuming equal survivorship of egg, yolksac and preflexion larvae for all taxa,

$$QFSHEGGS = TOTEGGS * QFSHFRAC, \hspace{2cm} EQU (2)$$

B - 3

where QFSHFRAC = (queenfish yolksacs + preflexions) divided

by (total yolksacs + preflexions).

The queenfish spawning season extends from February or March through July or August, depending on year (DeMartini and Fountain 1981; DeMartini, unpubl. data). MEC's data are available for the period 1978-1986; during 1981, however, only one cruise was made during the queenfish spawning season). Because of the large variability in abundance estimates among surveys within years, we calculate a weighted mean over all cruises and years, weightings are the number of days from the mid-point of adjacent cruises. Estimates of the abundance of queenfish eggs are listed in Table B1a. Calculations analogous to those for queenfish are made to estimate the abundance of white croaker eggs based on the fraction of white croaker in all yolksac and preflexion larvae. The croaker spawning season is defined as October through May for the period 1978-86. Estimates are listed in Table B.1b for each of the eight croaker spawning seasons spanning 1978-86.

B.2.2 Daily Egg Production

In turn, we estimate daily egg production from mean egg abundance based on the following relation:

$$P = Z * N / (1 - e^{-zt}), \qquad \text{EQU (3)}$$

where P = daily egg production,

N = mean egg standing stock,

Z = instantaneous mortality rate of eggs (daily basis),

and t = duration of egg stage (in days).

We set the length of the egg stage at 2.5 days; this value is representative of small pelagic fish eggs at average water temperature (16°) in the Bight (W. Watson, *pers. comm.*). In lieu of accurate empirical estimates of queenfish and croaker egg mortality rates (see below), a constant egg mortality rate of $Z = 0.25$ (~22% per day) is selected based on published data for the northern anchovy (Smith 1985). Since anchovy, queenfish and croaker all have small pelagic eggs, the mortality for eggs is probably similar for these taxa. Mortality rates which typically range from 10-60% per day are typical for pelagic marine fish eggs (reviewed by Dahlberg 1979, Table 1: mean survivorship, $S = 62\%$, $SD = 26\%$, $n = 10$ taxa). We standardize a daily egg production per 1-m wide cross-shelf strip to daily production within the Bight by multiplying the number/m by 5×10^5, where 500 km is the longshore extent of the Bight (Appendix A). We list estimates of daily egg production in Table B.1.

B.3 Queenfish and Croaker: Batch Fecundity

We estimate "batch fecundity" (the number of eggs released per individual spawning) for queenfish by the method described by DeMartini and Fountain (1981) from samples collected by the UCSB Fish Project during 1979, 1980, 1984, 1985, and 1986 near SONGS. Fecundity-to-body length and fecundity-to-gonad-free body weight regressions are calculated, and mean batch fecundity is estimated for females of average body weight in each year. For white croaker, an analogous estimate is made for the pooled 1978-81 spawning seasons using the data of Love *et al.* (1984) and M. Love (*pers. comm.*). Table B.2 lists the weight-specific fecundities (numbers

of eggs/g), mean female body weights, and mean batch fecundities for queenfish and white croaker by relevant spawning season.

B.4 Queenfish and Croaker: Spawning Fraction

"Spawning fraction" (the fraction of total mature females spawning during a given time interval) is estimated for queenfish on a daily basis. During 1979, female queenfish in the San Onofre region spawned on average about once a week (Demartini and Fountain 1981). Spawning fraction is re-estimated for each of four additional years. The spawning fraction seems to have varied little among recent years for queenfish (Table B.3; DeMartini, unpubl, data). Love *et al.* (1984) estimates that female white croaker spawned once every 5.3 days during 1978-81, equivalent to a spawning fraction of 0.19 (Table B.3).

B.5 Queenfish and Croaker: Female Fraction

We estimate the "female fraction" (numbers or biomass) of adult queenfish using the sex ratio of adults caught by lampara seine during the spawning season. Numbers are converted to biomass by applying the general length-weight regression, $W = 8.7x10^{-6}SL^{3.11}$ (DeMartini and Fountain 1981, DeMartini *et al.* 1987, Appendix F) to the mid-points of 5-mm length classes, multiplying the mean weight of fish in that class by the frequency of male and female fish, and then summing the weights of all sample fish by sex over all length classes. Sex ratios are estimated for each year in which sufficient data are available. Ratios did not vary substantially among years (Table B.4).

For white croaker, we calculate weighted means of the sex ratios of croaker caught in otter trawls (day samples; 6, 12, and 18 m depths) during 1978-85 (SCE 1982, 1983, 1984, 1985, and 1986). These estimates are used to determine the fraction of females.

B.6 Northern Anchovy Stock Estimation

Table B.5 summarizes available data on stock (numbers and biomass) of the central subpopulation of the northern anchovy for the period 1978-1986. Anchovy comprise three stocks in the eastern Pacific; the central subpopulation inhabits the region between San Francisco and northern Baja (Vrooman *et al.* 1981). Literature sources for stock estimates are listed in Table B.5.

B.7 Estimates of Adult Stock Size

B.7.1 Northern Anchovy

During 1978-86, estimated stock size of anchovy central subpopulation varied from a low of about 20 billion fish weighing 300,000 MT (in 1984) to a high of about 50 billion fish weighing 870,000 MT (in 1980) (Table B.5). The standing stock was approximately 58 billion fish but fish were small and total biomass was only 652,000 MT. Average stock size during 1978-86 was 37 billion anchovy weighing about 534,000 MT (Table B.5).

B.7.2 Queenfish

Estimated stock sizes varies 60-fold, from a low of 12 million queenfish weighing 400 MT in 1982 to a high of 690 million fish weighing about 21,000 MT in 1985 (Table B.6). For the entire nine-year period from 1978-1986, the average queenfish stock was an estimated 140 million fish weighing about 4,300 MT (Table B.6).

B.7.3 White Croaker

Estimated stock sizes varies 50-fold, from a low of about 2.5 million fish weighing 235 MT in 1984 to a high of 120 million fish weighing about 11,500 MT in 1981 (Table B.7). During the eight spawning seasons from 1978-1985, stock size of white croaker averaged 55 million fish weighing nearly 5,300 MT (Table B.7).

B.8 Potential Inaccuracies: Factors Affecting Stock Estimates

Three major factors contribute to stock size estimates based on the Egg Production Method. These are estimates of: (1) egg production by the stock based on egg surveys, (2) egg production by the average female individual, and (3) adult female contribution to adult stock (Parker 1980, 1985). Egg production for queenfish and croaker stocks cannot be estimated directly because their eggs cannot be readily identified in plankton samples.

Of all potential sources of error, our method of estimating stock egg production based on stock egg abundance and an assumed egg mortality rate may

have introduced the most serious inaccuracies. As with the published anchovy estimates, estimates of egg abundance in MEC's plankton samples have large variances. In addition, our procedure includes the added step of estimating egg abundance of a taxon based on total unidentified egg abundance. The adjustment factor we used is the fraction that yolksac and preflexion larvae of the taxon contribute to all yolksac and preflexion larvae (Section B.2). This assumes that egg mortality of all taxa is proportionate to the mortality rates of yolksac and preflexion larvae of all taxa. This is probably a valid assumption because the eggs of almost all taxa are small (.9 $\pm$ .1 mm diameter) and share the same water-column habitat at the same time.

Another assumption is that the mean egg abundance in the San Onofre-Oceanside region is representative of mean abundance throughout the Bight. This assumption is probably weaker than our assumption of proportionate egg mortality rates, because the abundance of spawning fish probably varies regionally. However, no data exist to evaluate it rigorously (see analogous argument regarding regional variation in larval abundance, Appendix A).

A more likely source of error is our use of the average mortality rate of anchovy eggs, instead of empirical estimates for queenfish and white croaker eggs. The range in magnitude of estimates of egg production using bracketed egg mortality values illustrates the potential effect that this assumption has on our estimates of stock size. Using the anchovy mortality rate of 22% per day (Z = .25) over a 2.5 day egg stage duration, egg production is 54% of egg standing stock (Table B.1). If instead we had used an egg mortality rate of 10% per day (Z = .11) over this interval, egg production would have been 46% of egg stock. On the other

B - 9

hand, a mortality rate of 50% per day ($Z = .70$) yields an egg production of 85% of egg stock. Therefore, depending on the true value of egg mortality rate, we may have underestimated queenfish and croaker egg production (hence underestimated adult stocks) by as much as 36%, or we might have overestimated egg production and stocks by as much as 17%.

For both queenfish and croaker, estimation of egg production per female is based on two parameters, batch fecundity and spawning fraction. This is because the females of these two taxa, like anchovy, spawn multiple times per spawning season. For queenfish, our estimation of these parameters is based on a comprehensive, five-year series of data, and the precision of the estimates during each of the five years is reasonable (Tables B.2, B.3). (Of course, the implicit assumption here is that the batch fecundity and spawning frequency of queenfish in the San Onofre-Oceanside region is representative of the bight-wide stock. Again, we have no data to evaluate this assumption directly, but our data have never suggested any pattern to variation at sampling locations within the San Onofre-Oceanside region.) For white croaker, Love *et al.*'s (1984) estimates of batch fecundity and spawning fraction are used. Without multiple-year data for comparison, we do not know how representative these point estimates of white croaker are. Love *et al.* (1984) do not provide measures of the precision of their estimates. We can only conclude that because of fewer data on the egg production of individuals, our estimates of white croaker stock may be less accurate than our estimates of queenfish stock, but we cannot quantify the relative levels of accuracy.

EPM-based stock determinations are also influenced by estimates of female contribution to adult stock. For queenfish, characterization of sex ratios are based

on samples taken over eight to nine years off San Onofre. (Again, we have made the reasonable assumption that sex ratios in the region are representative of bight-wide stock.) For white croaker, numerical sex ratios are based on a long-time series of data (1978-85) off San Onofre. The sex ratio in terms of biomass for croaker, however, has to be based on a qualitative adjustment of the numerical ratio data. Thus, we have less confidence in the biomass spawning fraction estimates for croaker than in our analogous estimates for queenfish. Poorer accuracy in estimating the spawning fraction for croaker contributes to our overall lower confidence in the stock estimates for this taxa. However, even the most extreme sex ratio values that are reasonable (say, 4-0.6) would have relatively little effect on stock estimates compared to probable inaccuracies in estimating egg production of the average female croaker and (especially) inaccuracies in estimating bight-wide egg production of the white croaker stock.

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TABLE B.1.

Estimates of egg abundance and egg production for (a) queenfish and (b) white croaker. Estimates are on a spawning season basis, with cruise estimates weighted by interval between cruises within spawning season. Also presented are estimates of the abundance of total unidentified pelagic eggs, plus the fractional contribution of the yolksac and preflexion larvae of queenfish (QFSHFRAC) and white croaker (WCRKFRAC) to all yolksac and preflexion larvae. These yolksac and preflexion estimates are used to subdivide total unidentified eggs into queenfish and white croaker eggs. We estimated egg production assuming that egg mortality, $Z = 0.25$ (Section B.2).

(a) QUEENFISH

SPAWNING SEASON	NO. CRUISES	UNID EGG ABUNDANCE ($\#/M; \times 10^5$)	QUEENFISH EGG ABUNDANCE ($\#/M; \times 10^5$)	QUEENFISH EGG PRODUCTION ($\#/M; \times 10^5$)	"QFSHFRAC"
197812	9.1	1.7	0.89	0.182	
19796	5.5	1.0	0.511	0.176	
198023	7.9	1.7	0.91	0.218	
19811	10.4	0.9	0.50	0.089	
19823	8.2	0.2	0.09	0.026	
19833	5.5	0.4	0.20	0.078	
19844	9.8	6.0	3.21	0.685	
19855	22.5	6.7	3.60	0.299	
19864	6.9	0.8	0.43	0.078	
9 yr Wtd. MEAN		9.1	2.1	1.13	0.216

(b) WHITE CROAKER

SPAWNING SEASON	NO. CRUISES	UNID EGG ABUNDANCE ($\#/M; \times 10^5$)	WHITE CROAKER EGG ABUNDANCE ($\#/M; \times 10^5$)	WHITE CROAKER EGG PRODUCTION ($\#/M; \times 10^5$)	"WCRKFRAC"
1978-79	9	5.6	2.7	1.45	0.489
1979-80	10	5.3	3.0	1.60	0.565
1980-81	2	2.2	0.3	0.16	0.138
1981-82	2	7.7	4.8	2.58	0.624
1982-83	2	4.0	3.0	1.62	0.752
1983-84	4	7.0	0.4	0.21	0.056
1984-85	5	5.6	1.0	0.05	0.018
1985-86	4	4.5	3.2	1.74	0.713
8 yr Wtd. MEAN		5.4	2.2	1.21	0.427

TABLE B.2.

Estimates of batch fecundity and related parameters for (a) queenfish and (b) white croaker. Estimated means, standard errors of means, and sample sizes are listed for each spawning season in which data are available.

SPAWNING SEASON	BATCH FECUNDITY (x 10³) MEAN	FEMALE BODY WT. (G) MEAN	NUMBER FEMALES	MO.	NO. EGGS PER G MEAN	SEM	N
(a) QUEENFISH							
1979	15.2	45	872	6	339	21	44
1980	13.6	40	995	6	340	12	126
1984	9.4	35	295	5	268	16	71
1985	12.4	38	625	6	325	15	77
1986	13.1	40	951	6	327	15	75
5-yr mean	12.7	40			319		
4-yr mean (excl. '84)[a]	13.6	41			337		
(b) WHITE CROAKER							
1978-81	10.9	102[b]			107[c]	10	44

[a] 1984 was an El Nino year.

[b] Length frequency data for adults (>16.5 cm TL) captured at 18-109 m depths (Love et al. 1984, Fig. 2) converted to weight frequencies using the approximate length-weight regression, $W = 0.011TL^{3.02}$ (Love et al. 1984, Figs. 3,4).

[c] Length-specific fecundity data provided by M. Love, VRG, Occidental College. Converted to weight-specific fecundity using the length-weight relation, $W = 0.011TL^{3.02}$ (Love et al. 1984).

TABLE B.3.

Estimated "spawning fraction" (see Section B.4) for (a) queenfish and (b) white croaker. Estimates are listed for each spawning season in which data are available.

| SPAWNING SEASON | --------- SPAWNING FRACTION --------- | | |
	MEAN	SEM	NO. SAMPLES
(a) QUEENFISH			
1979	0.11	0.02	25
1980	0.15	0.04	19
1984	0.16	0.06	11
1985	0.06	0.01	38
1986	0.08	0.02	35
5-yr mean	0.11		
(b) WHITE CROAKER			
1978-81	0.19	--[a]	_[a]

[a] No data on variance of estimate and sample sizes available (Love *et al*. 1984).

TABLE B.4.

Estimated "female fraction" (females/adults) for (a) queenfish and (b) white croaker. Mean is averaged by month over the number of months (Mo). Estimates are listed for each spawning season in which data are available.

	FEMALE FRACTION						
	NUMBERS				**BIOMASS**		
SPAWNING SEASON	MEAN	NUMBER FEMALES	MO.		MEAN	FEMALE WT. (KG)	NUMBER MO. SAMPLES
(a) QUEENFISH							
1979	0.47	872	6		0.58	39.4	6
1980	0.32	995	6		0.46	39.8	6
1981	0.34	3210	6		0.44	112.0	6
1982	0.27	1523	6		0.32	45.7	6
1984	0.43	295	5		0.48	10.4	5
1985	0.35	625	6		0.44	23.5	6
1986	0.41	951	6		0.47	38.5	6
7-yr mean	0.36				0.46		
5-yr mean	0.39				0.48		
(b) WHITE CROAKER							
1978-81	0.52[a]				0.55[b]		

[a] Based on numeric sex ratio for total white croaker trawled at 6-18 m depths off San Onofre during 1978-1985 (SCE 1982, 1983, 1984, 1985, and 1986).

[b] Numeric sex ratio (0.52) is adjusted for faster growth rate and greater longevity of adult females (Love *et al*. 1984).

TABLE B.5.

Estimated stock (in numbers and biomass) and mean body weight per individual adult for the central subpopulation of northern anchovy, <u>Engraulis mordax</u>, during each of nine years from 1978 to 1986.

YEAR	STANDING STOCK NUMBERS	STANDING STOCK BIOMASS (MT)	MEAN BODY WT. (g)	SOURCES
1978	2.0×10^{10}[a]	300,000[c]	15[f]	Smith & Eppley 1982
1979	2.67×10^{10}[a]	400,000[c]	15[f]	Smith & Eppley 1982; Stauffer 1980
1980	4.99×10^{10}[b]	870,000[d]	17.4	Stauffer & Parker 1980
1981	4.75×10^{10}[b]	635,000[d]	13.4	Stauffer & Picquelle, 1981
1982	2.20×10^{10}[b]	415,000[d]	18.8	Picquelle & Hewitt, 1983
1983	5.82×10^{10}[b]	652,000[d]	11.2	Picquelle & Hewitt, 1984
1984	$2.57 10^{10}$[b]	309,000[d]	12.0	Hewitt 1985
1985	$3.60 10^{10}$[b]	522,000[d]	14.5	Bindman 1986
1986	4.67×10^{10}[a]	700,000[e]	15[f]	Methot & Lo 1987
9-yr mean	3.7×10^{10}	534,000	15	

[a] Stock numbers based on estimate of stock biomass and an assumed average body weight of 15 g.
[b] Stock numbers based on estimate of stock biomass and empirical data on mean adult body weight.
[c] Stock biomass based on "Larva Census Method."
[d] Stock biomass based on "Egg Production Method."
[e] Stock biomass based on "Stock Synthesis Method."
[f] Mean body weight estimated at 15 g, based on long-term average of known average body weights.

TABLE B.6.

Estimated spawning stock (in biomass and numbers) for queenfish. Estimates are provided for each of the years 1978-1986; differences among years in input data are noted.

	QUEENFISH	
	ADULT SPAWNING STOCK	
SPAWNING SEASON	BIOMASS (MT)	NUMBERS (x10^6)
1978[a]	2,758	88
1979[b]	1,190	33
1980[b]	1,949	70
1981[a]	1,616	52
1982[a]	391	12
1983[a]	634	20
1984[b]	7,810	249
1985[b]	20,966	691
1986[b]	1,757	50
9-yr mean	4,341	140

[a] No data available on reproductive parameters for individual females; stock estimate calculated using five-year average (1979-80, 84-86) data on female fecundity, spawning fraction, and adult sex ratio, applied to year-specific estimates of egg abundance and production.

[b] Stock estimated using year-specific data on female fecundity, spawning fraction, and adult sex ratio.

TABLE B.7.

Estimated spawning stock (in biomass and numbers) for white croaker. Estimates are provided for the years 1978-1986; differences among years in input data are noted.

| | WHITE CROAKER | |
| | ADULT SPAWNING STOCK | |
SPAWNING SEASON	BIOMASS (MT)	NUMBERS ($\times 10^6$)
1978-79a	6,501	67
1979-80a	7,150	74
1980-81a	722	7
1981-82b	11,522	120
1982-83b	7,243	75
1983-84b	940	10
1984-85b	234	2
1985-86b	7,792	81
8-yr mean	5,263	55

[a] Stock estimated using Love *et al.*'s (1984) data on female fecundity and spawning fraction, applied to spawning season-specific estimates of egg abundance and production.

[b] No data available on reproductive parameters for individual females; stock estimate calculated using 1978-81 data of Love *et al.* (1984), applied to spawning season-specific estimates of egg abundance and production.

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APPENDIX C

ESTIMATING THE ENTRAPMENT RATE OF YOUNG ADULTS

C.1 Introduction

We cannot estimate daily entrapment rates for juveniles because we do not have data on density of juveniles. Consequently, we estimate an average juvenile entrapment rate according to an exponential rate of decrease from the daily entrapment rate of post-flexion larvae to the daily entrapment rate of young adults (Appendix D). In this Appendix, we estimate (1) daily inplant loss, (2) bight-wide standing stock and (3) the entrapment rate of young adults, by taking the ratio of (1) to (2).

C.2 Inplant Loss and Bight-Wide Abundance of Young Adults

Technical Report C (based on DeMartini *et al.* 1987) presents estimates of yearly loss for Units 2 and 3 for pooled juveniles-adults (see Technical Report C, Tables 11 and 12). We convert these to daily losses by dividing by 356. Table C.1 lists these estimates of daily inplant loss for juveniles-adults for each of the ten taxa at risk as juveniles-adults at SONGS. We report estimates of loss at Units 2 and 3 as "maximum" and "adjusted." Maximum losses assume that all individuals entrapped die; adjusted losses debit diversion subtotals for the percentage survivorship of fish discharged by the Fish Return System. Table C.2 lists these percentage survivorship estimates by taxon (from Technical Report C; based on DeMartini *et al.* 1987).

C - 1

Next we estimate the fraction of young adults entrapped and in the spawning stock. On a taxon-by-taxon basis, we identify a segment of the adult length frequency distribution of smallest body size that represents 25-50% of total adults entrapped. For this we use entrapment data from Units 2 and 3. (Our rationale is to choose a fraction large enough to be within a factor of 2-4 of total adults, yet small enough to represent a reasonably short segment of the adult age distribution. For example, for queenfish young adults 10.5-11.4 cm SL, equivalent to 12-15 months of age represent 25% of adults entrapped.) We use an analogous method to calculate the fraction that young adults contribute to total adult stocks: the total length distribution is characterized for each taxon for which we had estimates of adult stock size or for which published harvest data could be substituted for estimates of stock size.

Table C.3 lists the length range representing "young adults" for each of the ten target taxa and the fractional contribution of young adults to total adults for both SONGS' losses and natural stocks (Table C.3). We also document data sources in Table C.3. For anchovy, queenfish and white croaker, young adults represent a larger fraction of the numbers of lost adults. This is expected, given the greater susceptibility of smaller fish to entrapment (Appendix D).

Next we provide estimates (or proxies) of the bight-wide abundance of adults. Sources for estimates differ with taxa. For northern anchovy, we take estimates of stock size from published papers and unpublished National Marine Fisheries Service reports; most anchovy estimates used the Egg Production Method (EPM; Appendix B). We use a modification of the EPM to estimate stocks of queenfish and white croaker (see Appendix B for details of calculation). Stock sizes

cannot be estimated for all taxa. In these latter cases, the annual fishery harvest is used as a minimum estimate of adult stock size. For commercially protected taxa (California corbina, the basses), National Marine Fisheries Service (NMFS) data on the recreational fishery are used (U.S. Department of Commerce, 1981, 1983, 1985, 1986, 1987). For taxa subject to commercial exploitation (e.g., California halibut), California Department of Fish and Game (CF and G) data on commercial catches are added to the recreational harvest data.

Table C.4 summarizes available data on the average annual harvests and stock sizes of the adults of ten target taxa. Harvest data are partitioned into the recreational and commercial fisheries, if possible.

Table C.5 lists, by taxon for each of the ten taxa, the key input data used to calculate the entrapment rate for young adults. Parameters listed are daily inplant loss (L) and estimated stock size (S). Since the complement of adult-equivalent loss $(1-R_c)$ for the old juvenile stage is equal to its entrapment rate multiplied by its duration, the duration of the old juvenile stage is to assist setting up the data for calculation.

C.3 Taxa Account: Discussion of Problem Data and Assumption Violations

C.3.1 Northern Anchovy

We believe we underestimate entrapment rate for young adult anchovies ($E = \sim 2 \times 10^{-10}$, Table C.5). However, we believe that E for anchovies is actually very low at SONGS for the following reasons: Entrapment rate for the old juveniles of this taxa includes our best, long-term data on stock numbers (S) and the percentage that young adults contribute to adult stock for any taxon on our list. Estimated inplant loss of young adult anchovies (9.5-9.9 cm SL, Table C.3) is known to be low at Unit 1 (DeMartini *et al.* 1987). We estimate, however, that anchovies longer than 9.0 cm SL are retained on the 3/8 inch mesh of the Units 2 and 3 screens, so entrapment of young adult anchovy at the new units should be accurately estimated; more than 90% of total entrapment occurs in Units 2 and 3.

C.3.2 Queenfish

We have confidence in our estimate of E for queenfish (7×10^{-6}; Table C.5) for the following reasons: First, the estimate of inplant loss of old juvenile queenfish is among the best for any taxa on our list; young adults (10.5 -11.4 cm SL) are retained on the screens of Unit 1, as well as Units 2 and 3, and our SONGS' entrapment estimates are precise (numbers: CV=8-13%; DeMartini *et al.* 1987, Appendix G, Table 1). Average stock size of queenfish was estimated based on the Egg Production Method, using five years of extensive data (Appendix B).

C.3.3 White Croaker

We think that our estimate of E for white croaker (3×10^{-6}) is reasonable but our confidence in this estimate is less than that for queenfish. Estimated inplant losses of old juvenile croaker are based on a large amount of precise data (numbers: CV=25-32%; DeMartini *et al.* 1987, Appendix G, Table 2). White croaker are fully retained. Therefore, entrapment data are accurate for young adults that are 13.5-13.9 cm SL.

Croaker loss estimates from 1983 to 1986 are undoubtedly lower than the long-term average because of the offshore emigration of adults and recruitment failure during the El Nino years, both of which contributed to low abundance of adults nearshore during 1983-86 (DeMartini *et al.* 1987). Stock size estimates for white croaker are based on fewer data, and thus are probably not as representative as our queenfish estimates. We estimate stock sizes of white croaker with confidence for the period 1978-1981 only; during this period, abundance was higher than during the El Nino years which are used to characterize inplant loss. If the 1979 and 1981 stock abundance and 1983 - 1986 inplant losses are used to determine entrapment rate, the rate will be an underestimate. However, even if the adult stock size is lowered by an order of magnitude, the estimated entrapment rate will be reduced by only 1/3 ($\sim 2 \times 10^{-6}$). A similar result is found if average daily losses at Unit 1 during 1978-1980 are used to estimate combined Unit 1 and Units 2 and 3 losses for this period, had the new units been operational. Using a factor of 100 times greater entrapment of white croaker (total in numbers) at both new units versus Unit 1 (DeMartini *et al.* 1987, Chapter 2, Table 14), losses at Unit 1 (an estimate of 50 pooled juveniles-adults per day) plus the new units (adjusted for

FRS-discharge survivorship), might have totaled ~4000 total white croaker per day. Generously assuming that one-fourth of these fish are adults, and that one-fourth of these adults are young adults, daily losses of young adult croaker might have been ~250 per day. Compared to average bight-wide abundances of 55 million adults (and 4 million young adults), the estimate of E still would have been only about 6 x 10^{-5}, i.e., still more than two orders of magnitude lower than the entrapment rate of post-flexion larval croaker. Thus, any reasonable combination of values indicates a relatively low entrapment rate for the young adult stage of white croaker at SONGS.

C.3.4 Taxa with Inplant Losses Estimable for Old Juveniles

Young adult losses are estimable for three additional taxa (black croaker, kelp and sand basses -- Table C.1). Although we are not able to estimate stock size for these taxa using the egg production method, we are able to estimate stock size of the basses from long-term fisheries harvest data (Table C.4). The magnitude of the bass harvest data (~4 million fish per year) is probably an order of magnitude less than stock size, so estimated entrapment rate based on harvest data (E = 2 x 10^{-8}) is overestimated. An entrapment rate as low, or lower than, 10^{-8} is negligible. However, the magnitude of the daily entrapment rate of juveniles is not the only factor that influences overall adult-equivalent loss. Duration of the juvenile stage and magnitude of the post-flexion entrapment rate are also important (Appendix A). For these reasons we hesitate to provide a numerical estimate of E for the basses, however we believe them to be very small.

In lieu of harvest data, using conservative estimates of stock numbers of black croaker (10^6) would result in similarly trivial entrapment rates for the old

juvenile stages of these two taxa (10^{-8} and 10^{-7}, respectively). Again, because the magnitude of the rate for old juveniles is not the only important factor, we hesitate to provide a precise value.

C.3.5 Taxa with Inplant Losses Inestimable for Juveniles

There are no length data for California corbina, grunion, jacksmelt, and salema entrapped at SONGS. For each of these taxa, the total number of fish entrapped is used to estimate inplant loss of older juveniles and therefore, older juvenile loss is underestimated. For all except salema, however, fisheries' harvest data are available as minimum estimates of stock size. For salema, a low estimate of stock size (10^6 fish) is used to provide an underestimate of S (Table C.5). The net result of a likely overestimated daily loss and a likely underestimated stock size in all cases should have produced an overestimate of E. The calculated values range from 10^{-5} to 10^{-6}, but we do not give them undeserved importance by including them in results.

C.3.6 General Patterns for All Taxa

Each of the ten taxa at risk to entrapment as juveniles-adults at SONGS has a low entrapment rate as an old juvenile. This is the case for taxa with high entrapment rates as post-flexion larvae (queenfish, white croaker), as well as taxa with very small post-flexion rates (e.g., the basses). We attribute the generally low E's primarily to the rapid increase in swimming speed (ability to avoid entrapment) at old juvenile-young adult body sizes, and secondarily to change in microhabitat as fish move offshore from the region of the SONGS' intakes as they age and grow.

C - 7

Losses during the juvenile stage can be relatively large even when E is small. This can occur if the duration of the juvenile stage is long or if our estimate of entrapment rate is high.

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TABLE C.1.

Estimated daily entrapment loss for each of ten select taxa considered at risk to entrapment as juveniles-adults at SONGS. Loss estimates for pooled juveniles-adults are subdivided into juveniles and adults, and the latter presented as TOTAL ADULTS and YOUNG ADULTS. Loss estimates are for the 39-month period from May 1983-August 1986, and include all operations at SONGS' Units 2 and 3. Loss estimates at the new units include a "maximum" (MAX) (assuming that all entrapped fish die) and an "adjusted" (ADJ) (i.e., with the diversion component adjusted for survivorship of FRS-discharged fishes). The "adjusted" value is the better estimate.

----- ESTIMATED DAILY LOSS (IN NUMBERS) -----

TAXON	POOLED JUVS-ADS		TOTAL ADULTS		YOUNG ADULTS	
	MAX	ADJ	MAX	ADJ	MAX	ADJ
Black croaker	1	0.35	0.08	0.03	0.03	0.01
California corbina[a]	4	0.64	no data[a]		no data[a]	
Grunion[a]	1	0.85	no data[a]		no data[a]	
Jacksmelt[a]	80	44	no data[a]		no data[a]	
Kelp & sand basses	8	2.5	3.91	1.25	1.13	0.36
Northern anchovy	11450	1416	457	56	213	26
Queenfish	3080	1604	816	424	212	110
Salema[a]	39	12	no data[a]		no data[a]	
White croaker	340	260	3.49	2.66	0.98	0.75

[a] No length frequency data exist for SONGS' inplant samples.

TABLE C.2.

Estimated percent mortality of FRS-diverted individuals of select species at SONGS' Units 2 and 3. See Technical Report C., Table 16. Estimates are based on results of Occidental College's "Offshore Survivorship Tests," or, if survivorship data are lacking for the particular species, are based on the survivorship of fishes in the appropriate size group ("Small," "Medium," or "Large").

TAXON	RELEVANT SIZE GROUP	EST. % DIV. SURVIVORSHIP
Black croaker	M	77%[a]
California corbina	L	100%[a]
Grunion	S	68%[a]
Jacksmelt	M	77%[a]
Kelp & sand basses	L	100%[a]
Northern anchovy	S	97%
Queenfish	S	68%
Salema	M	100%
White croaker	S	48%

[a] Diversion survivorship based on body size.

TABLE C.3.

Definition of the "young adult" stage (inclusive length range) for each of ten select taxa at risk to entrapment as juveniles-adults at SONGS. Also noted for each taxon is the fractional contribution (in numbers) of young adults to total adults for SONGS' Units 2 and 3 intake losses and the natural stock.

| | YOUNG ADULT | | |
| | | FRACTIONAL CONTRIBUTION TO ADULT | |
TAXON	LENGTH RANGE (SL, CM)	INPLANT LOSS	NATURAL STOCK
Black croaker	22.0-22.9	0.37	inest.[b]
California corbina[a]	no data[a]	no data[a]	inest.[b]
Grunion[a]	no data[a]	no data[a]	inest.[b]
Jacksmelt[a]	no data[a]	no data[a]	inest.[b]
Kelp & sand basses	21.0-21.9	0.29	inest.[b]
Northern anchovy	9.5-9.9	0.46	0.15[c]
Queenfish	10.5-11.4	0.26	0.13[d]
Salema[a] no data[a]	no data[a]	inest.[b]	
White croaker	13.5-13.9	0.28	0.07[e]

[a] No length frequency data exist for SONGS' inplant samples. Standard lengths in cm from the literature are as follows: California corbina 27.8 (Joseph 1962); grunion 11.9 (Clark 1925); jacksmelt 18.5 (Clark 1929); salema 11.5 (DeMartini unpubl.)

[b] No comprehensive data exist on size composition of stock.

[c] Estimate based on length frequency data for the southern California segment of the central subpopulation (CF&G Sea Survey data for the years 1979 - 1985).

[d] Queenfish from lampara seines near SONGS (night; 5-16 m depths; Mar-Aug 1984, 1985, and 1986).

[e] White croaker from San Pedro-area otter trawls (see Love *et al.* 1984, Figure 2: 18-109 m depths; Sept 1972-Feb 1980).

TABLE C.4.

Estimated average SONGS' entrapment loss (numbers, daily) and annual fishing harvests (in numbers) of TOTAL ADULTS for each of ten taxa at risk as juveniles-adults at SONGS. Inplant loss estimated from mean SONGS' Units 2 and 3 data for the 39-month period May 1983-August 1986. Loss expressed as "maximum" (assuming 100% loss of diverted fish at new units) and "adjusted" (corrected for survivorship of diverted fish). Average annual fishing harvests are presented as minimum estimates for population sizes. Harvest summaries include commercial (8 years: 1978-1985) and (or) recreational catches (7.5 years: mid-1979 through 1986; U.S. Dept of Commerce 1981, 1983, 1985-87), as appropriate for each species.

| | ----------------- TOTAL ADULTS ----------------- | | | | |
| | INPLANT LOSS (DAILY) | | AVERAGE ANNUAL CATCH | | STOCK SIZE (#S) |
TAXON	MAX	ADJ	SPORT	COMM	
Black croaker	0.08	0.04	no data	no data	no data
California corbina[a]	no data		66×10^3	trivial	no data
Grunion[a]	no data		191×10^3	trivial	no data
Jacksmelt[a]	no data		360×10^3	$30 \times 10^{3[b]}$	no data
Kelp & sand basses	3.91	1.25	4182×10^3	trivial	no data
Northern anchovy	457	56	$<30 \times 10^3$	$2 \times 10^{9[b]}$	$3.7 \times 10^{10[c]}$
Queenfish	816	424	554×10^3	$40 \times 10^{3[b]}$	$1.4 \times 10^{8[d]}$
Salema[a]	no data		no data	trivial	no data
White croaker	3.49	2.66	2825×10^3	$1480 \times 10^{3[b]}$	$5.5 \times 10^{7[e]}$

[a] Assumes harvest comprises adults only.

[b] Biomass (lbs.) converted to numbers using the following estimates of mean body weight for harvested adults: (anchovy: 15g/fish; jacksmelt: 100g/fish; queenfish: 50g/fish; white croaker: 100g/fish).

[c] Value is the 9-yr average for the period 1978-1986.

[d] Value is the 9-yr average for 1978-86.

[e] Value is the 8 spawning-season average for 1979-86.

TABLE C.5.

Estimated SONGS' Units' 2 & 3 entrapment losses (numbers, daily) and respective bight-wide abundance (in numbers) for young adults for representative stages of each of ten taxa at risk as juveniles-adults at SONGS. Duration of the old juvenile stage is noted (see Appendix D). "Maximum" (MAX) losses are provided (assuming that all fish entrapped at the new units die), in addition to "adjusted" (ADJ) losses (where total entrapment at Units 2 & 3 is corrected for the estimated percent survival of FRS-diverted fishes). Adjusted values are our better estimates of loss.

| TAXON | INPLANT LOSS (L) (DAILY) | | ESTIMATED STOCK (S) | L/S | DURATION (IN DAYS) |
	MAX	ADJ			JUV STAGE
Black croaker	0.03	0.01	$10^{6(a)}$	inest.[f]	na
California corbina[e]	4	0.64	$66 \times 10^{3(b)}$	inest.[f]	na
Grunion[e]	1	0.85	$191 \times 10^{3(b)}$	inest.[f]	na
Jacksmelt[e]	80	44	$390 \times 10^{3(b)}$	inest.[f]	na
Kelp & sand basses	1.13	10^{-1}	$42 \times 10^{5(b)}$	inest.[f]	na
Northern anchovy	212	26	$5.5 \times 10^{9(c)}$	4.33×10^{-9}	255
Queenfish	212	110	$1.8 \times 10^{7(d)}$	6.11×10^{-6}	288.5
Salema[e]	39	12	$10^{6(a)}$	inest.[f]	na
White croaker	0.98	0.75	$3.8 \times 10^{6(d)}$	1.97×10^{-7}	275.5

[a] Natural stock inestimable and no harvest data exist; a conservative value is used to allow computation.

[b] Natural stock inestimable; value used is the annual harvest (of assumed adults) as proxy for stock size of young adults.

[c] Value is the average of recent adult stock estimates (Table C.4), corrected for the fraction that young adults contribute to the stock (Table C.3).

[d] Value is the average of EPM-based estimates of stock size (see Appendix B and Table C.4), corrected for young adults (Table C.3).

[e] Inplant loss estimates for total juveniles-adults used as basis for conservative estimate of inplant loss of adults. This gross calculation was necessary for the 4/10 select taxa for which data on size composition of entrapped fish are lacking.

[f] Entrapment rate deemed inestimable because of insufficient data with which to approximate abundance (S) in determination of ratio.

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APPENDIX D

ESTIMATING JUVENILE ENTRAPMENT RATE

D.1. Outline of Methods

As discussed in Section 2.2, if the entrapment rate for immatures of age t is e(t), then the average rate is

$$e_i = I \, e(t)dt/d_i$$

the integral being from $t = t_i$, the beginning of the stage, to $t = t_i + d_i$, the end. In this Appendix, we will describe the entrapment rate as a function of body length, e(b), rather than of time. Since body length is assumed to grow linearly with time (i.e., the fish adds a constant amount of body length per day), the average rate is

$$e_i = I \, e(b)db/r_i$$

the integral being from $b = b_i$, the body length at the beginning of the stage, to $b = b_i + r_i$, the length at the end; r_i is the range of body lengths for the stage.

A fish will be entrapped by SONGS during a given time interval if (a) it is in the package of water withdrawn in that interval and (b) it is unable to escape from the water before it is withdrawn.

We define the <u>availability</u> of fish of a given body length as the entrapment rate that would obtain if these fish drifted passively with the water. Thus, in the terminology of Section 2.3.1,

$$A(b) = W_S D_S / W_B D_B.$$

We define the <u>vulnerability</u> of a fish of a given body length as the probability of it failing to escape from a package of water that is withdrawn. The entrapment rate is then the product of availability and vulnerability, i.e.,

$$e(b) = A(b)V(b).$$

It seems reasonable to assume that, in vulnerability and availability, early juveniles are like late larvae, and late juveniles are like young adults. Thus estimates of entrapment rate may be obtainable for species for which the vulnerability and availability of late larvae and early adults can be determined.

Since plankton are assumed to move passively with the water, the vulnerability of postflexion larvae is 1. Consequently the availability of late larvae is their entrapment rate.

Young adult vulnerability and availability are not so easy to estimate. Three numbers are needed: the numbers entrained per unit time, the relative density in the neighborhood of SONGS (as compared to other depths), and the Bight-wide population. Of these, the first is obtainable by inplant sampling (Technical Report C), and an approximation to the second is given by the results of lampara sampling in the 5-10 m depth zone (Interim Technical Report 3).

However, estimates of the Bight-wide population (or equivalently, of the average density in Blocks A-E) are lacking for all but two of the populations

D - 2

suffering juvenile entrainment (Table C.5). Egg production methods are needed for these estimates. The lampara catches are suitable for estimating relative densities but not for estimating total population size: fish actively avoid being caught, so the estimated densities need to be multiplied by an unknown catchability coefficient.

Fortunately, these two exceptions are queenfish and white croaker. These are the most important cases, since they (together with northern anchovy) make up the great majority of entrained larvae and juveniles, and (unlike anchovy) suffer the highest proportionate losses. The remainder of this Appendix concerns these cases.

Even for these cases, some assumptions about the data are needed. The queenfish estimate given in Table C.5 is the product of the total adult stock, as estimated by the egg production method, and the fraction of that stock which is young, estimated by the fraction of young adults in lampara catches. This may overestimate the numbers of young adults, since the lampara catches are made in the shallower part of the range, where the ratio of young adults is greater. The estimate of the fraction of young white croaker adults appears more reliable, since it is based on otter trawls, which are taken further offshore.

D.2 Minimum and Maximum lengths, Availability and Vulnerability for Queenfish and White Croaker.

For queenfish, the minimum length of juveniles is about b_{min} = 2 cm (Table E.1.A) and the maximum length is the minimum length of young adults, about b_{max} = 10.5 cm (Table C.3). The vulnerability of entering juveniles is taken to be

$$V_Q(2) = 1,$$

as for postflexion larvae, so the availability is the entrapment rate of postflexion larvae (Table A.3),

$$A_Q(2) = 0.00101.$$

To estimate the availability of young adults, we use $A = R_W R_D$, where R_W is the fraction of water in the Bight that is withdrawn by SONGS each day, and R_D is the ratio of the density of young adults near SONGS to the density in the Bight. (Thus $R_W R_D = W_S D_S / W_B D_B$, but we now use the same units for W_S as for W_B, and the same for D_S as for D_B.)

The amount of water withdrawn per day is, on average, about 6.8E+06 (Appendix A, Section A.2).

The amount of water in the Bight is the volume in a 1-meter strip (from the shore to the outer edge of Block E) multiplied by 500,000, the length of the Bight in meters. The volumes of 1-meter strips of blocks A, B, C, D and E are 4, 9, 30, 55 and 110 thousands of m^3 respectively (Interim Technical Report 5. Fish larvae and eggs, Appendix B). Thus the volume of water in the Bight is about 10^{11} m^3.

Accordingly, we take $R_W = 6.8 \times 10^{-5}$.

A rough estimate of the ratio of the density of young adults near SONGS to their density in the Bight generally can be obtained from Table 2 of DeMartini *et al.* (1987, Vol 1). We subtract the densities of adult males and adult females from the density given for older juveniles and adults. We do this for the operational period

D - 4

only, and for the Impact stations only, since there may be a behavioral reaction that has led queenfish to avoid the SONGS intake area. The differences are 6 (NI) and 0 (FI) for the 5 - 10 m depth zone, and 2 and 2 for the 11 - 16 m zone. We take the 5-10 figure to estimate the density in Blocks A and B, and the 11-16 figure to estimate density in Block C. Immature queenfish are not found beyond about 16 m depth, so we estimate the density in Blocks D and E to be 0. Thus the average density per lampara haul for Blocks A - E is: (A-B volume)×6 + (C volume)×4 all divided by A-E volume. These three volumes are 13, 30 and 208 thousand m³ respectively, so we estimate A-E density by $198/251 \approx 0.8$ per lampara net haul. The ratio of A-B to A-E density is thus $R_D = 6/0.8 = 7.5$.

Thus the availability of the largest juveniles is

$$A_Q(10.5) = 7.5 \times 6.8 \times 10^{-5} = 0.00051.$$

About 212 young adults are entrapped per day, not adjusting for those saved by the Fish Return System, which does not save juveniles. The total standing stock of young adults is estimated by the Egg Production Method to be $1.8 * 10^7$ (Table C.5). Thus the entrapment rate for young adults is the ratio, 11.8×10^{-6}.

Combining availability and entrapment rate, we estimate the vulnerability of young adults to be

$$V_Q(10.5) = 11.8 \times 10^{-6}/0.00051 = 0.023.$$

For white croaker, we obtain b_{min} = 1.9 cm and b_{max} = 13.5 cm. (Tables E.1.A and C.3). The vulnerability of postflexion larvae is again taken to be

$$V_{WC}(1.9) = 1,$$

so the availability is the entrapment rate (Table A.3),

$$A_{WC}(1.9) = 0.000522.$$

There are no separate figures for adult and immature white croaker, so we use the totals, which should reflect mostly young adults. (Older white croaker adults tend to be further offshore.) Average density per lampara haul is 29/2 for the 5-10 m depth zone (taken as giving the density in A-B Block) at the Impact stations in the operational period and 1 for the 11-15 m zone (C Block) (DeMartini *et al.* 1987, Table 2). Assuming there are no immatures beyond C Block, calculations similar to those for queenfish give the ratio of A-B density to A-E density to be R_D = 16.7. Thus the availability of late juveniles is

$$A_{WC}(13.5) = 16.7 \times 6.8 \times 10^{-5} = 0.001135.$$

Approximately 0.98 young adults are entrapped per day, from a standing stock of about 3.8×10^6 (Table C.5, again using the maximum entrapment figure). Dividing this by the availability gives a vulnerability of

$$V_{WC}(13.5) = [0.98/(3.8 \times 10^6)]/0.001135 = 0.00023.$$

D.3 The Shape of Availability and Vulnerability Functions

We assume that the availability and vulnerability functions at the beginning and end of the juvenile stage are as given in the previous section. However, we do not know how soon the late juvenile values are reached. The sooner this occurs, the lower will be the average entrapment rate. The estimates of entrapment in this Appendix are based on different guesses at the rapidity with which adult levels of availability and especially vulnerability are reached.

Availability. The evidence from mid-water lampara samples of queenfish suggests that juveniles of 6 - 7 cm, roughly midway between 2 cm larvae and 10.5 cm young adults, are distributed more like adults than like larvae. We have used three models, one assuming slow linear change, so that the young adult distribution is reached only at adult length, another assuming fast linear change, with the young adult distribution reached midway between postflexion and young adult, and the average of the two. Changes in availability functions have only a small effect on the estimates of losses, because availabilities of post-flexion larvae and young adults differ only by a factor of two.

Vulnerability. The decline in vulnerability with length probably depends mainly on swimming speed. Small fish are more likely to be entrapped than large fish because small fish are less able to outswim intake currents (Hanson *et al.* 1977; DeMartini *et al.* 1985; Schuler and Larson 1975; Larson 1979).

We expect a sharp reduction in vulnerability when the fish's maximum swimming speed is equal to 50 cm/sec, the average velocity of water at each of the

SONGS intakes (Units 2 and 3) (SCE 1987, Tables 1-5). (The average velocity at the Unit 1 intake is about 70 cm/sec, but this report concerns losses due to the new Units alone.) This maximum speed, which can be maintained for only a few seconds, is known as "burst" or "critical" speed, and is a measure of the brief anaerobic performance required when attempting to outswim a predatory fish (or an intake).

Present theory and empirical data indicate that several factors control swimming speed. Most important is body length (Blaxter 1969; Webb 1975; Wardle 1975, 1977) and then frequency of the tail beat (Hunter and Zweifel 1971). Amplitude of the tail beat is a constant proportion of body length, averaging about 0.2 x Total Length for the upper range of swimming speeds we are concerned with (Bainbridge 1958; Van Olst and Hunter 1970; Hunter and Zweifel 1971). Of course, mode of locomotion is also important (e.g., does the fish swim like an eel or like a bass), but all of the taxa at risk to entrapment as juveniles at SONGS are carangiform swimmers which swim by flexing their posterior body and/or caudal fin (Lindsey 1978).

For our purposes, estimates of burst swimming speed based on body length alone must suffice, because we lack specific data on tail beat frequency. The latter data exist for only a few local taxa (jack mackerel, Pacific mackerel: Van Olst and Hunter 1970; Hunter and Zweifel 1971), and the juveniles-adults of neither taxa are at major risk to entrapment at SONGS.

Our estimates are based on the generalization that carangiform swimmers are capable of burst swimming speeds that increase with total body length raised to

a minimum of the 0.5 power (for salmonids) to <u>a maximum of less than</u> the 1.0 power (for herring-like fishes) (Blaxter and Dickson 1959; Bainbridge 1960; Brett 1965; Fry and Cox 1970). Swimming speed may approach a linear relation with body length, but in general the increase appears to be less than linear (reviewed by Webb 1975). For example, burst speed increases as a decelerating function of increased body length in small clupeoid-like, gadid-like, and salmoniform fishes (Webb 1975; Wardle 1975, 1977; Hartwell and Otto 1978; Turnpenny 1983; Turnpenny and Bamber 1983).

Burst swimming speeds can range from about 25 body lengths/sec in 5-10 cm fish to much less than 10 body lengths/sec in fish greater than 20-30 cm long (Wardle 1975, 1977). Fish that are 10-20 cm long are capable of speeds of about 10 body lengths/sec. The observations of Dorn *et al.* (1979) support the "10 body lengths/sec" rule. The burst speeds of five taxa of local (sub)carangiform swimmers (including white croaker, one of the taxa on our list) averaged 8.5 body lengths/sec and ranged from 6-11 body lengths/sec for specimens 10-20 cm long (Dorn *et al.* 1979, Table 1).

Thus, in terms of published data for typical nearshore California fishes and for small herring-like, perch-like, and bass-like fishes elsewhere, a body length of about 5 cm seems sufficient to achieve a burst speed of 0.5 m/sec, the velocity of water entering the intakes at Units 2 and 3.

This appears more likely to overestimate the true critical length than to underestimate it. The "norm" of 10 body lengths/sec applies usually to larger fish, which are usually capable of fewer body lengths per second than smaller fish. For

example, if swimming speed is proportional to body length raised to the 0.75 power (midway between the rough minimum of 0.5 and a generous maximum of 1), and a 10 cm fish is capable of 10 body lengths per second, then a fish of only 2.8 cm is capable of a burst speed of 50 cm/sec. At the other extreme, if speed is proportional to body length and a 10 cm fish is capable of only 8.5 body lengths/sec, as for larger white croaker, then a fish needs to be 5.9 cm to be capable of 50 cm/sec.

Our estimates of the vulnerability function all have the form

$$V(b) = V(b_{min}) \text{ for } b \leq b_{crit}$$
$$= V(b_{max}) \text{ for } b > b_{crit},$$

where b_{crit} is the critical body length at which the fish is able to escape from water being drawn in to Unit 2 or Unit 3.

Thus we assume that vulnerability drops from the postflexion rate to the adult rate as soon as the fish is able to swim fast enough to escape a parcel of water that is at the entrance to the intake. The adult rate is not zero: some adults continue to be entrained, presumably due to surge, poor visibility, and confusion about escape direction.

One objection to this function is that vulnerability is likely to change continuously, rather than in a single step. However, since the proportional change in availability is far less than that in vulnerability, the estimated entrapment rate depends almost entirely on the average of the vulnerability function. Thus any function having the symmetry property $V(b_{crit} - x) + V(b_{crit} + x) = $ constant will lead

to essentially the same entrapment rate. (Large values of x, for which either b_{crit} - x or b_{crit} + x is outside the range of juvenile lengths, will have $V(b_{crit} - x) = V(b_{min})$ or $V(b_{crit} + x) = V(b_{max})$, whichever is appropriate.) We have merely picked the simplest of these.

We use three estimates of b_{crit}, roughly bracketing the range (2.8 to 5.9) given above: 3, 4, 5 and 6.

We argued above that the speed is likely to be less than 5. However, burst speed is not the only factor in escape. The fish must realize it is in danger, try to escape, and swim in the right direction to do so. If the fish tries to escape before it has reached the intake entrance, the water velocity will be less (it decreases roughly in proportion to $r^{-3/2}$, where r is the distance from the entrance), so a lower burst speed will suffice: smaller fishes will be able to escape. If the fish tries to escape after entry, turbulence, confusion and the need to maintain burst speed for a longer period will make the task harder: larger fishes will be unable to escape. We found only a few studies that assess vulnerability based on swimming speed of fishes at power plants (Schuler and Larson 1975; Dorn *et al.* 1979, Hartwell and Otto 1978, Turnpenny 1983, and Turnpenny and Bamber 1983). These did not address these questions for the species we are concerned with here.

D.4 Summary

The basic equation used to determine the fraction of juveniles escaping entrapment is

$$E = \exp\{ -d \, I \, A(b)V(b) \, db\}$$

where d is the time spent in the juvenile stage, b is body length, A is availability, V is vulnerability, and the integral is from b_{min} to b_{max}, the maximum and minimum juvenile body lengths of the taxon.

Three functions (high, middle and low) are assumed for availability and four for vulnerability, yielding 12 estimates of entrapment altogether. Our guess is that the correct value is between those given by critical lengths of 4 and 5, with the average vulnerability function.

The three availability functions are:

$$A_1(b) = [1 - F(b)]A(b_{min}) + F(b)A(b_{max}) \text{ for } b < b_{mid}$$
$$= A(b_{max}) \qquad\qquad \text{for } b > b_{mid}$$

where $F(b) = (b - b_{min})/(b_{mid} - b_{min})$ and $b_{mid} = (b_{max} + b_{min})/2$;

$$A_2(b) = [1 - G(b)]A(b_{min}) + G(b)A(b_{max})$$

where $G(b) = (b - b_{min})/(b_{maxd} - b_{min})$; and the average of these. A_1 is the low estimate if $A(b_{min}) < A(b_{max})$ as for queenfish; otherwise A_2 is the low estimate, as for white croaker. The average is always the middle estimate.

For vulnerability, the functions are:

$$V(b) = V(b_{min}) = 1 \text{ for } b \le b_{crit} \quad = V(b_{max}) \text{ for } b > b_{crit}$$

where b_{crit} = 3, 4, 5 and 6.

For queenfish, d = 288.5, b_{min} = 2, b_{max} = 10.5, A(2) = 0.00101, A(10.5) = 0.00051, and V(10.5) = 0.023. For white croaker, d = 275.5, b_{min} = 1.9, b_{max} = 13.5, A(1.9) = 0.000522, A(13.5) = 0.001135, and V(13.5) = 0.00023.

The entrapment rates, probabilities of avoiding entrapment, and adult equivalent losses that follow from these functions are given in Table 1. Again, our guess is that the correct value is between those given by critical lengths of 4 and 5, for the average availability function.

No estimate is possible for the remaining species whose juveniles are entrapped, because we do not have estimates of the entrapment rates of their adults. The juveniles of these species, relative to their larvae, are less susceptible to entrainment than are queenfish, because they live further from the intake and nearer to the bottom.

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TABLE D.1.

Entrapment Rates, Probabilities of Avoiding Entrapment, and Adult Equivalent Losses.

----------------- QUEENFISH -----------------

CRITICAL LENGTH	AVAILABILITY FUNCTIONS		

AVERAGE JUVENILE ENTRAPMENT RATE

CRITICAL LENGTH	HIGH	AVERAGE	LOW
3	0.0001302	0.0001271	0.0001239
4	0.0002361	0.0002279	0.0002197
5	0.0003353	0.0003187	0.0003020
6	0.0004278	0.0003993	0.0003708

FRACTION AVOIDING ENTRAPMENT (ALL STAGES)

CRITICAL LENGTH	HIGH	AVERAGE	LOW
3	0.9098	0.9106	0.9114
4	0.8824	0.8845	0.8866
5	0.8575	0.8616	0.8658
6	0.8349	0.8418	0.8487

PERCENT ADULT EQUIVALENT LOSS

CRITICAL LENGTH	HIGH	AVERAGE	LOW
3	9.02	8.94	8.86
4	11.76	11.55	11.34
5	14.25	13.84	13.42
6	16.51	15.82	15.13

------------- WHITE CROAKER -------------

CRITICAL LENGTH	AVAILABILITY FUNCTIONS		

AVERAGE JUVENILE ENTRAPMENT RATE

CRITICAL LENGTH	HIGH	AVERAGE	LOW
3	0.0000552	0.0000538	0.0000524
4	0.0001148	0.0001098	0.0001047
5	0.0001835	0.0001725	0.0001615
6	0.0002612	0.0002421	0.0002229

FRACTION AVOIDING ENTRAPMENT (ALL STAGES)

CRITICAL LENGTH	HIGH	AVERAGE	LOW
3	0.9471	0.9475	0.9478
4	0.9317	0.9330	0.9343
5	0.9142	0.9170	0.9198
6	0.8948	0.8996	0.9043

PERCENT ADULT EQUIVALENT LOSS

CRITICAL LENGTH	HIGH	AVERAGE	LOW
3	5.29	5.25	5.22
4	6.83	6.70	6.57
5	8.58	8.30	8.02
6	10.52	10.04	9.57

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APPENDIX E

ESTIMATING DURATION AT RISK FOR PLANKTONIC STAGES

We estimate the length of time (duration) a larval stage is at risk to entrapment by dividing the range in body length of larvae in a stage by the daily growth rate.

E.1 Estimating Range in Body Length of a Stage

Ideally we would estimate range in body length of a stage by subtracting estimates of initial mean length at the beginning of a stage from mean length at end of a stage. Here, the final length for a stage$_i$ would be the initial length of stage$_{i+1}$. Unfortunately, it was difficult to estimate initial and final lengths of each stage because the distribution of lengths overlap for adjacent stages.

We chose to use modal lengths to estimate the length of a stage: we estimate the range in length of stage$_i$ by subtracting the modal length of stage$_i$ from the modal length of the subsequent stage$_{i+1}$. In the case of the yolksac stage, we subtract length at first hatching from the modal length of the preflexion stage. For the post-flexion stage, we subtract the modal length of post-flexion from the length at metamorphosis. Estimates of lengths at hatching and metamorphosis are taken, or derived, from the literature (Table E.1A).

Since modal lengths probably overestimate initial length, the tendency would have been to overestimate the range in length at stage for preflexion stage and underestimate the same for post-flexion stage.

Since the length distribution for stages overlap, we encounter an additional problem in that the modal length for a stage is sometimes very close (or the same) to the modal length of an adjacent stage. While this tends to decrease the estimate of length at stage for the subsequent stage, the overall range in length, from hatching to metamorphosis, is unaffected. In general, similar modal lengths occurred for earlier stages, which had shorter ranges than later stages. The overall effect of closeness of modal lengths for adjacent stages on estimates of adult-equivalent loss is slight and is discussed by taxon in RESULTS. If there are multiple modes per stage, we choose the mode for the shortest length.

E.2 Growth Rate

For most taxa, we obtain estimates of growth rate from the literature, Table E.1B. For taxa without documented estimates of growth rate, we choose 0.25 mm/day, a mean rate (based on data in Table E.1A) characteristic of microcarnivorous fish larvae.

E.3 Duration in Time at Stage

We estimate duration of each stage by dividing the range in length at stage by daily growth rate (Table E.2). Here, we assume that growth rate is linear for larval stages. This was demonstrated by MEC's data on queenfish and white croaker

(Barnett *et al.* 1980) and published data on northern anchovy (Methot and Kramer 1979) and sardines (Lasker 1964). For eggs we use a duration of 2.5 days, the average embryonic period of small, pelagic fish eggs at 16 C^o (W. Watson, *pers. comm.*).

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TABLE E.1A.

Data summary for length-at-hatching (in mm), growth rate (mm day^{-1}), and length and age (in days, posthatching) at metamorphosis taxa of larval fishes at risk to SONGS' intake. References in Table E.1B.

SPECIES OR TAXON	LENGTH AT HATCHING	GROWTH RATE	METAMORPHOSIS AGE	METAMORPHOSIS LENGTH
Arrow goby	3.0	0.25[c]	48[f]	14.9[e]
Black croaker	1.7[a]	0.25[c]	55[f]	<15.5[d]
Blenny (unid.)	2.5,2.9,3.0	0.29	66	22.1
California clingfish	4.0	0.25[c]	24[f]	8-12
California corbina	1.7	0.25[c]	49[f]	<13.9[d]
California grunion	7.7	0.27-0.3;0.3-0.4	30-40	16,20
California halibut	2.0	0.20-0.27[b]	30	7.5-9.4
Cheekspot goby	3.1	0.25[c]	41[f]	13.4[e]
Pacific mackerel	3.1	0.54-0.6	21	15;19-25
Diamond turbot	1.7-2.3	0.25[c]	36[f]	11
Giant kelpfish	5.8	0.37[b]	60-90	25-42[e]
Hornyhead turbot	3.3	0.1	?87	12
Jacksmelt	6.9[a]	0.25[c]	40[f]	>17[c]
Kelp and barred sand bass	2.2	0.3[b]	30	11-12
Kelpfish (unid.)	4.5[a]	0.25[c]	42	15[e]
Northern anchovy	2.5-3.0	0.3	72	35
Queenfish	1.5	0.25	73	20
Reef finspot	4.0[a]	0.25[c]	52[f]	17[e]
Salema	1.9[a]	0.25[c]	54[f]	>15.5[d]
Shadow goby	3.0	0.25[c]	26[f]	9.5[e]
Spotfin croaker	1.7[a]	0.25[c]	47[f]	<13.5[d]
White croaker	1.6	0.20	81	19

[a] Length-at-hatching estimated as the observed average minimum length of the species' yolksac larva (or the average minimum length of its preflexion larva, if the yolksac stage is completed prior to hatching).

[b] Growth rate linearly interpolated, based on length-at-hatching, length- at-metamorphosis, and duration of larval stage.

[c] Growth rate characterized by the mean rate (0.25 mm day-1) of micro- carnivorous fish larvae

[d] Length-at-metamorphosis estimated as length of smallest known specimen that is fully scaled (or largest known specimen that is incompletely scaled).

[e] Length-at-metamorphosis estimated as length of smallest known benthic recruit.

TABLE E.1B.

References for data on length-at-hatching, growth rate, and length and age at metamorphosis, summarized in Table E.1A.

Species or Taxon	Literature and Other Sources
Arrow goby	Brothers 1975
Black croaker	H.G. Moser, *pers. comm.*; W. Watson, *pers. comm.*
Blenny (unid.)	Hubbs 1965; Ninos 1984; Stephens *et al.* 1970; Stevens & Moser 1982
California clingfish	Allen 1979; L.G. Allen, *pers. comm.*
California corbina	H.G. Moser, *pers. comm.*; W. Watson, *pers. comm.*
California grunion	Ehrlich & Farris 1971, 1972; Moffat & Thomson 1978; W. Watson, *pers. comm.*; White *et al.* 1984
California halibut	Ahlstrom *et al.* 1984; J.R. Hunter, *pers. comm.*
Cheekspot goby	Brothers 1975
Pacific mackerel	Fry 1936; J.R. Hunter, *pers. comm.*; Hunter & Kimbrell 1980; Kramer 1960; Zweifel & Lasker 1976
Diamond turbot	Ahlstrom *et al.* 1984; Sumida *et al.* 1978
Giant kelpfish	Stepien 1986
Hornyhead turbot	Ahlstrom *et al.* 1984; Budd 1940; Farris 1959; Sumida *et al.* 1978
Jacksmelt	W. Watson, *pers. comm.*; White *et al.* 1984
Kelp & barred sand bass	Butler *et al.* 1982; H.G. Moser, *pers. comm.*
Kelpfish (unid.)	C. Stepien, *pers. comm.*
Northern anchovy	Bolin 1936; Hunter 1976; Lasker & Smith 1977; Methot 1983; Methot & Kramer 1979; Smith 1985; Smith & Lasker 1978; Zweifel & Lasker 1976
Queenfish	H.J. Walker, unpubl.; W. Watson, *pers. comm.*
Reef finspot	J.S. Stephens, *pers. comm.*
Salema	W. Watson, *pers. comm.*
Shadow goby	Brothers 1975
Spotfin croaker	H.G. Moser, *pers. comm.*; W. Watson, *pers. comm.*
White croaker	H.J. Walker, *unpubl.*; Watson 1982; Watson, *pers. comm.*

TABLE E.2.

Estimated duration (in days) of stage, computed by dividing the range in body length in a stage by the daily growth rate. Range in length is computed by subtracting the modal length at stage from modal length at subsequent stage.

TAXA WHOSE JUVENILES ARE ENTRAPPED		MODAL LENGTH	RANGE IN LENGTH	DURATION T	GROWTH MM/DAY
Black croaker	egg	-	-	2.5	0.25
	yolksac	1.7	0.3	1.2	
	preflexion	2.0	3.5	14.0	
	flexion	5.5	1.5	6.0	
	post-flexion	7.0	8.5	34.0	
	metamorphosis	15.5	-	-	
Calif. corbina	egg	-	-	2.5	0.25
	yolksac	1.7	1.3	5.2	
	preflexion	3.0	1.0	4.0	
	flexion	4.0	2.0	8.0	
	post-flexion	6.0	7.9	31.6	
	metamorphosis	13.9	-	-	
Calif. grunion	yolksac	5.6	0.9	3.0	0.30
	preflexion	6.5	2.5	8.3	
	flexion	9.0	3.5	11.7	
	post-flexion	12.5	5.5	18.3	
	metamorphosis	18.0	-	-	
Jacksmelt	yolksac	5.0	2.0	8.0	0.25
	preflexion	7.0	3.0	12.0	
	flexion	10.0	4.5	18.0	
	post-flexion	14.5	2.5	10.0	
	metamorphosis	17.0	-	-	
Kelp & barred sand bass	egg	-	-	2.5	0.30
	yolksac	2.2	0.8	2.7	
	preflexion	3.0	1.5	5.0	
	flexion	4.5	1.5	5.0	
	post-flexion	6.0	5.5	18.3	
	metamorphosis	11.5	-	-	
N. anchovy	egg	-	-	2.5	0.30
	yolksac	2.8	0.3	0.8	
	preflexion	3.0	7.0	23.3	
	flexion	10.0	5.0	16.7	
	post-flexion	15.0	20.0	66.7	
	metamorphosis	35.0	-	-	

TAXA WHOSE JUVENILES ARE ENTRAPPED		MODAL LENGTH	RANGE IN LENGTH	DURATION T	GROWTH MM/DAY
Queenfish	egg	-	-	2.5	0.25
	yolksac	1.5	0.5	2.0	
	preflexion	2.0	4.0	16.0	
	flexion	6.0	3.0	12.0	
	post-flexion	9.0	11.0	44.0	
	metamorphosis	20.0	-	-	
Salema	egg	-	-	2.5	0.25
	yolksac	2.0	2.0	8.0	
	preflexion	4.0	0.5	2.0	
	flexion	4.5	2.0	8.0	
	post-flexion	6.5	9.0	36.0	
	metamorphosis	15.5	-	-	
Spotfin croaker	egg	-	-	2.5	0.25
	yolksac	1.7	0.3	1.2	
	preflexion	2.0	2.5	10.0	
	flexion	4.5	2.7	10.8	
	post-flexion	7.2	6.3	25.2	
	metamorphosis	13.5	-	-	
White croaker	egg	-	-	2.5	0.20
	yolksac	1.6	0.4	2.0	
	preflexion	2.0	4.0	20.0	
	flexion	6.0	2.0	10.0	
	post-flexion	8.0	11.0	55.0	
	metamorphosis	19.0	-	-	

TAXA WHOSE JUVENILES ARE NOT ENTRAPPED		MODAL LENGTH	RANGE IN LENGTH	DURATION T	GROWTH MM/DAY
Arrow goby	preflexion	3.0	2.0	8.0	0.25
	flexion	5.0	2.5	10.0	
	post-flexion	7.5	7.4	29.6	
	metamorphosis	14.9	-	-	
Blenny (unid.)	preflexion	2.5	2.5	8.6	0.29
	flexion	5.0	8.5	29.3	
	post-flexion	13.5	8.6	29.7	
	metamorphosis	22.1			

TAXA WHOSE JUVENILES ARE NOT ENTRAPPED		MODAL LENGTH	RANGE IN LENGTH	DURATION T	GROWTH MM/DAY
Calif. clingfish	yolksac	4.0	0.0	0.0	0.25
	preflexion	4.0	3.0	12.0	
	flexion	7.0	2.0	8.0	
	post-flexion	9.0	1.0	4.0	
	metamorphosis	10.0	-	-	
Calif. halibut	egg	-	-	2.5	0.24
	yolksac	2.0	0.5	2.1	
	preflexion	2.5	3.0	12.5	
	flexion	5.5	2.0	8.3	
	post-flexion	7.5	1.0	4.2	
	metamorphosis	8.5	-	-	
Cheekspot goby	preflexion	3.5	2.0	8.0	0.25
	flexion	5.5	1.0	4.0	
	post-flexion	6.5	6.9	27.6	
	metamorphosis	13.4	-	-	
Pacific mackerel	egg	-	-	2.5	0.57
	yolksac	2.2	0.3	0.5	
	preflexion	2.5	2.5	4.4	
	flexion	5.0	2.5	4.4	
	post-flexion	7.5	12.1	21.2	
	metamorphosis	19.6	-	-	
Diamond turbot	egg	-	-	2.5	0.25
	yolksac	1.7	0.3	1.2	
	preflexion	2.0	2.0	8.0	
	flexion	4.0	1.5	6.0	
	post-flexion	5.5	5.5	22.0	
	metamorphosis	11.0	-	-	
Giant kelpfish	preflexion	5.5	1.5	4.1	0.37
	flexion	7.0	2.0	5.4	
	post-flexion	9.0	24.5	66.2	
	metamorphosis	33.5	-	-	
Hornyhead turbot	egg	-	-	2.5	0.10
	yolksac	1.5	1.0	10.0	
	preflexion	2.5	2.5	25.0	
	flexion	5.0	2.5	25.0	
	post-flexion	7.5	4.5	45.0	
	metamorphosis	12.0			

Taxa Whose Juveniles Are Not Entrapped		Modal Length	Range in Length	Duration T	Growth mm/day
Kelpfish (unid.)	preflexion	4.5	2.0	8.0	0.25
	flexion	6.5	1.5	6.0	
	post-flexion	8.0	14.5	58.0	
	metamorphosis	22.5	-	-	
Reef finspot	preflexion	4.0	1.5	6.0	0.25
	flexion	5.5	1.0	4.0	
	post-flexion	6.5	10.5	42.0	
	metamorphosis	17.0	-	-	
Shadow goby	preflexion	3.5	2.0	8.0	0.25
	flexion	5.5	0.0	0.0	
	post-flexion	5.5	4.0	16.0	
	metamorphosis	9.5	-	-	

30 May 1989

to: MRC Members

fr: Keith Parker

Subj: Addendum to MRC 1988d, Tech. Report: Adult-Equivalent Loss

Please attach this to Final Technical Report on Adult Equivalent Loss (MRC 1988d).

The following thought occurred to me as I reviewed the MRC's report on adult-equivalent loss to the CCC: I may have underestimated adult equivalent loss for the juvenile stages of queenfish and white croaker (MRC 1988d). As explained in our Appendix D, we used an exponential function to model the relationship of entrapment rate of juveniles. An attached figure shows an exponential function and a linear function for juvenile queenfish -- the figure for white croaker would look similar. As I look at this figure, it seems to me that the exponential function gives an unrealistically low estimate of entrapment rate: it's hard to imagine that the rate decreases so quickly from the post-flexion stage. Contrast this is to the linear function. I suspect that for early juveniles the linear function gives a more realistic estimate of entrapment rate than the exponential function. For older juveniles, the exponential function may be more realistic. I think the best estimate of entrapment rate for juveniles lies somewhere between the exponential and linear functions -- perhaps the mean of the two would lie closest to the true rate.

The true shape of the function probably looks sigmoid, being relatively flat on both ends, with the steepest change in entrapment rate taking place somewhere near the center of juvenile age. The mean of the exponential and linear functions probably differs only a percentage point or two from that of a sigmoidal function.

For the juvenile stage only, here are estimates of entrapment rate and adult-equivalent loss (AEL) for exponential and linear functions, as well as their mean. Exponential rates are the same as those given by Parker and DeMartini (MRC 1988d). I computed mean adult-equivalent losses on mean entrapment rates.

Queenfish:

	Exponential	Linear	Mean
Ent. Rate	2.01×10^{-4}	5.08×10^{-4}	3.55×10^{-4}
AEL	5.6%	13.6%	9.7%

White Croaker:

	Exponential	Linear	Mean
Ent. Rate	6.60×10^{-5}	2.61×10^{-4}	1.64^{-4}
AEL	1.8%	6.9%	4.18%

The <u>total</u> adult equivalent losses for planktonic and juvenile stages combined are

		Total AEL	
	Exponential	Linear	Mean
Queenfish	10.9%	18.4%	14.7%
White Croaker	5.6%	10.5%	8.1%

In Section 3.3 (MRC 1988d) we computed losses in numbers and biomass of the adult standing stock by multiplying the percent total adult-equivalent loss times the estimated standing stock. For exponential, linear and mean rates these are

		Biomass (MT)	
	Exponential	Linear	Mean
Queenfish	471	799	635
White Croaker	295	553	424

		Numbers of Fish	
	Exponential	Linear	Mean
Queenfish	1.5×10^{7}	2.6×10^{7}	2.0×10^{7}
White Croaker	3.1×10^{6}	5.8×10^{6}	4.5×10^{6}

Biomass and numbers for the exponential rate are the same as in MRC (1988d).

For queenfish and white croaker the estimated adult-equivalent losses can arguably be as high as 18.4% and 10.5% respectively (based on the linear function). This would put the adult equivalent loss for all power plants in the bight at approximately twice these values -- 37% and 21%. The MRC might want to present pessimistic (linear) and optimistic (exponential) estimates in its report on adult equivalents to the CCC.

Reference

MRC. 1988d. Technical Report: Adult-Equivalent Loss.

Entrapment Rates - Juvenile Queenfish

Linear & Exponential Functions