DFG EXHIBIT 59

Exhibit 59, entered by the California Department of Fish and Game for the State Water Resources Control Board 1987 Water Quality/ Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta.

Summary of Delta Outflow Effects on San Francisco Bay Fish and Invertebrates

PREFACE

The Department of Fish and Game, as part of the Interagency Ecological Study Program, has carried out a study of the effects of Delta outflows on fish and invertebrate resources in San Francisco Bay since 1980. New field data was collected and much of it was analyzed in detail. These analyses were used to develop reports on some of the most important Bay species. These detailed reports can be found in DFG Exhibit 60. Since Exhibit 60 is a lengthy and technical document, we have prepared the following summary. This summary reviews significant findings from the technical document as well as information from the literature as discussed in another Interagency document on freshwater outflow (Exhibit 61). Exhibits 60 and 61 document in more detail the points made in this summary.

Interagency staff representing the Department of Fish and Game had lead responsibility in preparing this report. Draft copies have been reviewed by members of the Delta Outflow/San Francisco Bay Technical Committee of the Interagency Ecological Studies Program. The report reflects committee members' agreement on most points.

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INTRODUCTION

The confluence of the Sacramento and San Joaquin river systems forms a complex delta characterized by interconnected embayments, sloughs, marshes, channels, and rivers. Fresh water from this Delta flows downstream into Suisun Bay, San Pablo Bay, and San Francisco Bay where it mixes with marine water before passing through the Golden Gate into the Pacific Ocean. Much smaller amounts of freshwater also enter these bays from local watersheds and municipal waste discharges. In this report we summarize some of the relationships between freshwater flow and fish and invertebrate resources in that portion of the system downstream of the Delta. This area will be referred to as San Francisco Bay or "The Bay". With minor exceptions, striped bass and salmon data from this study were not independently analyzed, and their needs in the Bay are described in separate testimony on those species.

This estuary receives runoff from a 63,000 square mile drainage basin which covers 40% of the land area of California (Conomos 1979) and is one of California's most important aquatic ecosystems. No other estuary in California matches its rich fisheries potential. The Bay portion of the system acts as a transition zone between the Pacific Ocean and the Sacramento and San Joaquin rivers and delta.

The hydraulic regime of the Bay has been changed significantly since the turn of the century, primarily by the construction and operation of water storage and conveyence facilities although levee and reclamation projects which occurred much earlier may also have had an impact. Generally, the change has been one of reduced winter and spring inflows and increased summer and fall inflows resulting in an overall reduction of inflow. Decreases are projected to continue. The combination of reduced springtime flows and increased summer and fall flows has resulted in a dampening in Delta outflow variation. The broad question of concern is whether such changes are directly or indirectly detrimental or beneficial to fish and wildlife resources that occur in the Bay.

During the past forty years hydrological studies in the Delta have documented changes in magnitude and timing of freshwater inflow associated with water development in the watershed. Biological studies have shown that these changes, coupled with natural fluctuations in flow, stimulate biological and physical changes that largely control the survival and distributions of various fish and invertebrates (Herrgesell, Kohlhorst, Miller, and Stevens 1981). In the late 1970's various agencies and boards recognized the need for investigations concerning Delta outflow effects on San Francisco Bay. The following is a summary of the areas of support for such studies:

State Water Resources Control Board Water Quality Control Plan Sacramento-San Joaquin Delta and Suisun Marsh

The 1978 Water Quality Control Plan states in part that, "The Board has a statutory responsibility to protect all beneficial uses of water, including uses of the Bay. In determining the amount of water available for appropriation, the Board must take into account the amount of unregulated water needed to remain in the source for the protection of all beneficial uses (Water Code Section 1243.5)... Full consideration will be given to the unregulated outflow needs of San Francisco Bay in the Board's periodic review of the water quality standards in this plan. It is imperative that the necessary studies to determine the effects of these flows be initiated as soon as possible. In view of the pressing need for such studies, and in accordance with Water Code Sections 13165 and 13163(b), the Department shall initiate by October 1, 1979, the necessary studies to provide more complete and reliable information regarding the outflow needs of San Francisco Bay." (Pages VII-13 - VII-15) (The "Department" referred to in this quote is the Department of Water Resources.)

State Water Resources Control Board's Water Right Decision 1485

Order 10 of Decision 1485 for the Sacramento-San Joaquin Delta and Suisun Marsh requires that "environmental impacts related to operations of CVP and SWP can be made," and that "permittees shall, independently or in cooperation with other agencies or individuals: (c) Participate in research studies to determine: i) Outflow needs in San Francisco Bay, including ecological benefits of unregulated outflows and salinity gradients established by them."

San Francisco Bay Regional Water Quality Control Board Resolution No. 79-3 (March 20, 1979) - Policy Statement Regarding Tentative Allocations of 208 Planning Funds

This resolution notes that "The Regional Board is generally supportive of the program elements of and strongly supports inclusion of Delta outflow impact investigations in the Aquatic Habitat Management Program".

<u>San Francisco Bay Conservation and Development Commission (BCDC)</u>

> In a letter (Dec. 11, 1978) to DWR and SWRCB the Commission noted that "Freshwater inflows are equally important for protection of a wide variety of beneficial uses in the Bay-Delta system..." They further recommended that "...A thorough scientific determination of the effects of freshwater inflows and the potential adverse impacts of reducing or altering such flows is necessary."

As a result of these general concerns and a mandate by the SWRCB, the Interagency Ecological Study Program (Departments of Fish and Game and Water Resources, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, State Water Resources Control Board and the U.S. Geological Survey) developed in 1979 and implemented in 1980 a study program in the Bay. The overall goal of this program was to determine the relationship between freshwater outflows and abundance and distributions of fish and wildlife resources in the Bay downstream of the Delta. In order to attain that goal four general objectives were established. These objectives were:

1. Determine what elements of the Bay biota would be affected by significant changes in inflow of freshwater from the Delta.

2. Determine how total flow reductions associated with State and federal project operations would change the hydraulics and salinity gradients in the Bay.

3. Determine how these changes in hydraulics and salinity would affect fish and wildlife resources in the Bay.

4. Using all available information, develop flow and salinity standards, if necessary, (or other management stratagies) needed to maintain fish and wildlife resources in the Bay at some agreed upon level.

These objectives were addressed through a two fold approach including fisheries related field studies in the Bay itself and hydrodynamic/physical/chemical studies including modeling and field observations. The fisheries and hydrodynamic elements of the program began in January 1980. The hydrodynamic element of the program was expanded and implemented in full in the fall of 1984.

A literature review on the topic of freshwater inflows and estuarine resources was conducted in 1983 to summarize information on what was known about the effects of inflow on biological and physical characteristics in estuaries around the world. The report entitled, "Effects of Freshwater Outflow on San Francisco Bay Biological Resources" (Interagency Ecological Study Program Technical Report #7) developed from this review, provides an analysis of the available literature on freshwater outflow and its relation to estuarine hydrology and biology. Briefly, Technical Report Number 7 (Exhibit 61) describes the physical characteristics of outflow from the Sacramento-San Joaquin Delta, reviews historical and present outflows, projects levels of future outflows, and describes how projected changes in outflow levels may affect the physical/chemical environmental conditions of the Bay. It describes major biological resources of the Bay, the values of those resources, and the present condition of some of them. Information on the importance of flow to biological and hydrological conditions from estuarine studies in Texas, Canada, and Russia is presented. The major implications drawn from this review are:

1. Flow reductions definitely cause significant biological changes.

2. Some biological changes are system specific, while others are common to all estuaries.

3. Distributional changes occur universally, although they can be species and system specific.

4. Abundance changes are not well understood, therefore it is uncertain as to how general they are, however, they tend to be species and system specific.

5. Some changes are continuous functions of flow reduction, but others involve threshold effects. Threshold effects are more threatening in that small changes cause large biological effects, which are often disastrous and can occur with little warning.

6. The widespread nature of reported effects and the effects observed in the San Francisco Bay system warrant concern.

7. There is no sound basis for making general conclusions on abundance/flow impacts.

8. In light of the above conclusions, management agencies must await study results from San Francisco Bay before watershed management recommendations can be developed.

Since the completion of that 1983 literature review, we have analyzed data from our field studies and prepared a detailed technical analysis (Exhibit 60). Information in this exhibit provides an essential understanding of the life histories of important Bay organisms, and describes the effects of flow related physical factors on some important species. The remainder of this summary will discuss significant observations related to freshwater flow that are covered in more detail in Exhibits 60 and 61.

METHODS

Monthly fish and invertebrate samples were collected from 35 open water sites, 27 inshore sites and 9 pier sites in the area bordered on the upstream end by the Antioch bridge on the San Joaquin River, and Sherman Island on the Sacramento River and on the downstream end by the Golden Gate Bridge. The study area included all of South San Francisco Bay north of the Dumbarton Bridge and the main portion of San Francisco Bay north of the Bay Bridge (hereafter referred to as South Bay and Central Bay, San Pablo Bay, Suisun, Grizzly, and Honker bays). Samples were collected by boat at the open water sites using an otter trawl (samples bottom dwelling organisms), a midwater trawl (samples organisms in water column from near-bottom to surface) and a fine mesh egg and larval net (samples larval fish and invertebrates from near-bottom and throughout the water column). Shoreline sites were sampled by making one or two seine hauls with a beach seine at each site. Crabs were sampled from the pier sites using ringnets. Temperature and electrical conductivity measurements (an estimate of salinity) were taken at all sample sites and times (See Exhibit 60, page 9 for more detail on sample procedures).

OVERVIEW OF SAMPLE RESULTS

Data presented in this report were collected during the 6-year period 1980-1985. Sampling has continued until the present but these recent data (1986-87) are not described here because they were not available for analysis in time for preparation of this report.

Delta Outflow

Outflow from the Delta was quite variable during the study period. Monthly average flows, as estimated at Chipps Island by DWR, varied from a high 272,000 cfs during March of 1983 to a low average monthly value of approximately 2,300 cfs during October 1985. Each water year (October-September) is given a designation by DWR. Four of the six years used in this study, 1980, 1982, 1983 and 1984 were wet years and two, 1981 and 1985, were dry years (DWR Bulletin 120-80 through 120-85). It should be noted that 1984 was anomalous in that it was designated a wet year, but the amount of snowmelt was subnormal; hence, most of the runoff occurred during early winter. 1982 and especially 1983 were years of El Niño, during which the ocean waters were warmer than normal and spring runoffs were high and occurred later than usual.

Fish and Invertebrates

During the period January 1980 to December 1985, 122 species of fish were collected (See Tables 8-11 in Exhibit 60). Probably more than 200 species exist in San Francisco Bay (Miller and Lea 1972), but all these were not collected because we did not adequately sample all available habitat. In addition to fish, we collected 14 species of true shrimp and 4 species of cancer crabs in the Bay. We collected data for 10 other species of invertebrates. Life history information for the most abundant species of fish and invertebrates collected during our survey is summarized in Table 1.

<u>Overall Catches</u> - The otter trawl collected 144,385 individuals representing 85 species of fish, the midwater trawl collected 620,645 individuals representing 72 species, the beach seine collected 124,482 individuals representing 66 species, and the egg and larval net collected 752,224 individuals representing 62 taxa.

<u>Beach Seine Catches</u> - Topsmelt were the most abundant species of fish collected in the shoreline area. Overall topsmelt, Pacific herring, northern anchovy, jacksmelt, striped bass, Pacific staghorn sculpin, inland silverside and arrow goby comprised 90% of the catch in this shallow area. Topsmelt, northern anchovy, jacksmelt, and inland silverside were in the top 10% every year. Shiner perch, arrow goby, dwarf perch, and yellowfin goby occurred in the top 10% only in some years.

<u>Midwater Trawl Catches</u> - Catches in the open water were dominated by northern anchovies. The only exception to this was 1982 when longfin smelt and Pacific herring catches were greater. Northern anchovies made up 90% of the catch in 1981 and 1984. In other years northern anchovies, longfin smelt, Pacific herring and striped bass made up 90% of the catch.

<u>Otter Trawl Catches</u> - When considering the fish that are associated with the bottom of the Bay, longfin smelt, northern anchovy, striped bass, shiner perch, english sole, white croaker, Pacific staghorn sculpin, Bay goby, speckled sanddab, and yellowfin goby made up 90% of the catch. The group of fish making up the top 10% was remarkably consistent during the six years. Only two species, starry flounder and Pacific herring, were occasional members of this group. Based on catches from all our nets, the bottom areas of the estuary supports a larger, more diverse community than the pelagic (open water) or inshore area.

Table 1. Life history and descriptive information for the most abundant species of fish and invertebrates collected.

Species	Species Origin	Species Type	Life History			Center of Population	Importance of Species	Preferred Habitat	Use of Bay	Geographical Range	Life Stage Major Food Source	
			Spawning Time	Spawning Location	Nursery Area						Adult	Juvenile
Crangon franciscorum	N	E	Spring ‡	Bay-Ocean	SPB-SB	SPB-SB	Commercial Forage	Demersal	Nursery	San Diego-Alaska	B	B
Crangon nigricauda	N	M	Spring ‡	Bay-Ocean	CSFB-SPB	SSFB-SPB	Commercial Forage	Demersal	Nursery	Baja Calif.-Alaska	B	B
Palaemon macrodactylus	I	E	Summer ‡	Bay	SB-Delta	SB-Delta	Commercial Forage	Demersal	Residence	Orient S.F. Bay	B	B
Crangon nigromaculata	N	M	Spring ‡	Ocean	Ocean	Ocean	Commercial Forage	Demersal	Incidental	Baja Calif.-S.F. Bay	B	B
Callianassa californiensis	N	E	Winter-Summer	Bay	Ocean	CSFB	Forage	Demersal	Residence	Alaska-Calif.	B	B
Emerita analoga	N	M	Spring-Summer	Ocean	Ocean	Ocean	Forage	Littoral	Incidental	Baja Calif.-Alaska	P	P
Euphausiids	N	M	Winter	Ocean	Ocean	Ocean	Forage	Pelagic	Incidental	Pacific Ocean	P	P
Sagitta euneritica	N	M	unknown	unknown	unknown	Ocean	Forage	Pelagic	unknown	Pacific Ocean	P	P
Rhithropanopeus harrisii	I	E	Summer ‡	Delta	Delta	Delta	Forage	Demersal	Residence	Atlantic Coast, S.F.Bay	B	B
Cancer magister	N	M	Winter ‡	Ocean	Nearshore/Bay	Ocean	Commercial	Demersal	Nursery	Pt. Conception-Alaska	B	B
Yellowfin goby	I	E	Winter	Bay	SB-Delta	SPB-SB	Forage Commercial	Demersal	Residence	Orient, Newport-Tomales	B	B
Arrow goby	N	M	Spring-Summer	Bay	SSFB-SPB	SSFB-SPB	Forage	Demersal	Residence	Baja Calif.-Brit. Col.	B	B
Bay goby	N	M	Summer-Fall	Bay	SSFB-SPB	CSFB	Forage	Demersal	Residence	Baja Calif.-Brit. Col.	B	B
Topsmelt	N	M	Summer	Bay	SSFB-CSFB	SSFB	Forage	Littoral/Pelagic	Residence	Coastal N. America	B	B
Jacksmelt	N	M	Spring-Summer	Bay-Ocean	SSFB-CSFB	Ocean	Recreation Forage	Pelagic	Spawning Nursery	Coastal Mexico-Oregon	F	P
Northern anchovy	N	M	Spring-Summer	Ocean	Ocean	Ocean	Commercial Forage	Pelagic	Spawning Nursery	N.E. Pacific Ocean	P	P

N = native, I = introduced, E = estuarine, M = Marine, SSFB = South San Francisco Bay, CSFB = Central San Francisco Bay, SPB = San Pablo Bay, SB = Suisun Bay, P = plankton, B = benthos, F = fish.
‡ = eggs are extruded in the prior season.

Table 1 continued. Life history and descriptive information for the most abundant species of fish and invertebrates collected.

Species	Species Origin	Species Type	Life History			Center of Population	Importance of Species	Preferred Habitat	Use of Bay	Geographical Range	Life Stage Major Food Source	
			Spawning Time	Spawning Location	Nursery Area						Adult	Juvenile
Pacific herring	N	M	Fall-Winter	Bay	SSFB-SPB	Ocean	Commercial Forage	Pelagic	Spawning Nursery	Baja Calif.-Alaska	P	P
Longfin smelt	N	E	Winter	Rivers	SPB	SPB	Forage	Pelagic	Nursery Residence	N.E. Pacific estuaries	P	P
Pac. staghorn sculpin	N	E	Winter	Bay	Bay	CSFB-SPB	Forage	Demersal	Resident	Baja Calif.-Alaska	F,B	B
Starry flounder	N	E	Winter	Ocean	SB-Delta	Ocean-Bay	Commercial Recreation	Demersal	Nursery Residence	Coastal N. Pacific	B	B
Speckled sanddab	N	M	All year	Ocean	Ocean-CSFB	Ocean	Forage	Demersal	Nursery	Coastal N. America	B	B
English sole	N	M	Winter	Ocean	Ocean-Bay	Ocean	Commercial	Demersal	Nursery	Coastal N. America	B	B
California tonguefish	N	M	Summer-Fall	Ocean	Ocean-CSFB	Ocean	Forage	Demersal	Nursery	Baja-Coastal Calif.	B	B

N = native, I = introduced, E = estuarine, M = marine, SSFB = South San Francisco Bay, CSFB = Central San Francisco Bay, SPB = San Pablo Bay, SB = Suisun Bay, P = plankton, B = benthos, F = fish.

<u>Larval Fish Catches</u> - For all years, over 90% of the larval fish catch consisted of Pacific herring, northen anchovy, unidentified smelts, yellowfin goby and longfin smelt. Striped bass was also among those making up 90% of the catch in 1980 and 1983. Pacific herring were the most common in all years except 1980 and 1984. When considered as a group, gobies were in the top three most abundant species especially in 1980 and 1984.

FISH AND INVERTEBRATE USES OF THE BAY

There are many uses of the Bay associated with fish and wildlife resources and a prerequisite to protecting these resources is the maintenance of healthy Bay habitat. The following discussion briefly describes some of these important uses.

Use as a Nursery Area

One important function of the Bay is that it acts as a nursery area for marine and estuarine species. We documented the use of the Bay as a nursery area during our six year study. We found various life stages of many species that occurred in the Bay at some time of the year. Other researchers have documented the importance of San Francisco Bay as a nursery area, particularly for the Dungeness crab. Tasto (1983) found that crabs spawned offshore and reared in the Bay contribute to the fishery 3 years after hatching, while ocean spawned and reared crabs enter the fishery 4-5 years aftr hatching. Bay reared crabs grow almost twice as fast as ocean reared crabs. Reasons that organisms use estuarine systems as nursery areas include the following:

1. Reduced Predation and Parasitism - Increased turbidity (Minello, Zimmerman and Maitinez 1987), abundant submerged vegetation (Wilson, Heck and Able 1987) and lowered salinity (McCabe,et al. 1987) all have been shown to reduce predation or parasitism in estuaries and thereby enhance survival of juvenile forms using the estuary.

2. Increased Nutrients and Subsequent Food Production - Estuaries receive inflow from vast watersheds and are therefore usually rich in nutrients and other food sources. Such food is advantageous to young fish using the estuary as a nursery area (Odum 1971; Krygir and Pearcy 1986).

3. Estuaries Provide Variable Habitat Types - Habitat types are more variable in bays and estuaries than oceans. Such variability increases the chance that suitable conditions will be present for a greater number of

species. Variable substrate type (Pearcy and Meyers 1974) and water velocity (Blaber and Blaber 1980) are two habitat conditions that have been shown to be important in the survival of estuarine fishes.

Use of the Bay as a nursery area can be characterized by several general strategies. These strategies should be considered as beneficial uses of the Bay. The first strategy we observed involves adults living and spawning offshore in the ocean, and eggs, larvae, and juveniles being transported by tidal and non-tidal currents into the Bay nursery area. Dungeness crabs utilize this strategy; other species include English sole, starry flounder and bay shrimp. We suspect other species use this strategy (e.g., speckled sanddab and California tonguefish) but do not yet have enough life history information about them to be sure. Circulation patterns are involved in this process and freshwater flow plays a role in the effectiveness of this strategy from year to year (See later discussion). The second strategy is typified by species such as Pacific herring and northern anchovy, in that adults move into the Bay to spawn and then leave. The larvae and subsequent juveniles seem to survive well in the lowered salinities that occur in the Bay. The third strategy is for resident fishes that normally live and spawn in the Bay system. It is utilized by species such as yellowfin gobies and Pacific staghorn sculpin. Adults spawn in higher salinity areas and the young move to and utilize lower salinity areas.

Use As A Migration Corridor

Since the Bay lies between the ocean and the Sacramento and San Joaquin rivers it acts as a migration corridor for the passage of anadromous fish. Several species of fish such as striped bass, salmon, sturgeon, and American shad use the Bay as a migration corridor on their way to spawning areas in upstream tributaries. Young individuals of these species also pass through the Bay on their return trip to the sea.

Sport Uses

Sport fishing is the most popular recreational activity in the San Francisco Bay and Delta area. The 1980 user estimate at present facility capacity was 4.4 million recreational days, but the potential demand was estimated to be 19.0 million recreational days (The California Water Policy Center 1979). Facilities include piers, public beaches, skiff rentals, launching facilities, and more than 100 commercial passenger fishing boat operators.

The three most important species sought on commercial passenger fishing boats are chinook salmon, striped bass, and halibut, but most salmon fishing takes place in the ocean. In San Pablo Bay, Carquinez Strait, and Suisun Bay commercial passenger fishing boat effort concentrates on striped bass and sturgeon, but farther downstream additional species are sought after including brown rockfish, surfperch (seven species), lingcod, jacksmelt, topsmelt, white croaker, sharks and rays. Sharks and rays are especially sought after in South Bay, in particular soupfin shark, six and seven-gill sharks, and leopard sharks. Brown smoothhounds, spiny dogfish, and skates are also taken. None of these species are taken in significant numbers when compared to bass, sturgeon, and halibut catches.

Shore fishermen fishing from beaches and piers catch lingcod, cabezon, surfperch, starry flounders, and jacksmelt. Striped bass and salmon are caught from shore less often.

The primary beneficiaries of the sportfishery resources of San Francisco Bay are, or course, the anglers. However, anglers in turn also help support the Bay and Delta area economics because they spend money for bait, equipment, food, and gas necessary in order to pursue their hobby. Thus, sport fishing benefits the general economy as well as the anglers.

Commercial Uses

Commercial fishermen harvest herring, shrimp, and anchovy in San Francisco Bay. Other species have supported important commercial fisheries in the past, including striped bass, sturgeon, surfperch, sharks, shad, salmon, and shellfish (Smith and Kato 1979). These resources are no longer commercially exploited for various reasons, such as changes in abundance, overexploitation, and social considerations. Thus, their harvest has been restricted to the recreational sport fishery.

The commercial herring fishery is by far the most lucrative in San Francisco Bay at the present time. The fishery concentrates on herring roe, the ripe ovaries of females, and eggs-on-kelp which is gathered by divers in spawning areas. All of these are exported to Japan where they are sold as expensive gourmet items (Smith and Kato 1979). There is a valuable offshore fishery for English sole for which San Francisco Bay is probably the primary nursery area.

Northern anchovy presently supports a moderate commercial fishery (Smith and Kato 1979). The majority of the catch is packed and frozen as bait for recreational fisheries, but an additional amount is taken for use as live bait, which is primarily used in the sport fishery for striped bass and halibut. Both live and dead anchovies are sometimes used for bait in the commercial albacore tuna fishery. There is no estimate of anchovy biomass for San Francisco Bay.

A commercial shrimp fishery presently supplies bait for striped bass and sturgeon sport fishing. The shrimp are sold both frozen and live, but live bait is the most popular. The fishery is small, but lucrative, since sport fishermen will pay approximately $12.00 per pound for bait shrimp. Most fishing for shrimp occurs in San Pablo Bay, with limited fishing in South Bay. Since the Bay shrimp are small, there is limited demand for them as food, and it appears that they cannot be economically processed on a large scale.

Dungeness crab, Cancer magister, has undergone a population decline in recent years (See Exhibit 60, page 89), but it still supports one of the more important commercial fisheries in the San Francisco Bay area. The boats operate out of Bay fishing ports but all of the actual fishing takes place outside of the Golden Gate on sandy bottoms in shallow water (Skinner 1962). The commercial take in the 1985-86 season for the San Francisco area was 384,000 pounds.

Recreational Uses

Maintaining San Francisco Bay as a healthy estuary provides ecological value not only to the system itself, but also to the inhabitants of the ocean and upriver biological systems. Even more importantly, it is of value to the surrounding human community. A healthy bay is aesthetically pleasing and encourages much recreational use. User estimates for recreational activities in the San Francisco Bay and Delta area for 1980 have been determined (The California Water Policy Center 1979). Including fishing, hunting, nature walking, boating, picnicking, camping, and hiking, the actual use at present facility capacity was estimated to be about 10 million recreational days, but the potential demand was estiamted to be 60 million recreational days. Thus, there is a significant amount of unsatisfied recreational demand presently existing in the Bay-Delta area. There is no general agreed upon procedure for estimating the value of the aesthetic and therapeutic benefits of these consumptive and non-comsumptive uses, but it certainly contributes significantly to the health and well-being of the State's populace.

Estuarine Habitat

The varied habitats in San Francisco Bay and its ability to function as a nursery area results in a rich fish and invertebrate community. The diversity of fish and invertebrates shown by our sampling documents the importance of the Bay as an estuarine habitat. Such diversity provides resilience and long term stability. At this time we do not understand all interrelations between species in the Bay and the loss of one or a few presumed unimportant species may have unforeseen significant impacts on the rest of the community.

Other Uses

Other important uses of the Bay include wildlife habitat, habitat for rare and endangered species and shellfish propagation and limited shellfish harvesting.

LINKS BETWEEN THE BAY AND OCEAN

The Bay is not a separate entity independent of the upstream river, delta, or the ocean. Conditions that exist offshore affect physical and biological processes in the Bay. For example, Dungeness crab larvae hatch in coastal waters and are vulnerable to transport by ocean currents. The northward flowing Davidson Current may carry larvae so far north some winters that they do not return to the Gulf of the Farrallons with the subsequent southward flowing California Current in the spring. Tasto (1983) concluded that the year class strength of megalops (late stage larvae) in the Gulf of the Farallons is directly related to the year class strength of juveniles in the Bay. We found a strong positive relationship between the annual abundance of juvenile Dungeness crabs in the Bay and the January - March upwelling index (See Exhibit 60 page 90). The upwelling index is indicative of the strength of northward flowing currents (Bakun, 1973); a positive index indicates a relatively weak northward current and consequently more megalops in the Gulf of the Farrallons and the Bay.

The spawning and rearing of many fish in the Bay, their migration offshore, and subsequent recruitment into adult populations is also evidence of an important bay-ocean link. A good example is the Pacific herring. These fish spawn in the Bay and after early growth, the young leave the Bay and move offshore. English sole, speckled sanddab, and northern anchovy also grow in the Bay and then move offshore. The importance of estuarine produced fish to offshore commercial fisheries has been documented in other estuaries around the world. According to Clark (1967) and McHugh (1966, 1967) the young of up to 70% of the economically important Atlantic species of fishes inhabit estuaries during part of their early life. Our efforts to determine similar relationships between commercial landings in the San Francisco Bay area and freshwater inflow into the estuary were not successful (See Exhibit 60, page 317). However based on observations from other systems we are confident such links occur here, although they may not be as important as on the east coast where more estuaries per unit of coastline occur.

Another link between the Bay and ocean is demonstrated by incidental use of the Bay by some ocean species. Our collections have shown that invertebrates such as euphausiids, arrowworms, and sand crabs whose primary habitat is offshore in the ocean, use the

Bay merely as an extension of the ocean. Some marine fish like Pacific pompano and diamond turbot also use the Bay. They do not need the Bay for spawning, feeding or other activities but occur there because salinity conditions are acceptable or currents carry them there. Such use, even though incidental, is important as it contributes to fish and invertebrate production in the estuary.

One phenomenon that affected the incidental use of the Bay by marine organisms was El Nino. Occasionally, ocean currents shift bringing warmer water northward in the Pacific Ocean. Such warmer waters result in different species offshore; and some of them enter the Bay. An El Nino event occurred during 1982 and 1983 resulting in unusual storm patterns and the occurrence in the Bay of fish and invertebrates not usually part of the Bay fauna. During that time we collected barracuda, Pacific Saury, sardines, red swimming crabs, and Nyctiphanes simplex, a southern species of euphausiid. During El Nino the abundance of Crangon nigromaculata, a species of shrimp whose northern limit is the Gulf of the Farrallons, was also higher in the Bay.

FLOW RELATED MECHANISMS AND THEIR EFFECTS ON BAY RESOURCES

The results of the first six years of our study demonstrate that freshwater flows have a major influence on fish and invertebrate resources in the Bay, but all organisms do not respond in the same manner to flow variation. Flow effects were species specific. A consistent generalization is that biological responses to flow are variable, and it may be that such variability is important for the estuarine community.

Our data also provided insight into the flow related mechanisms causing the observed biological responses. We found that several interrelated mechanisms exist and that they affect life stages within species differently.

For discussion purposes, we will group the biological responses to flow that we observed into two categories and then discuss the mechanisms thought to cause those responses. The first biologicial response that can result from flow changes is altered abundance of individuals. The second response to changed flow is altered distribution. All other population responses will ultimately be reflected in one of these two results (including growth rate, death rate, fecundity, predation etc.).

The following sections discuss examples of these two responses as observed during the first six years of our study. However, the relatively short duration of our study placed three major limitions on our ability to define the influences of freshwater inflow on the biotic community in the Bay. First, we were unable to demonstrate whether observed flow related responses of one lifestage affect the abundance of a later life stage. For example, the six years of data allows only three pairs of data points for determining the effect of juvenile abundance on subsequent spawning stock size of starry flounder because it takes this species three years to reach maturity. The second type of limitation resulting from the short duration of our study has to do with our ability to accurately describe observed relationships between freshwater inflow and abundance of even a single life stage. Although we have in some cases been able to show a strong association between annual abundance and freshwater inflow, six data points have generally been too few to determine whether the mathematical relationship is described by a linear, geometric, logarithmic, or some other function. Our third limitation was that gear selectivity inherent in our sampling procedures did not sample adult fish adequately.

Flow/Abundance Effects

Flow related mechanisms causing variation in abundance are generally difficult to document because the cause and effect relationship between flows and organism abundances operates through a chain of events rather than through direct effects. Usually, other mechanisms that are stimulated or regulated by flows effect short or long term survival. Some of these mechanisms increase abundance, others lower abundance, while the abundance of other species is not affected at all by these mechanisms. For a discussion, including literature review, the reader is encouraged to see pages 49-50 in Exhibit 61.

<u>Flow Increases Resulted in Increased Abundance</u> - One response we observed consistently was that some organisms were more abundant during years or seasons of higher Delta outflow. Generally, the abundance of juvenile and adult life stages of three of the four shrimp species we studied correlated positively with freshwater flow (Table 2) (See Exhibit 60, Chapter 3). These three species were all native species. Further the juvenile stages of the estuarine fish also were more abundant during high flow years as were juvenile and adult abundances of three of the four flatfish species (See Exhibit 60, Chapter 10). As a rule, the period when freshwater flow was most likely to increase abundance of fish or invertebrates was the spring season (Table 2) when flows are most likely to be affected by water development projects.

<u>Flow Increases Resulted in Lowered Abundance</u> - The converse of the above relationship was also documented. Abundance of some species or life stages was lowered during periods of higher flow. This response, however was observed less frequently than increased abundance during greater flows. For those species with lower abundances during higher flow, the following observations were made: 1) the only introduced shrimp species in the system, <u>Palaemon</u> <u>macrodactylus</u> was less abundant during years with higher

Table 2. Relationship between freshwater outflow and abundance and distribution of various life stages of the most abundant fish and invertebrates.

Species	Life Stage	Abundance changes with increasing Delta outflow				In Bay distribution changes with increasing Delta outflow			
		Winter	Spring	Summer	Fall	Expand	Decrease	Shift	No Change
Crangon franciscorum	larval	-	-				x		
	juvenile		+				x		
	adult		+				x		
Crangon nigricauda	larval	-	-				x		
	juvenile		+				x		
	adult		+				x		
Palaemon macrodactylus	larval			-				x	
	juvenile			-				x	
	adult			-				x	
Crangon nigromaculata	juvenile		+				x		
	adult		+				x		
Cancer magister	juvenile		-				x		
Rhithropanopeus harrisii	larval			-				x	
Euphausiids	larval	+							x
Sagitta euneritica	adult	-							x
Callianissa californiensis	larval		-	-					x
Emerita analoga	larval		-	-					x
Yellowfin goby	larval	-					x		
	juvenile					x			
	adult		+	+					x
Arrow goby	larval								
	juvenile								x
	adult								x
Bay goby	larval			-	-		x		
	juvenile	+	+						x
	adult	+	+						x
Topsmelt	larval						x		
	juvenile								x
	adult						x		
Jacksmelt	larval								x
	juvenile								x
	adult								x

Table 2 continued. Relationship between freshwater outflow and abundance and distribution of various life stages of the most abundant fish and invertebrates.

Species	Life Stage	Abundance, changes with increasing Delta outflow				In Bay distribution changes with increasing Delta outflow			
		Winter	Spring	Summer	Fall	Expand	Decrease	Shift	No Change
Longfin smelt	larval					x			
	juvenile	+	+			x			
	adult					x			
Pacific herring	larval								x
	juvenile						x		
	adult						x		
Northern anchovy	larval								x
	juvenile						x		
	adult						x		
Pac. staghorn sculpin	larval	-					x		
	juvenile								x
	adult			+		x			
Starry flounder	juvenile		+	+		x			
	adult								
English sole	larval	+				x			
	juvenile		-				x		
Speckled sanddab	juvenile		+	+					x
	adult		+	+					x
California tonguefish	juvenile			+		x			
	adult		+	+		x			

flows, 2) the abundance of larvae of those organisms that spawn in the winter and spring in the Bay generally correlated negatively with outflow, and 3) negative flow relationships were observed for anchovy egg abundance and larvae of selected species of fish as well as Rhithropanopeus harrisii.

For Some Species Flow Variation Did Not Seem to Affect Abundance - The abundance of some species did not respond in a consistent way to flow variation. Most marine pelagic species of fish except jacksmelt and Pacific herring showed no strong relationship to flow on an annual basis (Table 2). This was surprising since one would expect these species to be correlated inversely with freshwater because they prefer saltwater conditions. In fact, we were not able to find a negative correlation with flow primarily because these organisms generally do not occupy the Bay in the winter when high flows occur (i.e., jacksmelt).

Flow/Distribution Effects

The second and most obvious response of organisms to flow was altered distribution. Many fish and invertebrates actively or passively changed locations when flow levels changed and these changes were species and life stage specific.

Increased Delta Outflows Expanded Organism Distributions - Some species respond to flow increases by expanding their distribution. Such expansion can occur in any direction. For example, species usually found upstream in fresher portions of the estuary can be displaced further downstream during high flow conditions. In our study we observed that various estuarine pelagic species including longfin smelt, Paleamon macrodactylus (an introduced shrimp), and larvae of Rhithropanopeus harrisii reacted this way. These same high flows can cause other species, usually located in the more marine areas of the Bay or open ocean, to move to areas further inside the Bay. Some lifestages of marine flatfish responded this way (Table 2).

Increased Flows Decreased Organism Distributions Within the Bay - The distribution of some organisms within the Bay was limited by flows rather than expanded. The distribution of larval and juvenile stages of all gobies decreased during higher flows, while the adults were not affected (Table 2). Likewise, the distribution of most life stages of the native shrimp and juvenile Dungeness crabs decreased during high flows.

The Distribution of Some Organisms was Not Affected by Flow - The Bay distribution of some marine invertebrates was not strongly affected by flow (Table 2). Additionally, earlier work documented that marine species increased in the Napa Marsh in 1976 as salinity was increasing during the first year of a drought. However, abundance of marine fishes decreased there in 1977 even though salinity was higher than in 1976. Apparently, other factors rather than salinity limited marine species abundance in the marsh (Herrgesell et al., 1981).

The foregoing discussion of abundance and distribution changes dealt only with species that were analyzed individually in detail and for which weighted abundance calculations were developed. In an effort to provide an overview of the changes in abundance and distribution of the fish and shrimp community including those species not analyzed in detail, a more cursory analysis was undertaken to assess the relationship between the fish and shrimp raw catches and water year type. Raw catches provide a less accurate measure of abundance because they do not reflect the amount of effort expended collecting the sample. For this general overview, wet and dry year catches and distributions were compared.

Annual catch differences were determined with a one-way ANOVA, using a general linear model. A contrasting of means from the ANOVA was used to determine if the catch in the wet years (1980, 1982, 1983, 1984), was different from that in the dry years (1981, 1985).

Species were separated into five groups based on results of the contrasting of the wet and dry year catches. Those species whose p value for the contrast was 0.05 or less were classified as wet if the mean catch was greater in the wet years and dry if the mean catch was greater in the dry years. If the p value was between 0.06 and 0.10, the species was classified as limited wet or limited dry, depending on whether the mean catch was greater in wet or dry years. All species with a p value greater than 0.11 were classified as having no preference.

The principal finding of this analysis was that 29 percent of the species tested were more abundant in the wet years than in the dry years, 10 percent were more abundant in the dry years and 61 percent were unaffected by water year type (Table 3). Nearly all of the more common estuarine species were more abundant in the wet years. Only 5 marine species were more abundant in dry years, while 21 marine, estuarine, anadromous and freshwater species were more abundant in the wet years. Of the marine species 22 expanded their distribution or range in the wet years, 9 expanded their range in the dry years and 13 showed no change in distribution between wet and dry years (See Exhibit 60, page 323).

The significant finding of this analysis of raw catches was that of the species showing a difference between wet and dry years, a greater number of species were more abundant and widespread in the wet years than the dry years. In our study plan it was postulated that abundances and distribution of marine species would be greater in dry years due to more marine conditions being available over a greater portion of the Bay for a longer period of time. This was not the case. Based on our short term studies we concluded that if conditions in the Bay were allowed to become similar to those found during dry years through increased

Table 3 Classification of fish and shrimp based on association with water year type.

Species Type	Association Class				
	Wet	Limited Wet	No Preference	Limited Dry	Dry
Freshwater	prickly sculpin splittail	white catfish	Sacramento squawfish bigscale logperch channel catfish common carp delta smelt inland silverside mosquitofish threadfin shad	tule perch	
Anadromous	green sturgeon white sturgeon	American shad striped bass	Chinook salmon Steelhead river lamprey	Pacific lamprey	
Estuarine	Crangon franciscorum longfin smelt starry flounder threespine stickleback yellowfin goby	Pacific staghorn sculpin	Palaemon macrodactylus rainwater killifish		
Marine	California tonguefish Pacific tomcod bay goby leopard shark speckled sanddab	California lizardfish Pacific herring Pacific sandlance	Crangon nigricauda English sole Pacific pompano Pacific sanddab arrow goby barred surfperch bat ray big skate black perch bonehead sculpin brown rockfish brown smoothhound chameleon goby cheekspot goby curlfin sole diamond turbot lingcod northern anchovy pile perch plainfin midshipman rubberlip seaperch sand sole shiner perch showy snailfish spiny dogfish spotted cusk-eel surf smelt topsmelt white croaker white seaperch whitebait smelt		California halibut bay pipefish dwarf perch jacksmelt walleye surfperch

diversions, only a few marine species would increase their abundance and the abundance of nearly all estuarine species would decrease. In addition, many of the major forage species would be negatively impacted under these conditions and this would have a negative affect on the recreationally important species.

Mechanisms

Changes in abundance and distribution can be caused by flow-related parameters in the Bay. We will discuss three general parameters in the Bay environment that can affect abundance and distribution. They are: salinity, direct transport by currents, and nutrients. When evaluating the importance of flow affects on these parameters, it is important to remember that effects of any given flow are greatest upstream and least near the Golden Gate. Low inflows may affect conditions significantly in Suisun Bay but have little effect in Central Bay. Salinities in the South Bay reach, where local inflow is low, are profoundly affected only after Delta outflows reach a threshold level of about 35,000 cfs. San Bruno shoal appears to be an effective block to landward penetration of gravitational circulation for a range of delta outflows up to about this amount (Imberger, Kirkland, and Fischer 1977).

Salinity - When salinity is changed, larger fish and invertebrates that are capable of movement often respond by moving to another part of the estuary where salinity is more favorable. The most obvious of such movements are short-term ones due to seasonal fluctuations in salinity. However, long-term trends in salinity intrusion will cause changes in average distributions of organisms if the salinity change is permanent. Changes in fish distributions due to flow caused salinity changes have been documented in this and other estuaries around the world. The reader is referred to pages 46-47 in Exhibit 61 for further detail on these previous results.

Other salinity effects can act on a delayed basis and result in increases or decreases in organism abundance. Abundance changes can be delayed because other mechanisms or processes must first be activated by salinity alterations and then those processes must, through time, impact organism survival.

An example of such a process occurs in South Bay. During periods of high outflow and neap tides, freshwater flows enter South Bay and cause salinity stratification. During these periods in early spring, surface chlorophyll a increases from <5 to >40 mg/m^3, indicating phytoplankton abundance increases. Cloern (1982) suggests that low grazing pressure by infauna (benthos) may partly explain the spring bloom during periods of stratification. He notes that algal cells retained in the surface layer are not subjected to benthic grazing, and therefore surface populations can grow rapidly. The point is that salinity stratification acts to inhibit the downward vertical mixing of algal cells and therefore reduces benthic grazing. The result is an increase in phytoplankton abundance. The actual duration of such a response by phytoplankton is short-term because it lasts only as long as the Bay is stratified. However, the impacts of such increased abundance could be reflected in increased survival of other food chain members that depend on energy derived from this phytoplankton.

Salinity preference plays a role in determining the distribution of most organisms in the estuary. We will discuss some examples from our study. Several species of shrimp exist in the Bay, and based on where they were caught, each appears to prefer a slightly different range of salinity (See Exhibit 60, Chapter 3). The most obvious differences occurred between the three species of _Crangon_. _C. franciscorum_ generally was more abundant in salinities below 15 ppt, while _C. nigricauda_ preferred levels above 15 ppt and below 30 ppt and _C. nigromaculata_ were more abundant in salinities in the range of 25-30 ppt. In general, the distributions of these three species within the Bay reflected salinity conditions compatable with their physiology. Further, we documented salinity interactions with shrimp life stage. We found that mature shrimp migrate to higher salinities. This life stage/preference interaction was also observed in some species of fish. The salinity preference of starry flounder changes with age. Our comparisons of mean length and surface conductivity suggested younger flounders prefer fresher water while older fish prefer saltier. Bay gobies responded similarly. Juveniles were usually more concentrated in San Pablo Bay than in Central or South Bay and usually more were caught in salinities below 20 ppt. Adults of this species were more tolerant of higher salinities.

Salinity also affected distributions of the juvenile English sole (See Exhibit 60, page 251). This observation is not surprising since English sole is a marine fish and suggests that salinity affects the juvenile distributions from year to year. During wet years when salinities in the Bay are lower, juvenile English sole, contrary to the larvae, are unable to use the San Pablo Bay area. On the other hand, during dry years subsequently higher salinities allow greater utilization by sole of the San Pablo Bay nursery area.

Circulation Processes - Organism distributions can be directly affected by currents and circulation patterns. Generally, it is the young or larval stages that are directly affected. Flow changes can alter water velocities and larvae that usually drift with currents can be displaced to other parts of the system. This dispersal can be behaviorally passive or active, in a landward or seaward direction, in an estuary or in the open sea, or in any combination of the above pairs (Shaw 1981). Since movement is dependent on currents, distributions change concurrently with flow changes.

In addition to altering distribution, currents associated with freshwater outflows can also alter the abundance of organisms. Young fish or shrimp, for example, can be carried to areas where their survival can be decreased or enhanced. Time is required for the young fish to grow in the new area and such responses to flow are long-term since increased survival of juveniles is likely to be reflected in increased numbers of adults some years later. The relationship between water movement and the distribution of fish and other organisms has been documented in the Delta of this estuary as well as other systems. The entrapment zone discussed in earlier Department testimony is one manifestation of a circulation effect. The reader is referred to pages 48 and 51-52 of Exhibit 61 for a brief review of those findings.

At least two types of currents can affect the distribution and/or abundance of young fish and invertebrates in the Bay. Tidal flows are those induced by the movement of ocean water in and out of the Bay on a regular basis. These basic flow patterns vary little and remain relatively unchanged throughout the year (Conomos 1979), although there is a strong fortnightly variation. Non-tidal currents, on the other hand, are variable and caused by density differences due to freshwater inflow (Smith 1987). Both types of flow can carry fish and invertebrates.

By averaging velocity data over one or more tidal cycles, one can demonstrate a landward flowing bottom current and a seaward flowing surface current. Such "gravitational circulation" has been defined in the Bay channels, over weekly and bimonthly time scales (Conomos 1979). Smith (1987) states "...net seaward - landward currents in the northern embayments appear to vary between 30 cm/s (1 ft/s) seaward and 30 cm/s (1 ft/s) landward, and are often less than 15 cm/s (0.5 ft/s)". Meaurements of tide and wind induced horizontal net circulation demonstrate that these characteristics dominate over the Delta discharge induced seaward flow except for short periods during large runoff events (Smith 1987). So, gravitational circulation increases with increasing delta outflows.

Many of the marine invertebrates observed during our study float passively with the currents and their occurrence in the Bay reflects their transport there by upstream flowing bottom currents. <u>Crangon</u> shrimp planktonic life stages are affected by these currents. Larvae are carried from the Bay in surface water to nearshore areas during winter and spring. Post-larvae, which are at or near the bottom, enter the Bay aided by tidal and flow enhanced non-tidal currents. We observed a positive correlation between post larvae abundance in the Bay and March-May outflows (See Exhibit 60, page 59).

Data on English sole larvae provide a particularly strong case for gravitational flows as a distribution altering mechanism. Greater numbers of larvae were present in the Bay during the higher flow years 1980, 1982, and 1983 and lower numbers occurred in the low flow years 1981 and 1985 (See Exhibit 60, page 248). The larvae were also more broadly distributed throughout the Bay during the wet years. A particularly interesting observation occurred in February of 1982 when larval English sole (5-6 mm long) were caught upstream as far as the Benicia Bridge. Intuitively, one would expect that higher flows would "flush" non-motile larvae downstream and out of the Bay. However, greater numbers and broader distributions of larvae were observed in the Bay during years of high inflows and subsequently stronger landward flowing bottom currents. Therefore, the operating mechanism affecting larval English sole abundance and distribution appears related to increased upstream bottom flows that occur during periods of greater delta outflow. It must be noted, however, that this increased distribution of larval English sole may not result in greater survival, since no relationship was found between larvae and young-of-the-year English sole. Further, investigation of this process must be completed.

We found that the numbers of larval starry flounder present in the Bay are not adequate to explain the extensive young of the year population of the upper parts of the Bay and lower part of the Delta (See Exhibit 60, page 287). The larvae we caught in Central Bay were large (7-10 mm) and in some cases were already metamorphosing into their bottom dwelling form. These facts suggest the possibility that as larvae living offshore begin moving to the ocean bottom they are transported into the Bay by upstream gravitational currents. If spawning were extensive in the Bay we would expect to see large numbers of smaller larvae, particularly in the 4-7 mm range, and we did not.

Finally, we concluded that our observations of increased abundance of the marine species, speckled sanddab,in the Bay during high flow years was due to an intensification of the bottom, landward moving gravitational circulation. Despite the fact that they occupy the more saline parts of the Bay, the juveniles and adults were most abundant in the Bay when freshwater inflows were high (See Exhibit 60, page 260). We also found evidence of currents carrying larval northern anchovy into the Bay.

Nutrients - The role of freshwater flows as an important source of nutrients has been documented in many estuaries. The reader is referred to pages 23-24, and 52-54 of Exhibit 61 for a more detailed discussion. Many elements (and biochemical mechanisms) collectively determine estuarine fertility and may have their origin outside the estuary (Kutkuhn 1966). Estuaries are not closed, self-contained ecological systems, and their production of organic matter, or their fertility, is dependent upon nutrients from the sea and from the land. Kutkuhn (1966) states that there is no tangible evidence that appreciable reduction in freshwater discharge and its "nutrient" load would not, in time, seriously impair estuarine fertility. All this means that flow-regulated nutrient levels can cause significant changes in organism abundance in estuaries.

The abundance of primary producers (e.g., phytoplankton, macrophytes, etc.) and consumers (e.g., zooplankton, shrimp, fish, etc.) in most aquatic systems, including estuaries, is ultimately related to the amount of nutrients available to "drive" the food web. Inorganic nutrients (e.g., dissolved silica, nitrogen, phosphorus, etc.) are important because they stimulate primary producers, while organic nutrients (detritus) are important because they provide a food source for consumers. Systems with increased levels of nutrients usually will be more fertile and will maintain higher abundances of biological resources. Systems that have small nutrient inputs may be nutrient "limited" and therefore may maintain lower abundances of various organisms.

We did not directly investigate trophic dynamics, yet we suspect that some of the responses we observed were related to food (nutrient) availability. We found a positive correlation between longfin smelt populations and the magnitude of Delta outflow (See Exhibit 60, page 128). Further, it appears that the longfin smelt abundance in the study area was controlled by the survival of juvenile smelt through their first spring and summer. This survival is significantly correlated with the magnitude of freshwater inflow during that winter, spring and summer. One of the factors that we believe is related to this positive association is that high flows can increase the levels of nutrients that form the base of the food chain in the Bay/Delta, therefore increasing overall productivity and survival of young smelt. Such a mechanism may also explain why some of the marine species do better during wet years. Increased food resources present during those times may also benefit marine species that use the Bay.

There appears to be no question that the input of nutrients into the estuary is directly related to freshwater flow and that the production of fish and invertebrates ranging from those discussed in the preceding paragraphs to striped bass and <u>Neomysis</u> discussed in earlier Department testimony are directly related to the magnitude of freshwater flow. Much of the greater nutrient load brought in with high flows during the winter, however, passes through the estuay unutilized and into the ocean. Hence, there is a question as to the degree that higher production in wet years is due to greater supplies of nutrients, as opposed to enhanced utilization of nutrients associated with the greater degree of stratification in wet years. Recirculation within the entrapment zone and enhanced phytoplankton production in the surface layer of South Bay are examples of mechanisms associated with flow which enhance utilization of nutrients.

PULSE FLOWS, FLOW TIMING AND MAGNITUDE

In most years, "outflow pulses" periodically occur with variable duration and timing. These pulses as well as the actual magnitude of annual flows can have significant impacts on fish and invertebrate resources.

Pulse Flows

When major storm events occur in the watershed, quantifiable "outflow pulses" pass through the Bay. These flows appear as spikes or peaks on the hydrograph which are greater than base flows. During pulses, flows increase rapidly and subside over a longer period of time. Sometimes they do not subside before another storm causes other pulses to enter the system. These pulses generally occur during the period between November and March each water year. Some years they do not occur until January and may continue until April.

We learned the following about short term pulses that occur in the Bay; 1) with few exceptions, they have little immediate effect on overall population abundance, 2) they can delay entrance into the Bay, and 3) the major effect of pulses is that they immediately alter organism distributions. The most significant question with respect to pulse flows relates to the long term impact of changes in distribution that occur in response to pulses on fishery populations. We are unsure whether the effects on organism populations are temporary or permanent. Further we have not been able to determine whether observed relationships between populations and the overall magnitude of flow are due to effects of pulses or to the higher annual outflow that usually occurs during years when significant pulse events occur.

Since very large pulse events can drastically alter salinities, circulation and nutrients, they can sometimes significantly affect the abundance of resources in the Bay. These are exceptions to the rule, however. For example, we observed a drop in the Bay abundance of ghost shrimp larvae during an extensive outflow pulse event in February 1983 (See Exhibit 60, page 19). Similarly, we documented an extreme drop in the number of Dungeness crabs per set we collected during March 1983 and February 1986 compared to previous months during those times of the year (See Exhibit 60, page 90). Large pulses of freshwater moved through the Bay system during March 1983 and February 1986. Likewise, the only months that we did not collect bay goby larvae in the Bay were March and April 1983, a period of extremely high freshwater inflow (See Exhibit 60, page 218). It appears that these pelagic larvae were carried out of the Bay during high inflow events. There is also evidence that these pulse events retarded the northern anchovy entrance into the Bay and that they also moved young-of-the-year English sole from San Pablo Bay to South Bay (See Exhibit 60, page 251).

It is important to realize that pulse flows may not affect organisms the same way each time they occur. For example, juvenile English sole decreased in abundance after pulses in December 1982 and 1983, and significantly increased after pulses in February 1982 and November 1983 (See Exhibit 60, page 295).

Importance of Flow Timing

The timing of outflow pulses in the Bay system is variable, yet pulses generally occur during winter and spring months due to watershed storms and spring snowmelt. Pulses occurring during the fall (October-December) are usually small with maximum discharges below 50,000 cfs. The largest outflow pulses usually occur in winter (January-March). Spring (April-June) pulses during most years tend to be moderate in volume. Since these pulse events affect fish and invertebrate distributions the timing of their occurrence is significant. If these events do not coincide with life stages that are affected by or dependent upon them, they will not result in noticable effects. The correlation between flow events and English sole larvae is a good example of this principle. A good correlation was observed between larval English sole abundance and flow during most years. The year 1984 was an exception in that annual outflow was relatively high, but English sole larval abundance was relatively low. During the winter of 1983-84, peak flows occurred in December while in other years, the peak flows occurred in January or February (See Exhibit 60, page 3). This suggests that during the 1983-84 winter, peak flows occurred before high numbers of English sole were present offshore to be transported into the Bay. We also found that the abundance of adult and juvenile speckled sanddabs is positively associated with the mean freshwater inflow in the previous month, again suggesting the timing of flow occurrence is important (See Exhibit 60, page 260). Further, despite positive relationships between flow and longfin smelt abundance during wet years, there was no such relationship during 1984, technically classified as a wet year (See Exhibit 60, page 113). We think the numbers of longfin smelt were low during 1984, because during the time when flow are important to longfin smelt larvae, flow conditions were equivalent to a dry year.

Timing of flows also affects when shrimp reach peak abundance in the Bay. The peak abundance of post-larvae and juvenile <u>Crangon franciscorum</u> occurred earlier during dry years (1981) and later in wet years (1983) during our study (See Exhibit 60, page 59). <u>Crangon nigromaculata</u> also entered the Bay from the ocean later during wet years. Northern anchovy remained in the Bay later in the fall during dry years than in wet years.

Importance of Flow Magnitude

Some evidence developed during our study suggests that the relationship between the strength of biological responses and the magnitude of outflows are not linear. We found that fish and invertebrate resources can be negatively impacted by flows that are too high or too low. One species that typifies this relationship is the yellowfin goby. Juvenile abundance was relatively low in both extremely high inflow years (1982 and 1983) and low inflow years (1981 and 1985), while it was high in moderate inflow years (1980 and 1984) (See Exhibit 60, page 216). Further, based on 1983 data we concluded that the effect of flow on English sole abundance also was not linear. Outflows were higher in 1983 than 1982, yet overall abundance of English sole larvae was lower in 1983 (See Exhibit 60, page 249). Given the flow/abundance relationship observed in other years, one would predict that larval abundances should have been higher. One hypothesis explaining this observation is that if flows exceed some, as yet, undetermined threshold, the physical process responsible for transporting larvae into the Bay (two layered flow) is overwhelmed by unidirectional flow. Under those circumstances, fewer larval English sole may enter the Bay.

Speckled sanddab data provide further insight into the flow magnitude/abundance relationship. Despite the fact that they occupy the more saline parts of the Bay, speckled sanddab appear to be influenced by the magnitude of freshwater inflow into the system. It apears that upstream bottom flows "draw" more fish into the Bay as outflows increase and subsequently decrease. However, flows above 125,000-150,000 cfs do not increase abundance in the Bay (See Exhibit 60, page 267). Flows above 200,000 cfs, in fact, causes the sanddab to move out of their preferred area into South Bay. This suggests a threshold flow in the range of 125,000-150,000 cfs. If flow increases above this level sanddab abundance in the Bay is not augmented and may be reduced.

The data discussed above support an hypothesis whereby fish abundance is not significantly increased until some threshold level of flow is reached and then are beneficially affected until some upper limit is reached where benficial impacts no longer occur. On the other hand, data collected previously (See p. 75 of Exhibit 61) have documented that some biological abundance responses are continuous functions of flow in that their survival increases or decreases incrementally with flow. Management of estuarine systems would require definition of the flow magnitude/abundance/distribution relationship for species of interest.

CONCLUSIONS AND IMPLICATIONS

Information collected during the six year study of San Francisco Bay fish and invertebrate resources verifies the majority of the conclusions developed during our 1983 literature review of freshwater inflow and biological effects (Technical Report 7, Exhibit 61). However, now we can make at least 12 conclusions that are important to management of the Bay system. Below we list these conclusions and implications of those conclusions to managers.

CONCLUSION #1 - FRESHWATER INFLOW IS A SIGNIFICANT FACTOR AFFECTING BIOLOGICAL RESOURCES IN THE BAY

During the hearing that led to Water Rights Decision 1485, no specific standards were set for protection of resources in San Francisco Bay because no evidence documenting the importance of flow to Bay resources had been presented. Instead, the State Water Resources Control Board mandated that studies be carried out to determine outflow needs in the Bay and to document the ecological benefits of unregulated outflows and salinity gradients established by them. Our study has documented relationships showing the importance of freshwater inflows to biological resources in the Bay and we now have a better, although incomplete, understanding of some of the flow related mechanisms that lead to these relationships.

IMPLICATION #1 - Now that we have documented that freshwater outflows from the Delta can significantly affect fish and invertebrate resources in the Bay, it is important to review water right permits with this fact in mind. At this time, we are unable to determine impacts associated with specific projects or amount of diversions, but we understand more about cumulative impacts associated with large flow reductions or changes. The most significant implication of our findings is that water project development in the Bay-Delta or its watershed must be prepared to identify and prevent, mitigate, or offset negative impacts associated with increased diversion from the system. Future information from our study efforts will aid in this process.

CONCLUSION # 2 - FRESHWATER INFLOW CAN AFFECT THE ABUNDANCE OF SOME IMPORTANT FISH AND INVERTEBRATES THAT ARE DEPENDENT UPON THE BAY

The abundance of about 40% of the species in the Bay was related to freshwater inflow. Besides salmon and striped bass, which have been treated elsewhere, important species in San Francisco Bay are anchovy, herring, longfin smelt, topsmelt, jacksmelt, yellowfin goby, starry flounder, shiner perch, English sole, staghorn sculpin, bay shrimp (primarily *Crangon franciscorum*) and Dungeness crab. Many of these species are important in the food chain and are dependent upon the Bay and freshwater flows. Halibut is an important sport fish in the Bay, but our study was not designed to identify factors controlling its abundance.

IMPLICATION #2 - Of those species mentioned above, our information to date indicates that anchovy, jacksmelt, topsmelt and shiner perch appear to respond to variations in flow less than the others. Hence the remaining species are likely to become the "key species" to consider in selecting measures to protect the Bay's resources.

CONCLUSION #3 - FRESHWATER INFLOW CAN AFFECT THE DISTRIBUTION OF BAY FISH AND INVERTEBRATE SPECIES

The most obvious direct effect of flow on fish and invertebrates is that it changes their distribution. Short term "pulse flows" and/or increased, long term base flows result in expanding the distributions of some estuarine pelagic fish and marine flatfish. The distribution of others, like juvenile gobies and Dungeness crabs and some life stages of native shrimp were decreased. The Bay distribution of marine pelagic fish and marine invertebrates was not affected by flow at all. The ultimate results of distribution changes is not always clear, but expanded distributions may be beneficial to some species like longfin smelt and Crangon fransicorum because of reduced competition and increased survival.

IMPLICATION #3 - Our data imply that reductions in either annual outflows or pulse flow levels could result in more intraspecific competition because some important "key species" are not spread as widely. If peaks are taken off pulse flows, greater numbers of individual organisms will stay in localized areas where increased competition may reduce recruitment into the adult population. This hypothesis must be tested further with more field observations.

CONCLUSION #4 - VARIABILITY IS THE NORM IN THE BAY

One key characteristic of the Bay is that conditions are seasonally variable. This variability allows estuarine systems to be productive and function as nursery areas for many species of fish and invertebrates. We observed extreme seasonal variation in flow and salinity conditions.

IMPLICATION #4 - It is important to maintain seasonal variability of inflow into the system. A reduction in seasonal variability would reduce productivity of some species and life stages that currently use the Bay habitat. The one group that would be most affected by loss of variable salinity conditions are the estuarine species that depend upon brackish water to live and reproduce.

CONCLUSION #5 - SALINITY IS A MAJOR FACTOR AFFECTING FISH AND INVERTEBRATE ABUNDANCE AND DISTRIBUTION

When salinity is changed by increases or decreases in flow, fish and invertebrates often respond by moving to another part of their range where salinity is more favorable. If they are unable to move or are unable to find favorable areas and their salinity tolerances are exceeded, they may die. It is important to maintain a desirable horizontal salinity gradient in the Bay so that the salinity preferences of a greater number of organisms can be met.

IMPLICATION #5 - Since salinity is an important factor affecting Bay organisms, management plans must consider project impacts on this parameter. Salinity gradients should be maintained such that fishery production can be maximized.

CONCLUSION #6 - DIRECT EFFECTS OF FLOW AS MANIFESTED IN CIRCULATION PATTERNS, PARTICULARLY GRAVITATIONAL CIRCULATION, INFLUENCE ABUNDANCE AND DISTRIBUTION OF FISH AND INVERTEBRATE RESOURCES

For those fish and invertebrates that are spawned offshore in the ocean and grow up in the Bay, gravitational circulation plays an important role in transporting them there. During our study some non-motile invertebrates and larval fish from the ocean occurred further upstream in the system during high inflow years than in low inflow years. An alternate mechanism that could result in such distributional patterns is transport by tides combined with selective behavior by the organism. However, if tidal transport was the ony mechanism responsible for larval fish and invertebrate distributions similar distributions should be observed each year since tidal patterns are similar each year. We however, observed more non-motile organisms, further upstream in the Bay during times of greater inflow and subsequent stratification of the water column. Net upstream movement of water and particles (larvae) is greater during such conditions.

IMPLICATION #6 - The velocity, duration, and geographical extent of residual upstream flows in Central, San Pablo or Suisun Bays, and the springtime stratification of South Bay during neap tidal cycles need to be considered in evaluating potential changes in freshwater flows. If these circulation processes are affected significantly, the successful use of the Bay nursery area by marine and important, abundant estuarine species (eg., *Crangon franciscorum*) could be reduced.

CONCLUSION #7 - THE TIMING OF FRESHWATER INPUT INTO THE BAY IS IMPORTANT

Flows need to coincide with certain life stages or life processes to provide some of the benefits we observed. Our study showed that the timing of flows was important to the abundance of larval English sole, longfin smelt, and *Crangon franciscorum*. If flow input occurred earlier or later than optimal for these species, abundances were reduced. Generally, our results showed that spring flows were the most important.

IMPLICATION #7 - A reduction of flow magnitude during biologically significant periods will reduce the abundance of some organisms. Our study indicated that the period between February and May of each year is a time when most "key species" in the Bay spawn and grow and therefore need preferred salinity or circulation conditions.

CONCLUSION #8 - THE MAJOR IMMEDIATE EFFECT OF PULSE FLOWS IS ALTERED ORGANISM DISTRIBUTION, BUT THE LONG TERM RESULT OF SUCH CHANGES ARE UNKNOWN

We learned that short term pulses that occur in the Bay have little immediate effect on overall population abundance, can delay entrance of marine organisms to the Bay, and immediately alter organism distributions. However, we are unsure whether the effects on organism populations are temporary or permanent. Further, it is not known if observed relationships between populations and the overall magnitude of flow are due to effects of pulses alone or the higher annual outflow that usually occurs during years when significant pulse events occur.

IMPLICATION #8 - The major implication of this conclusion is that more study must be carried out before the long term importance of pulse flows can be distinguished from the overall effects of flow.

CONCLUSION #9 - EFFECTS OF FLOW ON BIOLOGICAL RESOURCES ARE PROPORTIONALLY GREATER AT UPSTREAM AREAS IN THE SYSTEM

The effects of any given flow on salinity, circulation, or nutrient conditions and therefore biological resources are greatest upstream and least near the Golden Gate. Low inflows may affect conditions significantly in Suisun Bay but have little effect in Central Bay. Salinities in the South Bay reach are profoundly affected only after Delta outflows reach a threshold level of about 35,000 cfs.

IMPLICATION #9 - Since a lot more flow is needed to influence salinity in the Central Bay area, certain effects of falling flows would occur in that area first. If flows are reduced below the threshold level needed to stratify South Bay, the effects there would be proportionally greater than in Central Bay or upstream.

CONCLUSION #10 - THE BAY IS AN IMPORTANT NURSERY AREA FOR MARINE AND ESTUARINE SPECIES

We documented the use of the Bay as a nursery area during our study. Various life stages of many species occur in the Bay at some time of the year. This use occurs through at least 3 general strategies. Some species spawn offshore and eggs, larvae and juveniles are transported into the Bay by tidal and gravitational currents. Some species swim into the Bay, spawn and return to the ocean. Their larvae rear in the Bay but generally leave within a year. Others are residents that spend all their life in the Bay. Circulation and salinity conditions are two critical factors that allow these uses of the Bay.

IMPLICATION #10 - Each of the above strategies needs to be considered in evaluating management options for protection of the Bay.

CONCLUSION #11 - THE BAY IS NOT A SEPARATE ENTITY INDEPENDENT OF THE RIVERS, DELTA OR THE OCEAN

Many conditons exist in the ocean that affect conditions in the Bay. The Davidson current affects Dungeness crab juvenile abundance in the Bay, while large scale events like El Nino affect incidental use of the Bay by some ocean species. Likewise flows from the rivers and Delta carry organisms and nutrients into and sometimes through the Bay to the ocean. The Bay is part of a complex hydrological and biological system.

IMPLICATION #11 - More needs to be known about the links between the ocean, Bay, Delta and freshwater outflows. Past management decisions have been made based on impacts associated with selected reaches of the estuarine system (eg. the Delta). More information must be developed on the river-Bay-ocean link, and such a "systemwide" approach should be used in future management efforts.

CONCLUSION #12 - MORE INFORMATION MUST BE COLLECTED BEFORE THE SIGNIFICANCE OF FLOW/RESOURCE RELATIONSHIPS TO MANAGEMENT DECISION MAKING CAN BE ESTABLISHED

Our study has provided initial answers to many questions regarding the effect of freshwater flow on biological resources in the Bay downstream of the Delta. However, more information is needed to reach definitive conclusions on measures to protect resources in the Bay.

IMPLICATION #12 - Studies are particularly warrented in the following areas:

i) Further quantification of flow/"key species" relationships is needed. Currently, we have documented correlative relationships between key organisms and flow variation. We now need to refine these relationships and examine causes for the relationships. The requirement for variation in time and space for all conditions must be implicit in this determination.

ii) We must determine the relationship between Bay-produced/reared fishery resources and those fish recruited into the Bay/ocean fishery. Relatively few commercial species use the Bay as adults, so data available to address this issue are limited. Our program has determined how flow affects the various life stages of fish and invertebrates which occur in the Bay. Subsequent work must be directed towards identifying the significance of those effects to the overall production of the species.

iii) We must learn more about the relationship between larval use of the Bay and gravitational circulation. The hydrodynamic element of the Delta Outflow/San Francisco Bay Study is developing 3-dimensional mathematical models that will further our understanding of the physical aspects of this process. We need to carry out spatially and temporally intensive biological sampling during flow induced, gravitational circulation events in order to document more clearly the relationship between abundance and distributions of larval fish and invertebrates in the Bay and flow induced circulation patterns.

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