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December 29, 2005

To: IEP Agency Directors

Subject: IEP POD Investigation Review

Enclosed is a copy of a document entitled *Review Panel Report: San Francisco Estuary Sacramento-San Joaquin Delta Interagency Ecological Program on Pelagic Organism Decline.* The transmittal of this report fulfills a request of the California Bay-Delta Authority to provide independent external review of the Interagency Ecological Program's (IEP) Pelagic Organism Decline Investigation (POD). I convey this report to you on behalf of the Science Program Review Panel members listed herein: Drs. M.D. Bertness, S.M. Bollens, J.H. Cowan, Jr., R.T. Kneib, P. MacCready, R.A. Moll, P.E. Smith, A.R. Solow, and R.B. Spies.

The review was originally intended to provide an independent review of (1) the initial results of the POD Investigation's 2005 activities, and (2) the investigation's proposed 2006 workplan. However, due to time and staff constraints, the IEP was unable to provide a draft of the 2006 workplan, so the review focused on the 2005 IEP POD Workplan and the 2005 IEP POD Synthesis Report. These written materials were augmented by a two-day working seminar held jointly in Sacramento by the CALFED Science Program, the IEP Management Team, and available POD principle investigators on November 14-15, 2005, and by individual discussions between panel members and IEP staff. The report provides the panel's perspectives on the data synthesis presented and on IEP project element issues, and makes recommendations for improvements in analyzing, interpreting, and defining appropriate context for future IEP POD-oriented investigations.

In response to this report, CALFED Science Program and Interagency Ecological Program staff have agreed to develop an integrated, element-by-element response to the recommendations provided by the Review Panel. Many of the Panel's recommendations are already addressed in the emerging IEP 2006 annual workplan and budget proposal. Several recommendations will require continued coordination between CALFED Science Program and IEP agency activities beyond 2006. I propose that details of adjustments in existing programs and plans for programmatic refocusing within the IEP be discussed in a forthcoming joint response document to be issued by the IEP and the CALFED Science Program by March 1, 2006.

If you have any questions regarding the material contained in the Review Panel report, please do not hesitate to contact Steven Culberson, Science Program Staff Environmental Scientist at (916) 445-0584.

Respectfully,

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CALFED Lead Scientist

cc: Joe Grindstaff
IEP Coordinators
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REVIEW PANEL REPORT

(19 Dec 2005)

San Francisco Estuary Sacramento-San Joaquin Delta Interagency Ecological Program on Pelagic Organism Decline

Submitted by: **Mark D. Bertness** (Brown University), **Stephen M. Bollens** (Washington State University Vancouver), **James H. Cowan, Jr.** (Louisiana State University), **Ronald T. Kneib** (University of Georgia Marine Institute), **Parker MacCready** (University of Washington), **Russell A. Moll** (California Sea Grant College Program), **Paul E. Smith** (Scripps Institution of Oceanography), **Andrew R. Solow** (Woods Hole Oceanographic Institution), **Robert B. Spies** (Applied Marine Sciences)

Executive Summary

The review panel recognizes that addressing the issue of pelagic organism decline (POD) in the managed ecosystem and human-dominated watershed of the upper San Francisco Estuary (Sacramento-San Joaquin Delta) is a formidable challenge. We commend the Interagency Environmental Program (IEP) managers and scientists for seeking ways of balancing the needs for human use of the area's water resources with the survival requirements of other components of the ecosystem. The suite of problems in the Bay-Delta is of immense importance to California. Working under constant political scrutiny and demand for "instant results" the IEP has maintained a high-quality program that includes an invaluable long-term data set. The passion of the IEP employees for their program and the effort invested to make it succeed were very evident to the review team. When confronted with demands for more answers and political quick fixes to a deteriorating environment, the IEP produced a thoughtful and skilled response with a more elaborate research program that will hopefully reveal the underpinnings of the ecological disaster confronting the Bay-Delta. The review panel praises the IEP for a job well done and hope that our observations, comments and suggestions will be of assistance to the scientists and managers who are attempting to seek novel solutions to complex problems of critical resource management through this worthy program.

The IEP, together with the coordinating efforts of the California Bay-Delta Authority (CBDA), represents a unique collaboration of federal and state entities charged with the immense task of developing an understanding of the structure and functioning of the Bay-Delta ecosystem. Such a unique collaboration affords many opportunities and yet demands a high level of effort to make the IEP succeed. Such aspects as a well-developed management structure, regular management meetings, frequent informal communications and a clear reporting structure are the hallmarks of a good management approach. Each component of the IEP has an identified leader(s) and a clear set of management objectives that collectively point toward a thoughtful study program. The review panel commends the IEP for taking the necessary steps to make program management succeed. Further, we have the impression that management of the IEP is intended to serve the needs of the study program and not vice versa – a very healthy approach.

The review panel identified several strengths and weaknesses of the current program. These are summarized below and followed by summary recommendations. Subsequent portions of the report expand on these points and provide additional details and comments on specific projects.

Strengths:

- The program has developed a very substantial historical data base on important populations of pelagic and benthic organisms for the upper estuary and Delta. This provides the primary means for detection of changes in the ecosystem and is an essential source of insights into the possible causes for long-term decline of pelagic organisms.

- The management of the IEP appears to be working well and addresses many of the issues one could expect with such a complex collaboration.

- The research effort has been guided by a conceptual model approach with the potential to allow ideas to evolve as the information base is augmented.

Weaknesses:

- The program relies too heavily on local perspectives and resources for problem analysis, research and solutions. This can give rise to a culture of common assumptions that impedes exploration of alternative possibilities.

- The step-like decline in abundance of delta smelt and other pelagic species in 2001 has been interpreted as a recent shift in environmental or biological conditions, and is driving much of the recent research effort. However, the evidence is not convincing and the interpretation is open to question.

- Interest in understanding and presumably reversing the long-term decline in pelagic organism abundance in the Bay-Delta does not appear to be associated with specific restoration targets.

- Key pieces of basic information appear to be lacking on the habitat requirements and early life stages of pelagic species of interest. For example, there is very little information on where the eggs of delta smelt can be found in the system. Likewise, there are few reliable estimates of vital rates (e.g. stage-specific growth and mortality rates) required to adequately model spatially-explicit population dynamics of pelagic species under different scenarios.

- The data analyses and dynamic models lack the sophistication to match the complexity of the dynamics in the hydrological and population/community dynamics of the Bay-Delta system.

Recommendations:

- The IEP should consider a revision to its management structure to make better use of key academic partners in program decision-making. This should be done in a manner that avoids conflicts of interest yet provides a mechanism for input to management decisions from members of the academic community who are most knowledgeable about the Bay-Delta system. Seeking annual input from a small group of external advisors is one means of addressing this issue.

- The IEP is advised to make use of peer review at all possible opportunities in awarding and reviewing of contracts and grants. While recognizing that many high-quality studies have been supported in the past through these contracts and grants, the review panel recommends this step to assure that the best possible science remains a primary criterion of present and future work in the Bay-Delta.

- While it is recognized that conducting much of the research on this ecosystem is an explicit role of the resource agencies that constitute the IEP, extra-governmental assistance is needed in portions of the program. For example, external expertise may be sought to incorporate a strong spatially-explicit perspective into sampling protocols as well as in hypothesis development and testing. An open solicitation of proposals could be a valuable means of capitalizing on additional externally available expertise in these areas, particularly from within the academic community.

- Key information gaps involving the natural history and population dynamics should be filled for species of special concern. Spawning habitat of delta smelt should be identified and data from the most successful population abundance surveys should be placed within the context of dynamic stage-structured population models. For example, the number and fecundity of adults caught in the Kodiak trawl allows a prediction of larvae at 3-, 6-, 9- and 12-mm size classes. A direct survey of eggs in natural spawning substrata would improve these estimates immensely. This could proceed to an escapement- and evasion-corrected sample of juveniles from the Fall Midwater Trawl survey. Existing index data are adequate to design this approach. The inter-stage rates then become the first draft estimates of a list of population vital rates for a model that will not tolerate ambiguity in a closed population like the delta smelt.

- Use of the DSM2 hydrodynamic model should be phased out in favor of a 3-D numerical modeling system. With regard to the biological components of the system, the habitat-quality monitoring program should be improved and expanded to recognize species-specific ontogenetic requirements within the structure of the landscape at multiple spatial scales. There should be targeted studies to elucidate critical habitat requirements of key species of concern. These recommendations are intended to provide a better foundation for future ecosystem modeling.

SPECIFIC COMMENTS AND OBSERVATIONS

Programmatic issues – Review panel members had concerns that the input of the numerous external partners may be somewhat lessened by a management structure of the IEP that relies heavily on State of California and federal agencies. For example, few if any of the leads of elements within the IEP program come from the academic sector. Further it was not clear that academic participants play much of a role in the management of the IEP outside of their grants and contracts. Thus while relying heavily on university grants and contracts, the IEP may be overlooking the opportunity to derive decision-making input from the academic-based participants in the IEP studies. We suggest that the IEP develop a relationship with a few key academic partners that allows for input to the management of the program in a manner that avoids conflict of interests with contractors/grantees.

In addition the review panel sensed that the IEP tends to utilize a few academic contractors that have a long-standing relationship with the program. While we saw no reason to expect anything but the highest quality from these studies, we were unsure if full peer review is used to evaluate the contracts/grants in these instances. To avoid any appearance of favored status with contractors/grantees, the IEP is advised to make good use of the CalFED Science Program for review and selection of science projects.

In a similar fashion, regular peer review of the long-term monitoring employed by the IEP is an excellent method to ensure that the best methods are brought into this vital part of the program. Excessive reliance on internal perspectives may inhibit creative thinking about complex scenarios (e.g., suites of factors that interact at multiple spatial and temporal scales) controlling the population dynamics of pelagic organisms. Due to the very challenging nature of the problems facing this managed ecosystem, a more open solicitation of ideas for creative solutions seems appropriate.

Research- and concept-related issues: The Delta Pelagic Species Conceptual Model has driven the program focus and analysis of existing data and was considered by the panel to provide an effective initial framework to guide an approach to resolving the issues surrounding pelagic organism decline. Plans to update and revise the conceptual model to incorporate spatially- and temporally-explicit variation in factors that would likely impact the growth, survival and reproduction of pelagic fish populations are strongly supported by the panel.

The research supported under the program falls into two basic categories of (1) monitoring changes in the physical and biological environment of the Delta and (2) identifying the mechanisms driving that change. The first provides an indication of the past and present conditions in the system and the second provides the information required to direct any changes deemed necessary to achieve some desirable system state.

Exotic species effects are actually a subset of a broader category of tropho-dynamic effects that are considering changes in prey communities on which pelagic fishes of the delta are dependent. Water project effects and toxic effects have generally aimed to identify direct impacts on survival of the pelagic species of special interest, but water project effects also include some unspecified consideration for impacts on habitat suitability for pelagic fishes. Because habitat is defined by each species rather than being an arbitrary area that can be defined by physical watershed features or the presence/absence of other species, more information on ontogenetic habitat requirements for the species of special interest may be necessary.

Although the current round of projects has been directed toward identifying the causes of a recently perceived 'step-change' decline in pelagic fish abundance, the historical record on pelagic species abundance indicates a persistent downward trend spanning more than two decades within the context of the record span (1959-2005). The currently identified 'step-change' may simply be one of a series of such events and the panel advises that the need to understand the proximate cause(s) of recent POD should not overwhelm consideration of the long-term record.

Analysis of the abundance data that led to the conclusion of a significant recent step change was based on a single model that did not account for the dynamic nature of population variations. Also, a single source of data (fall midwater trawl survey) provided most of the evidence presented to support a recent general step decline in the abundance of pelagic organisms, while other data sources (e.g., Bay study midwater and otter trawls, fish salvage data) would not have led to the same conclusion. For this and other reasons, the results are not convincing. The question of whether such a shift occurred - or whether the apparent shift is simply part of the decline that has been occurring over decades - is important. The focus on a recent step-change has led to a search for causes and solutions in the immediate vicinity of the shift, while a focus on the historical decline would draw attention to long-term changes in the system.

The issue of POD in the Sacramento-San Joaquin Delta has been a concern for decades, and the purpose of expending the resources to understand how the system functions is presumably aimed at managing the system in a way that yields water resources for human uses while maintaining some desirable biological community. Because POD has continued for so long, largely unabated, restoration of some former condition appears to be mandated. However, it is somewhat surprising that specific restoration targets are not explicitly identified. For example, what is the desirable range (upper and/or lower threshold) of abundance for delta smelt or any other pelagic organism of interest in the Sacramento-San Joaquin Delta? Restoration of any ecosystem requires a set of specific goals or targets in order to measure success or failure.

Comments on Statistical Analyses

The statistical analyses conducted so far as part of the IEP program have tended to be relatively simple and exploratory in nature. In moving ahead, it will be important to base the analysis of data on a scientific model of the ecosystem in the upper San Francisco Estuary. In broad terms, the situation in the upper estuary involves spatial and temporal environmental variations (e.g., in hydrodynamics, toxics, habitat quality, etc.) acting upon the vital rates (e.g., fecundity, mortality, etc.) of spatially structured, trophically linked community that is itself changing through species introductions. In such a complex situation, simple analyses – for example, those aimed at correlating one variable with another – may be uninformative or even misleading.

Even interpreting variations in the abundance of a single population must rest on an understanding of its population dynamics. The analyses that identified step changes in the abundances of delta smelt and other pelagic organisms were based on a statistical model that failed to account for even the simplest kind of population dynamics in which abundance in one year depends on abundance in the previous year. Dynamics of this kind can give rise to an apparent step change in abundance without involving a shift in vital rates.

The basic model used in the analysis to test the significance of a step change has the form:

$$\log Y_t = f(t) + \varepsilon_t \qquad (1)$$

where Y_t is catch per unit effort (CPUE) in period t, $f(t)$ is a polynomial function of time that can include a step function, and ε_t is a normal error with mean 0 and variance σ^2. As an aside, the time of the possible step change is identified based on the data, but is left explicitly unspecified because it is recognized that using the same data to hypothesize and test for a step is inappropriate. This is a mildly tricky point and more could be done here. For example, it should be possible to test for a step change at an unknown time that is *common* to all species.

One could also argue with the use of principal components analysis to derive an index series for a multi-species complex, but the main concern remains the form of the model in (1). A basic assumption is that CPUE is proportional to abundance. This is a common assumption but may be worth a more detailed look. The assumption that CPUE is proportional to abundance may not be correct for schooling fish, especially when abundance is low. Even if the proportionality assumption is correct, changes in the sampling methods over time can affect the constant of proportionality. For the present, however, CPUE is assumed proportional to abundance and Y_t is treated as abundance.

A simple model for the dynamics of a fish (or other) population is:

$$Y_t = Y_{t-1}\, g_{t-1}(Y_{t-1}) \exp(\varepsilon_t) \qquad (2)$$

where *g* is the growth function. This model can be written as:

$$\log(Y_t / Y_{t-1}) = h_{t-1}(Y_{t-1}) + \varepsilon_t \qquad (3)$$

where *h* = log *g*. Consider the simple case:

$$g_{t-1}(Y_{t-1}) = \exp(\beta_o + \beta_1 (t-1)) \qquad (4)$$

where the growth function does not depend on abundance (i.e., density independence) and is log linear in time. Substituting (4) into (3) gives:

$$\log(Y_t / Y_{t-1}) = \gamma_o + \beta_1 t + \varepsilon_t \qquad (5)$$

where $\gamma_o = \beta_o - \beta_1$. Thus, it is the annual growth rate $\log(Y_t / Y_{t-1})$ that is a linear function of time, not log abundance as in (1).

For these and other reasons, the reality of the step change remains open to question. This issue is central to the design of the IEP program. If a step change in vital rates did indeed occur, then it makes sense to search for environmental or other changes that occurred immediately preceding the change. On the other hand, if no such step change occurred, the question as to its cause is moot and research should focus on the causes of the long-term decline.

More generally, in using historical data to infer the effect of an environmental variable on a biological population, it is important to go beyond simply attempting to establish a correlation between the environmental variable and abundance. Instead, inference should be based on an understanding of the direct effect of the environmental variable on population dynamics (e.g., on one or more vital rates) and how this direct effect would be reflected in abundance. As noted, when several factors are operating simultaneously, in identifying the effect of one, there is a need to control for the others through multivariate methods.

The review panel has a particular concern over the need for more spatially explicit data analysis. On the technical side, even when interest centers on average or aggregate quantities, there is a need to understand spatial variability to average or aggregate in an optimal way and for constructing confidence intervals or other measures of uncertainty. Furthermore, an understanding of both spatial and temporal variability is needed for efficient sampling design. More generally, spatial patterns in the variations over time in environmental conditions, vital rates, etc. are likely to be useful in distinguishing between alternative hypotheses about the factors contributing to the decline. The regional perspective outlined in the 2005 IEP synthesis report is a good step in this direction.

Comments on Contaminants studies

There is a paucity of historical data on contaminants and their potential effects in the Delta region of the San Francisco Estuary due to both the resistance of some government agencies to more actively investigate them and in the long held belief of many agency biologists that the existing problems in the Delta were due to other factors. So, turning belatedly to contaminants as a potential major factor in the decline of fish populations raises formidable challenges both from lack of historical data and construction of imaginative approaches to answering the obvious but difficult questions. Due to lack of attention, the thinking about these problems has not matured too far in many quarters. For example, there is an undue reliance on short-term survival bioassays, which were developed for regulatory tools in water quality management with no guarantees that they do indeed identify low-level chronic effects over multiple generations. These assay results may or may not be relevant to long-term toxicity, but there is a significant chance that any toxic problems from long-term, low-level exposures will not be manifest in or linked to such assay results. It is evident that some of the UC Davis biologists have taken seriously the possibility that long-term, sub-lethal effects are having effects and have produced some excellent studies and publications in this area. Most of these studies have included histopathological analyses with an emphasis on parsing the findings between toxic impacts and amounts of storage products available (e.g., glycogen) for various energetic demands. The histopathology findings will be useful only if they point to the life stage and mode of impairment caused by contaminants. Other studies can then be designed to measure changes in survival, fitness, growth and reproduction, as appropriate.

Looking for alterations in survival, fitness, growth and reproduction of delta fish species due to low-level exposures to biologically active mixtures of contaminants is the most productive approach to this potential aspect of the problem. This top-down approach will also yield data that can, in theory, be linked to other data needed by population modelers and possibly show where other factors can interact with contaminants, a possibility that we need to anticipate. The challenge is to link what has or can be done on alterations of normal biochemistry, physiology and anatomy to their ultimate contributions (positive or negative) to the population trajectories.

EXPANDED MONITORING

Overall expanded monitoring of the Bay-Delta is a very good idea. The review panel suggests that substantial consideration be given to enhanced spatial sampling to complement the current long-term temporal sampling program.

Delta smelt larvae survey – Expansion of surveys designed to assess abundance of early life stages of delta smelt and the other species of special interest are encouraged, if feasible. Although the addition of the surface nets for collection of larvae was considered feasible and efficient, this was largely because augmented sampling did not add significantly to survey duration. Relatively few larvae were actually captured. Perhaps additional consideration should be given to sampling locations for larvae and other early life stages (e.g., eggs). Ontogenetic shifts in habitat use are likely (i.e. the entire life history of some species, such as delta smelt, is not wholly spent in the pelagic environment), and sampling methods should consider issues such as location of spawning sites (e.g. where in the system, whether submerged aquatic vegetation is important), and whether current sampling methods are adequate and appropriately located to assess the abundance of early life stages for this and other species of interest.

Summer townet survey – The fact that indices of abundance for both striped bass and delta smelt were at or near historical lows may not reliably indicate the direction of the actual population change because the values are not likely to be distinguishable from zero even if they doubled. Once the populations reach the low levels achieved in recent years, one would not expect to observe a rapid increase in abundance from such a low standing stock, especially with delta smelt which have a relatively low fecundity for a small pelagic species. Even population growth rates that are increasing exponentially are difficult to detect at the low end of the population size curve. One would not expect the abundance indices to be sufficiently sensitive to measure an increase or decline at such low levels. For example, given that the abundance index for delta smelt currently stands at 0.3, the value would have to quadruple before reaching even 10% of the mean values observed in the 1960s and 70s. At these low levels, the populations are in 'stealth mode' and it will be very difficult to determine the direction of changes in abundance with any reasonable confidence.

Fall midwater trawl (FMWT) – This is the longest and most consistent of the time series data describing abundance of pelagic species of interest. It is expected that the FMWT surveys will continue to build on the historical database. Although the annual index for 2005 awaits the completion of the September to December survey set, it seems likely that the delta smelt and striped bass populations will remain perilously low. Whatever the cause for the pelagic organism decline, this situation requires constant and consistent attention. With the progressive decline in the number of tows yielding fish, the FMWT surveys have suffered a decline in precision, such that it may be difficult to detect even relatively large proportional changes (i.e. an increase or decrease of 100% of a small number is still a small number). Even as knowledge about the threatened species improves and as quantitative and regional approaches begin to replace the index, these rigorously standardized tows and sample patterns will continue to contribute to tracking broad scale trends in population abundance of pelagic organisms over the long term.

Other focused sample collections – feeding habits and condition, histopathology and *Microcystis* studies – These studies were a natural extension of perceived needs for information and should be completed. The continuation of a program of focused studies to address information gaps as they arise is encouraged, but caution is advised to avoid chasing causes of short-term variation at the expense of understanding the large-scale trends in system changes. Most of the focused studies are expected to provide discrete packets of information necessary to address specific information gaps over a finite period and should not normally be considered long-term or continuing contributions to the program. Some of these should focus on habitat quality, specifically with respect to aspects of life history features that are poorly understood (e.g. delta smelt spawning sites).

ANALYSES OF EXISTING DATA

Additional analysis of existing data is highly encouraged. The collective sense of the review panel is that the IEP databases contain a lot of good information that can greatly help to “connect the dots” in the POD. Further, the review team senses that the current staff of the IEP is running as hard as they can to keep up with the challenging situation in the Bay-Delta. Thus to make good inroads into the analysis of existing IEP data, additional staff should be brought on board to either relieve staff from current activities or to undertake the additional data analysis.

Summarize the spatial and seasonal presence of early-life stages of pelagic fishes and zooplankton – The seasonal presence data provide a good measure of when to expect the various life stages of each species in the estuary, but there appears to be less information on spatial habitat requirements, especially for spawning habitat of fishes. This may be of particular importance in the case of delta smelt, which have demersal eggs – the survival of which may depend on submerged aquatic vegetation or shallow waterways associated with intertidal habitat. The review panel had the impression that other likely spawning substrata (e.g. clean cobble or pebble beds) were uncommon in the system. Are the data on spatial requirements – in terms of habitat for early life stages – comfortably complete?

Apparent growth rates of pelagic fishes and relationships to abundance -- Growth rates based on length frequency distributions over time can be misleading under conditions of different sources of size-specific mortality. The apparent growth rates from this method seem unrealistically high (1.2-3.7 mm/day), as is often the case using this method. The analysis of growth based on otolith data should help here. In fact, growth data estimated from otolith analysis puts growth (0.34 – 0.37 mm/d) at almost an order of magnitude lower than that derived from size frequency data. Although otolith analysis is not without problems (e.g. still applies only to growth of survivors), growth data from this source provide more reliable and realistic measures of growth rates within a cohort. The review panel recommends this approach over continued use of size frequency to estimate actual fish growth rates, though recognizing that analysis of size frequencies are quicker, less expensive and can provide a useful means of comparing spatial and temporal variation in relative growth rates. Perhaps there could be a focused study on individual growth rates using marked (ferromagnetic tags) fishes in different parts of the estuary. This may be more feasible for striped bass than the smelts or shad. It may also provide data on movements of individuals within the estuary, which will assist in refining the spatial extent of habitat for each species.

Zooplankton fecundity and population structure – Monitoring the quantity and quality of the food supply available to pelagic fishes and understanding the factors responsible for temporal and spatial variation in this crucial resource for pelagic fishes is important. However, the level of resources necessary to provide crucial information on zooplankton populations is largely determined by whether this group is included among the specific pelagic organisms of concern or is viewed as a prey resource for pelagic organisms. Measures of fecundity and population size structure of these populations, if viewed as prey, may provide more detail than is necessary at this point to identify the proximate factors responsible for changes in pelagic community structure and abundance.

Toxic and other harmful effects of Microcystis aeruginosa blooms – The occurrence of *Microcystis* and other harmful algal blooms (HAB) may be more symptomatic of changes in turbidity/light levels or nutrient inputs with the Delta system. Blooms do not appear to be sufficiently widespread to be a feasible explanation for either the long-term or recent step-declines in pelagic fishes. Though worthy of pursuit as part of monitoring the larger system-wide changes that continue to occur in the Delta, HAB may be considered an additional symptomatic response to environmental stressors associated with human uses within the watershed. Studies of *Microcystis* should be completed as planned but if expanded in the future should be aimed at providing information applicable to the control of HABs in the system, with less emphasis on their effects on other components of the biological community, which can reasonably assumed to be negative. An additional useful perspective is to view *Microcystis* toxins as one a number of stressors that fish populations may face.

Use and toxicity of pyrethroid pesticides - It appears that pyrethroid insecticides are increasingly finding their way into the Delta from urban development and agricultural activities in the Sacramento-San Joaquin watershed. One might expect the toxic effects of these compounds to manifest in the primary prey communities (small crustaceans) of pelagic fishes before they reach levels that are sufficiently toxic to cause direct mortality of fishes. As these compounds represent only one group of contaminants that are expected to affect the biological communities of the Delta in the future, it may be less important to describe their specific effects in the system than to seek ways of reducing contaminant inputs to the Delta. However, given the known sensitivity of fish and invertebrates to pyrethroids and their increasing use in the watershed, this would be a good time to rapidly determine whether pyrethroid concentrations are involved in, or can be ruled out as, playing a major role in the recent POD. Without chemical measurements at key points in the environment where these compounds are suspected of having effects little progress can be made. Expanded, integrated chemical measurements of pyrethroids may be necessary to resolve their potential role in toxic effects as well as to raise awareness of other chemicals that my be having effects.

Use and toxicity of aquatic herbicides – One question that did seem to be considered with respect to aquatic herbicides is whether or not submerged aquatic vegetation (SAV) is providing a positive or negative habitat function for the early life stages of pelagic fishes. Is it worth considering the potential effects of herbicide use on spawning habitat of delta smelt or other species of interest? Spawning habitat and spawning substrata used by delta smelt in the Sacramento-San Joaquin delta region is unknown and a significant information gap in the life history of this species (see p. 13 and p. 59 in Bennett 2005, San Francisco Estuary and Watershed Science 3(2):1-71). If either shallow subtidal or intertidal vegetation play a role as spawning habitat for this species, it could provide a link between essential fish habitat and the application of aquatic herbicides, even if there are no lethal direct effects of the herbicides or the carrier compounds (e.g. surfactants) on the fishes.

Evaluation of changes in pelagic fish habitat quality using the IEP long-term monitoring data - This study was intended to characterize the aquatic area in the Delta that has suitable water quality conditions for young of the year delta smelt and striped bass. It determined that quantity of physical habitat has not decreased since 1970. However, the primary parameters defining 'physical habitat' were not clearly stated in the synthesis report and it is important to note that water quality is not the only factor that influences 'physical habitat'. Physical features of the landscape (channel edge configurations, depth, etc) that influence access to spawning or foraging sub-habitats can be very important in estuarine fish production (see Kneib 2003, Mar Ecol Prog Ser 264:279-296) and the configuration of intertidal landscapes are aspects of habitat quality that can be related to the abundance of nektonic populations in adjacent subtidal environments (see Webb & Kneib 2002, Mar Ecol Prog Ser 232:213-223).

Analysis/summary of recent changes in delta water operations – The emphasis on characterizing recent changes in water project operations in an attempt to account for an apparent step-change in pelagic fish abundance is understandable in terms of political pressure to do something now. However, if POD cannot be understood from an historical perspective, it would seem there is little chance of identifying a specific cause(s) for what is only the last portion of the variation in the record of fish abundance.

There are many reasons to be concerned about a focus on a time period that is too narrow, not the least of which is that conditions are likely to change in the near-term as well as long-term future. Also, some fish numbers are already low and it will be difficult to identify subsequent real changes in abundance – either up or down. The panel was surprised by the lack of data from certain sources that should have been readily available (e.g. fish losses due to impingement and entrainment associated with the operation of power plants in the Delta). It is important to obtain this information and compare it to the historical record of fish abundance based on independent surveys.

It would be useful to relate salvage densities to regional abundance indices because there is no *a priori* reason to expect the water diversion activities to operate in a density-dependent manner on pelagic organisms (i.e. salvage capture should be proportional to the size of the population). Independent collections of fishes in the net survey stations nearest the water diversion operations should be consistent with the salvage measures of fish abundance. If this is not true, then one or the other (or both) is inadequately representing the status of the fish populations.

Analysis of historical population dynamics – To date, the focus of this analysis has been on method development, and on recent (since 2001) changes in fish abundance indices. The principal source of evidence for a recent general 'step-change' in pelagic fish abundance appears to come from a single model approach (log-linear analysis) applied to the Fall Mid-water Trawl Data. Other approaches and data sources either do not support a significant recent step-change or provide weaker evidence for such a conclusion, particularly in the context of earlier historical changes in fish abundance patterns. This only strengthens the position that investment in investigations of the causes of POD should not sacrifice the goal of understanding factors underlying long-term patterns of decline in attempts to respond to recent short-term variation in the populations.

NEW STUDIES

Evaluation of delta smelt otolith microstructure and microchemistry – This line of research holds considerable promise for resolving a variety of crucial issues involving growth rates, movements and habitat use patterns involving pelagic fishes. As mentioned previously, use of otoliths to estimate growth rates is far superior to reliance on 'apparent growth rates' from length frequency analysis because otoliths analysis can be used to measure individual growth rates at multiple life stages. Mean or modal sizes of individuals are usually influenced by size-specific (or stage-specific) differences in mortality and reflect the cumulative influence of all physical and biological effects that shape the size structure of the population of survivors. Growth estimates from otoliths, while still measuring only the growth of cohort survivors, are not only more accurate but can provide insights into seasonal variation in growth. Furthermore, data from otolith microchemistry can provide insights into natal origin and movements within the estuary assuming there are reliable data on spatial and temporal variation in the chemical indicators used. These studies should be continued and expanded to other species of interest.

Liver histopathology and general pathobiology (starvation disease, and toxic exposure) for pelagic fishes – This study examined pelagic fishes for lesions which could be due to either starvation, disease or exposure to toxic chemicals, but the findings have limited applicablility because there is no identified path to link its findings to POD. Further, examining just a few sections of liver could miss significant lesions. More importantly, previous studies have identified other organ systems that are sensitive to the effects of contaminants (nervous system, reproductive system, respiratory system, i.e., gills, excretory system) and none of these were systematically examined. The authors did note that some gonads exhibited intersex conditions in 5-10% of the species examined, a finding of potential significance.

This study may characterize the general effects of environmental stressors on morbidity in pelagic fishes, but what can the findings contribute to a solution? Stressors acting on early life stages would be missed because the affected individuals likely died and are no longer in the population to present their condition. Furthermore, 'the general conclusion of the pathological reports was that findings were not out of the ordinary for wild fish populations.' Based on the results in hand the only conclusion may be that the pelagic fishes are under stress(es) and this in itself is not a great discovery. A multivariate analysis of the histopathology results with other variables might shed some insight into the stresses that impact the livers of these fishes.

The approaches to understanding the population-level effects of contaminants are much broader than histopathology. For example, one could relate growth and reproduction to contaminant concentrations in tissues, use alternative biomarkers, measure effects of experimental exposures to complex mixtures of contaminants, include much more environmental chemistry, etc. Then there is the real potential for interactive effects of contaminants with disease, food limitation, HABs, etc.

There appears to be no compelling reason to continue this work beyond completion of the 2005 sample analyses. Broader based creative approaches are needed to assess the potential role of contaminants in population trajectories. Some of the current work on striped bass shows real evidence of a broader based approach beyond what was done in summer of 2005.

Analysis of stomach contents, weight and parasites – These studies are time-consuming but could be essential basic information as input to a system-wide tropho-dynamic model if this is a direction later deemed of value. It is unlikely that samples could be processed within a sufficient time frame to track real-time changes in food supply. The simultaneous collection of pelagic fishes and zooplankton in net surveys would more directly address the issue of the availability of an adequate food supply. However, periodically sampling the stomach contents of fish populations would provide information on selective feeding by fishes. Plans to continue this study into 2006 based on the 2005 results is well advised but there is no compelling reason to invest a large effort in the analysis of stomach contents.

Field survey of *Microcystis aeruginosa* bloom biomass toxicity – Harmful algal blooms have affected fish populations in many estuaries undergoing eutrophication. Whether increased nutrient or light availability have been the principal factor(s) in the apparent expansion of Microcystis populations in the Delta remains to be seen. The research to date on *Microcystis* in the Delta has focused on identifying areas where the species is most abundant and in measuring the presence of microcystins in the food web below the level of fishes. It may be more important in considering the continued development of this area of research to establish a connection between *Microcystis* and pelagic fishes in the system. Is there any evidence of an association between fish kills and blooms of *Microcystis* or other potential HABs in the Delta? Historically, *Microcystis* blooms have not been identified as an issue in connection with historical POD. However, the IEP is encouraged to look into remote sensing techniques to develop a more cost effective way to assess the distribution of *Microcystis.* The collection of spot samples can continue to serve as the source of information to evaluate toxicity. Because there seems to be little doubt as to the toxic nature of *Microcystis* a suggestion is to place more emphasis on aerial distributions and bloom status (rapidly growing versus senescent) rather than toxicity testing. Unless a link can be established between *Microcystis* and pelagic fish population dynamics, continued research in this area may be more pertinent to the development of an ecosystem-level model of the estuary than to the search for the underlying causes of POD.

Acute and chronic invertebrate and fish toxicity tests -- There appeared to be little evidence of toxic effects of ambient levels of microcystins in Delta fishes. Although other compounds entering the system may be having negative effects on fishes and/or their primary prey resources either now or in the near future, it is unclear that this area of research will be strongly connected to the current or historical decline in pelagic fish abundance. Short-term assay results may not be linked to any underlying chronic toxicity affecting pelagic fish populations in the estuary. The findings of this study indicated some effects on certain crustaceans (e.g. amphipod, *H. azteca* and copepod, *P. forbesi*) within portions of the watershed, but no significant toxicity to fishes and other crustaceans (e.g. cladoceran, *C. dubia*). The review panel recommends completing toxicity tests as proposed in the 2005 Synthesis Report and 2006-2007 work plan. However, a broader based approach to potential long-term low-level effects of contaminants on these populations is needed.

Striped bass and delta smelt fecundity estimates -- Changes in individual fecundity do not appear to be related to POD, though population fecundity (due to low population sizes) will undoubtedly affect the speed with which pelagic fish populations recover from their historically low levels. These data will provide important input in the development of model of population dynamics, but appear to be sufficiently predictable to allow acceptable parameter estimates without additional sampling. The review panel recommends proceeding as proposed in the 2005 Synthesis Report and 2006-2007 work plan to complete the fecundity estimates. Spot checks of fecundity could be conducted to make sure that fecundity has not dropped and if yes, intensify this program. Otherwise do not expand the estimates until signs of lowered fecundity emerge.

Trends in benthic macrofauna biomass – With exception of some information on *Corbula* populations, particularly in the vicinity of Suisun Bay, there was little information on the benthic assemblages or their potential role in POD. Obtaining a sufficient number of benthic samples and the time involved in sample processing, can make this a very tedious source of information. While essential for developing linkages between benthic and pelagic portions of the system, this area may best fit into long-range plans for development of an ecosystem model of the Delta. The review panel recommends completing the sample analysis as proposed in the 2005 Synthesis Report and developing a refined sampling program for 2006 if warranted based on the 2005 results.

ONGOING STUDIES

Learning from the DSM-2 particle tracking model - The Winter Adult Entrainment (WAE) Hypothesis in the IEP Synthesis of 2005 Work relies on the Delta Simulation Model 2 (DSM2) hydrodynamic model to see if adult fish are being drawn closer to the Central Valley Project (CVP) and State Water Project (SWP) intakes, relative to the situation in the past. The model is a web of 1-Dimensional channels, calibrated to reproduce water transports due to tides, rivers, gates, and water project exports. The DSM2 has a number of advantages and disadvantages. While this approach has provided a good start, on balance, it may be best to phase it out in favor of more sophisticated modeling tools.

DSM2 Advantages:

- It is simple, runs on a personal computer (PC), and can be run by a number of different users in different agencies.
- It is linked to a particle tracking model.

- It has been validated against observed volume transport time series at many locations throughout the Delta.
- In its current form the DSM2 model appears to be adequate to answer questions raised by the WAE Hypothesis.

DSM2 Disadvantages:

- While the model can apparently include the transport of electrical conductivity (which is related to salinity and temperature) as a tracer, it does not have vertical density stratification, and thus may underestimate the potential for up-estuary salt intrusion.
- The documentation of the model leaves much to be desired. The most recent report on model calibration and validation available on the web was: http://www.iep.ca.gov/dsm2pwt/reports/DSM2FinalReport_v07-19-02.pdf. This report had many missing sections, which is understandable since it was a draft. However for a tool such as this to have scientific credibility it <u>needs</u> support from publications in the refereed scientific or engineering literature.
- The model does not include the effects of wind, which could, for short times, substantially alter transports.
- The model does not include temperature as a tracer. Given that habitat for spawning pelagic fish in the Delta has a defined temperature range, this seems like a crucial variable.
- The model, by it very nature as a web of 1-D channels, has difficulty with the hydrodynamics at channel junctions. With model physics of this simplicity, it is hard for the model to decide how much water should go "left or right" when it gets to a junction.
- The model treatment of marshes (e.g. fields reclaimed by dike removal) is extremely simplified, and seems unlikely to be able to address the potential for these areas to enhance primary productivity in the Delta.

Overall the DSM2 model is a good tool for its current uses, but it is not a good framework for any future "ecosystem modeling." A more modern circulation model can include 3-D effects, and can keep track of many more tracers (temperature, nitrate, plankton, even particles with fish-like behavior). Many scientists currently use such numerical tools for ecosystem modeling (e.g. Nutrient-Phytoplankton-Zooplankton-Detritus or "NPZD" models). While this is still far from an exact science, it is precisely the sort of tool that would be useful in exploring the effects of different management scenarios.

We do not recommend that the IEP undertake the effort to create a full ecosystem model of the Delta right now. However we do strongly recommend that they migrate to the use of circulation models, which could be used as a framework for future ecosystem modeling. Examples of such 3-D circulation models currently in use would be CORIE (Antonio Baptista, Oregon Health & Science University), the Finite Volume Community Ocean Model (FVCOM, Changsheng Chen, UMass Dartmouth), and the Tidal, Residual, Intertidal Mudflat 3-D (TRIM3D) Model already in use for modeling SF Bay and the Delta. All are appropriate for use in the complex channel system of the Delta, and are documented by peer-reviewed publications. Key considerations in choosing a model are that its code be open-source (e.g., the

CORIE system) and that it has earned acceptance by the estuarine modeling community.

An important issue to consider when migrating to a more complex circulation model is how it will be done in terms of staff. Running such models requires the effort of a dedicated, talented scientist, usually working with a programmer and substantial computing resources (although these don't cost much compared to field work). IEP could consider developing such expertise through collaborations with scientists at research universities in the region.

There is a strong trend in coastal and estuarine oceanography to move away from single "expedition-style" experiments and toward "observatory science" which involves integrating real-time observations from different disciplines in a given region. This is funded by NSF through the Ocean Research Interactive Observatory Networks (ORION) program and, on the more applied-operational side, by NOAA through the Integrated Ocean Observing System (IOOS) program. Given the substantial observational effort already underway in the San Francisco Estuary and Delta it would make sense to begin thinking of it in terms of an "observatory." An important step in this direction would be to have a modeling effort such as the 3-D modeling suggested above, that has the potential to integrate and assimilate many different sorts of observations. The benefit is that eventually we will have models of estuarine systems that have real predictive capability, much as is done in weather forecasting.

The review panel recommends a substantial upgrade of this model that in turn will require more sophisticated analysis of particle tracking and the impact of particle movements on pelagic organisms in the Bay-Delta.

South Delta Fisheries-Hydrodynamics studies - This and similar studies are useful in predicting an expected level of mortality under different scenarios associated with water diversion projects, but to determine the Delta-wide impact of fish mortality associated with water diversion operations, the effects must be placed within the context of the entire population, not just the subset susceptible to entrainment. Impacts of water diversion projects on pelagic fish populations are not expected to act in a density-dependent fashion. The fish salvage data together with entrainment/impingement losses associated with power plant operations should provide a measure of density independent losses due to these uses of the shared water resources.

Phytoplankton primary production and biomass in the Delta – Shifting algal species, harmful algal blooms, a change from autotrophy to heterotrophy, a shift from a pelagic-dominated to benthic-dominated food web are all key factors influencing the overall health of the Bay-Delta. The phytoplankton studies may be key in revealing the changes.

Research to date in this area has not supported the hypothesis that variation in phytoplankton communities has had substantive effects on food web dynamics that impact pelagic fishes. While there appears to be little direct evidence of a link between phytoplankton primary production and recent POD, unpublished comments from one of the current IEP funded academic partners suggest that historical declines in the quality of phytoplankton resources may be consistent with the long-term POD in the Bay-Delta. The somewhat conflicting evidence from this very important aspect of the food web suggests that additional effort is needed in this area.

Retrospective analysis of long-term benthic community data – Estuarine benthic communities are notoriously variable and often difficult to sample adequately. The focus here on bivalves increases the likelihood of developing functional links between the benthic and pelagic food webs. Although invasive bivalve species in the system are suspected of impacting phytoplankton production, the connection between known historical shifts in benthic assemblages and POD remains unclear. There are examples of other aquatic systems in which invasions of non-indigenous benthic species (e.g. zebra mussels) have induced major shifts in food web dynamics and ecosystem functioning. A modest investment of IEP resources may yield important inferences related to the long-term decline of pelagic organisms in the Bay-Delta.

SUMMARY

The long-term data sets developed by this program consist of time series of indices intended to reflect variation in population abundance. They serve primarily as an excellent means for detection of change. To implement studies for determining likely causes and remedial actions, several improvements are required in certain areas of the program including statistical procedures, modeling of physical and biological components of the system, and the development of targets for restoration.

Studies supported to date have helped to address specific questions of potential importance. Some of these have fulfilled their goals and purpose, while others may need to be continued or expanded. There is need for an expanded effort to fill information gaps on basic natural history of the species targeted by the program in order to characterize and understand POD. Studies involving crucial habitat (e.g. spawning habitat for delta smelt) or the estimation of vital rates (e.g. mortality and growth rates) should be conducted in a spatially-explicit manner to allow spatial pattern mapping and integration into landscape-level models. The review panel considered it crucial that new process studies should augment but not replace the time series surveys that will continue to provide context for the directed studies.

More frequent and focused sampling activity will be necessary to rectify differences in species composition and abundance as determined by tow surveys versus other sources of samples (e.g. fish salvage from water diversion operations and monitoring of impingement and entrainment at power stations, the data for which should be made available). The existing time series is insufficient for evaluating and designing management actions to minimize effects of whatever factor or synergistic suite of factors is found to cause POD.

Explicit restoration goals and targets should be developed for delta smelt and other pelagic organisms of concern. It is crucial to establish an intended target if restoration and maintenance of certain pelagic species populations within the system is the desirable condition. Implicit within the establishment of target ranges for population abundance values is the development of triggers for adaptive management. A worthy goal is to allow the ecosystem to become self-sustaining, but in highly managed systems, such as the Sacramento-San Joaquin Delta, this may be impractical and continued monitoring with triggers for corrective management actions will likely be a necessity.

Laboratory studies of contaminant effects, harmful algal bloom toxicity and starvation on vital rates within different life stages of pelagic organisms should be coupled to yield first-order estimates of life table parameters. These, in turn, will serve as starting points for improved life history models for evaluating the decline and recovery of pelagic organisms in the Bay/Delta region.