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BAY-DELTA OVERSIGHT COUNCIL

DRAFT

BRIEFING PAPER ON INTRODUCED FISH, WILDLIFE AND PLANTS IN THE SAN FRANCISCO BAY/ SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

Bay-Delta Oversight Council

May 1994

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INTRODUCED FISH, WILDLIFE, AND PLANTS IN THE SAN FRANCISCO BAY/ SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

BAY-DELTA OVERSIGHT COUNCIL

MAY 1994

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PREFACE

This briefing package is intended to provide additional information regarding introduced fish, wildlife and plants in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. This information is supplemental to that presented in the draft briefing paper prepared for BDOC titled "Biological Resources of the San Francisco Bay/Sacramento San Joaquin Delta Estuary", specifically the section entitled "Factors Controlling the Abundance of Aquatic Resources", dated September 1993.

The Executive Summary seeks to provide an overview of the information presented in the briefing paper. It deserves emphasis, however, that it should not be considered a substitute for the full text. Rather, it is intended to provide merely a snapshot of the major points, as the characterization and flavor of the entire prepared document cannot be replicated in an Executive Summary.

As has been our practice, attached as addenda are several perspective papers outlining the authors' views pertaining to the issues discussed in this briefing paper. These perspectives papers are reproduced here as submitted.

INTRODUCED FISH, WILDLIFE, AND PLANTS IN THE SAN FRANCISCO BAY/ SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

Prepared for the
Bay-Delta Oversight Council

Main Briefing Paper Prepared

by

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Executive Summary prepared
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INTRODUCTION

Regulatory actions over the past decade in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary have affected the operations of water projects, which provide the water supply for two-thirds of all Californians, as well as irrigation water for millions of acres of agricultural lands. Water management actions have been implemented in the Estuary during this period to protect the native winter-run Chinook salmon, the native delta smelt, and other depleted fishery resources. Some of the water users impacted by those actions have expressed concerns over whether other factors in the Estuary have been given sufficient consideration. One of the factors underlying this concern is the large number of introduced species in the Estuary in relation to the numbers of native species, which have been the focus of these regulatory actions.

In the draft briefing paper, prepared for the Bay-Delta Oversight Council, titled "Biological Resources of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary", specifically the section entitled "Factors Controlling the Abundance of Aquatic Resources" (September, 1993), the effect of introduced species was presented as a comparatively minor factor affecting the Estuary's fishery resources. Some commentors strongly disagree with this characterization and believe introduced species are a major factor that has and will affect the Council's efforts to "fix" the Delta. One illustration of the concern regarding introduced species is that in 1991 seven of the ten most abundant species salvaged at the State Water Project fish screens were introduced species and the sport catch of introduced species during the 1980s in the Estuary exceeded the catch of native species.

The role of introduced species in the Estuary and any possible limiting effects they may have on the recovery of certain depleted species and the overall restoration and protection of the Estuary ecosystem is not well understood. Conditions in the Estuary are ever changing and new introduced organisms continue to be documented as surveys and field work is conducted in the Estuary.

This briefing paper is intended to provide the Council with an overview of the current state of knowledge with respect to introduced species in the Estuary and discusses how the ecosystem may be affected by their presence.

BACKGROUND

Introduced species can affect native fish, wildlife, and plants through a wide variety of mechanisms. These include: competition for space, competition for existing food resources, predation, disturbance, hybridization, pathways for and sources of disease, and physical alteration of the environment. Non-native plants can contribute to the incremental loss of habitats and biological diversity by affecting the ecological process of succession, productivity, stability, soil formation and erosion, mineral cycling, and hydrologic balance.

Introductions of non-native species have occurred from the initial human settlement of the region. Such introductions, intentional or not, impact the native species populations by competing for available resources and habitat and predation. Intentional introductions were often the result of government agencies' intent to provide additional opportunities for anglers or attempt to control a pest species. Non-intentional introductions are incidental to normal day-to-day activities in the Estuary. Ballast water discharges and containerized freight, for example, are thought to be significant pathways.

Introduced species have probably affected the abundance of native species in the Estuary, but only in a few cases is the data available to document that an introduced species is a significant cause of the decline of native species. The ecological complexities of the Estuary are not well understood and the available data on impacts of native and non-native interactions is somewhat imprecise. Little is known about impacts resulting from early introductions due to limited monitoring. However, even with the more extensive monitoring of introduced species in the last 25 years, the current data may not fully document recent introductions to the system. Developing in-depth data for introduced species is difficult as they often are not noticed or studied in detail until they become nuisances.

The primary focus of concern over the role of introduced species within the Estuary are the processes of predation and competition. Evaluation of the consequences of introductions requires the formulation of evidence of the affects of these processes. This assessment is difficult due to the lack of historic data. Species introduced during the early part of the state's history are interacting with the native biota. Thus, potential impacts are difficult to discern due to this interaction. Additionally, the Estuary's ecology is continually evolving as a result of intensified land use and modifications to water project operations. These changes alter conditions to such an extent that the dynamics of the relationships between introduced species and native species interactions are affected.

Monitoring during the last 25 years has been much more extensive than in previous periods and has led Department of Fish and Game (DFG) biologists to conclude that only the depletion of the native copepod (*Eurytemora affinis*) by introduced copepods, and ,subsequently, the introduced Asian clam provides evidence of competition and predation by introduced species being the principal cause of a decline in the population of a native aquatic species. While another possible example is inland silversides and delta smelt, that needs further evaluation, particularly as to what happened during the 1993 rebound in delta smelt abundance.

Evidence of native wildlife depletion attributable to predation and competition by introduced species is more direct. Adverse effects on native wildlife and plant species by the red fox, Norway rat, Virginia opossum, feral cats, and several terrestrial and aquatic plant species have been documented.

One prominent perspective on the issue of the affects of introduced species on the native flora and fauna is that species such as the striped bass and largemouth bass were introduced into the system and have existed with native species since that time in the Estuary. Although some, and perhaps extensive, alteration of the native fishery resources undoubtedly occurred, the benefits derived from these introduced species were considered sufficient at the time to justify their introduction. In those cases, the non-native species are now considered part of the Estuary's biological system. Many fisheries management experts believe that restoration of the Estuary should include some non-native species such as striped bass which provide important recreational opportunities for sport anglers and contribute to the economy of the State. They also believe that this can be accomplished without compromising the goals of restoring and protecting the Estuary.

A second perspective is that from the very first time that a non-native species was introduced into the system the biotic uniqueness and structure of the Estuary as a whole was altered. This alteration of the Estuary was such that the non-native species were usually the winners and the native species the losers. Advocates of this position also tend to feel that management actions aimed at increasing the abundance of introduced species populations, such as striped bass, are in conflict with goals set for achieving recovery of native species.

A third perspective is held by those experts who contend that recovery efforts should focus on ecosystems in a more global nature. For example, Dr. Peter Moyle of the University of California Davis believes introductions may increase local diversity, but they often cause a decrease in global diversity when native species are driven to extinction. The U.S. Congress Office of Technology Assessment (OTA) states that the concept of "vacant niche", (which holds that some ecological roles may not be filled in a community, and species can be selectively introduced to fill these voids) is inappropriate because few species can fit the narrow ecological vacancies identified by managers, and because it is virtually impossible to predetermine the role a species will assume after it has been released. Dr. Phyllis Windle of the OTA further points out that in focussing on declines of natives and the often-ambiguous data on species extinctions, we lose sight of significant ecosystem changes in structure and function that usually accompany the introduction of non-native species.

Attempts to prevent new species from becoming established in the Estuary has resulted in elaborate, expensive, and difficult control efforts spearheaded by the Department of Fish and Game, Department of Boating and Waterways, and Department of Food and Agriculture.

INTRODUCED SPECIES

The Estuary is home to more than 150 introduced aquatic species of plants and animals including over 27 different non-native fish species and over 100 different species of marine invertebrates. The briefing paper discusses this collection in some detail. A selection of the more significant species are highlighted in this executive summary.

Fish

Government agencies have intentionally introduced certain species to expand the opportunities for angling and commercial fishing, to expand the forage base for predators, and to control pest populations. Other mechanisms for introduction include unauthorized transplants by individuals, and non-intentional introductions occurring incidental to commercial and sporting activities (i.e. discharge of ship ballast water, transport of organisms on the hulls of fishing boats, etc.).

Striped bass (*Morone saxatilis*) were introduced into the Sacramento-San Joaquin Estuary in the late 1800s. Striped bass were stocked by the DFG from 1982 through 1992 in an effort to support and maintain the existing population in the Sacramento-San Joaquin Estuary. This practice was suspended by the DFG in response to concerns that the stocking of striped bass, which was only a small portion of the natural process, was adding predators to the system which could harm populations of the winter-run Chinook salmon.

It is reasonable to believe that a top of the food chain predator like striped bass, which in the late 19th century became a dominant fish in the estuarine ecosystem, must have decreased the abundance of some other species. However, available evidence is not sufficient to identify those declines. Thus striped bass are an important part of the introduced species issue both because their introduction may have influenced the abundance of other species, and because more recent introductions of other species may have a role in the recent decline of striped bass. The evidence indicates striped bass decrease salmon abundance, but are not the principal controlling factor in recent declines of salmon or delta smelt.

The **largemouth bass** (*Micropterus salmoides*), a species introduced in the late 1800's to enhance sport fishing, is one of several members of the sunfish family which, it is theorized, may have collectively out-competed the native Sacramento perch for habitat. They have also been implicated in the decline of the red- and yellow-legged frogs in areas where they coexist. While the prevailing judgement is that largemouth bass probably contributed to declines in various native fishes in the Delta, conclusive evidence has not yet been demonstrated.

The **chameleon goby** (*Tridentigor trigonocephalus*), introduced sometime in the 1950's, had become the third most abundant species identified in the DWR's southern Delta egg and larval sampling by 1989, and it was the most abundant fish by 1990. Chameleon goby was the only species more abundant than 6 mm striped bass in 1991. However, there is insignificant data to assess the impacts of the chameleon goby's on native species.

The **inland silversides** (*Menidia beryllina*) was introduced into Clear Lake and migrated to the Delta by the mid 1970s. DFG biologists have argued that silversides had little effect on other species because increases in silversides did not coincide with the decline in other species. Dr. Bill Bennett of U.C. Davis, however, has hypothesized that predation by silversides on eggs and larvae of delta smelt may be important in the decline of delta smelt. Predation by inland silversides on delta smelt larvae in controlled experiments and the possibility that silversides may be more abundant than the DFG surveys indicate since shoreline areas are not sampled as extensively as midchannel areas has led other experts to concur with his hypothesis. While Dr. Bennett's hypothesis appears to have merit, further evaluation is necessary, particularly to explain the 1993 rebound in delta smelt abundance.

Amphibians

Bullfrogs (*Rana catesbeiana*) successfully introduced into California have been noted to prey upon and out compete native species such as the red-legged and yellow-legged frogs in areas where they coexist.

Reptiles

The impact of introduced **sliders** (*Psuedemys scripta*) and **softshell turtles** (*Trionyx spiniferus*) on native organisms is unknown. However, they do feed on frogs, aquatic invertebrates, and carrion. In addition, the release of aquarium trade turtles has the potential to introduce pathogens and parasites into southwestern pond turtle populations and can result in competition for resources.

Invertebrates

The changes in invertebrate populations have been more dramatic than those for fish in recent years. Several new species of zooplankton have dramatically changed the species composition in the brackish and freshwater portions of the Estuary.

Introduction of the **asian clam** (*Potomocorbula amurensis*) in 1986 and its consequential biological effects on the food chain have been detected by long term monitoring programs. The clam occupies bottom space to the exclusion of other benthic species, as measured by the reductions in their average densities, and also alters the benthic community's species structure. The asian clam has a higher plankton filtration rate than most native invertebrates and has been implicated in the reduction in chlorophyll biomass and production rate in Suisun Bay. Some experts theorize that this reduction in biomass could affect the quality of the entrapment zone and its ability to sustain larval fish and other native invertebrate populations. However, the ecological significance of these changes remains to be evaluated further.

Wildlife

Several non-native wildlife species reside in the Estuary. A number of these species may be viewed as desirable; providing hunting and other recreational opportunities. Other non-native wildlife species which were introduced have expanded their numbers into the Estuary and have increased predation upon the native wildlife populations, thus disrupting natural predator-prey relationships of the Estuary.

Norway rats (*Rattus norvegicus*) introduced and well established in many areas by the 1800s, are predators on waterfowl and nesting California clapper rails; reportedly taking about 33 percent of the eggs laid by clapper rails in southern portions of the Estuary. Once rats become established on colonial bird nesting islands, the reproductive success of these bird colonies may be greatly affected by these opportunistic predators.

Feral cats (*Felix catus*), abandoned and wild, are a major predator for bird and mammal populations in the wetland areas of the Estuary.

Red Fox (Vulpes Vulpes) was brought to California for hunting and for fur farming during the late 1800s. The red fox preys on eggs of Caspian terns and California least terns in the Bay area, causing complete nesting failure of entire colonies. The red fox is also implicated in contributing to the decline of the California clapper rail in the Estuary. Along the bay, red fox prey upon the eggs of black necked stilts, American avocets, and snowy plovers. The increase in the range and population of the red fox is due to the species ability to adapt to urbanization and the subsequent elimination of larger predators such as the coyote which would normally help in controlling the numbers of red foxes.

Terrestrial Plants

There is a long history of concern about the impact of non-native plant species on wetland areas. The extent or cumulative effect of these species on the native vegetation in the Estuary is not fully understood and more information is needed to better understand the complex, usually indirect, interactions of plants in natural environments; both for scientific understanding and to promote better vegetation management.

Broadleaf pepper grass (*Lepidium latifolium*) is widely distributed in the state, difficult to quarantine, and an economic threat to agriculture.

Eucalyptus (*Eucalyptus sp.*), in certain situations, may have crowded out native grasses and forbs by shading out these species, by the destroying the understory with debris and oils released by the trees, and competing for soil and water.

Aquatic Plants

Impacts on the Delta ecosystem from aquatic weeds include blocking flood control channels, increasing mosquito habitat, increasing siltation, changing water temperature, changing dissolved oxygen, obstructing boating recreation activities, and decreasing property values for properties adjacent to affected channels.

Waterhyacinth (*Eichhornia crassipes*) provides additional escape cover for fish and other organisms, but the relative value of escape cover provided by submerged native aquatic plants in contrast to cover provided by the submerged portion of hyacinths is not known. Although the effects on fish and wildlife are not well understood, the additional shade provided by the waterhyacinth negatively impacts phytoplankton and can cause rooted submergent plants to die.

PERSPECTIVES ON INTRODUCED SPECIES

An earlier version of the draft briefing paper was submitted to a diverse review panel representing federal, state, and local organizations for review and comment. In addition, they were requested to submit a separate perspective paper based on the particular focus of their agency or group which may have differing viewpoint than presented in the briefing paper. These perspective papers are reproduced, as submitted, and included as part of this briefing packet. The following summaries highlight only certain points within the papers and should not be considered substitutes for the full text.

The United States Congressional Office of Technology Assessment (OTA) submitted a report brief on "Harmful Non-indigenous Species in the United States" The brief states that harmful non-indigenous species have exacted a significant toll on U.S. natural areas, ranging from wholesale changes in ecosystems to more subtle ecological alterations. They have found that fundamental changes in structure and function of habitat were as much of a concern as species declines. That is, non-natives change the players, but can also change the rules of the game. The OTA believes the concept of "vacant niche", (which holds that some ecological roles may not be filled in a community, and species can be selectively introduced to fill these voids) is inappropriate because few species can fit the narrow ecological vacancies identified by managers, and because it is virtually impossible to predetermine the role a species will assume after it has been released.

Dr. Phyllis Windle of the Office of Technology Assessment comments that in focussing on declines of natives and the often-ambiguous data on species extinctions, we lose sight of these significant ecosystem changes. In addition, Dr. Peter Moyle of the University of California Davis comments that introductions may increase local diversity, but often cause a decrease in global diversity when native species are driven to extinction.

Lars Anderson of the Agricultural Research Service (ARS) comments that the objectives of the ARS are to sustain species diversity and improve aquatic habitats, as well as to conduct ongoing research and advise several state/federal programs which complement and partially address specific objectives of the BDOC process. In addition, he identifies three major needs: 1) increased systems-level approach to answering questions related to "fixing" the Delta; 2) efficient research coordination across federal, state, university, and private groups; and 3) current vegetation surveys coupled with the generation of GPS/GIS to establish a "baseline" so that future research can be planned and executed efficiently and effectively.

In support of the opinion that introduced species add diversity and value to the Estuary, Don Stevens, a senior biologist of the DFG comments that an appropriate goal is to restore a biologically diverse ecosystem which maximizes production of desirable recreational and economically important species while not jeopardizing the existence of natives. He states that, for the most part, native fishes have endured despite numerous more or less indiscriminate intentional introductions that have dominated the Delta's fish fauna for more than a century. In addition, he comments that the present declines of both native and introduced species have occurred concurrently with major changes in water management.

Randy Brown, Chief of the Environmental Services Office in the Department of Water Resources comments that introduced species and other factors result in a constantly changing Estuary and one where few management measures can be successfully used to control these species. He states that the scientific community does not have a good understanding of the interactions between newly introduced species and those already present. He comments that without a stable system it is almost impossible to define management actions that will result in specific changes in populations of target species and that deliberations regarding these actions should recognize that they may not achieve their intended objectives because of this instability. In addition, he believes federal and state agencies must do all in their power to limit future introductions, since it is essentially impossible to control species in the Estuary once they are introduced. He states that one of the most important unresolved issues related to introduced species, especially fish, is their impacts on native species through competition for the same, often scarce, food resources.

Dr. Peter Moyle of the University of California Davis comments that even when species overlap in diet and use of space does not mean they compete since the food source or space may not be in short supply. He continues that because competition has not been demonstrated it does not mean that it does not exist.

Karen Wiese, of the California Native Plant Society (CNPS) comments that the CNPS views the introduction and proliferation of non-native plants in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary as a threat that disrupts and displaces native ecosystems resulting in a loss of biodiversity. She states that the loss of biodiversity implies reduced functional values (or benefits) to the ecosystem and the region as a whole. In addition, she comments that introduced plants have had a history of detrimental effects on the native flora, thus, adversely altering the biodiversity of the ecosystem. The CNPS recommends that when aggressive non-native plants threaten to displace and destroy native plant habitat, control and eradication programs be implemented for those invasive species.

Ross O'Connell of the California Department of Food and Agriculture (CDFA) comments that the potential introduction and establishment of additional non-native species is not addressed in the briefing paper. He states that Hydrilla verticillata and the zebra mussel could be very devastating if they become established in the Delta. The CDFA has an eradication program that spends approximately one million dollars a year in eradication and detection survey efforts. In addition, various biocontrol agents are used to help in the control of "A" rated weeds in situations where current technology makes eradication unfeasible due to terrain or the size of the infestation. Plants rated "A", present an economic threat to agriculture and occur in very localized areas of the state.

Larry Thomas of the Department of Boating and Waterways (DBW) comments that there are at least three other non-native species (Egaria, Parrot feather, and Waterprimrose) in addition to waterhyacinth which have become a problem, or have the potential to become a problem. He states that the DBW agrees studies should be undertaken to better understand the significance of introduced species on the Estuary's fish, wildlife, and plants.

CONCLUSIONS

This paper acknowledges that the effects of introduced species and ecological complexities in the Estuary are far from definitive and more study is necessary to define the problem. Hence, continuing analysis of existing data and additional studies are warranted. However, by necessity, the BDOC will likely need to consider the issue utilizing existing information.

The effect of introduced plants has been pronounced in the Estuary. Aggressive non-native plants have significantly altered the California landscape and the Bay-Delta Estuary is no exception. Introduced fish species have undoubtedly affected the abundance of native species in the Estuary, but the magnitude of such effects is very uncertain.

Few opportunities exist to effectively reduce or eliminate introduced species from the Estuary. Most introduced species cannot be totally eliminated from the Estuary. Still, most resource managers agree that additional introductions are generally undesirable. Consequently, management activities focus on preventing additional incidental introductions and managing the existing mix of species. The desire to minimize the likelihood of new species becoming established has resulted in elaborate, expensive, and difficult control efforts. Efforts to control non-native predatory mammals such as red fox and Norway rats and invasive aquatic species such as white bass and northern pike should continue. In addition, a more aggressive effort to manage ballast water discharges, inclusion of invasive plant control in native plant restoration programs, and biological control of introduced invasive aquatic plants should also be undertaken. Future management actions will have to be undertaken recognizing that the full extent of impacts from introduced species on the Estuary is uncertain.

The Council and its technical advisors will need to consider how introduced species help define the Estuary's ecosystem and how they may impede recovery of specific native species. Properly considering introduced species in the context of evaluating alternatives to "fix" the Delta will help define a realistic, achievable plan for restoring the Estuary.

INTRODUCTION

INTRODUCTION

The Bay-Delta Oversight Council (Council), at its April 15, 1994 meeting, adopted an initial general objective for Biological Resources which states:

> **"Improve and sustain biological resources dependent on the estuarine ecosystem ."**

The Council will evaluate action options identified to achieve that objective and will combine these with options to address other objectives into alternatives for a comprehensive program to protect and enhance the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Estuary). In order to effectively evaluate action options and ultimately the anticipated success of achieving the general objective, factors such as how introduced (non-native) species have and are affecting the Estuary must be considered. This document is being prepared in response to a request from the Council for additional information on introduced species in the Estuary and their potential effects on the Estuary's flora and fauna.

The Council and its Biological Technical Advisory Committee can use this information for several purposes: first, to better understand the causes of the significant decline of biological resources in the Estuary since the 1970s, second, to determine if implementing measures to address introduced species issues can help in achieving the goal of protecting and restoring the Estuary; and, third, to help understand the degree to which introduced species may limit benefits of management measures directed towards other problems. This paper should not be considered an exhaustive treatment of issues related to species' introductions such as measures to avoid new introductions, control of introduced species, and the documented adverse effects on native flora and fauna. Conditions are ever changing and new organisms are being found as surveys and field work is conducted in the Estuary. We have undoubtedly missed some organisms and could only briefly describe the status of most of those species that are included in this paper. However, we did utilize the most current data available to meet the objectives of this paper.

Efforts to protect the winter-run Chinook salmon, delta smelt, and other depleted fishery resources have resulted in modifications to the operations of the State Water Project (SWP) and Central Valley Project (CVP). Those modifications have affected the ability of the Department of Water Resources and U.S. Bureau of Reclamation to manage water supplies for direct human use. Concerns have been expressed that constraints on water management were imposed without fully considering how other factors acting in the Estuary may have limited or precluded the recovery of species, as well as the restoration and protection of the Estuary ecosystem. Other factors that have been suggested include non-native species introductions, toxics, and harvest by humans. This paper is the first of three reports focusing on those areas of concern.

This paper complements information already provided to the Council on introduced species in the briefing paper titled "Factors Controlling the Abundance of Aquatic

Resources", dated September 1993. In that briefing paper, the effects of introduced species was generally thought to be a relatively minor factor affecting the Estuary's fishery resources, when compared to the influence of water flows into the Delta, Delta outflows, and water exports. Others strongly disagree with that conclusion and feel introduced species are a major factor that needs to be understood and addressed during the Council's efforts to "fix" the Delta.

The nature of the issue is illustrated by the fact that the sport catch of introduced species in the Estuary far exceeds the catch of native species. To further illustrate the point, 43 percent of the fish caught during extensive sampling in Suisun Marsh were introduced, with striped bass being more than twice as numerous as any other species (Moyle et al. 1986). Also in 1991, seven of the ten most abundant species salvaged at the SWP fish screens were introduced. These facts indicate the degree to which introduced species dominate, particularly in the freshwater portions of the Estuary, and the economic value derived from the introduced species.

To simplify issues somewhat, two schools of thought can be described concerning the issue of the effects of introduced species on the native flora and fauna. The first is that species such as the striped bass and largemouth bass were introduced into the system and have existed side by side with native species since that time in the Estuary. Although some, and perhaps extensive, alteration of the native fishery resources undoubtedly occurred, the benefits derived from these introduced species were considered sufficient at the time to justify their introduction. In those cases, the non-native species are now considered part of the Estuary's biological system. Maintaining this increased biological diversity, defined as "the full range of variety and variability within and among living organisms and the ecological complexes in which they occur, including; ecosystem or community diversity, species diversity, and genetic diversity" (Jensen 1991), is an important aspect of sustaining the Estuary's biological resources. (While introduced species have increased diversity in the Estuary, the long-term effect of introductions is expected to be reduced diversity globally.)

The second school of thought is that from the very first time that a non-native species was introduced into the system the biotic uniqueness and structure of the Estuary as a whole was altered. This alteration of the Estuary was such that the non-native species was usually the winner and the native species the loser. Advocates of this position also tend to feel that increases and recovery of introduced species populations, such as striped bass, are in conflict with achieving recovery of native species.

Everyone recognizes that most introduced species can not be eliminated from the Estuary. Furthermore, most resource managers agree than additional introductions are generally undesirable. Hence management focuses on preventing additional incidental introductions and managing the existing mix of species.

This paper will also indicate that knowledge of the effects of introduced species is far from definitive. Hence continuing analysis of existing data and additional studies are warranted.

DISCUSSION

DISCUSSION

Introduced species can affect native fish, wildlife, and plants through a wide variety of mechanisms. They include: competition for space, competition for existing food resources, predation, disturbance, hybridization and acting as pathways for and sources of disease. Introduced species can physically alter the environment. Non-native plants can contribute to the incremental loss of habitats and biological diversity by affecting the ecological process of succession, productivity, stability, soil formation and erosion, mineral cycling, and hydrologic balance (Pemberton 1985). Introduced species, in turn, are used by native and non-native species as a food source.

Non-native fish, wildlife, and plants in the Estuary are species introduced intentionally or unintentionally where they have never been before. It is not always clear which species are introduced. This is particularly true for less obvious groups such as the smaller invertebrates. For example, *Eurytemora affinis* occurs on both the Atlantic and Pacific coasts and dominates the zooplankton component of the diet of many young fishes. Did it really evolve on both coasts or was it accidentally introduced before zooplankton surveys were made? Introduced species often, but not always spread rapidly. Sometimes they are not noticed or documented until they become nuisances.

The task of enumerating introductions is much easier than the task of evaluating effects. Typically, interrelationships among species are complex and not easily defined. This is particularly true in the aquatic environment where direct observation of interactions is often not possible. The first step in evaluating effects is assembling information on the distribution, abundance, and life histories of the species of interest with a goal of identifying potential interactions.

Within the Estuary the primary interactions of concern are predation and competition. Hybridization has seldom been a significant concern, with the potential hybridization of delta smelt and wakasagi being a notable exception. While disease transmission is possible, so little is known about diseases for either native or non-native fauna that meaningful speculation of effects is not possible. Generally, the existence of predation is easily identified through food habits studies, but the consequences are much more difficult to define. Competition is more difficult to identify, e.g. two species may overlap in diet and use of space, but not compete if no shortage of food or space exists. Dr. Peter Moyle (pers. comm.) is aware of no rigorous test of competition in the Estuary. In this paper, competition is used in a general sense.

One principal effect of concern is whether predation or competition is significant enough to change the abundance of another species. Such changes are often difficult to detect, because most species fluctuate in abundance for a variety of reasons, measures of abundance are not precise and some effects might not be evident for several years.

In essence, evaluation of the consequences of introductions primarily involves seeking evidence of changes in abundance which are logical consequences of potential interactions, based on such things as similarities in distribution or evidence of predation. Such evaluations could lead to hypotheses about interactions, but would not provide proof of the hypotheses. Furthermore, they can only be only be expected to detect large changes in abundance.

The issue is not whether species introductions in the 1800s caused the decline of native species during recent times (such as delta smelt which became scarcer from 1950 to 1980) than would have otherwise, but whether introduced species contributed significantly to the changes in the Estuary as the result of introductions of non-native species.

AQUATIC SPECIES

The Estuary is home to more than 150 introduced aquatic species of plants and animals. Intentional introductions by government agencies occurred when species such as striped bass *Morone saxatilis*, American shad *Alosa spadissima*, or even carp *Cyprinus carpio*, were introduced to expand the opportunities for angling and commercial fishing and when species such as threadfin shad *Dorosoma petenense*, were released to increase the forage base for predators. Mosquitofish *Gambusia affinis*, were released in an effort to control pest populations. Deliberate unauthorized transplants by individuals have also occurred in California. The only fish in the Estuary attributable to that source is the inland silversides *Menidia beryllina*.

Non-intentional introductions occurred incidental to other activities. Most recent aquatic introductions usually occurred when ballast water from cargo ships was released into the Sacramento-San Joaquin Estuary. Yellowfin gobies *Acanthogobius flavimanus*, chameleon gobies *Tridentigor trigonocephalus*, and many of the invertebrate species currently found in the estuary are examples of ballast water introductions. Many earlier introductions of other invertebrates were incidental to the intentional transplanting of live Virginia oysters to the San Francisco Bay in the 1870s, and Japanese oysters in the early 1900s.

FISH

There are about 28 different non-native fish species, Table 1, that occur in the Estuary. We have selected several to discuss in paragraph form while others are covered in an outline format as presented in Appendix A.

Inland Silverside

Inland silversides were introduced illegally into Clear Lake, California in the 1960s They reached the estuary in the mid-1970s and are now common in the freshwater portions of the Estuary. This species has been recorded as far south as the San Luis Reservoir, and it is believed that they were transported there via the California Aqueduct and Delta Mendota Canal. This species was brought to California to evaluate as a biological control for gnats by the Lake County Mosquito Abatement District.

This species overlaps in distribution with other fish species, such as delta smelt and striped bass, and may compete for food (primarily zooplankton). In some circumstances they are also a predator on larval fish. However, the ability of its larval fish to feed at the surface probably reduces its competition with other species. They are separated spatially to a degree from open water species because they live principally along the shoreline. This and the fact that the increase in silversides did not coincide closely with the decline in other species, led Department of Fish and Game biologists to argue that silversides had little effect on other species. Recently, Dr. William Bennett, U.C. Davis, has hypothesized that the silverside may have decreased delta smelt abundance by concentrating in spawning areas and eating smelt eggs and larvae. This hypothesis was stimulated by his observations of predation by silversides on striped bass larvae in controlled experiments and because silversides may be more abundant than DFG surveys indicate since shoreline areas are not sampled as extensively as midchannel areas. He points out that this could be particularly significant for delta smelt which probably spawn principally in inshore areas.

Bennett's hypothesis has merit but it needs to be examined in light of the recovery of smelt, at least during 1993. Many hypothesize that this recovery is apparently due to high spring river flows and increases in nursery areas.

Striped Bass

Striped bass *Morone saxatilis*, were introduced into the Sacramento-San Joaquin Estuary in the late 1800s and within several years supported a thriving commercial fishery.

This fish is an anadromous fish that resides in the ocean and brackish waters and spawns in the fresher waters of the Estuary and Sacramento River. Striped bass are higher order predators in aquatic systems and are quite voracious in their eating habits. Stevens (1966) found that in the Delta channels, the diet of adult striped bass consisted primarily of fish, however, the proportions of native fish in the diet was nominal. In more saline portions

Table 1. List of Introduced Fish in the Sacramento-San Joaquin Estuary.

Family: Clupeidae ■American shad ■Threadfin shad **Family: Cyprinidae** Goldfish ■Carp Golden shiner Fathead minnow **Family: Ictaluridae** Brown bullhead Black bullhead ■White catfish ■Channel catfish Blue catfish **Family: Cyprinodontidae** Rainwater killifish **Family: Poecillidae** ■Mosquitofish **Family: Atherinidae** ★Inland silverside	**Family: Percichthyidae** ★Striped bass **Family: Centrarchidae** ■Green sunfish Pumpkinseed Warmouth ■Bluegill Redear sunfish Smallmouth bass ★Largemouth bass White crappie Black crappie **Family: Percidae** Big scale logperch Yellow perch **Family: Gobiidae** ■Yellowfin goby ★Chameleon goby

★ Species discussed in paragraph form in this paper.

■ Species covered in outline format in Appendix A of the Estuary, principal foods were their own young, anchovy, shiner perch, herring, and bay shrimp (Thomas 1967). Data gathered in Clifton Court Forebay suggest that the incidence of predation in some localized situations is substantially higher.

Striped bass were once stocked by the Department of Fish and Game starting in 1982, largely as mitigation for various projects, in an effort to maintain the population occurring in the Sacramento-San Joaquin Estuary. The Department stopped stocking in 1992, due to concerns that the stocking of striped bass was adding predators to the system which might eat the winter-run chinook salmon. It is unknown at this time if elimination of stocking will be of benefit to the populations of native fish species that are potential prey for the striped bass.

Striped bass support the single most important sportfishery in the Estuary, and their population is only about a quarter of what it was around 1960. Thus striped bass are at issue both because their introduction may have influenced the abundance of other species, and because more recent introductions may have a role in the recent decline of striped bass.

As for their effect on other species, the greatest concerns since their establishment have been for effects on salmon abundance. Young salmon sometimes constitute a substantial part of the diet of bass in the Sacramento River upstream from the Estuary but few salmon are eaten by bass in the Estuary. Salmon stocking sites and Clifton Court Forebay are localized exceptions. Since the abundance of salmon probably does not trigger intra-specific competition or other factors influencing their mortality in the Estuary or ocean, predation by bass must decrease adult salmon abundance, but the magnitude can not be quantified with existing information.

On the other hand, salmon and bass populations coexisted in much greater abundance than the populations existing today. Further, the available historical information on population trends does not suggest that high periods in bass abundance coincided with lower populations of salmon (Chadwick and von Geldern 1964), as would be expected if bass were a major factor limiting salmon abundance.

Start here

As for the potential effect of bass on delta smelt, bass rarely ate delta smelt when the smelt and bass were both more abundant. For example, Thomas (1967) found delta smelt in less than 1% of bass stomachs in most locations and seasons. This suggests a minimal risk that striped bass predation is sufficient to depress delta smelt abundance.

The most powerful evidence of effects of striped bass on salmon and delta smelt comes from population trends during the last 30 to 40 years. During that time, striped bass abundance has fallen to one fifth to one third of their abundance at the start of the period. If bass abundance had been the dominant or even a major factor controlling the abundance of salmon and delta smelt, salmon and smelt populations should have increased. Instead smelt and many salmon stocks have decreased during this period, so bass have clearly not been the principal controlling factor. On the other hand, it is reasonable to believe that a top of the food chain predator like striped bass, which became a dominant fish in the estuarine ecosystem following its introduction, must have decreased the abundance of some native fishes. The available evidence is not sufficient to identify those declines.

Turning to the question of whether non-native introductions have played a role in the recent decline in bass abundance, the abundance of potential competitors and predators among fish populations did not increase coincident with the bass decline (IESP 1987). In fact, most fish populations had declining trends generally coinciding with the bass decline. This included threadfin shad which have been shown to depress largemouth bass populations through competition for food among the young in some California reservoirs (von Geldern and Mitchell 1975).

Introductions may also have affected bass through changes in the food chain. The principal food of the youngest bass in the most productive portion of the bass nursery area was a copepod *Eurytemora affinis*. That species has almost disappeared, due first to competition with an oriental copepod, *Pseudodiaptomus forbesi*, and later competition and predation by an introduced clam, *Potamocorbula amurensis*, as discussed in more detail later in this paper.

While some degree of food limitation probably exists for striped bass, no direct evidence of starvation has been found, and bass have changed their diet, including eating recently introduced species of copepods and amphipods. In that regard, it is interesting to note that Larkin (1979), an internationally recognized expert on predator-prey relationships in fish, stated, "To be sure the growth and survival of the predator may not be precisely the same with a different prey, but in general these will be minor considerations. The moral is not to expect big changes for a predator that loses a species of prey."

These facts have led Department of Fish and Game biologists to conclude that introduced species have probably not been a major cause of recent declines in striped bass abundance.

Largemouth Bass

Largemouth bass *Micropterus salmoides*, were first introduced into California waters in the late 1800s and have since spread throughout suitable warm-waters habitats. This species is a popular game fish in warm-water habitats of California. In the past year, in the Sacramento-San Joaquin Delta over 45 largemouth bass tournaments were scheduled to be held. The largemouth bass is a top predator in the Estuary and where introduced it has a tendency to out compete and displace native fauna. The largemouth bass is one of several members of the sunfish family which collectively have probably out competed the Sacramento perch for habitat. It also has been implicated in the decline of the red- and yellow-legged frogs in areas where they coexist (John Brode, pers. comm.). Largemouth bass probably contributed to historical declines in various native fishes in the Delta, but specific evidence is lacking.

Chameleon Goby

Despite being unintentionally introduced into the Estuary sometime in the 1950s, probably in ship ballast water, the chameleon goby, a euryhaline native to Asia, was limited to San Francisco Bay until recently. Their abundance rapidly increased in the late 1980s. By 1989, they had become the third most abundant species identified in DWR's southern Delta egg and larval sampling, and in 1990 it was the most abundant fish. Chameleon goby was the only species more abundant than 6 mm striped bass in 1991 (Miller and Arnold 1994).

The recent extension of the chameleon goby into the upper portion of the Estuary coincides with the prolonged drought that began in 1987. However, this is not the first drought since its introduction, so it is not clear why the population only recently exploded in this portion of the Estuary (Miller and Arnold 1994). Since it has become abundant only after 1987, it should not have been a significant cause of declines of striped bass, delta smelt and other species which occurred prior to 1987.

Despite the recent increase in goby abundance, it is relevant that the chameleon goby generally spawns after striped bass have spawned (Miller and Arnold 1994). Thus, it appears that goby larvae have minimum effect on early survival of striped bass. However, the potential for chameleon goby competition increases for later stages of striped bass.

More information is needed on chameleon goby size, diet, and effects on food density to assess whether significant competition is likely.

AMPHIBIANS

Bullfrog

The bullfrog *Rana catesbeiana*, has been successfully introduced and has formed a reproducing population throughout California. This species is the largest of the frog family found in California. The bullfrog is a game species in California with harvesting being limited to part of the year and a daily take limit. Bullfrogs have been noted to prey upon native species such as the red-legged and yellow-legged frogs in areas where they coexist. The reintroduction of red-and yellow-legged frogs into areas where bullfrogs exist or where bullfrogs have a direct line of water access is not likely to be successful.

REPTILES

Sliders

Sliders *Pseudemys scripta,* are part of the aquarium trade and it is believed that their populations in California are the result of public releases. Sliders are observed in California usually around man-made impoundments, however, it is not known if these populations are reproducing. The impact of sliders on native organisms is unknown; however they do feed on frogs, aquatic invertebrates, and carrion.

No management practice has been established for the slider. The release of aquarium trade turtles can introduce pathogens and parasites into southwestern pond turtle populations and result in competition for resources.

Soft Shell Turtle

Spiny softshell turtle *Trionyx spiniferus*, breeding populations exist in southeastern California with reports of softshell turtles occurring in the Sacramento-San Joaquin Delta. The impact of softshell turtles on native organisms is unknown; however they do feed on frogs, aquatic invertebrates, and carrion. This turtle is a part of the aquarium trade and is captured in the wild and eaten by humans. The release of aquarium trade turtles can introduce pathogens and parasites into southwestern pond turtle populations and result in competition for resources.

INVERTEBRATES

The changes in invertebrate populations have been more dramatic than those for fish in the last 30 or 40 years. Several new species of zooplankton have dramatically changed the species composition in the brackish and freshwater portions of the Estuary. Table 2 lists introduced invertebrates that are normally found in the brackish and freshwater portions of the Estuary.

Table 2. List of Introduced Fresh/Brackish-water Invertebrates in the Sacramento-San Joaquin Estuary (*Denotes species that will be discussed).

Acantholysis aspera
Sinocalanus doerrii
Limnoithona sinensis
Oithona davisae
Pseudodiaptomus forbesi
Pseudodiaptomus marina
Palaemon macrodactylus
**Potamocorbula amurensis*
Gammarus daiberi
Corbicula fluminea
Manayunkia speciesa
Limnodrilus hoffmeisteri
**Procambarus clarkii*

Asian clam

The Asian clam *Potamocorbula amurensis*, was introduced into San Francisco Bay in 1986 presumably through the discharge of ship ballast. During the last drought period (1987-1992), this species spread throughout the saltier portions of the Estuary and into Suisun Bay and was recorded at densities of over 20,000 organism per square meter. This species has a high plankton filtration rate and has been implicated in the reduction in phytoplankton biomass and production rate in Suisun Bay. This reduction in phytoplankton would affect the quality of the entrapment zone and its ability to sustain larval fish and other native invertebrate populations. In the laboratory, they also feed on zooplankton so concerns exist as to their effect on zooplankton populations.

Introduction of the Asian clam *Potamocorbula amurensis*, provided an opportunity to observe a number of biological interactions such as the correlations of dense concentrations of the clam in shallow areas with reduced phytoplankton concentrations in the overlying water column (Kimmerer 1993). Abundances of *Neomysis mercedis* and the copepods *Acartia* spp., *Eurytemora affinis,* and *Sinocalanus doerrii* all declined precipitously in 1987. Kimmerer (1993) believed that the declines in zooplankton probably occurred through a combination of competition for food and, for the copepods, direct predation on the nauplii. He believed it is unclear whether *Acartia* declined because of predation, food limitation, or both, although the clams can consume the nauplii of *Acartia* as they can those of *Eurytemora*. In contrast, the harpacticoid copepod *Eutepina acutifrons,* which is susceptible to clam predation, appeared to be very abundant, compared to previous years (Kimmerer 1993). In addition, other benthic species are depleted in areas where *P. amurensis* is abundant, probably through consumption of their larvae.

Biological effects from the introduction of the Asian clam have been detected by long-term monitoring programs (Kimmerer 1993). The clam not only occupied bottom space at the expense of other benthic species, as measured by reductions in their average densities, but also altered the benthic community's species structure. The increased density of the clam in Suisun Bay has been correlated to declines in concentrations of phytoplankton, which has had repercussions throughout the food chain. Kimmerer (1993) found that there is anecdotal information to suggest that the clam has become a popular prey item for demersal fish, such as sturgeon and rays. The Asian clam probably provides one pathway by which selenium enters white sturgeon (Urquhart and Regalado 1991). The degree to which entrapment zone conditions have enhanced or diminished the clam's biological effect cannot be discerned from the available sampling sites located in and out of the entrapment zone (Kimmerer 1993).

The ecological significance of changes in invertebrate populations during the 1980s is uncertain. The most widely accepted evidence of a major consequence is the virtual disappearance during the summer and fall of the dominant native copepod, *Eurytemora affinis*, near the upper end of the salinity gradient. An oriental copepod, *Pseudodiaptomus forbesi,* largely replaced *Eurytemora* in the late 1980s. *Eurytemora* populations declined further during 1988 apparently in response to predation by the more recently introduced

Asian clam.

The observations related to *Eurytemora* illustrate both the approach biologists use in making judgements about the consequences of species introductions and the uncertainties about the ultimate ecological effects. *Eurytemora* populations fell after the Asian clam became abundant in Suisun Bay. Laboratory evidence indicated Asian clams can eat *Eurytemora*. Those observations support the hypothesis for the cause in *Eurytemora*'s decline, but the consequences for fish are uncertain.

Eurytemora had been the principal initial food for striped bass larvae near the upper end of the salinity gradient. Much work has been done to try to determine whether food supply limits striped bass production. Most biologists interpret available evidence as indicating that some degree of food limitation exists, probably through slowing growth, thus increasing mortality rates. No direct evidence, however, of starvation of bass has been found. Also, bass have changed their diet, with another newly introduced amphipod, *Gammarus daiberi*, becoming a major food item for young striped bass. Thus, while the composition of the available food supply has changed, no general relationships have been found between food supply and bass mortality. Nevertheless, the changes in food supply might inhibit the recovery of some fish species.

The Asian clam may have caused a profound change in the ecosystem of the Estuary by diverting a portion of biomass from the planktonic portion of the food webb to the benthic portion, where it is likely less available to fish. The effects may have been masked by the 1987-92 drought. Since production is typically low in droughts, it is difficult to tell whether the drought, Asian clams, or both caused the low production. The significance of that remains to be evaluated during the recovery from this drought.

Crayfish

The crayfish, *Procambarus clarkii*, was introduced into California in 1925 from the Midwest. A native species of crayfish, *Pacifastacus leniusculus*, is fished commercially and recreationally in the Estuary for consumption as well as for scientific use. The best available evidence indicates that the introduced crayfish has not established a population in the Estuary (Moyle, pers. comm.).

Marine Invertebrates

The marine component of the Sacramento-San Joaquin Estuary has been invaded by over 100 different species of aquatic invertebrates. The introduction of these organisms started over 120 years ago when ships carrying passengers and cargo came into San Francisco Bay. These ships and many more to come carried with them many invertebrates that live in similar environments from other parts of the country and from other countries around the world. This list of invertebrates is ever changing with new introductions being identified yearly. Table 3 lists the invertebrates identified in the Sacramento-San Joaquin Estuary prior to 1973 and Table 4 lists invertebrates discovered since 1973. Some overlap exists with species that principally occur in the brackish portions of the Estuary. One such introduction that has caused severe economic damage is the shipworm *Teredo navalis*. This mollusk bores into wood and destroys the integrity of the structure it inhabited and within a few years of its introduction to San Francisco Bay it caused the collapse of piers and wharfs. To combat this organism structures were and still are coated with toxic substances that repel the organism and also causes other local organisms to perish.

Table 3. List of Introduced/Non-native Invertebrate Species Identified in the Sacramento-San Joaquin Estuary Prior to 1973 (Carlton 1979).

Porifera
- *Haliclona sp.*
- *Microciona prolifera*
- *Halichondria bowerbanki*
- *Prosuberites sp.*
- *Tetilla sp.*

Coelenterata

Hydrozoa
- *Garveia franciscana*
- *Clava leptostyla*
- *Cordylophora lacustris*
- *Turritopsis nutricula*
- *Syncoryne mirabilis*
- *Corymorpha sp.*
- *Tubularia crocea*
- *Obelia spp.*

Anthozoa
- *Diadumene franciscana*
- *Diadumene leucolena*
- *Diadumene sp.*
- *Haliplanella luciae*

Platyhelminthes

Turbellaria
- *Childia groenlandica*

Trematoda
- *Austrobilharzia variglandis*
- *Parvatrema borealis*

Annelida: POLYCHEATA
- *Neanthes succinea*
- *Marphysa sanguinea*
- *Boccardia ligerica*
- *Polydora ligni*
- *Polydora spp.*
- *Psuedopolydora kempi*
- *Psuedopolydora pauchibranchiata*
- *Streblospio benedicti*
- *Capitella capitata*
- *Heteromastus filiformis*
- *Asychis elongata*
- ? *Sabellaria spinulosa*
- *Mercierella enigmatica*

Mollusca

Gastropoda
- *Littorina littorea*
- *Crepidula conexa*
- *Crepidula plana*
- *Urosalpinx cinerea*
- *Busycotypus canaliculatus*
- *Ilyanassa obsoleta*
- *Ovatella myosotis*
- *Tenellia pallida*
- *Eubranchus misakiensis*
- *Okenia plana*
- *Trinchesia sp.*
- *Odostomia bisuturalis*

Bivalva
- *Musculus senhousia*
- *Ischadium demissum*
- *Gemma gemma*
- *Tapes japonica*
- *Petricola pholadiformis*
- *Mya arenaria*
- *Teredo navalis*
- *Lyrodus pedicellatus*

Arthropoda: CRUSTACEA

Ostracoda
- *Sarsiella zostericola*

Copepoda
- *Mytilicola orentalis*

Cirripedia
- *Balanus improvisus*
- *Balanus anphitrite amphitrite*

Amphipoda
- *Ampithoe valida*
- *Ampelisca abdita*
- *Chelura terebrans*
- *Corophium acherusicum*
- *Corophium insidiosum*
- *Corophium uenoi*
- *Corophium sp.*
- *Grandidierella japonica*
- *Melita nitida*
- *Jassa falcata*
- *Podocerus brasiliensis*
- *Parapleustes sp.*

Amphipoda-continued
- *Stenothoe valida*
- *Orchestia chiliensis*
- *Caperella acanthogaster*
- *Caperella spp.*

Arthropoda: Crustacea

Isopoda
- *Synidotea laticauda*
- *Limnoria quadripunctata*
- *Limnoria tripunctata*
- *Dynoides dentisinus*
- *Sphaeroma quoyanum*
- *Iais californica*
- *Ianiropsis serricaudis*

Chelifera
- *Tanais sp.*

Decapoda
- *Palaemon macrodactylus*
- *Rhithropanopeus harrissii*

Arthropoda: INSECTA

Dermaptera
- *Anisolabis maritima*

Entroprocta
- *Barentsia benedeni*

Ectoprotca
- *Alcyonidium sp.*
- *Victorella pavida*
- *Bugula spp.*
- *Conopeum spp.*
- *Schizoporella unicornis*

Chordata: TUNICATA
- *Ciona intestinalis*
- *Molgula manhattensis*
- *Styela clava*

Table 4. List of Introduced/Non-native Invertebrate Species Identified in the Sacramento-San Joaquin Estuary Since 1973 (Carlton et. al. Marine Ecology Progress Series).

Coelenterata	Crustacea-continued
Hydrozoa	Copepoda
Cladonema uchidai	*Oithona davisae*
	Sinocalanus doerrii
Crustacea	*Limnocalanus sinensis*
Amphipoda	*Pseudodiaptomus marinus*
Corophium alienense	*Pseudodiaptomus forbesi*
Caprella mutica	
	Mollusca
Isopoda	Bivalva
Dynoides dentisinus	*Potamocorbula amurensis*
Ianiropsis serricaudis	*Theora fragilis*
Cirolana arcuata	
Carcinus maenas	Chlorophyta
	Codium fragile tomentosoides
Cumacea	
Hemileucon hinumensis	

WILDLIFE

Several non-native wildlife species reside adjacent to the Estuary. A number of these species may be viewed as desirable; providing hunting and other recreational opportunities. Other non-native wildlife species which were introduced have expanded their numbers into the Estuary and have increased predation upon the native wildlife populations. Several other important introduced wildlife species are discussed in Appendix B.

Ring-necked pheasant

The ring-necked pheasant, *Phasianus colchicus*, is the largest upland bird found in the Estuary and is extremely popular with hunters. The ring-necked pheasant is a non-native species imported from Asia. This species thrives on some agricultural lands. Within the Estuary, the pheasant is most abundant in the Delta.

Red Fox

The non-native red fox, *Vulpes vulpes*, was brought to California for hunting and fur farming during the late 1800s and early 1900s. The only region where native red foxes, *Vulpes vulpes nector*, exist in California is in the higher elevations of the Sierra Nevada and Cascade Range. The other populations of red foxes in California are from the imported stock (DFG 1992). The earliest known population of non-native red fox formed in the southern Sacramento Valley in the 1870s and by the 1970s the non-native red fox was well established in northern California and Sacramento Valley and was expanding into the central part of the state. Non-native red foxes are now widespread in lowlands in the Central Valley and the coastal counties south of Sonoma County.

Predation is a natural component to a healthy ecosystem. Introduced predators, however, can disrupt natural predator-prey relationships. The non-native red fox is one of the most widespread and abundant predatory land mammal species in the world. Many native wildlife species having evolved in natural ecosystems without the red fox have little defense against this active predator. The problem is particularly serious in isolated, remnant, or degraded natural areas, or in wildlife habitats near urban areas, where native animals are especially vulnerable to disturbances and predation. Thus, the non-native red fox can become a dominant species in ecosystems already placed under heavy stress by human-caused impacts on habitats (DFG 1991).

In 1990, this introduced species preyed on eggs of Caspian terns and California least terns in the Bay area, causing complete nesting failure of entire colonies. Similarly the red fox is also implicated in contributing to the reported population crash of California clapper rail in this area. In the 1980s the population of the California clapper rail was estimated to be 1,500 rails. By 1991 the population was less than 500. Along the bay, red fox prey upon the eggs of black necked stilts, American avocets, and snowy plovers.

The increase in the range and population of the red fox is due to the species ability to adapt to urbanization and the subsequent elimination of larger predators such as the coyote, which would normally help in controlling the numbers of red foxes.

Presently, there is no State or federal governmental agency in California which has proposed or adopted a policy to eradicate the red fox. The non-native red fox has become so abundant and widespread that any effort to eliminate or even significantly reduce the statewide population would be impractical with currently available methods and resources. The cost likely would be prohibitive (DFG 1992). Efforts to control the non-native red fox have been conducted in some local areas such as wildlife refuges. Foxes are killed to protect endangered species or other wildlife where nonlethal methods have not worked or are not feasible. Property owners may request Animal Damage Control (ADC), a U.S. Department of Agriculture agency, to trap any foxes which are causing damage. ADC has authority to trap red foxes and the expertise to conduct red fox control measures. Presently, this is done in 38 counties which contract with ADC for predator control. For example, ADC was called upon to trap red foxes at San Jose International Airport, because the foxes which were being struck by aircraft on run ways, had become a hazard (DFG 1992). State and federal wildlife agencies may control foxes on public lands for protection of wildlife or may contract with ADC.

Norway Rat

The Norway rat, *Rattus norvegicus*, was unintentionally introduced, and was established in many areas by the mid-1800s. Generally the Norway rat is in close proximity to urban areas in the Estuary, however, the increase in urban development, numerous landfills and rip-rap areas have created large populations of these rats along the bay shores. Norway rats are predators to waterfowl and nesting California clapper rails; reportedly taking about 33 percent of the eggs laid by clapper rails in South Bay (Harvey 1988, Foerster et. al. 1990). Once rats become established on colonial bird nesting islands, the reproductive success of the colony may be greatly affected by these opportunistic predators (SFEP 1992). Because it is easier to distribute rat poison, many urban programs emphasized this approach rather than dealing with the issues contributing to their increasing populations. The availability of anticoagulant rodenticide and their general effectiveness and safety, makes it difficult to get political support for an environmental approach and to enforce it. Use of biological control in the sense of environmental management is the fundamental recommendation. Removal of garbage and rubbish and proper construction of residences and food storage structures prevent rats from establishing themselves, and increase the effectiveness of existing predators. In field crops such as corn, the stubble can be broken down to expose the rodents to the local raptors during winter (Chapman and Feldhamer 1982).

Virginia Opossum

The opossum, *Didelphis virginianus*, was first established in California from introductions in the San Jose area in 1910, and became well established within the Central Valley by the 1940s. Five released animals, plus five others which escaped from a fur farm, formed the initial breeding population which has expanded into every county in the Estuary. The opossums may eat: plants, insects, carrion, and bird eggs. Their impact on native wildlife is unknown, however it is likely that ground nesting birds have suffered as a result of the expanding opossum population (SFEP 1992). The opossum has been identified has a primary predator in causing duck nest loss in Suisun Marsh (McLandress et al. 1988).

Feral Cat

Unwanted and abandoned feral cats, *Felis catus*, are a major predator to bird and mammal populations in the wetland areas of the Estuary. To better protect and manage the wildlife population in the Estuary the feral cat population should be actively controlled. However, proposals to kill feral cats have met with public opposition. In response to providing an alternative to eradication of feral cats, some animal welfare groups have captured the feral or stray cats, spayed and/or neutered the animals, and set up colonies of cats. The areas of choice for colonization often is away from urbanized areas; however, in the Estuary many of the colonies are adjacent to wetlands. These feral cat colonies may range up to 20 to 30 cats. Cat colonies are generally not favorable for wildlife particularly in wetland areas. For example, in Bodega Bay a promoted feral cat colony was set up in close proximity to an area known to be inhabited by black rails, *Laterallus jamaicensis coturniculus*.

AQUATIC PLANTS

The impact of introduced aquatic plants is not well understood. Of particular concern is waterhyacinth, *Eichhornia crassipes* which was first introduced in California in 1904 from South America and has since become established and spread throughout the Sacramento-San Joaquin Delta (R. O'Connell, pers. comm.). Casual observation indicates it did not become abundant in the Delta until after the 1976-77 drought.

Waterhyacinth creates dense mats of surface vegetation that alter the aquatic environment as it becomes covered. Blocking light can cause rooted submergent plants to die and shade out phytoplankton. It changes the escape cover for fish and other organisms, but the relative value of escape cover provided by submerged aquatic weeds in contrast to cover provided by the submerged portion of hyacinths is unknown. The California Department of Boating and Waterways is actively spraying and removing waterhyacinth from Delta waterways. Approximately $400,000 is spent on control efforts each year in the Delta. The focus of this effort has been primarily to clear concentrations of this plant from around marinas and boat launch ramps to minimize the impacts on these businesses and on boating recreation activities. The effects of waterhyacinth on fish and wildlife are uncertain. It certainly changes the habitat dramatically where dense mats occur and diverts energy from the planktonic food web. Since dense mats cover only a small fraction of the Delta, its overall effect has probably been small.

Other aquatic plants that are of concern include dense-leaved elodea, *Egeria densa,* and Parrotfeather, *Myriophyllum aquaticum*. These are both discussed in Appendix C.

A plant which has not yet been found in the Delta, but has been found in nearby counties is hydrilla, *Hydrilla verticillata*. Hydrilla has been under a detection and eradication program since 1977 in California (L. Anderson, pers. comm.).

Several researchers in the field of evaluating control measures for problematic introduced aquatic plants feel that the impacts of those introduced plants is well understood. There is extensive evidence of aquatic weeds blocking flood control channels, increasing mosquito habitat, increasing siltation (accumulation of sediments), changing water temperature and dissolved oxygen, and decreased property values for properties adjacent to affected channels. Aquatic plant problems are widespread in other states as well. For example, Minnesota has recently experienced a rapid invasion of Parrotfeather, and hydrilla has created massive problems in Texas, Florida, Louisiana, Tenessee and North Carolina (Anderson 1990).

TERRESTRIAL PLANTS

There is a long history of concern about the non-native plant species in wetland areas, both from the standpoint of the intrinsic value of the plants and potential effects on wildlife. Underlying this concern is a value judgement, or ecological ethic, that native species should dominate natural wetlands and recently introduced species should be eliminated. Reasons for this desire are: 1) California's coastal wetlands are small and few (there are about 130 in the entire state). 2) The remaining wetlands have been highly modified and severely reduced in area (losses of 75 - 95% are commonly estimated). 3) The native plants are essential to many native animals (e.g. insects with high host specificity) and preferred by others. The native vegetation performs a variety of functions such as providing food, shelter, and nesting materials, that may or may not be replaced by non-native species. 4) Non-native species can spread rapidly and displace native plants, but the conditions that promote invasion cannot always be predicted. 5) Once established, naturalized non-native are difficult, if not impossible, to eradicate (Zedler 1992).

Concerns associated with non-native terrestrial plants are principally focused on the invasive introduced species rather than non-aggressive non-native species. The emphasis of this portion of the paper is, therefore, on the invasive non-natives. Furthermore, the botanical community generally agrees that the term "native plants" refers to those plants indigenous to California prior to the advent of European influence in the 1700s or which have adapted since that time and are not related to human activity. ?

Habitat structure is the most important attribute of the wetland plant community, whether on the scale of microhabitats provided to small insects or the protection and cover afforded for egrets, herons, and rails (Josselyn et. al 1984). The salt marsh harvest mouse, a native endangered wildlife species, is entirely dependent upon the continuous dense cover, such as that provided by pickleweed, *Salicornia sp.*, and fat hen, *Atriplex patula*. The harvest mouse will not cross large open unvegetated areas (Shellhammer and Harvey 1982). Bird dependence upon marsh vegetation varies with species. The salt marsh song sparrow has specific vegetation requirements and other species such as shorebirds forage on the bare areas of the salt marshes during low tides. The establishment of suitable and productive marsh vegetation is a primary goal of restoration. If these areas are properly planned, the vegetated habitat created or maintained will attract and support a diverse animal population.

Other aggressive introduced plants include Himalaya berry, *Rubus discolor*, Spanish broom, *Spartium junceum*, Medusa head, *Taeniatherum caput-medusa*, (*Elymus caput-medusa*), tamarisk, *Tamarix parviflora*, pampas grass, *Cortaderia jubata*, yellow star thistle, *Centaurea solstitialis*,and artichoke thistle, *Cynara cardunculus*. Several of these are discussed in Appendix C.

The following discussion profiles several non-native terrestrial plant species. Many of these non-native plant species were identified by area plant biologists and ecologists as plants which may adversely affect the Estuary's wetlands and adjacent upland areas. The extent or cumulative effect of these species on the native vegetation in the Estuary is not fully understood and more information is needed to better understand the complex, usually indirect, interactions of plants in natural environments; both for scientific understanding and better vegetation management.

Eastern Cord Grass

The eastern cordgrass, *Spartina alterniflora*, is native to the east coast. This non-native plant species was first introduced through a salt marsh restoration project in the Bay Area to mitigate for the loss of wetlands destroyed by a flood-control project near Hayward. Following its introduction, the eastern cordgrass has spread to five additional sites on both sides of the bay. One of these sites was also the result of a restoration project transplant.

The eastern cordgrass has the ability to establish itself in the higher and lower areas in the tidal zones more successfully than the native cordgrass. This prolific non-native species out competes the native cordgrass and can turn mudflat areas into cordgrass islands.

Although eastern cordgrass can provide additional habitat for such species as the endangered clapper rail, it diminishes mudflat communities. These mudflat communities include snails, worms, crabs, and other crustacean which provide an important food source for shorebirds, wading birds, and gulls at low tide, and for diving and dabbling ducks and bottom feeding fish during high tide.

To improve management designed to enhance the Bay-Delta ecosystem, the San Francisco Estuary Project funded a study of how eastern cordgrass is affecting the Bay Area. This study compared the wetland functions of the eastern cordgrass and those of the native Pacific coast cordgrass, *Spartina foliosa*. Two types of Bay Area locations were studied; a sandy spot in Alameda and a mudflat near San Francisco airport. The wetland functions examined were; sedimentation rates, shoreline erosion control, abundance of bottom-dwelling organisms, plant debris and use by shorebirds. In the study areas, the introduced cordgrass was found to spread two to three times faster, grew more densely and colonized the mudflat zones at lower tidal levels more successfully than the native Pacific coast species. The dense stem of the eastern cordgrass also trapped more sediment, in turn, reducing erosion and more effectively controlled the loss of high marsh to wave action. This study also suggested that biological differences were less pronounced. No strong differences were indicated in the number of bottom dwelling organisms or visiting shorebirds. However, when the two species were grown side by side, the eastern cordgrass spread into and eventually replaces the Pacific coast species. This may suggest a cumulative effect of the invasion of the introduced eastern cordgrass altering the makeup of the intertidal environment by the colonization of the mudflat which would ultimately reduce the foraging area for shorebirds.

The primary management concern about the ever-expanding distribution of the eastern cordgrass is the loss of mudflat habitat for shorebird feeding. Dense vegetation changes the character of the substrate and reduces habitat for the birds' preferred invertebrate prey. There is no lower-marsh species like the clapper rail that can take advantage of the grass (Zedler 1992). Presently, there is no active management to control or eliminate this non-native species. A herbicide such as Rodeo might be an effective control, however, this possibility should be evaluated carefully and measures taken to protect native wetland species.

Pepper Grass

Broadleaf pepper grass, *Lepidium latifolium*, is a perennial herb, native to Eurasia. Presently this introduced plant species is widespread in North America. The pepper grass may be found in several counties in the Estuary: San Joaquin, Solano, Yolo and Santa Clara counties. Pepper grass may be located in waste places, roadsides and in fields. This introduced plant species is a problem in the natural areas of Yolo and Solano counties, displacing native vegetation. Native plant species such as Delta tule pea, *Lathyrus jepsonii var. jepsonii*, (Federal Category 2 and a California Native Plant Society (CNPS) listing status as a rare and endangered vascular plant of California) and the soft bird's beak, *Cordylanthus mollis mollis,* (Federal Category 2, State and CNPS listing status as a rare) are threatened by this extremely invasive plant species which displaces and out competes these listed native plant species (J. Horenstein pers. comm.).

The California Department of Food and Agriculture evaluates weedy or noxious plant species and assigns an "agricultural pest rating" of "A", "B", "C", or "Q". Plants rated "A", present an economic threat to agriculture and occur in very localized areas of the state; "B" rated plants also present an economic threat to agriculture but are more widely distributed in the state; "C" rated plants have adverse economic effects on agriculture, but are widely and generally distributed in the state. These are the common agricultural weeds that are figured into the cost of agricultural production; and the "Q" rated plants are potentially serious agricultural weeds that are not yet established within the state.. This rating is assigned to plants or seeds of species intercepted by quarantine inspectors (Barbe 1991). The pepper grass is a "B" rated plant, the rating allows the agricultural commissioner to eradicate or contain the weed in the county as they see fit but this also involves allocating limited county resources. Management of the pepper grass through quarantine measures is advised, however limited funding makes this difficult (D. Barbe, pers. comm.) The pepper grass is widely spread and difficult to quarantine. Herbicide spraying is used to control pepper grass; however, to better manage this species the manner of plant dispersal should be further investigated.

Eucalyptus

Several species of eucalyptus, *Eucalyptus sp.*, such as red iron bark eucalyptus and dwarf blue gum were introduced from Australia as ornamental trees for landscaping and fire wood. Eucalyptus is the dominate tree species in the Suisun Marsh. In certain situations, the eucalyptus may have crowded out native grasses and forbs by shading out these species, by the destruction of the understory caused by the debris and oils released by the trees, and competition for soil and water. Adverse effects of eculyptus trees are due to 1) the allelopathy and resulting exclusion of other plant species, 2) the high water uptake of eucalyptus trees, 3) the invasive and aggressive growth behavior of this plant and, 4) the diminished habitat value to native wildlife species. Eucalyptus, nevertheless, have been protected in the Suisun Marsh and retaining them in the Estuary has strong public support in spite of their effects on native plants.

SUMMARY AND FINDINGS

The introduction of non-native species in the Estuary has occurred in one of two ways: intentional and non-intentional. Intentional introductions were usually conducted by management agencies to provide additional opportunities for anglers or in an effort to control a pest species. The introduction of fish species such as striped bass and American shad helped shape the early economic history of the state by supporting a commercial fishery within a few years of their introduction. Non-intentional introductions occurred incidental to other activities (e.g. ballast water discharge).

Within the Estuary, introductions that occurred during the early part of the state's history have formed an interaction with the native biota of the state and have become identified as part of the system. Species, such as, striped bass, American shad, largemouth bass, and pheasant have been around so long that they have become an integral part of the Estuary and have generated considerable economic value. In addition, introduced species, such as striped bass, have been used as indicators of the estuarine system's health. Measures are being developed to achieve a doubling of the striped bass population in the Estuary as part of the comprehensive effort to implement the Central Valley Project Improvement Act.

Introduced fish species have undoubtedly affected the abundance of native species in the Estuary, but the magnitude of such effects is very uncertain. Moyle (1976 b) reached a similar conclusion regarding fish introductions in the whole state. He stated "the only change that seems best attributed completely to competition is the virtual elimination of Sacramento perch from its native habitat."

The best chance of identifying effects of introduced aquatic species has been during the last 25 or so years when monitoring has been much more extensive than in previous periods. That monitoring has led Department of Fish and Game biologists to conclude that only the depletion of the copepod (*Eurytemora affinis*) by introduced copepods and subsequently the Asian clam provides classical evidence of competition and predation by introduced species being the principal cause of decline. While another possible example is inland silversides and delta smelt, further evaluation is necessary, particularly as to what happened during the 1993 rebound in delta smelt abundance.

For other aquatic resources, Department of Fish and Game biologists believe the effects of introduced species in recent years has probably been much less. This is evidenced by a lack of clear-cut coincidence in introductions and changes in abundance, by the failure of native species to increase as striped bass decreased, and by evidence of other factors causing observed changes in abundance. This conclusion should not be interpreted as a contention that the introductions have had no recent effect--only that effect has not been measurable based on the available somewhat imprecise measurements and the ecological complexities in the Estuary.

Representatives of water development interests continue to suggest a more significant effect of introductions (e.g. Reiser et al. 1994).

At least two of the recent introductions, the Asian clam and waterhyacinth, cause structural changes in the food webb. Both tend to divert energy from the planktonic portion of the food webb, which is the principal support for many fish, and tie the energy up in biomass which is probably less available to fish. Those introductions created concerns somewhat different than those generated by competition and predation among species.

While ongoing evaluations need to continue, with modifications as appropriate to provide better evidence, the BDOC process will likely need to be completed largely based on existing information. Recommendations will ultimately have to be made with the recognition that the full extent of how introduced species affect the Estuary is uncertain.

Few opportunities exist to effectively reduce or eliminate introduced species from the Estuary. However, the desire to minimize the likelihood for new species to become established has resulted in elaborate, expensive, and difficult control efforts. Examples include efforts to control white bass and northern pike. While those two efforts were initially successful, long-term success is not assured. Such activities should continue. A more aggressive effort to manage ballast water discharges could also be undertaken.

The effect of introduced plants has been pronounced in the Delta. Aggressive non-native plants have significantly altered the California landscape and the Bay-Delta Estuary is no exception.

The Council and its technical advisors will need to consider how introduced species help define the Estuary's ecosystem and how they may impede recovery of specific native species. The Department of Fish and Game believes restoration of the Estuary should include some non-native species such as striped bass which provide important recreational opportunities for sport anglers and contribute to the economy of the State. The Department of Fish and Game also believes that this can be accomplished without compromising the goals of restoring and protecting the Estuary. Properly considering introduced species in the context of evaluating alternatives to "fix" the Delta will help define a realistic, achievable plan for restoring the Estuary.

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