RMP UPDATE

NEWS FROM THE REGIONAL MONITORING PROGRAM FOR TRACE SUBSTANCES

August 2005

Contaminants and Effects in Fish: Links to Population Declines?

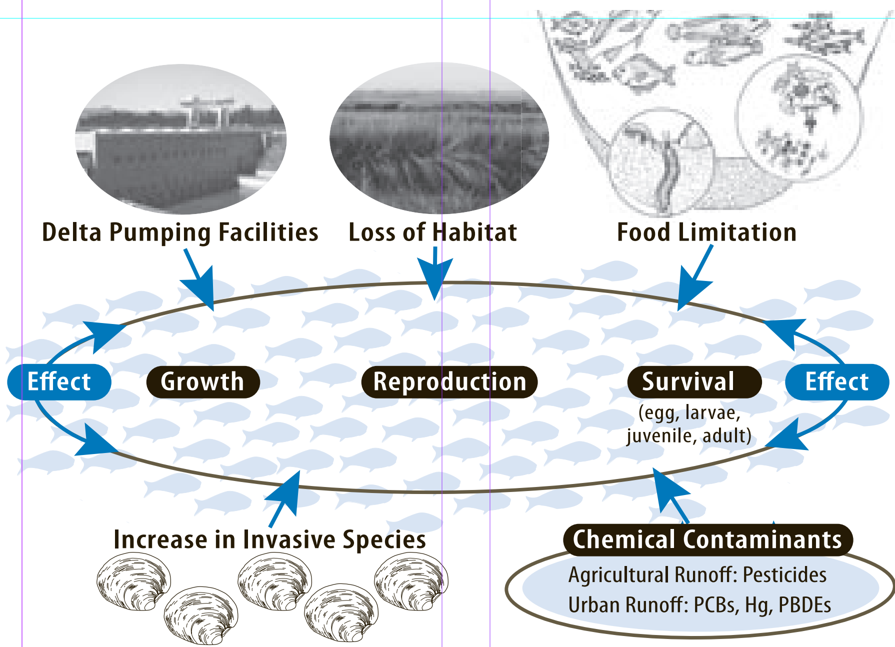


Figure 1. *A conceptual model of stressors that may be impacting fish populations.*

by Jennifer Hunt (SFEI), Robert Spies (AMS) and Katherine Springman (UC Davis)

The recent decline in certain fish populations in the Delta has sounded the alarm for scientists and resource agencies. (See Estuary Newsletter June 2005). Interagency Ecological Program (IEP) data on the abundance of certain Delta fish species, such as striped bass, longfin smelt and delta smelt, show very low juvenile population numbers and what appears to be an overall decline in abundance for these species (Hieb, In Press). Striped bass and longfin smelt are anadramous species that spend part of their life cycle in the Bay and part in the Delta. These species are potentially affected by the continual changes, natural and anthropogenic, occurring in both systems. Scientists have been working for decades to understand fluctuations in fish populations and have linked fluctuations to freshwater outflow from the Delta, fish entrainment at Delta pumping facilities, loss of habitat, food limitation, increases in invasive species, and chemical contaminants (Bennett and Moyle, 1996). Bennett and Moyle concluded that it is most likely a combination of these forces that are causing the population declines and that the model for understanding fish population declines should utilize this 'multifold' causal approach *(Figure 1)*.

Fish Effects

Several recent studies suggest that contaminants may be affecting survival of early life stages of important fish species in the Bay/Delta. Laboratory toxicity tests are used to determine contaminant effects in fish and other species but short-term testing is not representative of the lifetime contaminant exposure and accumulation of populations in the wild. If effects are observed in lab tests at contaminant concentrations that exist in natural environments then it can be deduced that effects are probably occurring in wild fish. How-

Continued on page 2

Emerging Contaminants: Pyrethroids

by Daniel Oros (SFEI) and Jennifer Hunt (SFEI)

The U.S. EPA decision to phase out or eliminate certain uses of the insecticides chlorpyrifos, diazinon, and malathion because of their potential for causing toxicity in humans, especially children, has led to increased use of another class of insecticides, the pyrethroids. The increasing use of pyrethroids, which have been shown to have toxic effects on early life stages of fishes and their primary food sources (i.e. zooplankton), could be negatively impacting fish growth, survival and reproduction in the Bay/Delta. Pyrethroids are synthetic derivatives of pyrethrins, which are natural insecticides that are produced by certain species of the chrysanthemum flower. The first report of pyrethrin use occurred in Asia around 1800 where pyrethrins were applied to control human lice, mosquitoes, cockroaches, beetles, and flies. Pyrethroids are persistent compounds, are not very soluble in water, and have a tendency to accumulate in aquatic organisms. Benthic (sediment dwelling) and pelagic (water column dwelling) aquatic species are at risk for adverse effects due to exposure and accumulation of these contaminants. Since pyrethroids are more readily bound to sediment particles, benthic organisms may be at greater risk.

Application and Use

Pyrethroids are applied in urban areas primarily for structural pest control, in agricultural areas on crops such as almonds, alfalfa, cotton, lettuce, pistachios, and peaches, and in the home in pet sprays and shampoos. In 2003, permethrin was ranked the 43rd most used pesticide

Continued on page 4

For more information about the RMP, or to receive the RMP newsletter, contact the San Francisco Estuary Institute (SFEI) at 510-746-7334 or visit the RMP Web site at www.sfei.org/rmp.

Regional Monitoring Program
San Francisco Estuary Institute
7770 Pardee Lane, 2nd floor
Oakland, CA 94621
www.sfei.org

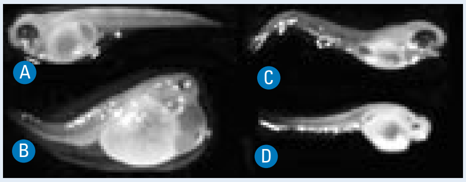
Fish Effects

Continued from page 1

ever, a lack of effect in laboratory studies does not necessarily mean a lack of effect in wild fish. The link between contaminants and population declines is harder to determine since there are a multitude of factors, both natural and anthropogenic, that can impact populations. However determination of effects thresholds can help build the case for contaminants being a factor in population declines.

Fish early life stages sometimes exhibit adverse effects to contaminants in lab tests. Egg and larval stages are often used in lab tests since they are the life stages that are most sensitive to toxic effects. There are two main categories of effects that can be measured in toxicity tests: acute (generally lethal) and chronic (generally sublethal). Chronic effects are less immediate and can develop long after contaminant exposure ends. Some examples of chronic effects include genetic mutations, changes in behavior such as swimming ability, physical deformities such as curvature of the spine *(Figures 2 and 3)* and a host of physiological abnormalities (Teh et al., 2005, Teh et al., 2004a, Teh et al., 2004b). Although chronic effects may not lead to immediate mortality, these effects may increase mortality by decreasing the fitness of an individual fish. For example, a fish that has impaired or slowed swimming ability may be more susceptible to predation and ultimately, mortality.

The link between contaminants and population declines is difficult to establish since there are a multitude of factors, both natural and anthropogenic, that can impact populations



A. Normal
B. Yolk-Sac Edema
C. Abnormal Vertebral Column
D. Abnormal Head

Figure 2. *Physical deformities seen in fish exposed to contaminants.*

Local Fish Effects Research

Contaminant effects have been shown in laboratory tests with local species. Wild hatched striped bass larvae that were raised under laboratory conditions were of poorer quality than hatchery hatched larvae raised under the same conditions (David Ostrach in SFEI, 2005). Growth was reduced, yolk-sac depleted more quickly, and brain growth was reduced in the wild larvae. Contaminant concentrations including PCBs and polybrominated diphenyl ethers (PBDEs) were also higher in the wild larvae. In another study, Sacramento splittail showed sublethal responses such as curvature of the spine and reduced fish length in laboratory tests with juveniles fed varying concentrations of dietary selenium (Se) (Teh et. al., in SFEI 2005). This finding is significant since selenium concentrations in splittail prey items in the Bay/Delta are at similar levels that led to effects in lab tests. The invasive Asian clam species *Potamocorbula amurensis*, which is believed to be an increasing part of the splittail diet, shows selenium concentrations as high as 20 ppm (Linville et al., 2002; SFEI, 2005).

White sturgeon also showed effects from selenium in lab tests (Linures et. al., in SFEI 2005). Like the splittail, a large portion of sturgeon diet is made up of *Potamocorbula*. Sturgeon may pass selenium, accumulated from their diet, onto their offspring. Yolk-sac sturgeon larvae injected with selenium exhibited spinal deformities, tissue swelling, and mortality at increasing selenium concentrations (Linares et al., 2004). Selenium concentrations found in wild sturgeon eggs from the Sacramento River were in the same range of concentrations that caused effects in the lab experiments.

The US Fish and Wildlife Service is currently screening male splittail fish for the presence of a female reproductive protein known as vitellogenin (Cathy Johnson, pers. comm.). The presence of this protein, normally found in female fish, has been utilized to indicate fish exposure to xenoestrogens (a class of endocrine disrupting chemicals (EDCs)) in male fish (see RMP Newsletter Winter/Spring 2005). Xenoestrogens can act as mimics of naturally produced estrogen and potentially disrupt certain endocrine system functions and reproduction (Schwaiger and Negele, 1998). In fish, EDCs can affect hormone balance, inhibit gonadal growth, inhibit egg production, alter sex ratios of offspring towards a higher ratio of females, and reduce egg hatchability (Mills et al., 2001; Brion et al;, 2004).

Figure 3. *Spinal deformities have been seen in fish exposed to contaminants.*

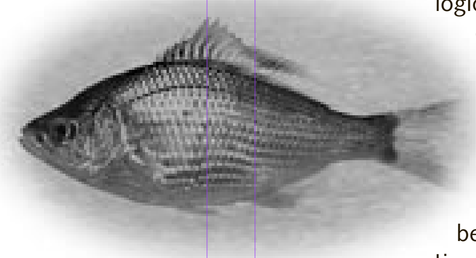
These laboratory studies help establish thresholds with which to compare contaminant concentrations in wild populations. If concentrations in wild fish are in the range of effects thresholds there will be concern as to the impact to the population. Many of these studies established that some Bay/Delta fish species are in the range of effects thresholds for single contaminants. These laboratory tests do not take into consideration the potential effects of multiple contaminants.

Multi-Contaminant Approach

Most of the effects research to date has focused on the effects of a single contaminant. The single contaminant approach may give valuable information regarding the toxicity of a particular contaminant but it does not take into account that Bay wildlife are exposed to multiple contaminants over their lifetime. Contaminants can act antagonistically with the result being little or no effect. Alternatively, contaminants can also act synergistically and magnify effects. One way to approach this problem is through monitoring the general health of selected fish species. Major advantages of this approach are that it could provide an integrated response to all of the contaminant and non-contaminant stressors faced by an organism. A disadvantage is that linking the health effects to specific contaminants or other stressors would likely be challenging.

Effects of Contaminants on Surfperch: A RMP Pilot Study

Chemical contamination in San Francisco Bay and Delta sportfish has been firmly established (Greenfield et al., 2003; Davis et al., 2000; Davis et al., 1999). The RMP has mostly focused on discerning the concentrations of these chemicals in fish but now the Program is looking at the potential links between contaminant exposure and effects in fish. The RMP has recently funded a pilot study to look at the potential effects of contaminants on a Bay species: the shiner surfperch.



Juvenile shiner surfperch populations in the Bay have fluctuated over the period of record (1980-2004) and took a precipitous decline in the late 1980s and through the 1990s (Hieb, 2004). Since 2001 this species appears to be in a modest recovery period (Hieb, In Press). Surfperch in the Bay are known to be high in certain lipophilic ('fat loving') contaminants such as PCBs and DDTs (Greenfield et al., 2003, Davis et al., 1999). This species also has high site fidelity so it can be a good integrator of site-specific contamination. Their habitat is in the shallows of the Bay where there are corresponding sediment and water chemical data that can be utilized to examine relationships between contaminant levels in water and sediment and contaminant levels in fish. This study will investigate whether there is any effect on the growth, reproduction, or fitness of this species due to contaminants. This pilot study will also attempt to establish surfperch as a model for evaluating and monitoring effects in a Bay fish species.

The first year sampling plan (2005) includes collection of surfperch from contaminated and uncontaminated sites in the Bay and measuring fish for contaminant concentrations, reproductive output (number and size of embryos in females), and biological markers of chemical exposure. Comparisons between the results from contaminated and uncontaminated sites will be made to discern if contaminants are having effects in this species at the molecular and/or organismal level. The second year of the study will involve collection of surfperch from an uncontaminated site for use in laboratory tests. Adult fish will be exposed to contaminant mixtures collected from Bay sampling stations and will be measured for growth and body condition. Exposing fish to contaminant mixtures will better represent the fish's natural environment. Reproductive output will be measured in all pregnant females and the size and condition of juveniles born during the test period will also be measured. Biological markers of exposure will also be measured at the end of the test period. Behavior of fish during the experiment will be noted. The information derived from this pilot study will be beneficial in adding to the state of knowledge of contaminant effects. It will also add much needed information on potential effects of contaminant mixtures since this mirrors more realistically what is occurring in Bay fish.

An Integrated Approach to Understand Population Declines

Contaminant exposure and effects are one piece of the puzzle in determining what is influencing population declines of these species. There is a growing body of evidence suggesting that effects due to contaminant exposure are possible. We know that contaminants can affect mortality and can induce a host of sublethal effects. The next level of development of this information is linking effects at the organismal level to effects at the population level. The Bennett and Moyle (1996) multifold causal approach is a good model for investigating declining fish populations since it looks at all potential factors that could affect a population. An integrated approach will more readily illuminate all environmental stressors and the impact these stressors have on fish populations in the Bay/Delta.

References

Bennett, W.A. and P.B. Moyle. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary. In J.T. Hollibaugh, ed., San Francisco Bay: The Ecosystem. Pacific Division, American Association of the Advancement of Science. San Francisco, CA.

Brion, F., Tyler, C.R., Palazzi, X., Laillet, B., Porcher, J.M., Garric, J., and P. Flammarion. 2004. Impacts of 17 -estradiol, including environmentally relevant concentrations on reproduction after exposure during embryo-larval-, juvenile- and adult-life stages in zebrafish (Danio rerio). Aquatic Toxicology. 68(3):193-217.

Davis, J.A., Greenfield, B.K., Ichikawa, G., and M. Stephenson. 2003. Mercury in sport fish from the Delta region (Task 2A). SFEI. 88 pp.

Davis, J.A., May, M.D., Wainwright, S.E., Fairey, R., Roberts, C., Ichikawa, G., Tjeerdema, R., Stoelting, M., Becker, J., Petreas, M., Mok, M., McKinney, M., and K. Taberski. 1999. Contaminant concentrations in fish from San Francisco Bay, 1997. RMP Contribution #35. SFEI, Richmond, CA. 1999, 65 pp.

Greenfield, B.K., Davis, J.A., Fairey, R., Roberts, C., Crane, D., Ichikawa, G. and M. Petreas. 2003. Contaminant concentrations in fish from San Francisco Bay, 2000. SFEI Contribution #77. SFEI, Oakland, CA. 2003, 82 pp.

Hieb, K., Bryant, M., Dege, M., Greiner, T., Slater, S., and K. Souza IEP. In Press. 2004 Fishes Annual Status and Trends Report for the San Francisco Estuary. Spring 2005 IEP Newsletter. 18(2)

Hieb, K., Grenier, T., and S. Slater. 2004. San Francisco Bay Species: 2003 status and trends report. Spring 2004 IEP Newsletter. 17(2).

Linares, J., Linville, R.G., Van Eenennaam, J. and S. Doroshov. 2004. Selenium effects on health and reproduction of white sturgeon in the Sacramento-San Joaquin Estuary. Final Report for CALFED Project ERP-02-P35. November 2004.

Linville, R., S.N. Luoma, L. Cutter, and G.A. Cutter. 2002. Increased selenium threat as a result of invasion of the exotic bivalve Potamocorbula amurensis in the San Francisco Bay. Aquatic Toxicology. 57:51-64.

Mills, L.J., Gutjahr-Gobell, R.E., Haebler, R.A., Horowitz, D.J., Jayaraman, S., Pruell, R.J., McKinney, R.A., Gardner, G.R. and G.E. Zaroogian. 2001. Effects of estrogenic (o,p'-DDT; octyphenol) and anti-androgenic (p,p'-DDE) chemicals on indicators of endocrine status in juvenile male summer flounder (Paralichthys dentatus). Aquatic Toxicology. 52(2):157-176.

Schwaiger J. and R.D. Negele. 1998. Plasma Vitellogenin - a Blood Parameter to Evaluate Exposure of Fish to Xenoestrogens. Acta vet. Brno. 67:257-264.

SFEI. 2005. The Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary. SFEI contribution 78. SFEI. Oakland, CA.

Sohoni, P., Tyler, C.R., Hurd, K., Caunter, J., Hetheridge, M., Williams, T., Woods, C., Evans, M., Toy, R., Gargas, M. and J.P. Sumpter. 2001. Reproductive effects of long-term exposure to Bisphenol A in the fathead minnow (Pimephales promelas). Environ. Sci. Technol. 35(14):2917-2925.

Spies, R.B. and D.W. Rice, Jr.. 1988. The effects of organic contaminants on reproduction of starry flounder, Platichthys stellatus (Pallas) in San Francisco Bay. Part II. Reproductive success of fish captured in San Francisco Bay and spawned in the laboratory. Marine Biology 98, 191-202.

Sumpter, J.P. and A.C. Johnson. 2005. Lessons from endocrine disruption and their application to other issues concerning trace organics in the aquatic environment. Environmental Science and Technlogy. 39(12):4321-4332.

Continued on page 4

Fish Effects

Continued from page 3

Teh, S. J., Deng, D., Werner, I., Teh, F., Hung, S. 2005. Sublethal toxicity of orchard stormwater runoff in Sacramento splittail (Pogonichthys macrolepidotus) larvae. Marine Environmental Research. 59(3):203-216.

Teh, S. J., Zhang, G.H., Kimball, T., and F.C. Teh. 2004a. Lethal and sublethal effects of esfenvalerate and diazinon on splittail larvae. American Fisheries Society Symposium. 39:243-253.

Teh, S.J., Deng, X., Deng, D.F., Teh, C-F., Hung, S.S.O., Fan, T.W.F., Liu, J. and R.M. Higashi. 2004b. Chronic effects of dietary selenium on juvenile Sacramento splittail (Pogonichthys macrolepidotus). Environmental Science and Technology. 38:6085-6093.

Pyrethroids

Continued from page 1

in California: 443,676 pounds applied over 755,978 acres and there has been a 25% increase in pyrethroid use in the past few years (California Pesticide Use Reporting database: www.cdpr.ca.gov; Amweg et al., 2005). The primary way that pyrethroids enter local rivers and ultimately the Bay from agricultural applications is through agricultural irrigation drainage and spray drift (Weston et al., 2004). Pyrethroid concentrations, and subsequently toxicity, are most likely at their highest levels in aquatic systems soon after agricultural application with the peak application period occurring during summer (Weston et al., 2004). The timing of peak application coincides with spawning and early life stages (larval and juvenile) of many fish species that use the Bay/Delta as a nursery including the threatened Delta smelt, which spawns from February to June (Moyle, 2002).

Toxicity Test Results

This class of chemicals has been shown to be highly toxic to early life stages of certain aquatic crustaceans and fishes in laboratory tests (Amweg et al., 2005; Weston et al., 2004). Effects in crustaceans include reduced growth rate, which can decrease the fitness of an organism and affect survival, and mortality. Laboratory tests of pyrethroids have also shown toxicity, including mortality, to early life stages of fish such as fathead minnow, rainbow trout, brook trout, bluegill, and sheepshead minnow (TDC, 2003).

There is wide variation in reported toxicities of these individual compounds due to pyrethroids being a complex mixture of isomers (compounds that have very small differences in chemical structures), rather than one single pure compound. (ATSDR, 2003). The pyrethroids of greatest interest to water quality include bifenthrin, cyfluthrin, cypermethrin, deltamethrin, esfenvalerate, lamba-cyhalothrin, and permethrin. Some of the newer pyrethroids such as cypermethrin, which is used in much lower amounts, could be up to 20 times more toxic than permethrin. For instance, 1 kg of cypermethrin has about the same toxic potency as 18 kg of permethrin (Amweg, 2005). Therefore much lower concentrations of these more potent pyrethroids can have a much larger effect on aquatic species.

Researchers are beginning to look for potential links between contaminants and the declining fish populations recently observed in the Delta. The declining fish populations may be linked to an overall change in the Bay/Delta food web structure. Declines in Bay/Delta phytoplankton and zooplankton abundance have also been seen in conjunction with declining fish populations. One hypothesis being evaluated is that the food web could be impacted due to pyrethroid exposure and toxicity especially during periods of peak agricultural and urban runoff discharge.

There are very few data on concentrations of pyrethroids in Bay/Delta water and sediment. More information is necessary to determine if pyrethroid concentrations are at levels that could cause effects. Several additional key questions could be posed in future pyrethroid research including: Which pyrethroid compounds are present in the Delta and Bay? Are they found at biologically relevant concentrations that could cause toxicity? Do chronic, low doses of pyrethroids cause toxicity? Do pyrethroids interact additively or synergistically with each other or with other contaminants (e.g., PCB, PAH) to induce toxicity? Which species are most susceptible to pyrethroid toxicity?

Analytical Methods

Measuring pyrethroid concentrations in environmental samples is still in the development stages. SFEI has teamed up with AXYS Analytical Services, Inc. to develop new chemical methods to detect pyrethroids in Delta and Bay water and sediment samples at effects level concentrations for aquatic species. The development of these methods will allow researchers to detect and confirm the presence of pyrethroids in environmental samples and establish baseline measurements for tracking any changes in concentrations in the Delta and Bay.

Similar efforts are underway in a joint venture between three government laboratories: CA Department of Fish and Game's Water Pollution Control Laboratory, CA Department of Food and Agriculture, and the U.S. Geological Survey's Organic Chemistry Laboratory. The goals of the labs are to develop routine methods for measuring pyrethroids in water, sediments, and biota. In a related effort, SFEI has also teamed up with UC Davis Marine Pollution Studies Laboratory, to determine the pyrethroid concentrations at which adverse effects are seen in Bay species. In addition, this team and UC Berkeley are both working on developing and validating toxicity identification evaluation (TIE) procedures for sediment toxicity tests targeting toxicity caused by pyrethroids. TIEs are laboratory tests that try to identify the chemicals in water and sediment environmental samples that are causing toxicity to test organisms. TIEs can often determine a class of contaminants, such as pyrethroids, as causative agents of toxicity but often cannot distinguish the individual contaminants, such as permethrin or cypermethrin. More information about these research efforts is available on the Urban Pesticide Pollution Prevention (UP3) Project website (www.up3project.org/up3_index.shtml).

In summary, pyrethroid insecticides are presenting a serious new challenge to environmental researchers. Research to better understand pyrethroid transport, toxicology, and fate in the San Francisco Bay and Delta region is currently underway.

References

Amweg, E.L., Weston, D.P. and N.M. Ureda. 2005. Use and toxicity of pyrethroid pesticides in the Central Valley, California, USA. Environmental Toxicology and Chemistry. 24(4):966-972.

ATSDR. 2003. Toxicological Profiles for Pyrethrins and Pyrethroids. Agency for Toxic Substances and Disease Registry. Website: http://www.atsdr.cdc.gov/toxprofiles/tp155.html.

Moyle, P.B. 2002. Inland Fisheries of California: Revised and expanded University of California, Berkeley, CA, 517 pp.

TDC. 2003. Insecticide Market Trends and Potential Water Quality Implications. TDC Environmental Report for the San Francisco Estuary Project. 105 pp.

Weston, D.P., You, J.C. and M.J. Lydy. 2004. Distribution and toxicity of sediment-associated pesticides in agriculture-dominated water bodies of California's Central Valley. Environmental Science & Technology. 38: 2752-2759.