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Bay-Delta Workshop 2
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Additional Scientific Information Related to Pelagic Fish Species, Recommended Changes to the Bay-Delta Water Quality Control Plan, and Recommendations to Address Scientific Uncertainty and Changing Circumstances

Workshop 2: Bay-Delta Fishery Resources

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Submitted to the State Water Resources Control Board on behalf of:
The Bay Institute
Natural Resources Defense Council

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I. Response to Question 1: Additional Scientific Information and Recommended Changes to the Bay-Delta Water Quality Control Plan Regarding Pelagic Fish Species

In order to protect pelagic fishery resources,[1] the State Board's 2010 Delta Flow Report identified more flow, of a more natural flow pattern, including increased winter/spring Delta inflows and outflow, limitations on reverse Old & Middle River (OMR) flows and exports, and increased fall Delta outflows. New scientific information developed since 2010 largely confirm these recommendations and the Board's conclusion that "*the best available science suggests that current flows are insufficient to protect public trust resources*" (SWRCB 2010:2). For longfin smelt and other estuarine species, spring outflow continues to be the driver of abundance, and, as demonstrated by the high entrainment rates seen in 2012, additional restrictions to reduce and limit entrainment of adult, larval, and juvenile longfin smelt in the winter and spring months are necessary. For Delta smelt, substantial scientific information shows the necessity of limiting entrainment through OMR restrictions and the necessity and benefits of providing increased fall outflows. Additional evidence suggests that Sacramento splittail and other fishes benefit from increased flow rates on inundated floodplains, but that limitations on entrainment are also important (2011 was a record year for entrainment of Sacramento splittail (~9,000,000 individuals were salvaged at the SWP/CVP facility). And new scientific information since 2010 continues to show strong relationships between Delta outflow and the abundance of zooplankton and copepods that comprise much of the prey base for these species (diversions and barriers also play a role in altering and reducing available food supply).

Freshwater flow continues to be the "master variable" driving the health and productivity of the San Francisco Bay-Delta estuary, other estuarine systems, and pelagic fisheries. In our submission for Workshop 1 (cited here as TBI et al 2012), and in our prior submissions to the Board's 2010 proceedings (TBI et al. 2010), we:

- Identified the population status of pelagic fish species in the Delta;
- Documented the substantial declines in seasonal outflow due to increased diversions, particularly in recent decades by the State and Federal water projects;
- Documented the scientific basis demonstrating that improved outflow during the winter/spring, and fall (and possibly late summer) months is necessary to protect and restore pelagic fisheries;
- Discussed new science relating to other stressors on pelagic fisheries and the health of the estuary, including scientific information demonstrating that flow and physical habitat interact but are not interchangeable; and,
- Provided detailed information to guide the Board's development of adaptive management in the program of implementation.

[1] Pelagic fishes are those that spend all or most of their lives in open, flat water. For our purposes here, "pelagic" fishes include native smelt species (longfin and Delta), starry flounder, and striped bass as well as zooplankton and the foodwebs for these species. For simplicity (to avoid creating another category) we also include in this group Sacramento splittail, which are much more associated with shallow water habitats on the margin of larger water bodies.

In this submission we briefly summarize those prior findings and focus on issues relating to entrainment and in-Delta flows (including OMR flows), which were not previously addressed in Workshop 1. Based on the available scientific information, we conclude that these new studies and publications support the Board's findings in the 2010 Delta Flow Report, including:

(1) Existing flows are inadequate to protect Public Trust resources;
(2) Winter/Spring outflows should be substantially increased to levels that are sufficient to achieving restored population viability and ecosystem function, and should be implemented as a percentage of unimpaired flows occurring in a narrow averaging period;
(3) Fall (and possibly late summer) outflows should be increased to provide sufficient habitat, especially following wetter year types;
(4) Restrictions are needed to limit entrainment and poor survival in the Delta, beyond those described in the federal biological opinions and the State Incidental Take Permit for longfin smelt, including OMR flows and restrictions on exports; and
(5) Non-flow measures (such as physical habitat) interact with flow, but are not interchangeable and cannot substitute for flow.

A. FRESHWATER FLOW IS A "MASTER VARIABLE"[2] DRIVING THE HEALTH AND PRODUCTIVITY OF THE SAN FRANCISCO BAY-DELTA AND OTHER ESTUARINE ECOSYSTEMS.

In the hearing process that culminated in the Delta Flow Report (SWRCB 2010), and again in Workshop 1, the Board heard overwhelming scientific evidence that declines in freshwater flow into, through, and out of the Delta, resulting from increasingly intrusive human water management activities (diversions and storage), play a central role in the both the long-term and shorter-term declines in our once-abundant fisheries.[3] After reviewing this wealth of evidence, the State Board found:

> *The best available science suggests that current flows are insufficient to protect public trust resources.* [SWRCB 2010:2].

In its closing comments in the 2010 proceeding, the U.S. Department of Interior concluded that:[4]

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[2] I interpret this term, coined by Poff et al. 1997, to mean that freshwater flow drives or strongly interacts with a wide variety of ecosystem variables and processes of importance to the physical characteristics and biota of river and estuarine systems. I interpret testimony during workshop #1 of this proceeding, from Dr. Cliff Dahm and Dr. Ted Sommer (DWR) to be completely consistent with this meaning of the term.

[3] These findings do not diminish the imperative to address other long-standing or emerging stressors to the Bay-Delta ecosystem, including water quality issues, sediment toxins such as selenium, and habitat loss; however, the evidence and testimony provided to the State Board demonstrates unequivocally that improved freshwater flow conditions (increased volumes of freshwater flow during key periods that match the needs imposed by the life histories and ecology of key species) must be part of any real solution to the Bay-Delta's ecological collapse – flow improvements are essential, even if flows alone are insufficient to address all the Bay-Delta's environmental challenges.

[4] United States Department of Interior. July 29, 2010. Comments regarding the California State Water Resources Control Board Draft Report: Development of flow criteria for the Sacramento-San Joaquin Delta Ecosystem. Available at:

> *Native fish populations dependent on the Delta have declined across the board, with some species on the brink of extinction. Food web dynamics have undergone significant changes in both abundance and composition. While we do not discount the importance of other stressors on the Delta ecosystem, such as urban runoff, other pollutants, and invasive species, flow in the Delta is one of the primary determinants of habitat availability and one of the most important components of ecosystem function. Timing, magnitude and variability of flow are the primary drivers of physical habitat conditions including: turbidity, temperature, particle residence time, nutrient loading, etc. The Draft report's recommendations to mimic the natural hydrograph under different hydrological conditions (both Delta inflows and Delta outflow) is consistent with the information provided to the State Board by most of the scientific experts involved in this process.* [p. 1]

Subsequent scientific information discussed in our Workshop 1 submission and below reinforces these conclusions.

[California Department of Fish and Game. 2010. Quantifiable biological objectives and flow criteria for aquatic and terrestrial species of concern dependent on the Delta. Available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=25987]

DFG's final report on flow criteria for the Delta was released in December 2010. The Department concluded that,

> *Fish population declines coupled with these hydrologic and physical changes suggest that current Delta water flows for environmental resources are not adequate to maintain, recover, or restore the functions and processes that support native Delta fish.* [p. 1]

They also concluded that flow is the critical factor for native fisheries in the Delta:

> *Flow is the critical factor in maintaining suitable habitat conditions that support all or some of the life stages (spawning, rearing, and adult) of native fish species that depend on the Delta and its tributaries. Flow is the key factor in determining or maintaining water quality factors which determine the extent and suitability of habitat, temperature, turbidity, salinity, and dissolved oxygen.* [p. 96]

DFG summarized its findings as follows:

> *Water flow is a major determinant of species abundance and fish production. In general, the data and information available indicates:*
>
> 1. *Recent Delta flows are insufficient to support native Delta fishes in habitats that now exist in the Delta.*

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http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/closing_comments/doi_closing.pdf

2. *Water flow stabilization harms native species and encourages non-native species.*
3. *For many species, abundance is related to water flow timing and quantity …*
4. *For many species, more water flow translates into greater species production or abundance.*
5. *Species are adapted to use the water resources of the Delta during all seasons of the year, yet for many, important life history stages or processes consistently coincide with the winter-spring seasons and associated increased flows because this is the reproductive season for most native fishes and the timing of outmigration of most salmonid fishes. Examples:*
    a. *Propagation of splittail depends on the annual winter-spring flooding of the floodplains.*
    b. *Salmon life stages in the Sacramento River depend on certain base and pulse flows.*
    c. *Salmon life stages in the San Joaquin River need spring outflow to transport smolts through the Delta.*
    d. *Spring pulse flows in the Mokelumne River and other eastside streams are needed to support localized in-Delta water quality, salmon migration, and floodplain inundation.*
    e. *Winter Delta outflow has a positive effect on delta smelt.*
    f. *Fish species are dependent on adequate water temperature in spawning and rearing areas upstream of the Delta and sufficient dissolved oxygen for egg incubation, juvenile development, rearing, smolting, and migration.*
6. *The source, quantity, quality, and timing of Central Valley tributary outflow affects the same characteristics of mainstem river flow to the Delta and interior Delta water flows. Flows in all three of these areas influence production and survival of Chinook salmon in both the San Joaquin River and Sacramento River basins.*
7. *Some invasive species negatively influence native species abundance. The best evidence is the negative effects of overbite clam and several species of aquatic plants. Certain flows in and through the Delta may influence these undesirable species, both positively and negatively.*
8. *More research is needed on the effects of nutrients on the Delta ecosystem and its food web.…* [pp. 94-95]

The Department explicitly acknowledged the Delta ecosystem has been fundamentally altered, but concluded that implementing a combination of adequate flows and other measures can restore and maintain fisheries in good condition. [p. 96]

1. AQUATIC SPECIES POPULATIONS DISPLAY STRONG, PERSISTENT, HIGH ORDER CORRELATIONS BETWEEN RELEVANT INDICATORS OF FRESHWATER FLOW CONDITIONS

In our Workshop 1 submission, we reviewed data, scientific information and publications that have come to light since publication of the Delta Flow Report with respect to the effect of freshwater flow on the Low Salinity Zone and the species that reside or spawn in that environment, including Thomson et al 2010, Mac Nally et al 2010, Rosenfield 2010, FWS 2012, and NRC 2012. These new studies, life cycle models, and reviews all found strong relationships between outflow and longfin smelt abundance and viability, as well as persistent relationships between outflow and copepods that comprise the prey base for delta smelt and longfin smelt (TBI et al 2012: 7-16)

Pelagics – winter-spring outflow -- As we emphasized in our 2010 submission to the State Board (TBI et al 2010, Exhibits #1 and #2) and in our submission for Workshop 1 of the current proceeding, populations of numerous pelagic species (fish and invertebrates) have displayed statistically significant, high power (over orders of magnitude), correlations with Delta outflow over several decades of fish community sampling. Although "correlation is not causation", statistically significant correlations are rarely accidental (that is the entire meaning behind statistical significance) and the existence of such strong relationships across a wide diversity of species is incredibly powerful evidence that Delta freshwater flows drive (or interact strongly with the drivers of) population dynamics of aquatic species in the Delta. In fact, we know of no other single factor that better explains population dynamics of more Bay-Delta species over the past 5 decades (the temporal extent of data from many of our aquatic community sampling programs). Although the specific mechanism (or, more likely, *mechanisms*) behind these flow relationships remain somewhat uncertain, the State Board correctly declared in its 2010 Delta Flow Report:

> *There is sufficient scientific information to support the need for increased flows to protect public trust resources; while there is uncertainty regarding specific numeric criteria, scientific certainty is not the standard for agency decision making* [SWRCB 2010:4]

Mechanisms

Different flow-related mechanisms are believed to produce the similar responses to Delta outflow displayed by numerous species in the bay-Delta ecosystem (Kimmerer 2002 *and including species not explicitly studied by Kimmerer*). The four species whose population dynamics are depicted in Figure 1 represent three very different families of fishes and one invertebrate, and wide variety of life history patterns and ecological tolerances. Yet, these, species, and others not depicted here, have shown very similar relationships between abundance and winter-spring freshwater outflow for several decades (e.g., Stevens and Miller 1983, Jassby et al. 1995; Kimmerer 2002a; Sommer et al. 2007; Kimmerer et al. 2009; Mac Nally 2010).

It is almost certain that these species are responding to different flow-related mechanisms. For example, as described below, Sacramento splittail probably benefit from the effect of flow on

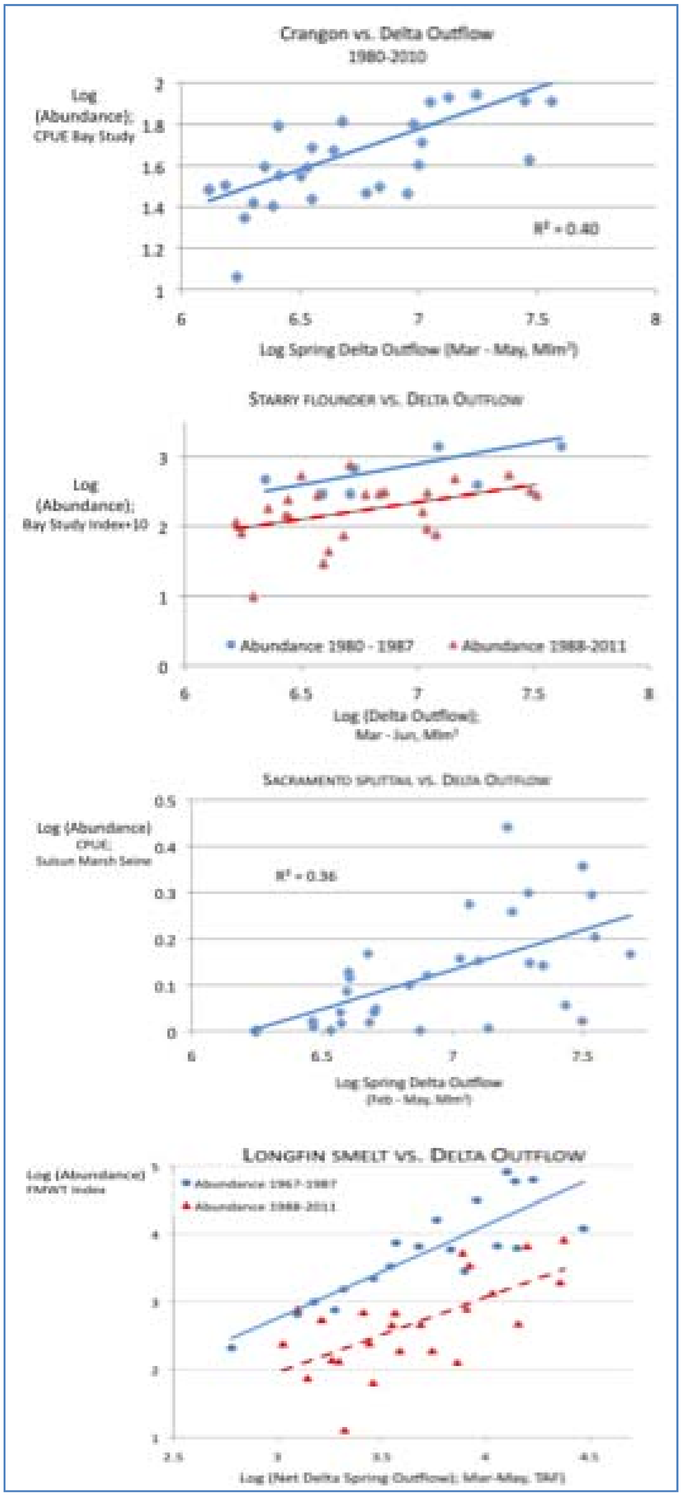

Figure 1: Long -term relationship of abundance indices with Delta freshwater outflow for four species of fishes native to the estuary. All relationships, except for the 1980-1987 starry flounder v. abundance relationship (p=0.075) are statistically significant.

creation and quality of spawning habitat as well as on transport to splittail rearing habitat in the Delta-proper and beyond; longfin smelt larvae and starry flounder juveniles rarely, if ever, occur on floodplains and are much more likely to benefit from kinetic energy mechanisms (low-salinity zone habitat area and position and retention from gravitational circulation in the estuary). The abundance of starry flounder and the bay shrimp, *Crangon franciscorum*, almost certainly respond to the strength of gravitational circulation (Kimmerer 2002a, b) and, probably also to the volume of available brackish habitat.

Just as the particular mechanisms driving the flow-abundance relationship for some species are unknown, those species/life stages for which a flow-related mechanism has been described may also be affected by additional, complimentary mechanisms that have not yet been studied. For example, the relationship between Sacramento splittail (a minnow species, found nowhere else in the world) and fresh water flow rates arises in part from this species' reliance on inundated floodplains for spawning and rearing (e.g. Sommer et al. 2001); clearly, floodplain inundation is very important to this species. Floodplain inundation is an interaction of floodplain elevation (or levee elevation) and the volume of freshwater flow. The relationship between floodplain inundation flows and splittail abundance is not binary (flood or no flood) – season, frequency, and duration of inundation are all extremely important (e.g., Moyle et al 2002, Sommer et al. 2001). Furthermore, even after a floodplain has been inundated, the magnitude of flow across the floodplain is an important indicator of the benefits it provides to native fishes (Figures 2 and 3).

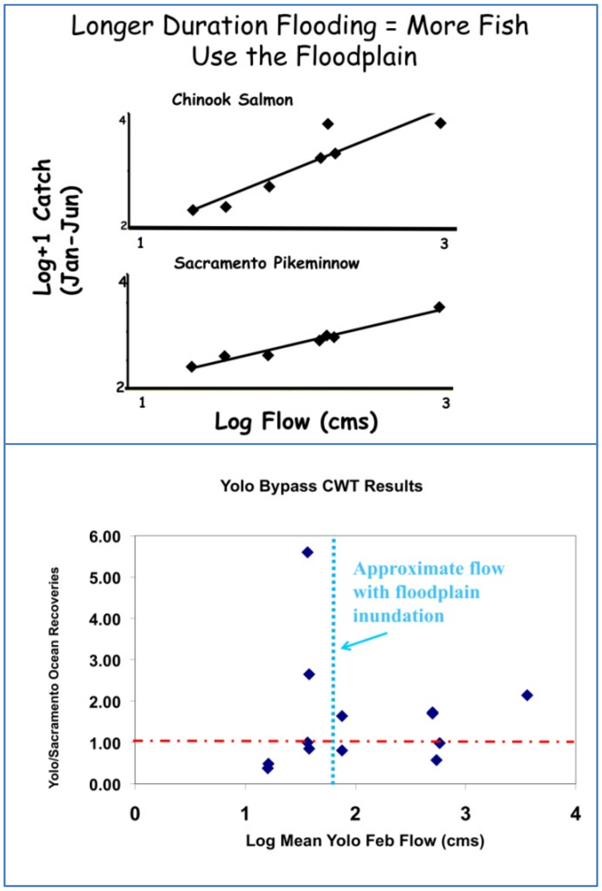

Figure 2: Chinook salmon survival (tag recoveries) as a function of flow rate on the Yolo Bypass. Figure from T. Sommer, CDWR, *personal communication*

The well-documented relationship between floodplain inundation and abundance of splittail (or other species) does not preclude or "disprove" additional mechanisms driving relationships between splittail abundance (or abundance of other fish) and flows elsewhere in their range, including Delta outflow. Given that juvenile and post-spawning splittail adults (and rearing Sacramento blackfish[5] and juvenile Chinook salmon that also use floodplains) move quickly from the floodplain habitats into the lower estuary, it is very likely that a mechanistic relationship between survival and Delta flow rates exists, although it is difficult to tease apart the effect of Delta inflow and Delta outflow in this case. Indeed, the Suisun Marsh Study (O'Rear and Moyle 2010) describes a likely mechanism by which Delta outflow affect Sacramento splittail (and other fish) populations in the Marsh:

> *… the timing, variability, and magnitude of Delta outflow continue to be important factors affecting the abundance of fishes recruiting into the marsh from upstream or downstream areas ... Additionally, Delta outflow, through its influence on marsh salinities, has also affected fishes produced in the marsh* [p 3].

For this reason, Figure 1 portrays the relationship between Sacramento splittail abundance in Suisun Marsh and Delta outflow; for simplicity's sake, we have not presented an analogous graph of Delta inflow and splittail abundance because we take that relationship as a given.

2. Flow and Antecedent Population (Stock) Explain the Vast Majority of Variation in Longfin Smelt Population Size and Reduced Delta Outflows Limit LFS Resilience and Productivity

Longfin smelt and starry flounder both exhibit a "step decline" in the relationship between abundance and freshwater flow after 1987 that is commonly associated with the introduction and invasion of the Amur clam (*Corbula amurensis*; Figure 1). Much has been made of this significant change in the number of fish that correspond to any given flow for these two species, including assertions that this change indicated that flow was no longer a driving force for

[5] *Orthodon microlepidotus*, is a Central Valley native fish species. A cyprinid (minnow), it is the only member of its genus. This fish is caught and sold commercially, particularly in Asian markets.

abundance of these two species; such conclusions reflect a fundamental lack of statistical understanding. For both species, the statistically significant, high power, and persistent relationship between winter-spring Delta outflow and subsequent abundance remains; even the slope of the relationship has not changed (Kimmerer 2002; Rosenfield and Baxter 2007; Kimmerer et al. 2009; TBI et al. 2010, exhibit #2), meaning that for each incremental increase or decrease in annual flow, we see the same proportional increase in abundance today as we saw in the pre-clam period. This bears repeating: *for both longfin smelt and starry flounder, abundance has historically been and still is strongly and significantly correlated with winter-spring freshwater outflow from the Delta*. Additionally, the significant positive relationships between winter-spring Delta outflow (and its close correlate, X_2) and (a) bay shrimp abundance, (b) striped bass survival, (c) Sacramento splittail abundance, and (d) Pacific herring survival remained unchanged following the introduction of the amur clam and the abundance of American shad *increased* at any given flow following the introduction of the amur clam,[6] (Kimmerer 2002a).

In our 2010 testimony to the Board (TBI et al. 2010 Exhibit 2), we demonstrated that, *even following the introduction of the Amur clam*, inter-generation population growth was strongly and positively associated with winter-spring Delta outflows. This analysis demonstrated that the population size in any one year was related both to environmental conditions that prevailed during the winter-spring larval-juvenile rearing period and to the antecedent population size of the generation that produced the current stock of longfin smelt. By accounting explicitly for the size of the spawning stock, this analysis removed the effect of environmental variables that display a time-trend (e.g. ammonium concentration, phytoplankton concentration, etc.) -- impacts of these variables are already reflected by the stock variable. Only conditions that occur within the two-year generation length of longfin smelt can affect the *change* in abundance between sequential generations. This "stock-recruit" or (more accurately) "stock-stock" effect is well known in fisheries biology and, in particular, among the longfin smelt population in this estuary (Rosenfield and Baxter 2007; Mac Nally et al. 2010).

3. ECOLOGICAL IMPLICATIONS OF REDUCED DELTA INFLOW

As described in our previous testimony (TBI et al. 2010, exhibits 1-4) and our Workshop 1 submission (TBI et al 2012), severe alteration of the historical Delta inflow hydrograph (including the magnitude, timing, frequency, and duration of flows) reduces the viability of numerous species that contribute to the Public Trust. We list a small sample of these effects below (and note that there are likely to be similarly significant effects for species/attributes of viability that have not been well-studied at this time):

- Reduced access of native fishes (including splittail, Chinook salmon, Sacramento blackfish, etc.) to inundated floodplains and side channel rearing areas during the appropriate season and for the necessary duration to facilitate their spawning, rearing, and migration (*impact*: reduced abundance and productivity)

[6] Little attention has been paid to populations of American shad, which displayed a step-increase in population for any given flow after the clam invasion (Kimmerer 2002); shad live mainly in the freshwater Delta; their abundance relationship with flow is contrary to what might be expected from suppression of the food web in the freshwater Delta.

- Inadequate transport flows from upstream spawning and rearing areas to and through the Delta (*impact*: reduced abundance and productivity, reduced nutrient and sediment transport affects ecosystem productivity in the Delta)
- Diminished and or undetectable migration cues for both downstream migrants (e.g. salmon smolts) and upstream migrants (e.g. spawning salmon) (*impact*: reduced abundance, productivity, spatial distribution, and life history diversity)
- Migration pathways that are blocked by physical barriers (e.g. weirs) or physio-chemical barriers (e.g. temperature and low dissolved oxygen) (*impact*: reduced spatial distribution and life history diversity)

4. Considerations for Implementing Flow Standards Based on a Percentage of Unimpaired Flow

As detailed in our Workshop 1 submission, the National Research Council has endorsed the Board developing flow objectives as a fixed percentage of unimpaired flows:

> *… it appears that if the goal is to sustain an ecosystem that resembles the one that appeared to be functional up to the 1986-93 drought, exports of all types will necessarily need to be limited in dry years, to some fraction of unimpaired flows that remains to be determined. Setting this level, as well as flow constraints for wetter years, is well beyond the charge of this committee and accordingly we suggest that this is best done by the SWRCB, which is charged with protecting both water rights holders and the public trust.* [NRC 2012: 105]

We strongly agree that the Board should develop new objectives for Sacramento River (and San Joaquin River) inflow and Delta outflow in the winter and spring months based on a percentage of unimpaired flows. Such standards (with a narrow time-period for averaging and measuring the percentage of unimpaired flows that is feasible, such as 14 days) should form the basis[7] of new flow standards in a revision to the WQCP.

Constructing flow recommendations as a percentage of unimpaired flows will also result in great improvements in the timing, duration, and frequency of actual flows into, through, and out of the Delta because the percentage of unimpaired flows approach results in flows that mimic the pattern of natural hydrological conditions (the conditions that native species evolved with) in the ecosystem. We note that, as the percentage of unimpaired flows increases, the timing, duration, and frequency of critical flows will more closely match unimpaired flows – thus, with a standard based on a percentage of unimpaired flow, the magnitude of flows that the Board allocates to protection of the Public Trust is directly connected to other beneficial attributes of flow, including timing, duration, and frequency of beneficial flows.

[7] We recommend the use of the percentage of flow (POF) approach with respect to winter-spring inflows and outflows, while also recognizing that the Board may need to deviate from this basic template in specific cases, such as human health and safety benefits (e.g., flood control and human drinking water needs), as well as to provide flows in other seasons to provide other benefits (for instance, to mitigate impacts to salmon species that rely on upstream operations to provide habitats that were cut-off by construction of impassable dams).

The percentage of unimpaired flow approach is strongly supported in the literature, however, the Board's 75% criteria is actually low compared to other systems in which a "percentage of flow" (POF) approach has been implemented. The State Board's (2010) findings regarding the freshwater flow needs of this ecosystem represent a dramatic improvement over current flow conditions, and we firmly believe that such significant improvements are essential to restore the Bay-Delta's Public Trust resources (especially in the absence of credible plans to address other stressors in this ecosystem).

[Richter, B.D. M.M. Davis, C. Apse, and C. Konrad. 2011. A presumptive standard for environmental flow protection. River and Research Applications. River research and applications. DOI: 10.1002/rra.1511]

Richter et al. (2011) conducted a review of ecologically protective river flow standards developed by experts for other river systems to determine whether a presumptive standard could be developed for use when more exhaustive and detailed review and analysis of a particular system's needs had not or could not be performed. Although we believe that the State Board is appropriately engaged in a detailed analysis of Central Valley flow needs that supersedes application of a default, presumptive flow standard, Richter et al.'s findings are still informative as they set a context for protective standards in this system. Richter et al.'s review (and their significant professional expertise in the area of river hydrology and conservation) led them to conclude that:

> *"… a large body of scientific literature supports the 'natural flow paradigm' as an important ecological objective to guide river management (Richter et al., 1997; Poff et al., 1997; Bunn and Arthington, 2002; Postel and Richter, 2003; Arthington et al., 2006). Stated simply, the key premises of the natural flow paradigm are that maintaining some semblance of natural flow regimes is essential to sustaining the health of river ecosystems and that health is placed at increasing risk with increasing alteration of natural flows (Richter et al., 2003; Richter, 2009).*
>
> and
>
> *The POF* [percentage of natural flow] *approach has several strong advantages over other approaches. For instance, the POF approach is considerably more protective of flow variability than the minimum threshold standards. Minimum‐threshold‐based standards can allow flow variability to become 'flat‐lined' as water allocation pressure increases and reservoir operations are designed only to meet minimum release requirements. Statistically based standards, although usually more protective of flow regimes than minimum thresholds, can be confusing to non‐technical stakeholders, and complex statistical targets have proven difficult for water managers to implement (Richter, 2009). By comparison, POF approaches are conceptually simple, can provide a very high degree of protection for natural flow variability and can also be relatively simple to implement (i.e. a dam operator simply releases the prescribed*

percentage of inflow, or cumulative water withdrawals must not reduce flow by more than the prescribed percentage).

and

We found the recommendations for flow protection emerging from … expert groups to be quite consistent, typically resulting in a range of allowable cumulative depletion of 6% to 20% of normal to low flows, but with occasional allowance for greater depletion in seasons or flow levels during which aquatic species are thought to be less sensitive (Table II). These results suggest a consensus that modest alteration of water flows can be allowed with minimal to no harm to aquatic ecosystems and species.

Table 1: Summary table of environmental flow standards case studies. Copied from Richter et al (2011).

Table II. Summary of per cent-of-flow environmental flow standards from case studies

Location	Ecological goal	Cumulative allowable depletion	Considerations	Decision process
Florida (SWFWMD)	Avoid significant ecological harm (max. 15% habitat loss)	8–19% of daily flow	Seasonally variable extraction limit; 'hands-off' flow	Scientific peer review of site-specific studies
Michigan	Maintain baseline or existing condition	6–15% of August median flow	Single extraction limit for all flow levels	Stakeholders with scientific support
Maine	Protect class AA: 'outstanding natural resources'	10% of daily flow	Single extraction limit for all flow levels above a 'hands-off' flow level	Expert derived
European Union	Maintain good ecological condition	7.5–20% of daily flow	Lower flow; warmer months; 'hands-off' flow	Expert derived
		20–35% of daily flow	Higher flow; cooler months	

and

We suggest that a <u>high level of ecological protection will be provided when daily flow alterations are no greater than 10%</u>; a high level of protection means that the natural structure and function of the riverine ecosystem will be maintained with minimal changes. A <u>moderate level of protection is provided when flows are altered by 11–20%</u>; a moderate level of protection means that there may be measurable changes in structure and minimal changes in ecosystem functions. <u>Alterations greater than 20% will likely result in moderate to major changes in natural structure and ecosystem functions, with greater risk associated with greater levels of alteration in daily flows</u>. These thresholds are well supported by our case study review, as well as from our experiences in conducting environmental flow assessments for individual rivers (e.g. Richter et al., 2003, 2006; Esselman and Opperman, 2010). [Richter et al. 2011, emphasis added]

As the State Board prepares to implement flow standards needed to protect and restore the Bay-Delta's critically imperiled Public Trust resources, water managers will undoubtedly raise concerns that such standards cannot be implemented because of operational constraints or water supply implications. It is instructive that Richter and his colleagues have encountered some of these same concerns in other river systems, writing that:

> *In our experiences in working with water and dam managers, we have found that a remarkable degree of creativity and innovation emerges when engineers and planners are challenged to meet targeted or forecasted water demands with the least disruption to natural flow patterns. Solving the water equation will require new thinking about how and where to store water, conjunctive use of surface water and groundwater, sizing diversion structures or pumps to enable extraction of more water when more is available during high flows, sizing hydropower turbines such that maximum power can be generated across a fuller range of flows, and other innovations. When such creativity is applied as widespread common practice, human impacts on freshwater ecosystems will most certainly be reduced substantially.* [Richter et al. 2011]

Finally, we agree with Richter et al.'s (2011) recommendation about how to proceed *if* the State Board opts not to provide the level of flow protection that it has already determined will be necessary to protect fisheries resources and other aspects of the Bay-Delta's Public Trust values (SWRCB 2010):

> *Some water managers will feel excessively constrained by having to operate within the constraints of the presumptive sustainability boundaries suggested here. However, managing water sustainably necessarily implies living within limits (Richter et al., 2003; Postel and Richter, 2003; Richter, 2009). We suggest that a strong social imperative has emerged that calls for setting those limits at a level that avoids damaging natural systems and the benefits they provide, at least as a default presumption. Where other socioŒeconomic priorities suggest the need for relaxation of the presumptive sustainability boundaries we suggest here, we strongly encourage governments and local communities to invest in thorough assessments of flow–ecology relationships (Richter et al., 2006; Poff et al., 2010), so that decision making can be informed with scientific assessment of the ecological values that would likely be compromised when lesser degrees of flow protection are adopted.* [Richter et al. 2011]

B. REDUCED DELTA FRESHWATER INFLOWS AND INCREASING SOUTH DELTA WATER EXPORTS RESULT IN ENTRAINMENT MORTALITY AND GENERATE IN-DELTA FLOW PATTERNS (HYDRODYNAMICS) THAT INCREASE THE ECOLOGICAL FRAGMENTATION WITHIN THE DELTA AND BETWEEN THE LOWER BAYS AND RIVER CORRIDORS.

As increasing amounts of water are removed from the southern Delta by the State and Federal water Projects and Delta inflows decrease, flow patterns in Delta channels are increasingly disrupted. These disruptions lead to a variety of ecological effects, including increased retention time, net reverse flows, inaccurate migratory cues (e.g. physico-chemical gradients that fish use to cue their migration pathway and timing), export of nutrients and food items, and entrainment of fishes. The last of these effects receives the bulk of public attention, probably because the notion of millions of fish every year being drawn into the export facilities is so compelling and the harm this causes is readily understood.

1. Recent Studies and Life Cycle Models Demonstrate Substantial Adverse Effects of Altered Flows and Entrainment on Delta Smelt

[Kimmerer, W.J. 2011. Modeling Delta Smelt Losses at the South Delta Export Facilities. San Francisco Estuary and Watershed Science, 9(1). Available at: http://escholarship.org/uc/item/0rd2n5vb]

[Miller, W.J. 2011. Revisiting assumptions that underlie estimates of proportional entrainment of delta smelt by state and federal water diversions from the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 9(1). Available at: http://escholarship.org/uc/item/5941x1h8.pdf]

In response to a critique of his earlier paper (Kimmerer 2008[8]) that attempted to estimate the population level impact of entrainment mortality on populations of salmon and Delta smelt, Kimmerer (2011) modified and expanded his earlier analysis. This re-analysis of entrainment-related impacts to Delta smelt concluded that:

> *Miller* [2011, to which Kimmerer 2011 responds] *raises some valuable points about the data and methods used in calculating proportional losses. He also introduces new developments in understanding (e.g., turbidity effects) and in the delta smelt population (e.g., spatial distribution) that occurred recently. I do not believe these points cast doubt on the overall conclusion of my paper, which is that export–related losses to the delta smelt population during some of the years analyzed were substantial.* [Kimmerer 2011:8, emphasis added].

Kimmerer further addresses Miller's (2011) chief complaint, which was that entrainment-related population impacts to Delta smelt are not detectable on a continuous basis throughout the Delta smelt population abundance index record. Kimmerer's analysis demonstrates that:

> *… the* [entrainment-related] *losses were not generally detectable in the regression until P_{max}* [the maximum decrement in the population by the end of the season attributable to export pumping] *reached about 60% to 80%. The levels of loss reported by Kimmerer (2008) were obscured by interannual variability in nearly all simulations, and maximum losses less than 20% were undetectable. Yet a P_{max} of 20% (mean annual loss of ~10%) results in a 10-fold reduction in population size by the end of the 26–year simulation (Figure 3). Repeating the above simulation 10,000 times with P_{max} = 20%, the upper 95% and 90% confidence limits of the regression slope excluded zero (i.e., was statistically detectable) in 5% and 9% of the cases, respectively. Thus, a loss to export pumping on the order reported by Kimmerer (2008) can be simultaneously nearly undetectable in regression analysis, and devastating to the population. This also illustrates how inappropriate statistical significance is in deciding whether an effect is*

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[8] Kimmerer, W.J. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary Watershed Science 6(2). Available at: http://escholarship.org/uc/item/7v92h6fs

> <u>*biologically relevant*</u> *(Stephens and others 2007).* [Kimmerer 2011:7, emphasis added].

Kimmerer, who has previously published papers showing that entrainment did not appear to have population level effects on striped bass or mysids, acknowledged that *"my labors on export losses of delta smelt began with a strong skepticism about the importance of these losses, and ended with considerable surprise at their magnitude."* [Kimmerer 2011:8]

[Thomson, J.R., W.J. Kimmerer, L.R. Brown, K.B. Newman, R. Mac Nally, W.A. Bennett, F. Feyrer, and E. Fleishman. Bayesian change point analysis of abundance trends for pelagic fishes in the Upper San Francisco Estuary. Ecological Applications 20:1431-1448. Available at: http://online.sfsu.edu/~modelds/Files/References/ThomsonEtal2010EcoApps.pdf]

[Mac Nally, R., J.R. Thomson, W.J. Kimmerer, F. Feyrer, K.B. Newman, A. Sih, W.A. Bennett, L. Brown, E. Fleishman, S.D. Culberson, and G. Castillo. 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). Ecological Applications 20:1417-1430. Available at: http://online.sfsu.edu/~modelds/Files/References/MacNallyetal2010EcoApps.pdf]

These two intensive analyses of pelagic species population dynamics in the estuary (co-authored by many of the leading researchers in the Bay-Delta) found that entrainment/salvage appeared to have a population level impact on Delta smelt and other pelagic species.

> *Increases in water exports in both winter and spring were negatively associated with abundance of delta smelt and increases in spring exports with abundance of threadfin shad. Losses of delta smelt previously have been related to exports through entrainment and mortality at pumping facilities and may be important to population dynamics under some circumstances, particularly during dry years (Kimmerer 2008). Effects of spring exports on threadfin shad have not been measured but possibly are important given that this is the only species of the four to occupy freshwater throughout its life cycle and whose main distribution is near the export facilities (Feyrer et al. 2009).* [Thomson 2010:1426]

Mac Nally et al. (2010) found that high summer water temperatures, spring water exports, abundance of largemouth bass, abundance of summer calanoid copepods, and winter water exports were negatively associated with Delta smelt abundance to some degree. The modeled covariates explained 51% of the variability in abundance, and the authors concluded that water exports and X_2 are associated with the declines and can be managed.

[Maunder, M.N. and R.B. Deriso. 2011. A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt (*Hyposmesus transpacificus*). Can. J. Fish. Aquat. Sci. 68: 1285–1306. Available at: http://www.nrcresearchpress.com/doi/pdf/10.1139/f2011-071].

This paper described a life cycle modeling framework, which it illustrated with application to Delta smelt. Maunder and Deriso (20111) reached very different conclusions regarding the factors affecting Delta smelt than Mac Nally et al. (2010), Thomson et al. (2010), or Kimmerer (2011). The paper's principle finding is that parameters of, and variables identified as important by, its multi-stage population modeling framework were heavily influenced by a finding of density-dependent population dynamics among Delta smelt – a finding that the authors admit "*… was probably heavily influenced by three consecutive years of data*" from early in the data record (Maunder and Deriso 2012:1296). The authors concede that: "*At the recent levels of abundance, density dependence is probably not having a substantial impact on the population, and survival is impacted mainly by density-independent factors*" [Maunder and Deriso 2012:1303].

When populations experience density-dependent mortality, losses at a given stage may be somewhat mitigated by improved survival in later stages because the initial loss reduced impacts related to density (e.g. competition) in the later life stage. However, when population dynamics are density independent, losses at any given life stage are expected to translate proportionately to the final population size (they are not compensated for by increased survival later, because survival/mortality rates are not a function of density); for example, a loss of 10% of a populations eggs or larvae would be expected to result in a 10% decrement to the final adult population size. Thus, it is surprising that Maunder and Deriso (2012) conclude that entrainment of adult Delta smelt at the south Delta export facilities is probably unimportant to overall status of this species, despite the fact that: (a) Kimmerer (2009) concluded that Delta smelt salvage appeared to represent a substantial portion of the population periodically; (b) the authors acknowledge that Delta smelt survival is probably density-independent at current levels of abundance; and (c) the modeling framework they present <u>identified adult entrainment as a significant factor</u>. The authors wrote:

> *"The coefficients are similar magnitudes for most covariates except those for water clarity (Secchi) and, particularly, adult entrainment (Aent), which had much larger effects. These both occurred before the stock–recruitment relationship from adults to larvae, which had a very strong density dependence effect. Pred2 had a small effect. The confidence intervals on the coefficients support inclusion of the covariates in the lowest AICc* [=best] *models .... The effects for* [water clarity] *and* [adult Delta smelt entrainment] *appear to be unrealistically large, and their coefficients have a moderately high negative correlation. This appears to be a consequence of the unrealistically strong density dependence estimated in the stock–recruitment relationship from adults to larvae for those models …"* [Maunder and Deriso 2012: 1295].

The authors do not explain why they felt the effect of adult entrainment on population dynamics was too "large" to be retained in the model nor what it says about their modeling framework that they believed it mischaracterized the importance of two variables (Secchi depth and Adult Entrainment) and that its estimate of density dependence (the major finding of the manuscript) was "*unrealistically strong*." In summary, Maunder and Deriso's (2012) modeling framework found that entrainment of Delta smelt adults had a large effect on the population modeling, before the authors inexplicably removed that term from the model.

A. Scientific Critiques of Maunder and Deriso 2012

[BDCP "Red Flag" Documents [California Department of Fish and Game; US Fish and Wildlife Service; and National Marine Fisheries Service. April 2012 BDCP EA (Ch. 5) Staff "Red Flag" Review Comprehensive List. Available at: http://baydeltaconservationplan.com/Libraries/Dynamic_Document_Library/Effects_Analysis_-_Fish_Agency_Red_Flag_Comments_and_Responses_4-25-12.sflb.ashx]

[U.S. Fish and Wildlife Service 2012. First Draft 2011 Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project and State Water Project. Available online at: http://www.usbr.gov/mp/BayDeltaOffice/docs/Signed_FINAL%202011-F-0043_%20SWP-CVP%20BO%20Dec%2014%20FIRST%20DRAFT.pdf]

[National Research Council. 2012. Sustainable water and environmental management in the California Bay-Delta. National Research Council. The National Academies Press, Washington, DC. Available at: https://download.nap.edu/catalog.php?record_id=13394]

As discussed below, the state and federal fishery agencies and the National Research Council have raised substantial criticisms regarding the accuracy of Maunder and Deriso (2012), including its conclusions regarding density dependence and effects of entrainment. For instance, in the Red Flag comments on BDCP, the Fish and Wildlife Service notes that:

> *… the Maunder-Deriso model is a new application that needs additional collaborative work before it reaches maturity. We are concerned that the present model may have identifiability problems, as we discussed in our technical comments last fall. Until that concern is resolved, we are unsure whether the parameter estimates developed in that model represent what they are described to represent.*
>
> *….*
>
> *The model also assumes a specific form of density dependence between generations. We have questioned the appropriateness of this choice, because on very thin ground it limits the universe of plausible explanations for delta smelt reproductive success that can be derived from the model. The intent of this new model was to explain a specific historical dataset, and other than some broad assumptions it does not contain much of the mechanism presented in current delta smelt conceptual models (like DRERIP, or POD conceptual model, or the Fall Outflow Adaptive Management Plan conceptual model). <u>The published version of the model used data through 2006. The model was updated for the Effects Analysis to include data through 2010. When this was done, the model fit deteriorated dramatically relative to what was reported in the paper</u>.* [BDCP Red Flags 2012:18] (emphasis added)

Likewise, in its 2011 draft Delta smelt biological opinion, FWS raised similar questions about the Maunder and Deriso (2011) model, particularly its assumption of density dependent mortality. (FWS 2011) The Service explained that there is strong evidence of density dependence during the summer and fall months, but that since the early 1980s recruitment between generations has been density independent:[9]

> *Since the decline, recruitment has been positively and essentially linearly related to prior adult abundance, suggesting that reproduction has been basically density-independent for about the past 30 years. This means that since the early 1980s, more adults translates into more juveniles and fewer adults translates into fewer juveniles without being 'compensated for' by density- dependence.* [FWS 2011: 154; *see also* p. 193].

The Service reviewed the three life cycle models in the draft biological opinion and showed that they reached different conclusions regarding the role of winter and spring exports. (FWS 2011:206-213, 243-244) FWS concluded that adult entrainment can have significant effects on Delta smelt abundance because of the lack of compensatory density dependence and that the effects of entrainment would probably not be discernable using correlation statistics (citing Kimmerer 2011, *see above*). (FWS 2011) In the biological opinion, FWS reached similar conclusions with respect to juvenile entrainment, and recommended that proactive OMR restrictions in the spring are necessary. (FWS 2011:244-250)

The National Academy of Sciences also raised questions about the Maunder and Deriso (2011) model, stating that, "*Maunder and Deriso (2011) recently published a life cycle model of delta smelt. This model includes some assumptions that need further additional evaluation (e.g., role of density-dependent survival).*" (NAS 2012: 84)

Finally, it is important to note that, although Maunder and Deriso (2012) is presented, appropriately, as an illustration of a modeling framework, the outputs of that illustration are unreliable not only because of its assumption of density dependence, but also because of substantial concerns with the covariates used in the model. Many of these covariates underwent substantial mathematical manipulation that is not adequately explained, other covariates are not described with sufficient detail to be reproduced by other researchers, and many covariates appear irrelevant and/or not what their labels purport to be. As the authors acknowledge,

> *Several factors were chosen for inclusion in the model (Table 3). <u>These factors are used for illustrative purposes only, and they may differ in a more rigorous investigation of the factors influencing delta smelt</u>. The environmental factors are taken as those proposed by Manly (2010b).* [Maunder and Deriso 2012:1290] (emphasis added)

Thus, while the modeling *approach* developed by Maunder and Deriso (2012) may become useful in the future, it is unlikely to produce a valid *model* of Delta smelt population dynamics until the inputs to that framework include all of the variables that ecologists believe may be relevant to the Delta smelt population.

[9] Maunder and Deriso themselves acknowledged that the density-dependent term in their population model was related to three data points from the early 1980's and that at current abundances, survival was likely density-independent.

B. Estimates of Salvage Dramatically Underestimate Delta Smelt Mortality

[Castillo, G. J. Morinaka, J. Lindberg, Robert Fujimura, B. Baskerville-Bridges, J. Hobbs, G. Tigan, L. Ellison. (*in review*). Pre-Screen Loss and Fish Facility Efficiency for Delta Smelt at the South Delta's State Water Project, California. Submitted to San Francisco Estuary and Watershed Science. Available at: http://www.fws.gov/stockton/jfmp/docs/DRAFT-Delta-Smelt-Pre-Screen-Losses-SWP.pdf]

One of the major problems with estimating the overall effect of entrainment on any particular fish species is that we are only able to directly measure "salvage", which is related to the number of fish species enumerated at the fish screening facilities of the State and Federal Water Projects. These facilities do not enumerate losses of fish eggs or larvae that are too small to respond to the behavioral screening system. In addition, predation just outside the fish screens is known to be extraordinarily high because predators aggregate in this area and have been trained to respond to the daily operations of the export facility (e.g. opening of intake gates). Historically, these pre-screen (but, post-entrainment into the diversion canals) losses have been estimated by multiplying salvage by a factor <10. Castillo et al (*in review*) reports on experimental releases of fish into Clifton Court Forebay. The study investigates "*two key sources of entrainment losses of delta smelt at the SWP: fish facility losses (i.e. fish lost within the fish facility due to partial louver efficiency and predation) and pre-screen losses in [Clifton Court Forebay]*. Their findings include:

> *Mean pre-screen losses increased over time: February (94.3%); March (99.1%) and June (99.9%). We concluded that: 1) entrainment losses of delta smelt could be higher at times compared to other species previously studied at the SWP; 2) pre-screen loss was the largest source of mortality for delta smelt; 3) increased distance from the SFF* [Skinner Fish Facility] *and residence time in CCF* [Clifton Court Forebay], *and decreased exports, resulted in lower percent of recovered fish at the SFF.* [Castillo et al. *in review*]

In other words, the number of Delta smelt entrained into waterways directly adjacent to the State Water Project may be ~16 to 1000 times greater than that enumerated during salvage. More work is needed to understand the relationship between pre-screen mortality for Delta smelt and other fishes (to say nothing of the larger impact to fishes before they are drawn into the water bodies directly adjacent to the fish salvage facilities), but it is critical that the Board recognize that salvage estimates are an extremely small fraction of the actual (but unestimated) mortality that is directly attributable to South Delta exports.

C. Forthcoming Scientific Studies and Life Cycle Models Also Conclude that Entrainment Has Population Level Effects on Delta Smelt

[Rose, K.A., W. J. Kimmerer, K.P. Edwards, and W.A. Bennett. *in prep.*, Individual-based population dynamics model of delta smelt: comparing the effects of food versus entrainment. Abstract Available at: http://www.water.ca.gov/iep/docs/041812agenda_abstracts.pdf]

Rose et al are developing an individual-based population dynamics model that they intend to use to assess potential causes of the Delta smelt population decline. While this work is ongoing, Dr. Rose presented the results to-date at the 2012 Interagency Ecological Program conference and reported that:

> *We simulated the population decline using 1995 to 2005 conditions, and explored the relative influence of historical changes in food and entrainment on delta smelt population dynamics. … Simulations indicated that the effect of entrainment on simulated delta smelt population growth rate was between 50% and equal to the effects of food; thus, both were important to the population decline. Increased understanding of how changes in food and entrainment affect delta smelt population dynamics will inform the protection and restoration of delta smelt.*

Several papers are being prepared for publication from this study, which should be available during this State Board proceeding.

[Bennett, W.J. 2012. Statistical Modeling of Unnatural Selection, and the Dialectics of Causation in the Decline of Delta Smelt. Presentation to the 2012 Interagency Ecological Program Conference]

In this presentation, one of the world's leading experts in Delta smelt ecology and population biology, Dr. Bill Bennett asks, "*Did water exports "Cause" the decline of delta smelt?*" and answers with an emphatic "*Yes*" [Slide 2]. The presentation identifies that detrimental entrainment-related impacts to Delta smelt include negative impacts to population abundance, productivity, spatial distribution, and life history. Thus, in addition to simple (though episodic) population-level impacts to Delta smelt, ongoing entrainment impacts have destroyed Delta smelt habitat and eroded the population's natural ability to recover and avoid temporally or geographically-restricted, catastrophic impacts. The author is preparing one or more publications based on the materials summarized in this presentation, which we hope will be published during this proceeding.

2. ENTRAINMENT OF LONGFIN SMELT MAY HAVE SIGNIFICANT POPULATION LEVEL EFFECTS IN SOME YEARS

[Rosenfield, J.A. 2010. Conceptual life-history model for longfin smelt (*Spirinchus thaleichthys*) in the San Francisco Estuary. California Department of Fish and Game, Sacramento, CA. http://www.dfg.ca.gov/ERP/conceptual_models.asp]

The California Department of Fish and Game's Ecosystem Restoration Program (formerly the CALFED ERP) has produced life history conceptual models for key native species. These models describe the magnitude and likelihood of impact of various stressors to particular life history stages of organisms that may contribute to the Public Trust. Regarding the impact of diversions on longfin smelt in this estuary, the CDFG life history conceptual model for longfin smelt (Rosenfield 2010) states that:

> *Mortality of sexually mature adult LFS at water diversions may represent a significant impact on the LFS population in some years (Tables 2, 3). .... Although overall entrainment (which largely reflects entrainment of Age 0+ fish) is significantly and negatively correlated with outflow …, entrainment of sexually mature Age 1+ LFS is significantly and positively correlated with fresh water export rates at the south Delta pumping facilities (ln(SWP+CVP exports):ln(age 1+ salvage)): $R^2 = 0.418$; $p < 0.01$; Fig 11). This result is consistent with that of Grimaldo et al. (2009) who studied the relationship between Old and Middle River flows (that are heavily impacted by export rates) and longfin smelt entrainment. This relationship is not an artifact of a correlation between entrainment and Age 1+ population size (Sommer et al. 2007). Age 1+ LFS entrainment is significantly negatively correlated with the Age 1+ LFS population size as measured by the FMWT index (Fig. 12). Entrainment has increased in recent years as the population declined.*
>
> *Spawning (Age 1+) LFS migrate eastwards, towards the Delta (Fig. 7). Their migration patterns expose these spawning fish (and their subsequent offspring) to entrainment at the CVP/SWP pumps. Significant Age 1+ LFS entrainment at CVP/SWP facilities has occurred in months between December and June. Between 1993 and 2007, longfin smelt entrainment was recorded in 12 years; in 7 of those years, the annual maximum entrainment occurred in January whereas December produced the maximum entrainment in three years.* [p. 21].

In addition, the conceptual model notes that entrainment/salvage mortality likely affects the spatial distribution of longfin smelt in addition to the negative impact to viability caused by negative effects of mortality on abundance:

> *Water export operations in the southern Delta may be responsible for the near-absence of spawning LFS in the lower San Joaquin River. The CVP/SWP pumps are located near where one would expect LFS to spawn in the lower San Joaquin River. If LFS spawned historically in areas of the San Joaquin River that were similar to those currently used in the lower Sacramento River, it is likely that CVP/SWP export operations entrained large numbers of spawning adults and recently- hatched larvae in this area. Deterioration of water quality in the lower San Joaquin River (a product of water exports and agricultural operations supported by those exports) could also be responsible for the absence of LFS spawning in this area if San Joaquin flows were toxic to developing eggs or prohibit spawning in this area. Furthermore, the low freshwater outflow rates from the San Joaquin River that result from operation of the larger hydrosystem may make this area unsuitable for spawning and/or incubation.*

[U.S. Fish and Wildlife Service. 2012. Endangered and Threatened Wildlife and Plants; 12-month Finding on a Petition to List the San Francisco Bay-Delta Population of the Longfin Smelt as Endangered or Threatened. 50 CFR Part 17. [Docket No. FWS-R8-ES-2008-0045]. Available at:

http://www.fws.gov/cno/es/speciesinformation/Longfin%20Smelt%2012%20month%20finding.pdf]

In its notice announcing that longfin smelt warranted protection under the Endangered Species Act, FWS acknowledged that entrainment can have significant effects:

> *Conversely, during low outflow periods, negative effects of reduced transport and dispersal, reduced turbidity, and potentially increased loss of larvae to predation and increased loss at the export facilities result in lower young-of-the-year recruitment.* [p. 38].

FWS analyzed the potential for significant entrainment effects, and found that entrainment levels in 2002 threatened the population.

[Salvage Data for Longfin smelt, 2012. Data available for download at: http://www.dfg.ca.gov/delta/apps/salvage/SalvageExportCalendar.aspx]

Salvage of longfin smelt during 2012 was among the highest recorded since 1993; through April, the number of Age 0 longfin enumerated at the salvage facility was second only to entrainment in 2002 (the year in which FWS suggested entrainment threatened the population). This occurred despite provisions in DFG's Incidental Take Permit (ITP) for the SWP. The ITP sets OMR flow targets based on detection of longfin smelt at a variety of sampling stations -- each of these OMR targets represents a net average negative ("reverse") flow. The ITP has no provision to increase Delta outflow, despite the wealth of documentation (e.g. Dege and Brown 2004; Grimaldo et al. 2009; Rosenfield 2010) that longfin smelt become susceptible to entrainment by the South Delta pumps only when X_2 is located relatively far to the east (i.e. during below normal and drier winter-springs). Nor does the ITP impose limits on how many longfin smelt may be entrained.

Based on the very high entrainment of longfin smelt in 2012, the low longfin smelt population currently, and the results of previous studies on entrainment of longfin smelt and other species (e.g. Grimaldo et al. 2009), I conclude that there is no scientific justification that would permit net negative OMR flows during larval and early juvenile period (April-May) of longfin smelt during years with hydrology that is classified as Critically Dry or Dry. Net negative flows represent a significant threat to several pelagic species under such conditions.[10]

3. Entrainment of Other Pelagic Species

[Cloern J.E. and A.D. Jassby *in press*. Drivers of Change in Estuarine-Coastal Ecosystems: Discoveries from Four Decades of Study in San Francisco Bay. Submitted to the SWRCB in Workshop 1]

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[10] In preparing this testimony, I reviewed TBI's previous submission to the Board on in-Delta hydrodynamics (TBI et al. 2010, exhibit #4). In so doing, I became aware that a recommendation we made regarding protective OMR flows for longfin smelt (which I helped to develop) was misreported as a result of a typographical error. The recommendation reported in TBI et al. (2010, exhibit #4) on p. 8 and also Table 1, p. 30 should have read that net OMR flows be positive (>0 cfs) during April and May during Critically Dry years, Dry years ***or*** whenever the preceding longfin smelt FMWT index is below 500. That was and remains my recommendation.

Although most attention is focused on entrainment of commercially valuable and/or listed species, CVP and SWP operations in the Delta also export a significant proportion of phytoplankton from the system. Jassby and Cloern conclude that:

> *Water export from the Sacramento-San Joaquin Delta is a direct source of mortality to fish, including imperiled species such as delta smelt and longfin smelt (Grimaldo et al., 2009; NRC, 2010), and export plus within-Delta depletion alters system energetics of an already low-productivity ecosystem by removing phytoplankton biomass equivalent to 30% of Delta primary production (Jassby et al., 2002).*

In addition to removal from the system, barriers, exports, flows and other operations affect residence time in the estuary, which affects the production and geographic distribution of phytoplankton biomass. For a system in which, many researchers believe, fish productivity is food limited, export and removal of Delta primary production (not to mention tens to hundreds of millions of fish, fish larvae, and fish eggs – which are all food for other fish and avian predators) represents a major impact.

[The Bay Institute. 2012. Collateral Damage: A citizen's guide to fish kills and habitat degradation at the state and federal water project pumps in the Delta. Novato, CA. Available at: http://www.bay.org/publications/collateral-damage]

Earlier this year, The Bay Institute produced a white paper describing a range of impacts caused by excessive south Delta exports, including specifically entrainment/salvage of huge numbers of a wide variety of species at the SWP and CVP export facilities. The report describes that:

> *•Every day, between 870 and 61,000 fish – including from 200 to 42,000 native and endangered fishes – are "salvaged" at the pumps. Most die in the process.*
>
> *•On average, over 9 million fish – representing the twenty fish species considered in this report – are "salvaged" each year at the pumps. As many as 15 million fish of all species encountered are "salvaged" each year.*
>
> *•Up to 40% of the total population of the endangered delta smelt and 15% of the endangered winter-run population of Chinook salmon are killed at the pumps in some years. In the first half of 2011, over 8.6 million splittail were salvaged.*
>
> *•Salvage estimates drastically underestimate the problem. The numbers do not factor in the results of "indirect" mortality, as high levels of export pumping disrupt fish migration, shrink the amount of non- lethal habitat available to fish species, and remove vast amounts of biomass, including fish eggs and larvae too small to be screened at the pumps.*
>
> *•Export pumping causes the lower San Joaquin River to flow backwards most of the year and removes the equivalent of 170 railroad boxcars of water – and the*

> *<u>accompanying fish, other organisms, and nutrients – from the Delta ecosystem every minute</u>.*
>
> *•Large numbers of fish being entrained is a problem even for species that are not currently listed as "endangered." Killing large numbers of fish year after year cuts off population growth in response to favorable conditions and can start the species on a downward path to extinction. As the species declines, the population impacts of entrainment become proportionately larger.*
>
> *•Entrainment is a real problem. But the same interests in the Delta export community who claim that it isn't also back constructing expensive new conveyance facilities such as a peripheral canal or tunnel to solve the problem that they say doesn't exist.* [TBI 2012:4]

Collateral Damage also documented a record salvage[11] of almost 9 million Sacramento splittail in 2011 (Table 2); as the report describes, the salvage total almost certainly vastly underestimates (by perhaps two orders of magnitude) the total mortality to this and every other fish species captured in the export facilities' salvage mechanism. Salvage of Sacramento sucker in 2011 (27,362 fish) was also a record for this species and the 203 white sturgeon juveniles captured at the south Delta export facilities represented the highest salvage total for that species since 1998.

Although it is true that abundances of many fish species increased in 2011 (which may account in part for increased salvage of splittail), it is extremely unlikely that 2011 (following on years of record or near-record low populations) was a year of record high abundance for native fishes (although it did produce the highest level of water export from the south Delta ever recorded). Also, the loss of tens to hundreds of millions of fish, fish larvae, and fish eggs represents a severe impact to the food web of an ecosystem whose productivity is said to be declining. This type of impact demonstrates how Bay-Delta water management reduces species' productivity – even when conditions become suitable for population growth, native fish populations are held down artificially by high direct and indirect mortality at the south Delta export facilities; thus, these populations cannot capitalize on good years to recover from years of artificially prolonged and severe drought.

[11] Most salvaged fish are believed to die either from handling, transport stress, or predation at release sites.

Table 2: Summary of salvage of selected species through time at the South Delta export facilities. Numbers do not reflect pre-screening mortality (believed to be up to 100 times greater than actual salvage), larval fish or eggs, or other negative impacts. Table copied from *Collateral Damage* (TBI 2012).

STATUS KEY:

- Endangered - Federal
- Endangered - California
- Threatened - Federal
- Threatened - California

LEGEND:

- Native to CA
- Recent decline
- Important Fishery
- Commercial/Sport Fisheries Destroyed
- Protection Removed (for political reasons; species has not recovered)

[1] Fish were selected to encompass the wide range of species and life history types that are affected by water pumps.

[2] "Average annual salvage" is mean yearly salvage from 1/1993 through 12/2011; "Maximum salvage" is the value for the calendar year with the highest salvage numbers (years differ among species).

These numbers underestimate the actual fish kills by not counting the fish that slipped through the bypass system and were killed by the pumps, and by not including indirect mortality. "Yearly Total" refers only to the 20 species listed.

Selected Fish Species	1993-2011 Annual Salvage Average	1993-2011 Annual Salvage Maximum	Status
American shad	1,022,700	2,510,184	Important Fishery; Recent decline
Bluegill	127,133	394,952	
Channel catfish	45,799	131,484	
Chinook salmon (winter run)			Endangered - Federal; Endangered - California; Native to CA; Commercial/Sport Fisheries Destroyed; Recent decline
Chinook salmon (spring run)	51,955	183,890	Threatened - Federal; Threatened - California; Native to CA; Commercial/Sport Fisheries Destroyed; Recent decline
Chinook salmon (fall run)			Native to CA; Important Fishery; Recent decline
Chinook salmon (late-fall run)			Native to CA; Important Fishery; Recent decline
Delta smelt	29,918	154,820	Threatened - Federal; Endangered - California; Native to CA; Recent decline
Green sturgeon	58	363	Threatened - Federal; Native to CA; Recent decline
Inland silverside	62,838	142,652	
Largemouth bass	54,180	234,198	Important Fishery
Longfin	6,228	97,686	Threatened - California; Native to CA; Recent decline
Prickly sculpin	76,403	274,691	Native to CA
Steelhead (Rainbow trout)	5,278	18,580	Threatened - Federal; Native to CA; Commercial/Sport Fisheries Destroyed; Recent decline
Redear sunfish	1,609	5,611	
Riffle sculpin	155	798	Native to CA
Sacramento sucker	3,443	27,362	Native to CA
Sacramento splittail	1,201,585	8,989,639	Protection Removed; Native to CA; Important Fishery; Recent decline
Striped bass	1,773,079	13,451,203	Important Fishery; Recent decline
Threadfin shad	3,823,099	9,046,050	Recent decline
White catfish	296,543	941,972	
White sturgeon	151	873	Native to CA; Important Fishery; Recent decline
Yellowfin goby	193,399	1,189,962	

Average yearly salvage total: 9,237,444

RECOMMENDATIONS

With respect to pelagic species, we recommend that the Board consider the following measures in its update of the water quality control plan, consistent with the potential objectives identified in the 2009 staff report:

1. Delta Outflow Objectives: Increase winter/spring Delta outflow objectives, using a percentage of unimpaired flows approach, to achieve quantifiable targets for increased abundance of longfin smelt and zooplankton species (see our Workshop 1 submission for guidance on setting targets to define desired outcomes). Increase fall (and possibly summer) outflow objectives to achieve quantifiable targets for increased abundance of delta smelt.

2. Floodplain Habitat Flow Objectives: Establish Sacramento River inflow (and possibly structural modifications objectives) such that flows from the Sacramento River inundate floodplains for 15-120 days between December and May every year or twice in every three years.

3. Reverse Flow Objectives / Export: Inflow Objectives: Establish objectives limiting reverse flows in Old and Middle River (OMR) and/or other restrictions on hydrodynamics and exports (e.g., I:E ratios) that reduce entrainment and improve survival of pelagic species in the winter and spring months, including net positive OMR flows during Dry and Critically Dry year-types to help transport pelagic fishes away from the south Delta export facilities.

In our Workshop 1 submission (TBI et al 2012) we provided detailed recommendations regarding the use of adaptive management; we briefly expand on those recommendations here. In an Appendix to our Workshop 1 submission, we described the construction and application of a planning architecture we call "the Logic Chain." The Logic Chain sets conservation actions (such as those contained in the Water Quality Control Plan) in the context of overall and regionally specific goals (desired outcomes) and S.M.A.R.T. targets that articulate the goals (i.e. define what success looks like). Description of stressors that are believed to prevent attainment of the goal, stressor reduction targets (which are also S.M.A.R.T.) and the expected outcomes (positive and potential negative) of conservation actions force planners to identify the level of certainty and key assumptions behind different courses of action.

These assumptions and declarations regarding relative certainty of the response to specified actions become the fuel for an adaptive management implementation strategy. To the extent possible, adaptive management should actively seek to increase certainty and test assumptions that underlie the actions that are implemented. In theory, as different assumptions are tested and progress (or lack thereof) becomes clearer, the most effective and efficient pathways to the desired outcomes will come into focus.

However, this vision of adaptive management can only become reality if the implementation plan identifies specific outcomes/targets and specific and robust decision pathways that make clear how and under what circumstances management will "adapt" to new information and/or changing circumstances. Also, the decision pathways must identify what entities will make the decision to adapt, who has the final authority to make the decision to alter course, when (what time frame and under what circumstances) will those decisions be made, and what are the likely alternative actions. Decision pathways will thus identify adaptive management ranges, within which key variables will be managed to determine their effect, and adaptive management triggers, thresholds that when crossed lead to definitive adjustments in the implementation strategy.

The exact nature and structure of and adaptive management decision pathway depends in large part on information gleaned from the Logic Chain architecture (for example, what is the time bound (the “t” in SMART) for attainment of a particular conservation target?). Thus, we cannot develop a specific example of a decision pathway here. However, we strongly believe that, wherever an action plan will rely on adaptive management going forward, a clear and specific decision pathway should be defined in advance of implementing the relevant action. Developing the decision pathway “as we go along” is reactive management occurring under the guise of adaptive management. We stand ready to provide advice and expertise to the Board and Board staff on the development of these essential adaptive management decision-pathways as you move towards specific revisions of the Bay-Delta Water Quality Control Plan.

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SHORT COMMUNICATION

A PRESUMPTIVE STANDARD FOR ENVIRONMENTAL FLOW PROTECTION

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ABSTRACT

The vast majority of the world's rivers are now being tapped for their water supplies, yet only a tiny fraction of these rivers are protected by any sort of environmental flow standard. While important advances have been made in reducing the cost and time required to determine the environmental flow needs of both individual rivers and types of rivers in specific geographies, it is highly unlikely that such approaches will be applied to all, or even most, rivers within the forseeable future. As a result, the vast majority of the planet's rivers remain vulnerable to exploitation without limits. Clearly, there is great need for adoption of a "presumptive standard" that can fill this gap. In this paper we present such a presumptive standard, based on the Sustainability Boundary Approach of Richter (2009) which involves restricting hydrologic alterations to within a percentage-based range around natural or historic flow variability. We also discuss water management implications in applying our standard. Our presumptive standard is intended for application only where detailed scientific assessments of environmental flow needs cannot be undertaken in the near term.

KEY WORDS: environmental flow; sustainability; Sustainable Boundary Approach; river management; corporate water use; water stewardship; water allocation; water scarcity

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Available freshwater supplies are being increasingly strained by growing human demands for water, particularly for irrigated agriculture and urban uses. The global population is growing by 80 million people each year, and if consumption patterns evolve as expected, two-thirds of the world's population will live in water-stressed areas by 2025 (WWAP, 2009). Whereas differing patterns of population growth, lifestyle changes and climate change will pose different scenarios on each continent, water managers and planners are challenged to meet growing water needs virtually everywhere.

At the same time, societies around the world are increasingly demanding that water managers also protect the natural freshwater ecosystems that are being tapped for water supplies. The need to protect 'environmental flows'—defined as the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems (Brisbane Declaration, 2007)—is now being addressed in many governmental water allocation policies, dam development plans and urban water supply plans. The stimuli for protecting environmental flows are varied and many, including the desire to protect biodiversity, ecosystem services (especially fisheries production), water-based tourism or recreation, economic activities such as hydropower generation and other cultural or spiritual values (Postel and Richter, 2003).

However, many good intentions to protect environmental flows have stalled upon encountering confusing and conflicting information about which method for environmental flow assessment is appropriate or 'best' and perceptions that the more credible and sophisticated methods require considerable investment of time, expertise and money to apply. These real and perceived hurdles have too often resulted in doing nothing to protect environmental flows, leaving the vast majority of rivers on the planet vulnerable to over-exploitation (Richter, 2009).

The environmental flow science community has long been attuned and responsive to the need for more cost-efficient and time-efficient approaches to determining environmental flow needs. Beginning in the 1970s with the Tennant (1976) method and continuing with the recent publication of the 'Ecological Limits of Hydrologic Alteration' (ELOHA; Poff *et al.*, 2010), a long series of efforts have been put forth by scientists to streamline and expedite environmental flow assessment while maintaining scientific credibility. However, widespread environmental flow protection across the planet's river networks has yet to be attained.

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Of particular concern and relevance to this paper is the fact that it is proving difficult to implement ELOHA in some jurisdictions even though the approach was explicitly designed to address the issues that have prevented other methods from being applied widely. The four co-authors of this paper have been actively encouraging government entities to apply the ELOHA framework; the difficulties we have experienced in these efforts have provided strong motivation for writing this paper. As we explain later in this paper, we continue to believe that ELOHA provides the best available balance between scientific rigor and cost of application for setting environmental flow standards for many rivers simultaneously. The ELOHA framework is currently being applied in various jurisdictions around the world. However, we are finding that many government entities are unable (or unwilling) to afford the cost of applying ELOHA (generally ranging from \$100k to \$2M), especially in situations where existing biological data and hydrologic models have poor spatial coverage. Time constraints are an even more frequent hindrance to the implementation of the ELOHA framework, particularly for jurisdictions embroiled in politically challenging situations such as responding to extreme droughts, legislative mandates or lawsuits. We suggest that until ELOHA or some variation can be applied everywhere, a presumptive, risk-based environmental flow standard is needed to provide interim protection for all rivers.

Another strong motivation for putting forth a presumptive standard at this time is the fact that many large water-using corporations are now looking for environmental indicators that can help them screen their operations and supply chains for water-related risks (e.g. SABMiller and WWF-UK, 2009). These corporations are increasingly coming to understand that, when environmental flows are not adequately protected, freshwater ecosystems will be stressed, jeopardizing ecosystem services valued by many people for their livelihoods and well-being. This can lead to conflicts that can ultimately endanger a company's 'social licence to operate' (Orr *et al.*, 2009). Presently, many corporations are using estimates for environmental flow requirements put forth by Smakhtin *et al.* (2004); these estimates range globally from 20% to 50% of the mean annual river flow in each basin. We agree with Arthington *et al.* (2006) that such a low level of protection as suggested by Smakhtin 'would almost certainly cause profound ecological degradation, based on current scientific knowledge'. We hope that the presumptive standard we offer in this paper will replace corporate use of the Smakhtin estimates for water risk screening.

The presumptive standard for environmental flow protection put forth in this paper is intended for use only in situations where the application of ELOHA or site-specific environmental flow determinations (e.g. Richter *et al.*, 2006) cannot be applied in the near future; in other words, it is intended for use as a default placeholder. This presumptive standard is derived from the sustainability boundary approach (SBA) described by Richter (2009), which involves maintaining flows within a certain percentage-based range around natural flows (i.e. flows in the absence of dam regulation or water withdrawals).

Before discussing our proposed presumptive standard in greater detail, we provide a short discussion of the advantages of 'per cent-of-flow' (POF) approaches such as the SBA for expressing environmental flow requirements. We then summarize efforts around the world to apply flow protection standards based on POF expressions. Finally, we propose a specific presumptive standard using risk bands placed around natural flow variability and conclude with management implications in applying this presumptive standard.

APPROACHES FOR SETTING FLOW PROTECTION STANDARDS

A primary challenge in setting flow protection standards is to employ a practical method that limits water withdrawals and dam operations in such a way as to protect essential flow variability. As described by Richter (2009), a large body of scientific literature supports the 'natural flow paradigm' as an important ecological objective to guide river management (Richter *et al.*, 1997; Poff *et al.*, 1997; Bunn and Arthington, 2002; Postel and Richter, 2003; Arthington *et al.*, 2006). Stated simply, the key premises of the natural flow paradigm are that maintaining some semblance of natural flow regimes is essential to sustaining the health of river ecosystems and that health is placed at increasing risk with increasing alteration of natural flows (Richter *et al.*, 2003; Richter, 2009).

Three basic approaches have been employed for setting environmental flow standards across broad geographies such as states or nations: minimum flow thresholds, statistically based standards and POF approaches. The most commonly applied approach to date has been to set a minimum flow level that must be maintained. For example, the most widely used minimum flow standard in the USA is the annual 7Q10, which is defined as the lowest flow for seven consecutive days that occurs every 10 years on average. Whereas the original intent of the annual 7Q10 flow standard was to protect water quality under the federal Clean Water Act of 1972, it has become either explicitly in rule or by default the minimum flow threshold in many states (Gillilan and Brown, 1997; IFC, 2001). The growing recognition that this threshold was not sufficiently protective of aquatic habitats led in the 1980s and 1990s to several states setting higher flow thresholds, such as by setting the minimum level at 30% of the mean annual flow (MAF) or by setting thresholds that vary seasonally, such as at the

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level of 60% of MAF in winter, 30% of MAF in summer and 40% of MAF in spring and fall (Gillilan and Brown, 1997; IFC, 2001).

More recently, statistically based standards have been used to maintain certain characteristics of the flow regime. For example, such a standard may call for protecting a high flow of a specified magnitude, with specified duration, to occur with a specified inter-annual frequency. The application of a statistically based standard in regulating water use generally involves using computerized hydrologic models to simulate the cumulative effects of licenced or proposed water withdrawals and dam operations on the flow regime; hydrologic changes are allowed to accumulate until the statistical standards would be violated by further withdrawals or dam effects.

Flow standards set in the USA, the European Union and elsewhere in the past decade have increasingly been based on a POF approach (see case studies later in this paper). This approach explicitly recognizes the importance of natural flow variability and sets protection standards by using allowable departures from natural conditions, expressed as percentage alteration. The POF approach has several strong advantages over other approaches. For instance, the POF approach is considerably more protective of flow variability than the minimum threshold standards. Minimum-threshold-based standards can allow flow variability to become 'flat-lined' as water allocation pressure increases and reservoir operations are designed only to meet minimum release requirements. Statistically based standards, although usually more protective of flow regimes than minimum thresholds, can be confusing to non-technical stakeholders, and complex statistical targets have proven difficult for water managers to implement (Richter, 2009). By comparison, POF approaches are conceptually simple, can provide a very high degree of protection for natural flow variability and can also be relatively simple to implement (i.e. a dam operator simply releases the prescribed percentage of inflow, or cumulative water withdrawals must not reduce flow by more than the prescribed percentage).

Sustainability boundary approach

Recognizing that human-induced flow alterations can both deplete and unnaturally augment natural flows to the detriment of ecological health, Richter (2009) expanded upon the POF approach by suggesting that bands of allowable alteration called 'sustainability boundaries' could be placed around natural flow conditions as a means of expressing environmental flow needs, as depicted in Figure 1.

To apply the SBA, the natural flow conditions for any point of interest along a river are estimated on a daily basis, representing the flows that would have existed in the absence of reservoir regulation, water withdrawals and return flows (Richter, 2009). Limits of flow alteration, referred to as sustainability boundaries, are then set on the basis of allowable perturbations from the natural condition, expressed as percentage-based deviations from natural flows. Those withdrawing water or operating dams are then required to maintain downstream river flows within sustainability boundaries. Whereas maintaining flows within the targeted range may be infeasible on a real-time basis in many cases, such management can be facilitated by creating computerized hydrologic models to evaluate what the likely perturbation to natural flows would be under existing or proposed scenarios of water withdrawal and dam operations and by licencing such water uses accordingly.

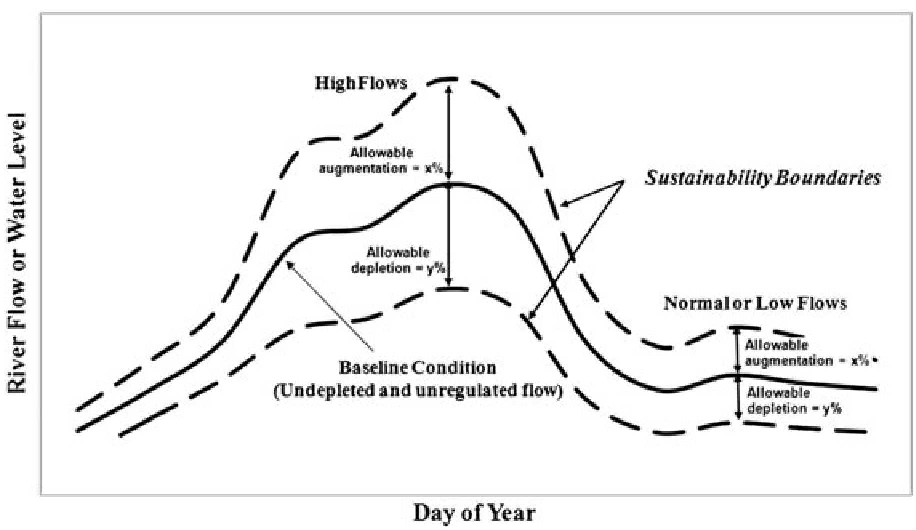

Figure 1. Illustration of the sustainability boundary approach from Richter (2009; reprinted with permission). The sustainability boundaries set limits on the degree to which natural flows can be altered, expressed as a percentage of natural flows.

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The allowable degree of alteration from the natural condition can differ from one point to another along the same river. This determination for any point of interest along a river requires a negotiation or optimization between the following: (i) the desired consumption or dam regulation of water upstream, which might either deplete or unnaturally augment river flows; (ii) the desired uses of water downstream; and (iii) the desired ecological condition and ecosystem services to be maintained. As such, the SBA forces an explicit integration of environmental flow objectives with water withdrawals and dam operations. We recognize and emphasize that this is a socio-political decision-making process as much as it is a scientific one. As suggested by Richter (2009), the application of the SBA in setting river flow management goals requires transparent, inclusive and well-informed stakeholder engagement.

The basic challenge confronting environmental flow proponents is the difficulty of determining how much alteration from natural flows can be tolerated without compromising ecological health and ecosystem services to an undesirable degree. In the absence of such an understanding, water managers and governmental regulators have focused solely on water withdrawals and dam operations, providing only minimum flow protection or neglecting ecosystem considerations altogether. This highly undesirable situation calls for the adoption of a precautionary approach to fill the gap, until more detailed and regionally tailored studies of environmental flow needs can be completed and used to set flow protection standards.

We believe that sufficient scientific evidence and knowledge now exist to propose an SBA-based presumptive standard that can serve as initial guidance for regulating water withdrawals and dam operations in rivers. In designing the presumptive standard recommended later in this paper, we reviewed numerous other efforts to set environmental flow standards that apply across broad regions and many different rivers.

CASE STUDY REVIEW

The following case studies represent environmental flow policies and management guidelines that are being applied in the USA and Europe to limit flow alteration and to achieve relatively high levels of ecological protection, while allowing for carefully managed water development to proceed. Whereas not all of these cases can be characterized as pure POF approaches, we believe that these case studies illustrate useful and progressive water management policies that fulfill the intent of the SBA. They are described here to demonstrate the feasibility of applying standards in a manner consistent with the SBA and to support our recommendations for the presumptive standard described later in this paper.

Example #1—Southwest Florida Water Management District

Under the Florida state law, the state's five water management districts must determine 'minimum flows and levels' (MFLs) for priority water bodies of the state. Methods to determine MFLs differ among the five districts. The Southwest Florida Water Management District (SWFWMD) uses a POF-based approach that includes use of multiple environmental flow assessment methods, including the Instream Flow Incremental Methodology and the Wetted Perimeter approach (see IFC, 2001 for descriptions of these methods), to inform the setting of percentage alteration limits. The intent of the resulting MFLs is to limit water withdrawals such that physical habitat losses do not exceed 15% (Flannery *et al.*, 2002, 2008). The allowable flow reduction, which is referenced to as previous-day flows at a specified river gauge, can vary with season and with magnitude of flow and includes a 'hands-off' low flow threshold, meaning that all withdrawals are curtailed once the flow threshold is reached (see Rules of the Southwest Florida Water Management District, Chapter 40D-8, Water Levels and Rates of Flow, Section 40D-8.041 Minimum Flows at www.swfwmd.state.fl.us).

These MFLs are used in water management planning and incorporated as water withdrawal permit conditions. The percentage of allowable depletion has been set by SWFWMD for five non-tidal rivers in the district, ranging from 8% to 15% during high flows and 10% to 19% during low flows. Allowable depletions tend to be larger for freshwater flows into estuaries. For example, the lower Alafia River can be depleted up to 19% as it enters its estuary, based on limiting fish habitat loss caused by changes in salinity and dissolved oxygen to no more than 15%. No withdrawals are allowed when flows fall below 120 ft^3/s, based on chlorophyll residence time in the estuary, fish, dissolved oxygen and comb jellyfish. The proposed MFL for the Lower Peace River and its estuary limits withdrawals to flows above 130 ft^3/s, with allowable 16% reduction of daily flow up to a flow rate of 625 ft^3/s, 29% flow reductions in fall/winter and 38% flow reductions in summer above 625 ft^3/s (Flannery *et al.*, 2002, 2008).

Example #2—Michigan's Water Withdrawal Assessment Tool Approach

The Great Lakes–St Lawrence River Water Resources Compact and related state law require limits on water withdrawals to prevent 'adverse resource impact', defined as the point when 'a stream's ability to support characteristic fish populations is functionally impaired'. Zorn *et al.* (2008) documented the work of the Michigan Department of Natural Resources to develop a predictive model of how

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fish assemblages in different types of Michigan streams would change in response to decreased summer base flows, using habitat suitability information for over 40 Michigan fish species. The approach involved classification of all river segments in the state based on size and temperature regime and the development of a fish response curve that relates assemblage richness to an index flow (median August streamflow) for each of the 11 river classes. This index flow serves as a surrogate for withdrawals as a POF.

Across the majority of river types in Michigan, 'baseline or existing' ecological conditions are predicted to be maintained with cumulative withdrawals less than 6–15% of the index flow, depending on the stream type (Seelbach *et al.*, 2009). This is roughly equivalent to maintaining excellent ecological condition for many rivers, but some rivers that have historically been degraded would only be maintained in their current condition (Paul Seelbach, personal communication, University of Michigan, Ann Arbor). Adverse resource impacts are predicted to occur on most types of rivers with withdrawals greater than 17–25% of index flow. Rivers classified as 'transitional' between cold and cool rivers are very sensitive to withdrawals and are limited to withdrawals of 2–4% index flows before adverse resource impact is predicted to occur.

The Michigan Water Withdrawal Assessment Tool (WWAT) allows estimation of the likely impact of a water withdrawal on nearby streams and rivers using these threshold values. Use of the WWAT is required of anyone proposing to make a (large) new or increased withdrawal from the waters of the state, including all groundwater and surface water sources, prior to beginning the withdrawal. The WWAT is online at http://www.miwwat.org/.

Unlike Florida's POF approach, which references allowable depletions to a percentage of the previous day's flow, the Michigan approach references its withdrawal limits only to the August median flow. Because August is typically the lowest flow month in Michigan and Michigan flow regimes are fairly predictable, it is unlikely that cumulative withdrawals beyond the adverse resource impact level would frequently exceed the percentage guideline in other months. However, in very dry summers, one would expect the adverse resource impact percentage to be exceeded for a portion of the summer.

Example #3—UK Application of the European Union Water Framework Directive

The European Union (EU) Water Framework Directive, passed in 2000, was designed to protect and restore aquatic ecosystems by setting common ecological objectives across EU member states. The Water Framework Directive requires member states to achieve a 'Good Ecological Status' in all surface waters and groundwaters that are not determined to already be 'heavily modified'(Acreman *et al.*, 2006). It is assumed that meeting the Good Ecological Status requires protecting or restoring ecologically appropriate hydrological regimes, but the Water Framework Directive itself does not define environmental flow standards for any country in the EU (Acreman and Ferguson, 2010).

In the UK, a Technical Advisory Group worked with conservation agencies and academics to begin defining environmental standards for physio-chemical and hydromorphological conditions necessary to meet different levels of ecological status (Acreman *et al.*, 2006). A key part of this work was defining thresholds of allowable water withdrawal as a percentage of natural flow. To achieve this, a literature review was prepared, and numerous expert workshops were convened. Each river in the UK was assigned to one of 10 classes, based on physical watershed characteristics, to facilitate application of withdrawal thresholds (Acreman and Ferguson, 2010).

Withdrawal standards were based on professional knowledge and discussion of the flow needs of various plant and animal communities—primarily macrophytes, macroinvertebrates and fish. Quantitative standards for achieving Good Ecological Status were specified for four groupings of river types, two seasons and four tiers of withdrawal standards based on annual flow characteristics (Table I). The allowable abstraction values in Table I are intended to be restrictions on cumulative withdrawals, applicable to any point on a river of that type.

The withdrawal standards in Table I were derived from an expert consensus workshop approach by using the precautionary principle to deal with considerable uncertainty. Different tolerances to flow alteration were recognized across taxa groups, but a 10% flow alteration was generally seen by experts as likely to have negligible impact for most taxa, stream types and hydrologic conditions (Acreman and Ferguson, 2010). The workgroup also generally agreed upon a Q95 (i.e. fifth percentile) flow as being 'hands-off', meaning that at that flow withdrawal would either stop or be significantly reduced. The recommended allowable withdrawal levels increase with magnitude of flow and in cooler months. Thus, permissible alterations range from 7.5% to 20% in warm months at lower flows (below Q70) and from 20% to 35% during cooler months at higher flows (Acreman *et al.*, 2006).

Example #4—Maine sustainable water use rule

In 2001, the Maine State Legislature passed a law requiring 'water use standards for maintaining instream flows…lake or pond water levels…protective of aquatic life and other uses…based on the natural variation of flows'. The resulting environmental flow and water level protection rule, finalized in 2007, establishes a set of tiered flow protection criteria

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Table I. Standards for UK river types/subtypes for achieving Good Ecological Status, given as per cent allowable abstraction of natural flow (thresholds are for annual flow statistics)

Type or subtype	Season	Flow >Q60	Flow >Q70	Flow >Q95	Flow <Q95
A1	Apr–Oct	30	25	20	15
	Nov–Mar	35	30	25	20
A2 (downstream), B1, B2, C1, D1	Apr–Oct	25	20	15	10
	Nov–Mar	30	25	20	15
A2 (headwaters)	Apr–Oct	20	15	10	7.5
C2, D2	Nov–Mar	25	20	15	10
Salmonid spawning and nursery areas	Jun–Sep	25	20	15	10
	Oct–May	20	15	Flow >Q80	Flow <Q80

From Acreman and Ferguson (2010).

linked to different stream condition classes (Maine DEP, 2010a). The environmental flow standards may be established by one of two methods: a standard allowable alteration of flow or a site-specific flow assessment. The standard allowable alteration is based on the natural flow regime theory (Poff *et al.*, 1997; Richter *et al.*, 1997) and was informed by considerable scientific research on environmental flow requirements for the eastern USA (e.g. Freeman and Marcinek, 2006).

For all streams falling into the state's best-condition class (class AA), 90% of the total natural flow must be maintained when the flow exceeds the spring or early winter 'aquatic base flow' (Maine DEP, 2010b). This aquatic base flow is defined as the median monthly flow of the central month of each season (Maine DEP, 2006). In other seasons, withdrawals of up to 10% of daily flow can only occur when daily flows exceed 1.1 to 1.5 times the seasonal aquatic baseflow. No flow alteration is allowed in any season when flows are below aquatic base flow levels. In addition, all rivers and streams that flow into class AA waters must meet the POF standard.

Although used only for those waters with the highest ecological condition goals, which make up approximately 6% of state waters, the Maine standard provides a good example of use of a hands-off flow level combined with a POF approach.

Summary of case study findings

The case studies summarized here have much in common (Table II). In each case, standards were developed with a general intent to avoid ecological degradation of riverine ecosystems. The specifics of management goals vary from case study to case study, but common among them is the desire to maintain ecological conditions that are good to excellent or to avoid ecological harm. Each of these efforts to set standards has utilized the best available science for their region, and each has engaged large numbers of scientists familiar with flow–ecology science, using expert-based decision-making processes.

We found the recommendations for flow protection emerging from these expert groups to be quite consistent, typically resulting in a range of allowable cumulative

Table II. Summary of per cent-of-flow environmental flow standards from case studies

Location	Ecological goal	Cumulative allowable depletion	Considerations	Decision process
Florida (SWFWMD)	Avoid significant ecological harm (max. 15% habitat loss)	8–19% of daily flow	Seasonally variable extraction limit; 'hands-off' flow	Scientific peer review of site-specific studies
Michigan	Maintain baseline or existing condition	6–15% of August median flow	Single extraction limit for all flow levels	Stakeholders with scientific support
Maine	Protect class AA: 'outstanding natural resources'	10% of daily flow	Single extraction limit for all flow levels above a 'hands-off' flow level	Expert derived
European Union	Maintain good ecological condition	7.5–20% of daily flow	Lower flow; warmer months; 'hands-off' flow	Expert derived
		20–35% of daily flow	Higher flow; cooler months	

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depletion of 6% to 20% of normal to low flows, but with occasional allowance for greater depletion in seasons or flow levels during which aquatic species are thought to be less sensitive (Table II). These results suggest a consensus that modest alteration of water flows can be allowed with minimal to no harm to aquatic ecosystems and species.

A PROPOSED PRESUMPTIVE STANDARD

Our review of the case studies described above suggests that an appropriate presumptive standard for environmental flow protection can be proposed at this time, subject to some important caveats.

We suggest that a high level of ecological protection will be provided when daily flow alterations are no greater than 10%; a high level of protection means that the natural structure and function of the riverine ecosystem will be maintained with minimal changes. A moderate level of protection is provided when flows are altered by 11–20%; a moderate level of protection means that there may be measurable changes in structure and minimal changes in ecosystem functions. Alterations greater than 20% will likely result in moderate to major changes in natural structure and ecosystem functions, with greater risk associated with greater levels of alteration in daily flows. These thresholds are well supported by our case study review, as well as from our experiences in conducting environmental flow assessments for individual rivers (e.g. Richter *et al.*, 2003, 2006; Esselman and Opperman, 2010). This level of protection is also generally consistent with findings from regional analyses such as the 'benchmarking' study in Queensland, Australia, by Brizga *et al.* (2002) and by a national (US) analysis of hydrologic alteration which documented that biological impairment was observed in some sites with hydrologic alteration of 0–25% (the lowest class of alteration assessed) and in an increasing percentage of sites beyond 25% hydrologic alteration (Carlisle *et al.*, 2010).

This presumptive standard can be represented graphically as shown in Figure 2, using the convention of the SBA (Richter, 2009), with risk bands bracketing the daily natural flow conditions. When a single threshold value or standard is needed, such as for corporate risk screening or water supply planning purposes, we suggest that protecting 80% of daily flows will maintain ecological integrity in most rivers. A higher percentage of flow (90%) may be needed to protect rivers with at-risk species and exceptional biodiversity.

Whereas we believe that such a presumptive standard of limiting daily flow alterations to 20% or less is conservative and precautionary, we also caution that it may be insufficient to fully protect ecological values in certain types of rivers, particularly smaller or intermittent streams. Seasonal adjustments of the per cent of allowable depletion may be advisable. Several of our case studies utilized 'hands-off' flow thresholds to limit impacts to the frequency and duration of low-flow events. This may be an additional consideration where fish passage, water quality or other conditions are impaired by low flows. Also, when applying this presumptive standard to rivers affected by hydropower dams, imposing our suggested limits on daily flow averages may be insufficient to protect ecological integrity because of the propensity for peaking power operations to cause river flows to fluctuate considerably within each day. In such cases, our presumptive standard may need to be applied on an hourly, rather than daily, basis. Adjustments to our suggested values

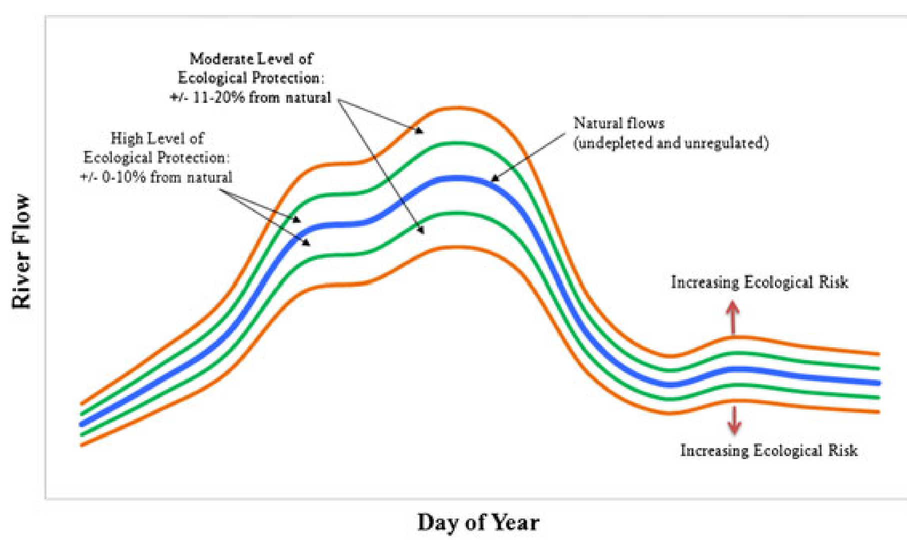

Figure 2. Presumptive standards are suggested for providing moderate to high levels of ecological protection. The greater the departure from natural flow conditions, the greater is the ecological risk to be expected. This figure is available in colour online at wileyonlinelibrary.com/journal/rra.

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should be considered when local or regional ecological knowledge indicates that narrower bands of allowable alteration are needed.

Most importantly, continued investment in detailed, site-specific or regional environmental flow assessment is urgently needed. Such research must continue to inform our understanding of flow–ecology relations and refine our presumptions about the adequacy of protecting different percentages of natural flows.

MANAGEMENT IMPLICATIONS

To properly apply our presumptive standard, water managers and other water stakeholders, such as corporations concerned about the sustainability of water use in particular river basins, will need to be able to do three basic things:

- Develop modelling tool(s) to estimate natural (unregulated and undepleted) flows on a daily basis; this provides the natural or 'baseline' flow data illustrated in Figure 1;
- Use the modelling tool(s) to evaluate whether *proposed* withdrawals, dam operations or other changes—when added to already-existing water uses—would cause the presumptive standard to be violated;
- Monitor daily flows at key locations, such as upstream and downstream of major water withdrawals and return flows, and at points of inflow to reservoirs, as a means for verifying and refining the modelling results and for regulatory enforcement purposes.

The capability to evaluate proposed hydrologic changes (second bullet in the above list) enables water managers to avoid issuing water use permits that would cause hydrologic variations to deviate outside of the sustainability boundaries set by the presumptive standard (±20%). Obviously, if a particular river's flow regime has already been altered more than ±20% during part or all of the time, water managers and stakeholders would need to decide whether to restore flows to a level consistent with the presumptive standard or adopt some other standard.

Application in over-allocated basins

Ongoing efforts to develop sustainable approaches to water management in the Murray-Darling river basin in Australia offer a highly relevant and useful example of re-balancing environmental and economic goals in a previously over-allocated basin. In response to considerable ecological degradation, heavy competition among water users, prolonged drought and climate change projections, the Commonwealth Parliament in 2007 passed a national water act calling for the development of a basin plan that would provide for integrated and sustainable management of water resources (MDBA, 2009). The Basin Plan is required to set enforceable limits on the quantities of surface water and groundwater that can be taken from the basin's water resources. These limits must be set at a level that the Murray-Darling Basin Authority, using the best available scientific knowledge, determines to be environmentally sustainable. This is defined as the level at which water in the basin can be taken from a water source without compromising the key environmental assets, the key ecosystem functions, the productive base or the key environmental outcomes of the water source. Considerable scientific analysis is being undertaken to determine environmental water requirements that will inform the determination of 'sustainable diversion limits'. Recent appropriations of federal funding to enable the buyback of historical entitlements can be used to reduce water usage to levels compatible with these diversion limits (Garrick *et al.*, 2009). The scientific assessment and decision-making being undertaken in the Murray-Darling basin exemplifies a situation in which our presumptive standard would have been violated by past water allocations, yet water managers and stakeholders are now striving to restore a level of ecological health and water use sustainability similar to the goals of our presumptive standard.

Technology requirements

The technology and capacity to manage water in this manner exist in many parts of the world, but we acknowledge that many water management institutions and corporations have not yet developed hydrologic modelling tools with the required level of temporal resolution (i.e. daily) to implement our presumptive standard. Similarly, few countries have been able to install and maintain daily flow monitoring networks with adequate spatial distribution to facilitate data collection and regulation of water uses in the manner we suggest. However, recent and ongoing advances in modelling approaches and technologies, as well as improvements in flow monitoring instrumentation, are driving down the expense of implementing this type of water monitoring and modelling programme. Given growing water scarcity and its economic implications, investment in this level of water management capacity should be given high priority by governments at all levels.

We recognize that many water planners continue to use hydrologic models that operate on a monthly time step. We can offer some guidance and caution. Although it is consistent with our presumptive standard to assume for planning purposes that 20% of the natural monthly mean flow can be allocated for consumptive use, this does not mean that a volume of water equivalent to 20% of the monthly mean can be allocated on a fixed basis without violating our presumptive standard. We illustrate this point

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with a simple hypothetical example. Let us say that the mean monthly flow in July is $100\,m^3/s$. You allocate a sum total of $20\,m^3/s$ (20% of mean) for that month. Our presumptive standard will be violated each day in July that natural daily flows (recorded upstream or modeled) drop below$100\,m^3/s$, which will be the case during the majority of the time for most river types. Therefore, the only way to be assured that our presumptive standard will not be violated given a monthly allocation will be to subsequently model the system at a daily time step to check for compatibility with the standard under the range of flows typically experienced by the river. Once such compatibility is assured, the water authority can confidently grant water use permits based on fixed amounts (i.e. monthly allocations or continuous rates of use) that provide the water user with desirable certainty.

Utility for water planning

Although implementation of our presumptive standard will require considerable investment in adequate technology and expertise as outlined previously in this paper, we want to emphasize that our presumptive standard will also be quite useful for initial water planning purposes that require less technological investment. As discussed in our introduction, many large corporations have become quite concerned about their water-related business risk and are interested in approaches that can help them screen for such risk across many facilities and parts of their supply chains. We suggest that our presumptive standard will be highly appropriate in risk screening, wherein estimates of water availability and use are available for river basins of interest. Our presumptive standard can be used to identify river basins in which water flows appear to have been altered by more than 20%, thereby posing considerable potential risk. In this sense, we are pleased to see the incorporation of a variation of our presumptive standard in the *Water Footprint Assessment Manual* (Hoekstra *et al.*, 2011), which is already being used by many corporations.

Implications for water supply and storage

We recognize that in most hydrologic settings, storage will be required to enable full utilization of up to 20% of the available daily flow for consumptive use. Creating such storage can lead to ecological impacts (such as impediments to fish migrations or blocking sediment transport) that can undo the ecological benefits that our presumptive flow standard is trying to protect. Therefore, we strongly urge water managers and engineers to employ innovative options for water storage—such as off-stream reservoirs or groundwater storage—that do not involve on-stream reservoirs. Alternatively, in systems in which storage reservoirs already exist, enlarging the capacity of those existing facilities will in most cases be far preferable to building new reservoirs.

Some water managers will feel excessively constrained by having to operate within the constraints of the presumptive sustainability boundaries suggested here. However, managing water sustainably necessarily implies living within limits (Richter *et al.*, 2003; Postel and Richter, 2003; Richter, 2009). We suggest that a strong social imperative has emerged that calls for setting those limits at a level that avoids damaging natural systems and the benefits they provide, at least as a default presumption. Where other socio-economic priorities suggest the need for relaxation of the presumptive sustainability boundaries we suggest here, we strongly encourage governments and local communities to invest in thorough assessments of flow–ecology relationships (Richter *et al.*, 2006; Poff *et al.*, 2010), so that decision-making can be informed with scientific assessment of the ecological values that would likely be compromised when lesser degrees of flow protection are adopted.

In our experiences in working with water and dam managers, we have found that a remarkable degree of creativity and innovation emerges when engineers and planners are challenged to meet targeted or forecasted water demands with the least disruption to natural flow patterns. Solving the water equation will require new thinking about how and where to store water, conjunctive use of surface water and groundwater, sizing diversion structures or pumps to enable extraction of more water when more is available during high flows, sizing hydropower turbines such that maximum power can be generated across a fuller range of flows, and other innovations. When such creativity is applied as widespread common practice, human impacts on freshwater ecosystems will most certainly be reduced substantially.

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Statistical Modeling of Unnatural Selection, and the Dialectics of Causation in the Decline of Delta Smelt

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UC DAVIS Center for Watershed Sciences

BODEGA MARINE LABORATORY

Did water exports "Cause" the decline of delta smelt?

Yes !

Cause ?

Oxford English ~ that which produces an effect, or gives rise to an action, phenomenon, or condition.

E. Mayr, 1961 ~ Proximate vs. Ultimate

R. Hilborn & S. Stearns, 1982 ~ Necessary & Sufficient

D. Levins & D. Lewontin, 1980s ~ Dialectical biology, or cause arises from the interactive nature of processes operating at different scales, or perspectives.

S. Sloman, 2005 ~ Causal Models. Probabilistic nature of cause, hierarcical structural equations

Bottom line: Cause – multiple processes acting at different scales, but in a coherent fashion.

Dialectical Perspective on the Role of Water Exports in Causing Decline in Delta Smelt

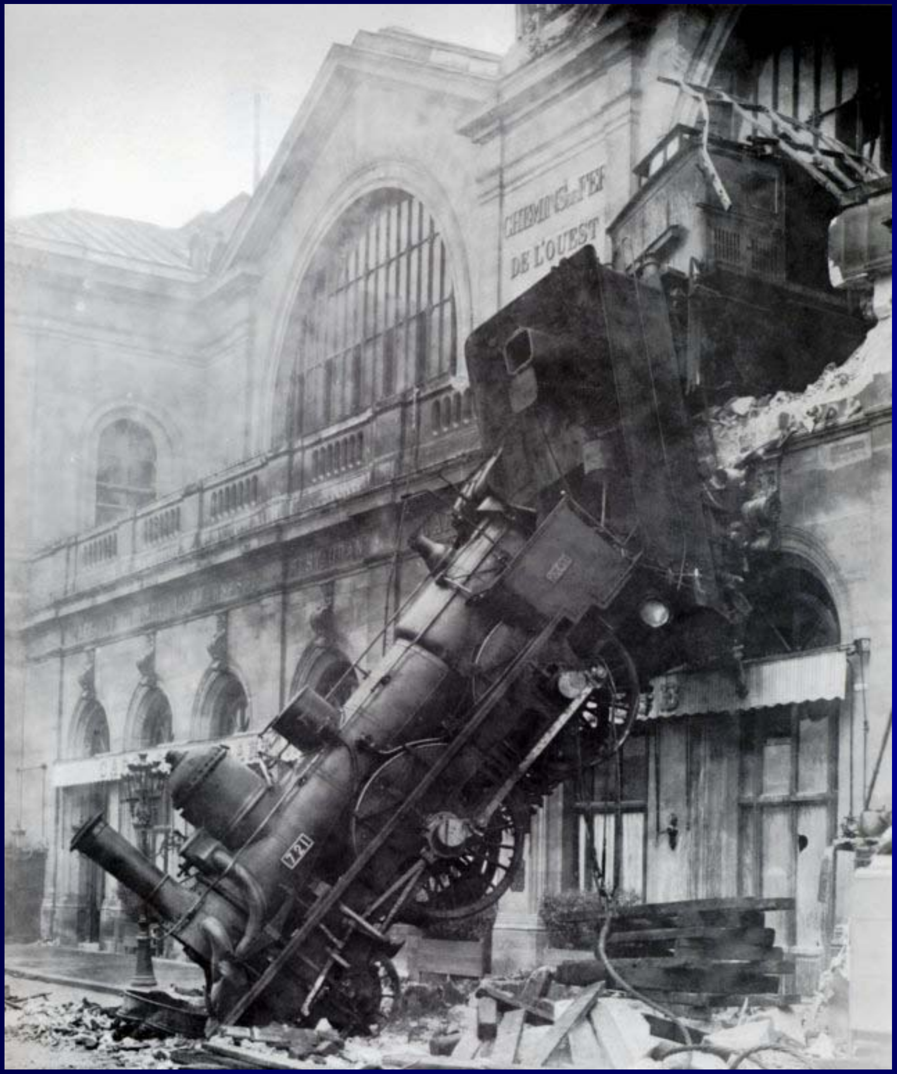
- **Landscape & Multi-decadal:** Dynamic Regime Shift.
- **Annual Year-Class Success:** Climate x Growth Selection.
- **Evolutionary:** Unnatural selection.

Major ecosystem transformation >2000. Loss of ability to spread risk spatially; puts limit on ability to rebound.

Early spring entrainment reduces numbers of fish more likely to survive adverse summer. Low annual abundance >2000.

Inter-generational loss of life history variation. i.e., unnatural selection pressure reduces adaptive fit. Loss of genetic diversity, reduced fecundity, survival, & potential to rebound.

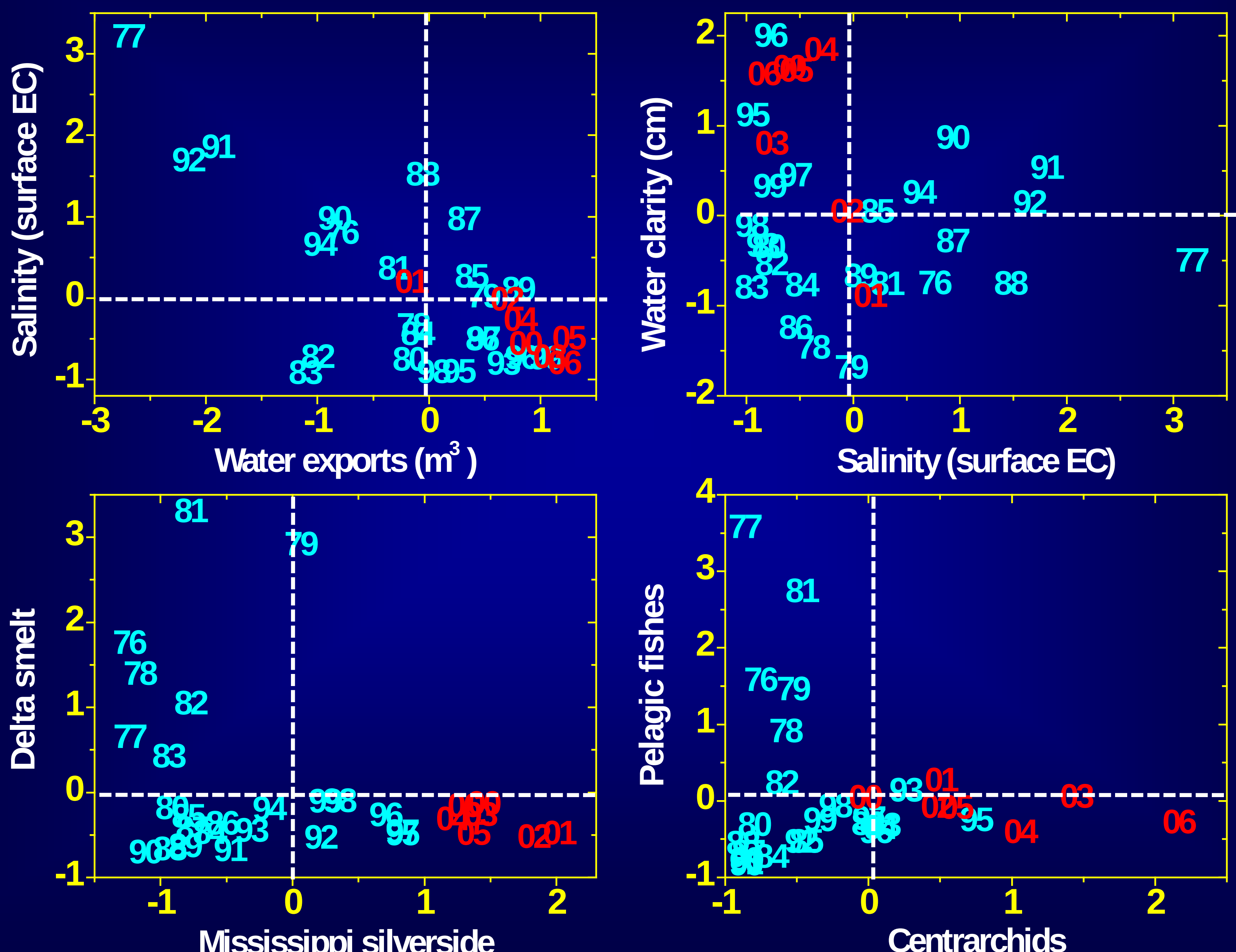
REGIME SHIFT in DELTA ~ TRAIN WRECK



Long-term "slow" physical & recent "fast" biological changes have produced a dynamic regime shift.

Lund et al.2010 "Comparing futures …"
Moyle and Bennett 2007. Appendix D. PPIC Report
Moyle et al. 2011. Variability. SFEWS.

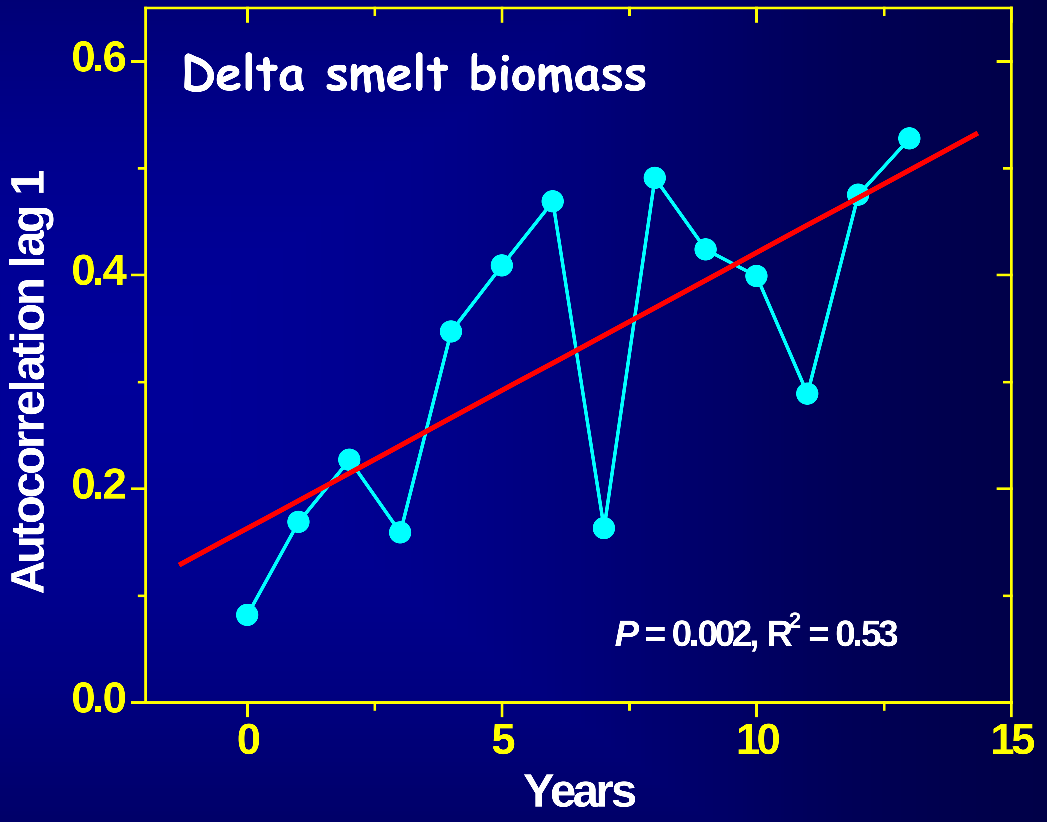
Ecosystem Regime Shift in the Delta ?



System Behavior Indicates Regime Shift
"Critical Slowing Down"

- Evidence for system dynamics slowing-down in years < 2001.
- Points = autocorrelation coefficients at lag 1, for years before 2001.

Method: Dakos et al. 2008 Proc. Nat. Acad. Sci.



Dialectical Perspective on the Role of Water Exports in Causing Decline in Delta Smelt

- Landscape & Multi-decadal: Dynamic Regime Shift.
- Annual Year-Class Success: Climate x Growth Selection.
- Evolutionary: Unnatural selection.

Bennett et al. 2008. Final Report, POD www

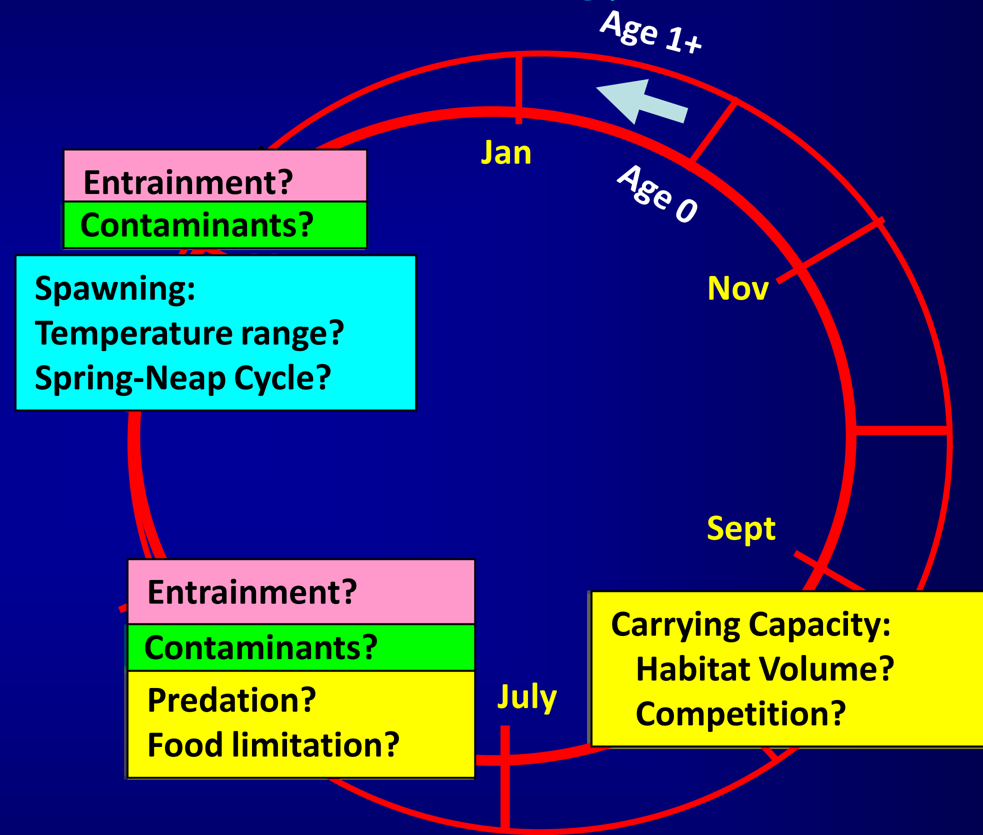
Delta Smelt Conceptual Model

Ocean & Climate forcing

1. DRY WINTERS – Hi X2
   - Short spawning season
   - OMR negative flow

2. HOT SUMMERS - +PDO
   - Habitat restriction
   - Physiological limitation

Spawning & Life History Strategy ?



Summer-Fall Mortality
Juvenile 'bottleneck" ?

Bennett 2005. San Francisco Estuary & Watershed Science

Dialectical Perspective on the Role of Water Exports in Causing Decline in Delta Smelt

- Landscape & Multi-decadal: Dynamic Regime Shift.
- Annual Year-Class Success: Climate x Growth Selection.
- Evolutionary: Unnatural selection.

Unnatural selection:
aka, Big Mama Hypothesis

Reproductive Potential & Fisheries

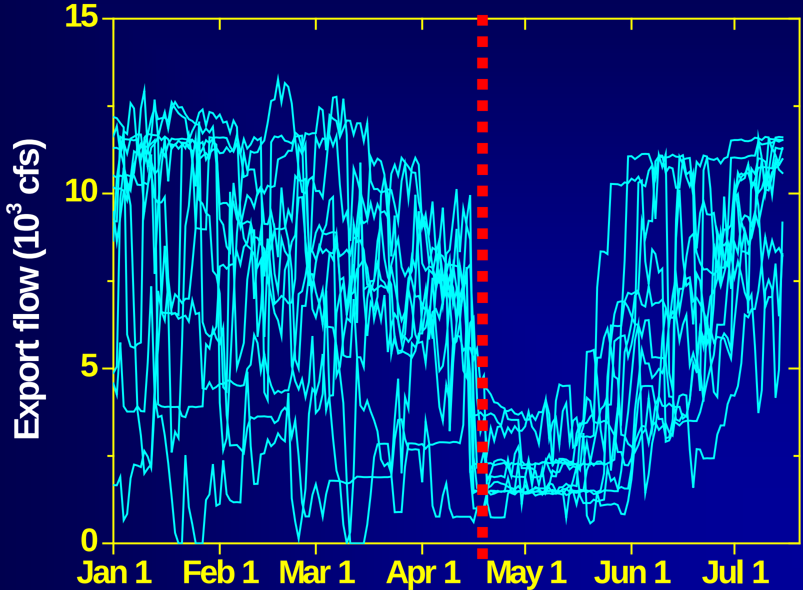
Individual life history strategies to enhance fitness

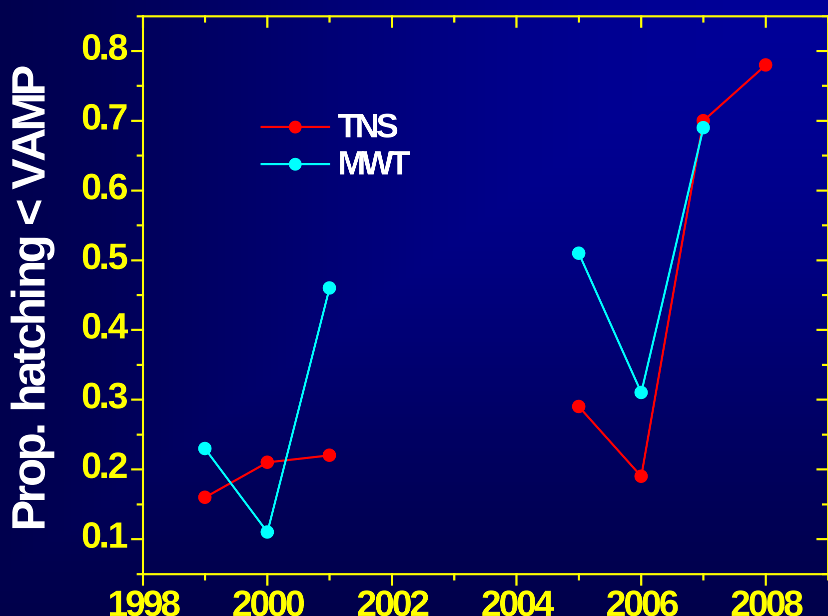
- Individual variation in spawning strategy ~ size/age.
- Larger/older females: higher fecundity (more eggs)
  larger eggs (larger oil globule)
  spawn early and repeatedly.
  offspring are more robust.

With human intervention…

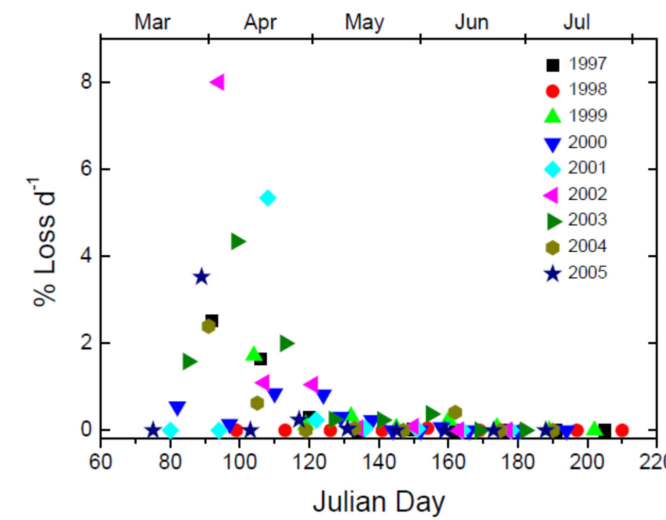
- Fisheries remove (select) larger/older fish.
- Over Time → higher proportion of individuals weaker & dumber…
- Loss of "reproductive potential" reduces probability of year-class success (population resiliency).
- Key Examples: North Atlantic cod fishery
  California rockfish fishery

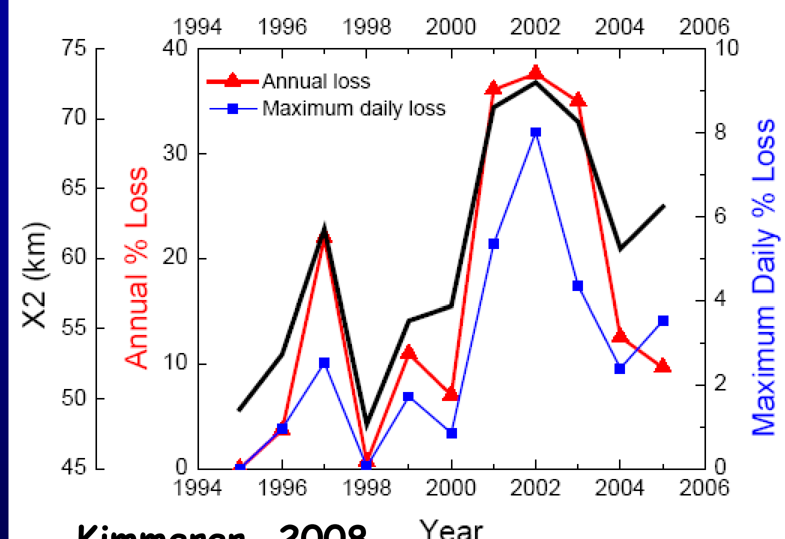
Export Trends '95-'08





Seasonal Pattern of Export Losses

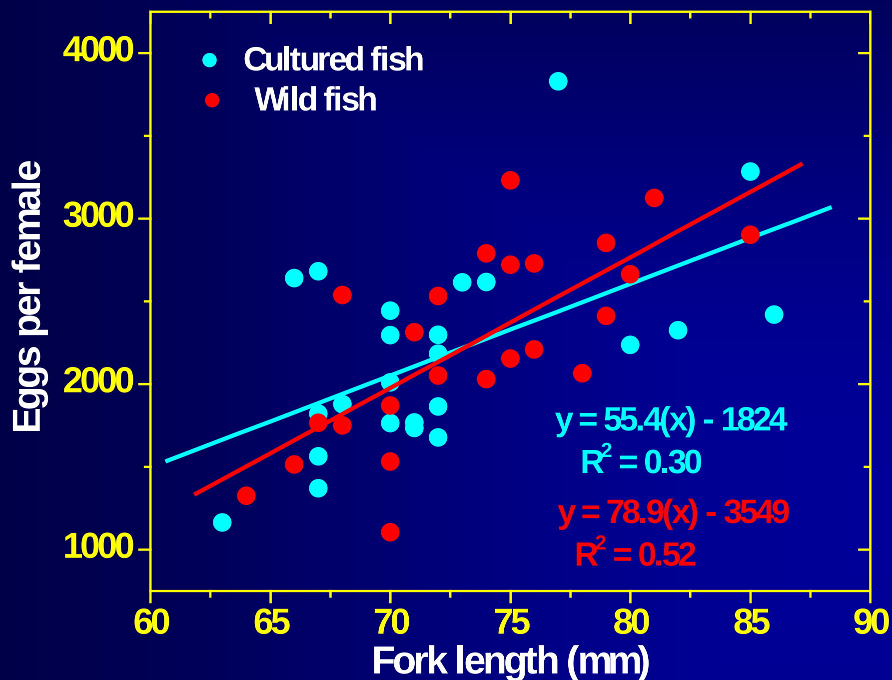


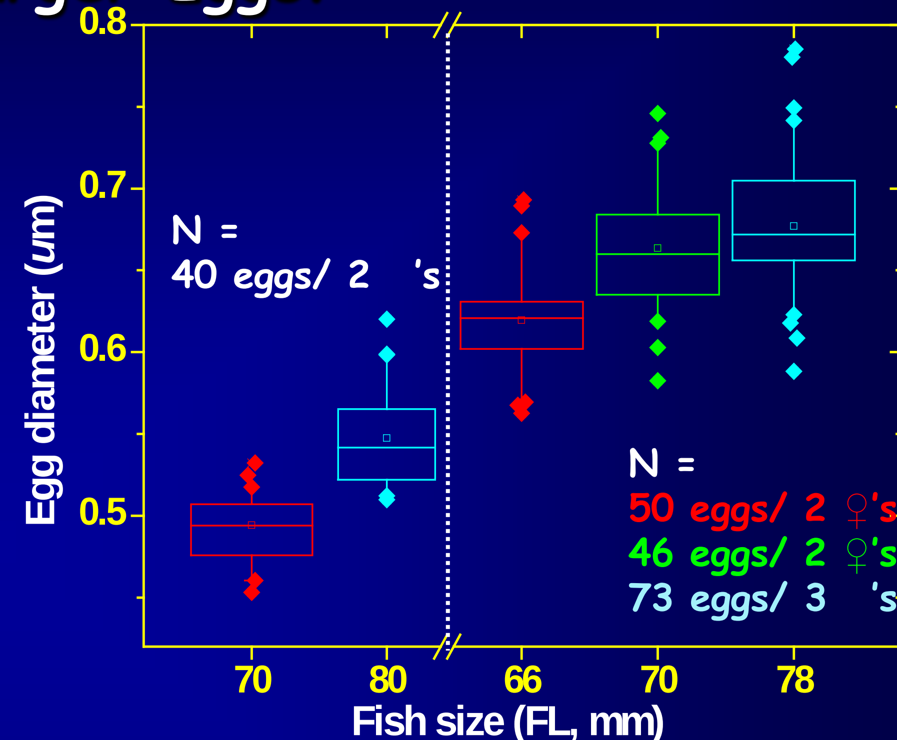


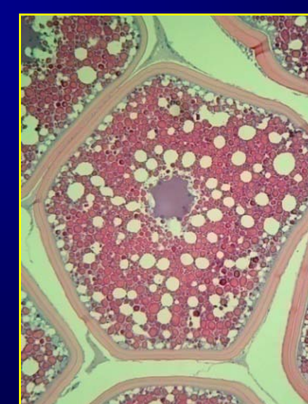
Kimmerer, 2008.

San Francisco Estuary & Watershed Science

Maternal Effects – Larger Females Produce More and Larger Eggs?







Late vitellogenic stage

- Egg number & size increases with female size
- Larger females have higher potential for spawning twice – serial spawners?

Developing an Age-Length Key: Expanding *N* of Age Estimates from Otoliths

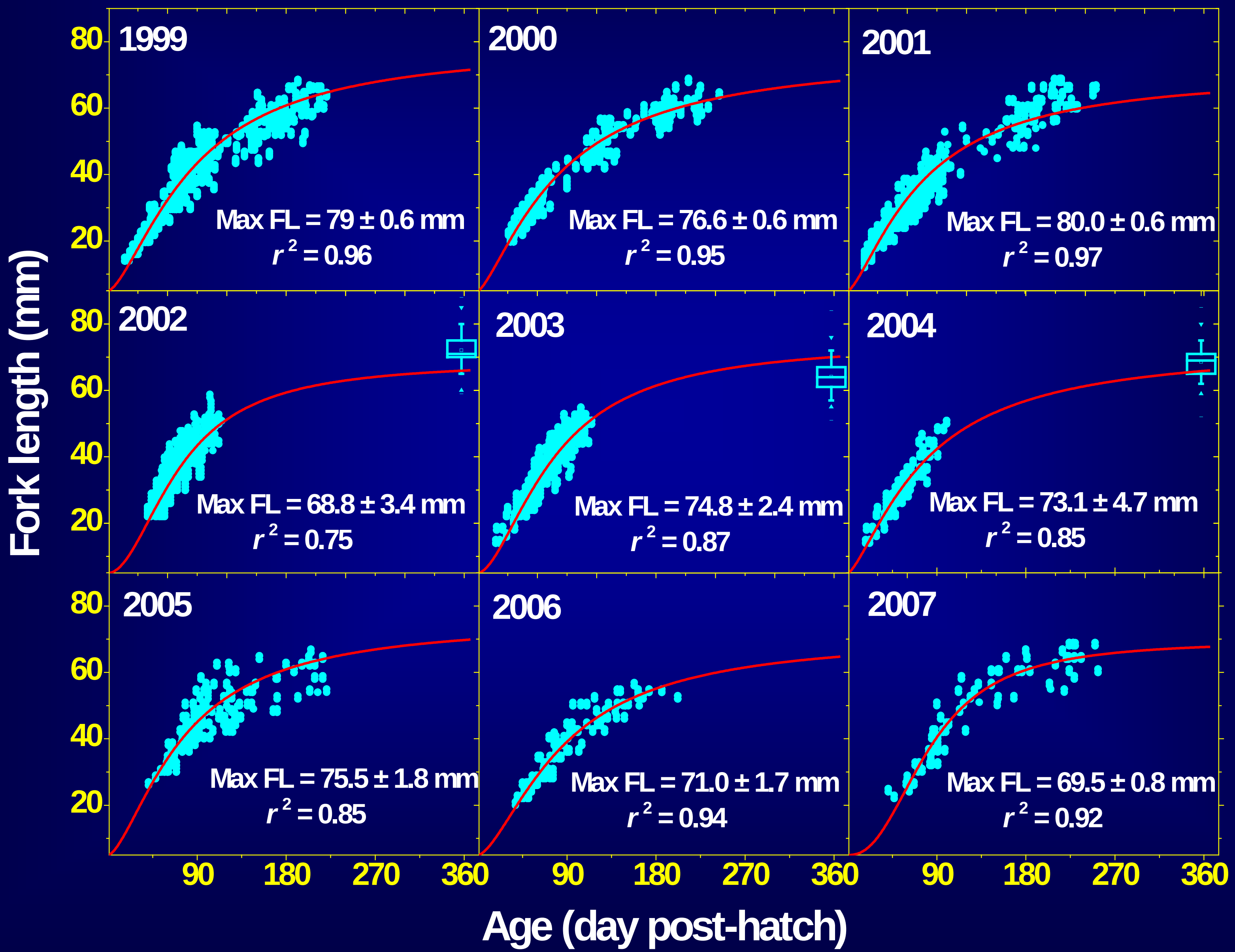
Sample sizes and ranges used to estimate age from lengths of delta smelt collected by IEP monitoring surveys .

Year	N(aged)	N(length)	Size range (FL, mm)
1999	378	9,434	14-70
2000	226	5,742	20-69
2001	398	5,500	12-70
2002	199	2,274	22-55
2003	287*	2,894	14-55
2004	89	1,516	14-50
2005	150	801	26-67
2006	93	926	20-57

* Pooled age samples from 2002 and 2004.

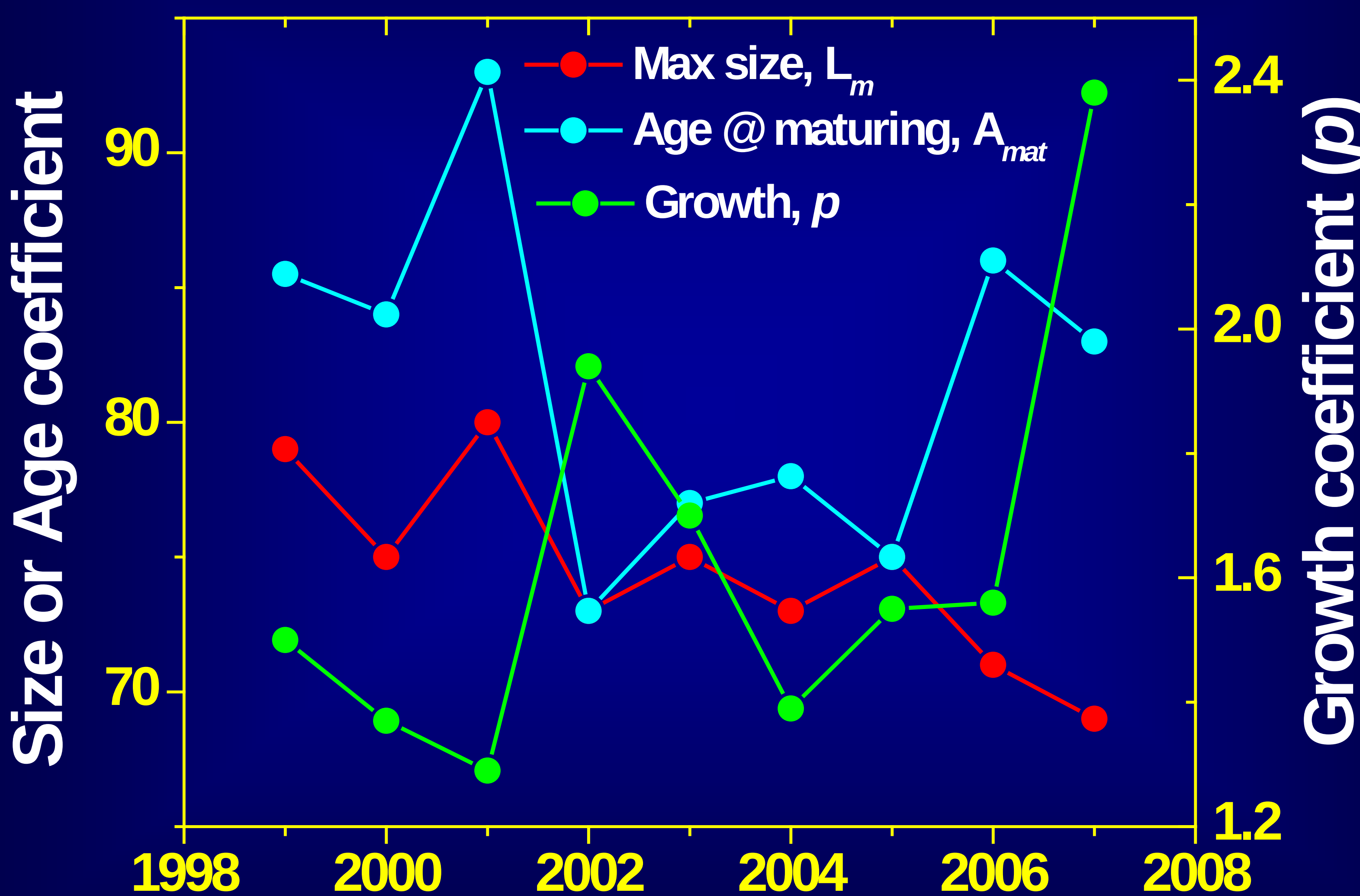
Growth Modeling of Size @Age

4 parameter formulation of Logistic Model



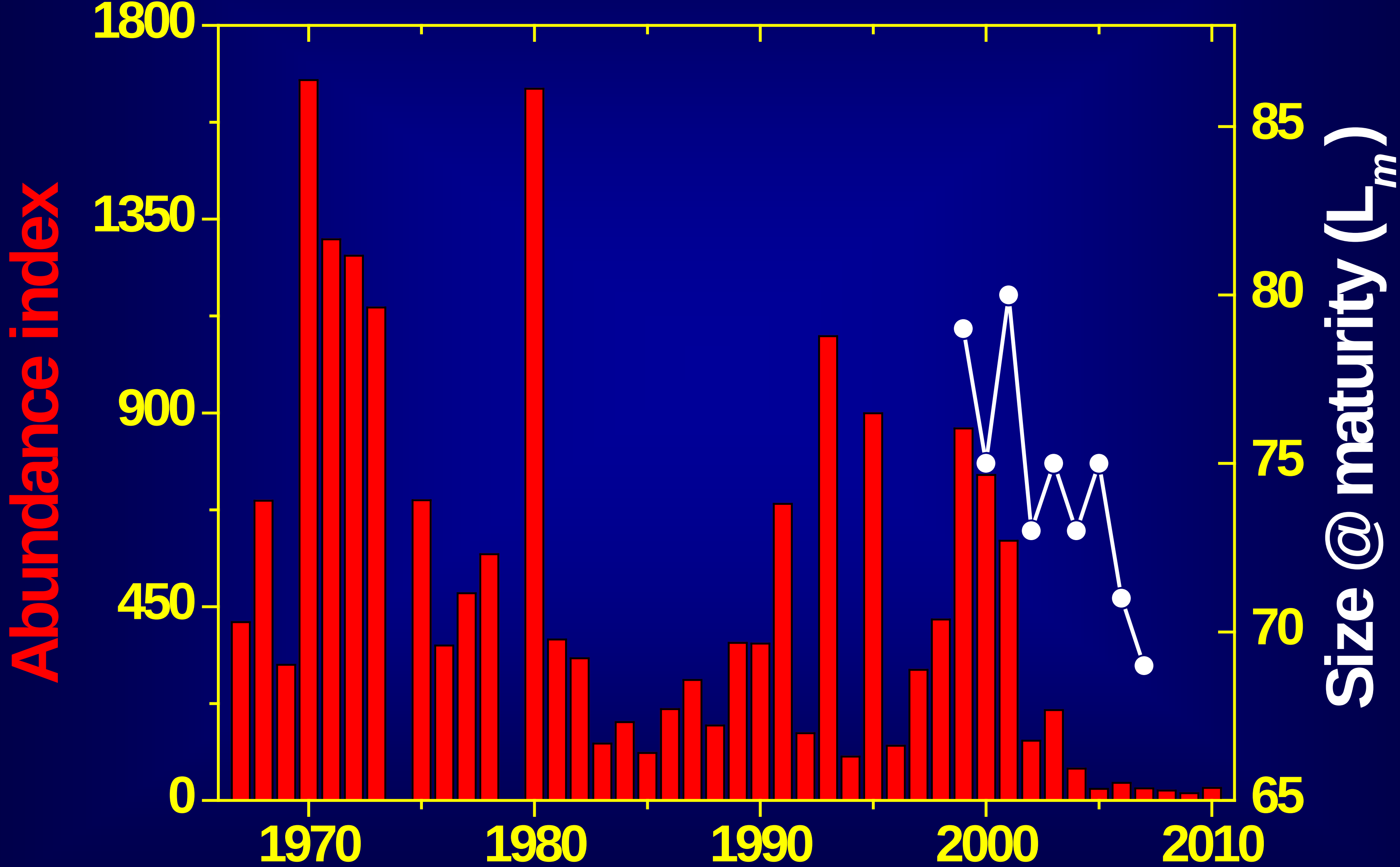
Trends in Key Fitted Model Parameters

Major Changes in Life History Strategy



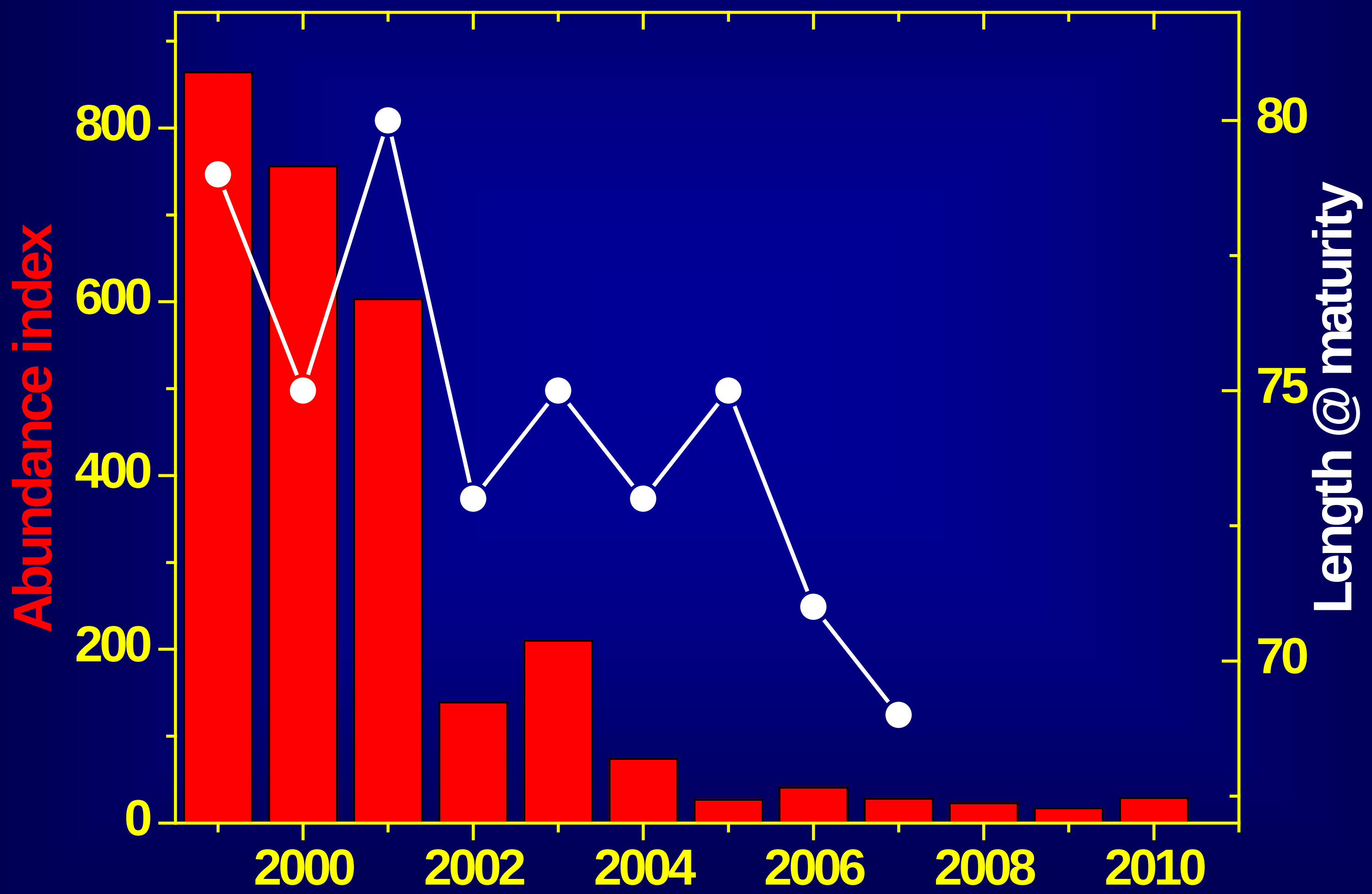
Trends in Abundance & Size @ Maturity

Lack of Population Resilience



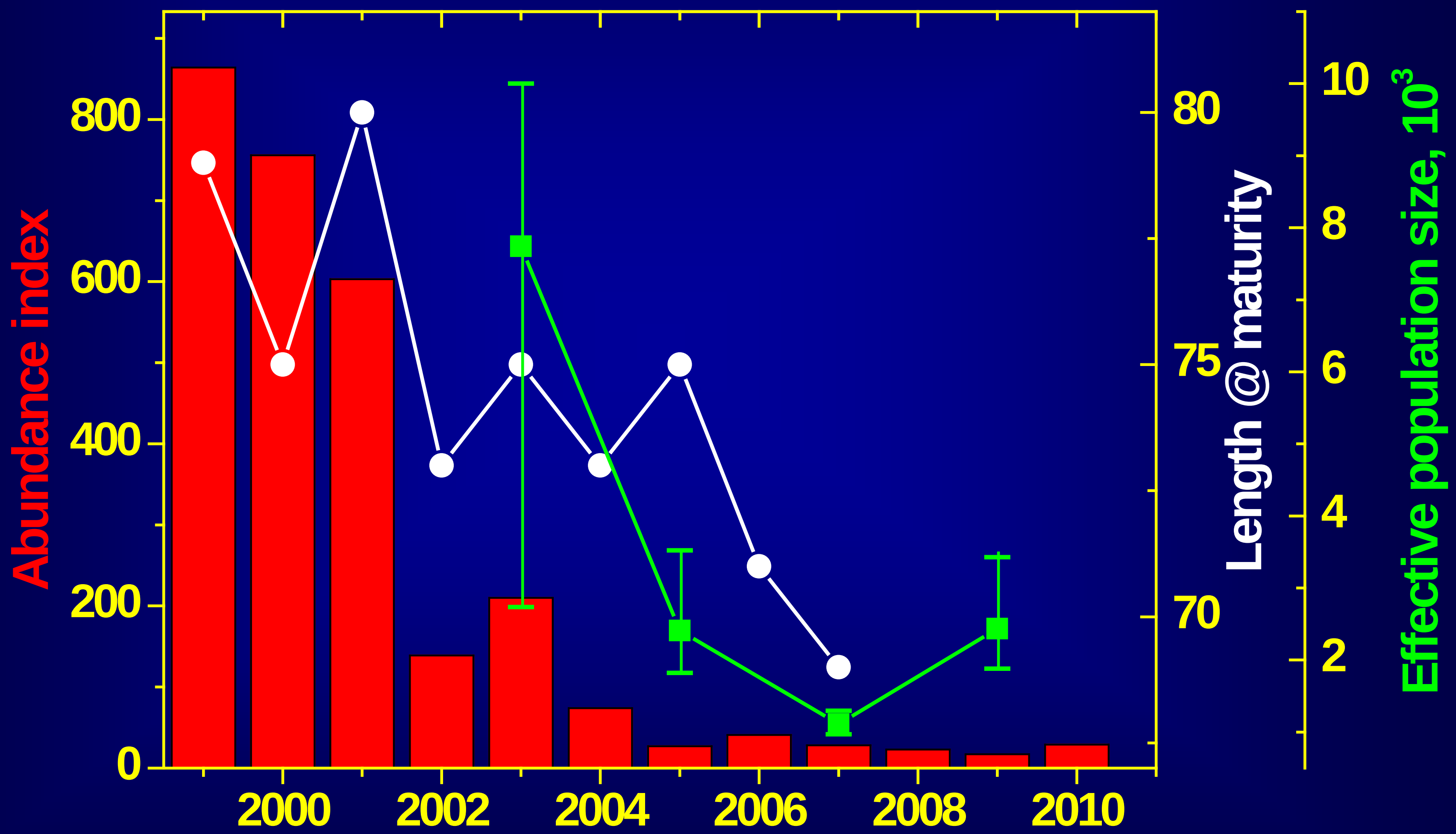
Trends in Abundance & Size @ Maturity

Lack of Population Resilience



Trends in Abundance & Size @ Maturity

Lack of Population Resilience



Nonlinear Mixed Effects Modeling:
Delta Smelt Growth and Condition

- Hierarchical treatment of individual growth patterns (random effects) and population average growth(e.g. Year, fixed effects).
- Very flexible (i.e. sometimes to much) in how to handle variances, and temporal autocorrelation.
- Can be a more logical way to handle covariates at different levels of the hierarchy.
- Objective 1: Model size @ maturity among years by fitting growth model to each individual's daily growth increments.

  Years 1999-2001 & 2005-2007

  Include various covariates.

  Data matrix: 134,848 x 21

Dialectical Perspective on the Role of Water Exports in Causing Decline in Delta Smelt

- **Landscape & Multi-decadal:**
  Dynamic Regime Shift.
- **Annual Year-Class Success:**
  Climate x Growth Selection.
- **Evolutionary:**
  Unnatural selection.

Major ecosystem transformation >2000.
Loss of ability to spread risk spatially; puts limit on ability to rebound.

Early spring entrainment reduces numbers of fish more likely to survive adverse summer.
Low annual abundance >2000.

Inter-generational loss of life history variation. i.e., unnatural selection pressure reduces adaptive fit.
Loss of genetic diversity, reduced fecundity, survival, & potential to rebound.

Who says no one is
interested in catching
a stringer of delta smelt?

Thanks !