Conclusions

In general, the DSM2 did well in simulating the travel time of the dye. Areas for greatest improvement are in the modeling of dispersion. DSM2 is currently being recalibrated by the DSM2 Project Work Team with newly collected bathemetry data. Hopefully this calibration with its improved model geometry will provide a better match between model results and observed data.

Non-indigenous Jellyfish in the Upper San Francisco Estuary: Potential Impacts on Zooplankton and Fish

John Rees, CSU Hayward

Introduction

There were almost certainly no native coelenterates in the native planktonic (as well as benthic) fauna of the upper San Francisco Estuary (northern San Pablo Bay and its tributaries and Suisun Bay). Today this area of generally low and variable salinity is host to a number of introduced cnidarians, especially hydroids (Cohen and Carlton 1995). Whereas hydroids have been reported from the upper estuary for many years (Hand 1951), hydroid jellyfish (hydromedusae) were not reported here until 1993, when two species, *Maeotias inexpectata* and *Blackfordia virginica* were collected in the Petaluma River (Mills and Sommer 1995). Since that time, a third hydromedusan introduction into the estuary has been collected, an as yet undesignated species of *Moerisia* (Rees and Gershwin, forthcoming). Preliminary field sampling and discussions with agency personnel and fisherman in the field indicate that all three species are present in the upper estuary. These jellyfish are thought to be present in the plankton from at least May through November, with peak abundances occurring from August though October. Anecdotal evidence suggests an increasing frequency of occurrence coupled with higher population densities within the upper estuary over the past ten years.

There are several reasons why jellyfish introductions into the ecologically sensitive upper estuary are not welcome. While not all alien introductions result in observable negative results to the receiving ecosystem, some do. The mitten crab (*Eriochier sinensis*) is among the most notorious recent local examples. Since they occupy the same ecological niche as fish in the aquatic food web as secondary consumers, jellyfish can be ecological competitors with resident fish species. Jellyfish are also known predators on fish eggs, fry, and juveniles, and can compete directly for zooplankton with juvenile and adult fish (Purcell 1985).

More worrisome are worldwide anecdotal reports of recent increasing jellyfish populations correlated with declines in resident fish populations. While evidence is scant and data difficult to interpret, there have been several recent reports of scyphozoan jellyfish populations increasing in areas where important commercial fisheries are located, such as the Bering Sea (Mills 1995; Mills, personal communication). In the North American Grand Banks, normally benthic hydrozoan polyps as well as hydromedusae have been recorded in high abundances in the plankton, and have been observed feeding directly on larval cod (S. Bollens, personal communication). Jellyfish are apparently filling a niche in some aquatic food webs formerly filled by fish. Whether hydrozoan populations will decrease in response to increasing fish populations is not known.

Preliminary Field Methods

Random plankton sampling was conducted at selected sites in North San Pablo and Suisun bays during 1997 and 1998. Sampling was done by a variety of methods, including routine plankton tows (with a 0.25 m diameter, 0.5 mm mesh net), hand nettings from boats and docks, and agency mid-channel tows. In one sampling excursion on the Napa River on 7 September 1998, mid-water and bottom plankton tows were taken in mid-channel at three locations along a ten-mile transect: (1) in the broad channel below the train trestle, (2) off Cuttings Wharf, and (3) north of the Kennedy Boat Launch just below the city of Napa. Other sampling was routinely conducted from August through November when jellyfish seem to be most abundant. It is known, however, that medusae had to be present in the water column before August and perhaps as early as May, since adults of all three species (the juveniles having been released several months previously) were routinely collected by August. Quantification of this initial sampling was not attempted. Salinity and temperature measurements were taken with a refractometer and conductivity meter, and growth stages of medusae were noted.

Results

Figure 1 shows various views of adult medusae of the three introduced species. For identification purposes, note that these are only the adult stages, and that growth stages as well as adults of any one or all three species may be present simultaneously in the water column.

Maeotias inexspectata is the largest, most conspicuous, and most readily identifiable of the three species. Bell diameters reach 4 cm or more, and the reddish coloration of the bell, coupled with white or brownish gonads, render this jellyfish easily visible at the surface, even when the water is quite turbid. The other two species, *Blackfordia virginica* and *Moerisia* sp. are smaller (0.5 to 1.5 cm in bell height and width) and, except for the gonads, are transparent, rendering these two species virtually invisible in the field, particularly in turbid water. All three have persistent benthic polypoid stages, but polyps and colonies have been found in the field so far for only two: *B. virginica* and *Moerisia* species. *Maeotias inexspectata* polyps and colonies are certainly present, perhaps in abundance.

Salinity and temperature spectra for medusae collected in the estuary have ranged from 2.5‰ to 11‰ and 16.5 to 25 °C, respectively. Calder (1967, 1969) reported *Moerisia lyonsi* in the Chesapeake Bay in salinities of 2.3‰, and *M. inexspectata* in salinities as low as 1.2‰. It is anticipated that estuary species have similar salinity tolerance profiles. Basic ecological data (including salinity and temperature tolerances and ranges for polyps, growth stages of medusae, diets, feeding behaviors, life histories, population dynamics, and times of initial annual appearance in the plankton), are not known for any of the three species. Mills and Sommer (1995) report that in the Petaluma River *M. inexspectata* adults fed primarily on zooplankton, but at least one adult *M. inexspectata* collected by the author in the Napa River in 1998 had a small, unidentified fish in its gut; *B. virginica* adults have been collected with their stomachs packed with zooplankton. In a Napa River collection in September 1998, *B. virginica* medusae were found in great numbers on the bottom; further upriver, they were present in abundance (about 5 individuals per m^3) in the water column on an incoming tide. Similarly, adult *M. inexspectata* medusae were routinely observed along a one-mile length of the Napa River near the shore in shallow water, but adults were not collected by routine tows in mid-channel. *Maeotias inexspectata* was also observed in virtually all quiet water areas of the Napa River (marinas, boat launches, shorelines) from the city of Napa to at least Cuttings Wharf, a distance of about 5 miles, in early September 1998. Sampling procedures for jellyfish and other invertebrates in shallow water habitats are not well developed, and methods for sampling in these areas need to be devised and implemented to obtain reliable estimates of abundance.

While most observations of medusae to date have been made in the more accessible rivers and sloughs of the upper estuary, there is no reason to assume that jellyfish are confined to shallow water habitats. Preliminary IEP results in 1998 revealed the presence of adult *M. inexspectata* in mid-channel from Mare Island to the "mothball" fleet and the Concord Naval Weapons station (and points in between) from 15 September to 15 October in salinities and temperatures ranging from 2.6‰ to 10.4‰ and 16.5 to 21.8 °C, respectively (R. Gartz, personal communication). More thorough tow collections will likely reveal the presence of jellyfish in deeper mid-channel estuary habitats, particularly during late summer and early fall.

Medusae have exhibited a sporadic and bewildering pattern of appearance in the estuary. *Maeotias inexspectata* and *B. virginica* were collected in the Petaluma River in downtown Petaluma during summer 1995 in great numbers, but were absent from this location in 1997 and 1998. *Maeotias inexspectata* and *Moerisia* sp. were routinely collected adjacent to the Suisun City marina in high abundances (about 10 to 20 per m^3) in 1997, but both were absent in 1998. Appropriate salinity ranges, temperatures, and hydrological conditions probably play a pivotal, but as yet unknown, role in the development of abundant medusa populations, and wet and dry years may prove to exhibit very different patters of medusa occurrence and abundance. Laboratory and field work will help delineate optimum salinities and temperatures for favorable development of field populations of medusae.

It is not known when these hydrozoans were introduced into the estuary. Discussions with agency personnel and other field workers have alluded to the presence of *M. inexspectata* in Suisun Slough as early as 1979 (P. Moyle, personal communication) and near Chipps Island in high densities during the mid-1990s (J. McLain and K. Webb, personal communications). One fisherman questioned along the Napa River in 1998 stated that he first noted jellyfish in about 1985 (undoubtedly the more readily observable *M. inexspectata*), and has subsequently noted increasing numbers over the intervening years. Several boaters testified that jellyfish had been present in the

Napa River in 1997 and 1998, and were most common in late summer and early fall. These were also undoubtedly adult *M. inexspectata* medusae. No sampling has been performed in the Central or South bays, but there is every reason to suppose that any one or all of these three species will eventually be found in suitable habitats in these parts of the San Francisco Bay.

Discussion

The "gelatinous" zooplankton, of which hydromedusae are but one constituent, forms an important and generally poorly studied component of planktonic aquatic ecosystems. Jellyfish are often destroyed by traditional net sampling methods, are routinely ignored when found in tows, are difficult to identify, and suffer from a lack of professional taxonomic expertise. When abundant, however, the effects of hydromedusae and their kin on planktonic ecosystem dynamics can be dramatic (Purcell 1985).

Major local wetlands restoration efforts, spearheaded by CALFED, are planned for the San Francisco Estuary over the next few decades. While data are available on the ecology of estuary fish species, similar information is needed for non-indigenous invertebrate species, including hydromedusae, particularly those inhabiting the sensitive upper estuary. *Maeotias inexspectata*, for example, has been found in shallow, calm, warmer water areas adjacent to tidal sloughs and river channels. Marinas appear to be suitable habitats for adults of this species, as the calm, relatively deep water affords suitable conditions for the medusae to feed. Shallow water restorations in the estuary could increase suitable habitats for these species, complicating efforts to enhance endangered fish populations.

In sufficient population densities, jellyfish also have the potential to clog fish screens and other devices used for prevention of fish loss in Delta water diversions. Our lack of knowledge of the biology of these hydrozoan species precludes predictions about habitat use and dispersal. Only through knowledge of the life cycles and environmental parameters that favor the formation of large populations of all three species will their habitat use become better known. Knowledge of optimal environmental conditions for growth of these medusae could also assist in more successful restoration efforts.

While there are many reasons for monitoring jellyfish populations in the estuary, perhaps the most compelling may be a deeper insight into the overall health of the planktonic communities of the estuary. If one accepts the inverse ratio hypothesis of secondary consumers in planktonic ecosystems (more fish, fewer jellyfish: fewer fish, more jellyfish) as espoused by Mills (1995), a simultaneous monitoring of fish and jellyfish populations should provide a gauge for estuary ecosystem health.

The fragile state of the entire upper estuary, which was affected by loss of wetlands, increasing contaminant loads from agricultural and industrial run-off, decreased freshwater flows, and negatively impacted fisheries, forms a backdrop of an accelerated pattern of alien aquatic introductions worldwide (Carlton 1985), of which the jellyfish discussed in this article are among more recent examples. The compromised ecology of the estuary shares an uncomfortable precedent with a similar ecosystem in Asia, the Black Sea (Caspers 1957). After years of environmental assaults, including overfishing and increased contaminant loads, the Black Sea fisheries suffered what could only be described as a catastrophic collapse coincident with the introduction of a brackish water planktonic ctenophore, *Mnemiopsis*, large populations of which proceeded to decimate remaining fish populations (Harbison and Volovik 1994). Incremental affronts to an aquatic ecosystem from a variety of sources culminating in a final calamity may not be coincidental, as many gelatinous zooplankters, especially the more robust estuarine forms, may be more resistant to chemical contamination and poor water quality in general than native species, and can quickly replace resident fish species. Field monitoring and laboratory studies on the life histories of all three of these non-indigenous jellyfish species as part of an estuarywide monitoring effort are needed to assess future potential direct threats to the upper estuary ecosystem.

Non-indigenous Jellyfish in the Upper San Francisco Estuary: Potential Impacts on Zooplankton and Fish

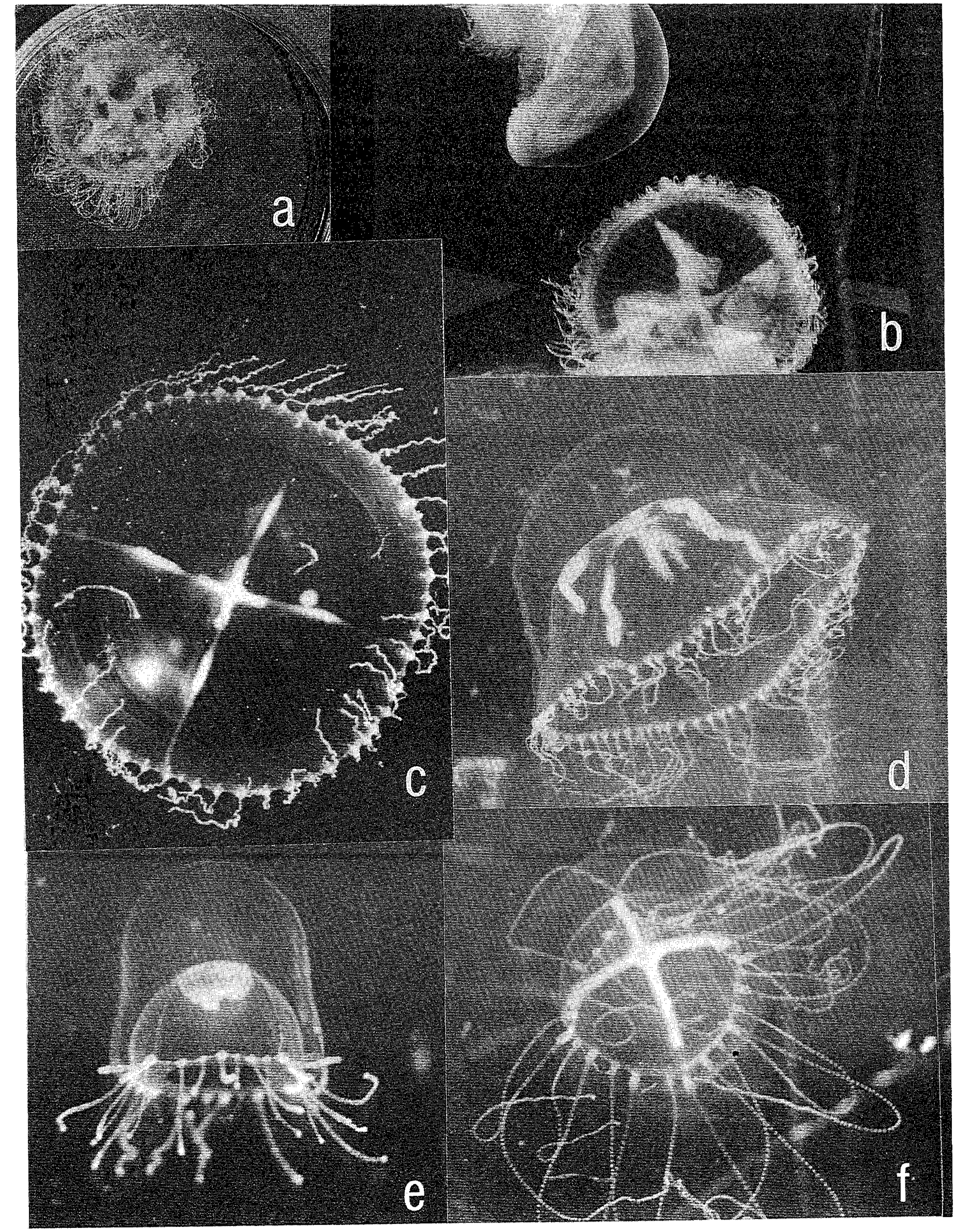

Figure 1 Introduced estuary jellyfish in various poses: (A) *Maeotias inexspectata*, 3.2 cm bell diameter, Suisun Slough, 27 Sep 1997; (B) *M. inexspectata*, 4.5 to 5.0 cm bell diameter, Suisun Slough, 10 Oct 1997; (C) *Blackfordia virginica*, 1.0 cm bell diameter, Napa River, 21 Oct 1998; (D) *B. virginica*, 1.0 cm bell diameter. Napa River, 15 Sep 1998; (E) *Moerisia* sp., 0.4 cm bell height, Suisun Slough, 19 Sep 1997; (F) *Moerisia* sp., 0.5 cm bell height, Suisun slough, 10 Oct 1997. All medusae were collected from the field.

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Evaluation of Fisheries Relating to Floodplain Restoration on the Cosumnes River Preserve

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Introduction

The worldwide alteration and degradation of aquatic ecosystems has stimulated interest in the multidisciplinary topic of stream restoration. Among the recent topics of research in stream restoration is the maintenance of the terrestrial aquatic interface through the restoration of shallow water habitats. There is a complexity of shallow water habitat types, including floodplain, tidal marsh, and shoal habitats, all of which function in distinct ways and cater to specific fish species. The loss of these habitats has been listed as a possible cause of population declines for several native species including chinook salmon, delta smelt, and splittail (Meng and Moyle 1995; Sommer and others 1997).

Floodplain habitats have many potential benefits to native fishes. The strongest link between food availability, food use, and growth rates of river fish is associated with the seasonal inundation of the floodplain (Schlosser 1991). This increased availability of organic matter and invertebrates during floods, along with the expansion of the physical habitat, results in increased food intake and growth rate and improved condition for most river fish (Schlosser 1991). It has also been suggested that floodplain habitats may play an important role in the spawning of some native fishes. The importance of floodplain habitat to the overall health of the Sacramento-San Joaquin basin has only recently been considered and its' preservation and creation is presently the focus of many State, federal, and private organizations.

In 1995, The Nature Conservancy began a plan of floodplain restoration on land adjoining the lower reach of the Cosumnes River. Initial restoration of this area included breaching levees and removing small parcels of farmland from production. Since 1995, further restoration efforts have included additional levee breaks, levee setbacks, and the reforestation of farmland. Within this area there is an abundant diversity of habitat ranging from farmland to old growth, riparian forest. This evaluation attempted to study a wide range of habitats during flood events to determine fish use.

Study Area

The Cosumnes River, a tributary to the Sacramento-San Joaquin Delta, contains no major dams or upstream impoundments and has a mostly natural, highly variable hydrograph. The study area is located adjacent to the Cosumnes River within the boundaries of the Cosumnes River Preserve. This large tract of land is owned and operated by several private and public agencies, including The Nature Conservancy, US Bureau of Land Management, Ducks Unlimited, and the California Departments of Fish and Game and Water Resources. These agencies have come together in an effort to conserve existing and create additional endangered valley habitats. The Cosumnes River Preserve is located just east of Interstate 5 near the town of Franklin (Figure 1).

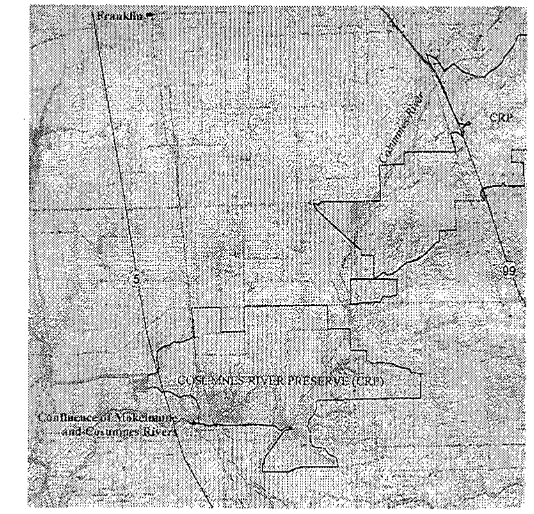

Figure 1 Geographical boundaries of the Cosumnes River Preserve, Galt, California

The Cosumnes River Preserve includes many types of habitat including fertile farmland, old growth, valley riparian forest, as well as land in various stages of wetland restoration. Ten sample sites were chosen within an area of the Cosumnes River Preserve that has been developed for seasonal flooding through the planned breaching of levees along the Cosumnes River (Figure 2).

Figure 2 Approximate locations of the ten sample sites in relation to the Cosumnes River and Wood Duck Slough in the Cosumnes River Preserve, Galt, California. The numbered red dots represent sample sites and the yellow bolts represent levee breaches.