*Int. J. Engng Ed.* Vol. 19, No. 1, pp. 213–226, 2003
Printed in Great Britain.

0949-149X/91 $3.00+0.00


# Can We Design Ecosystems? Lessons from the California Rivers*

MICHAEL BLACK
*284 Catalina Ave., Pacifica CA 94044, USA. E-mail: black@hmc.edu or michaelb@igc.org*

*For over a century, the US Fish and Wildlife Service and its predecessors have run the Coleman National Fish Hatchery on northern California's Battle Creek. Until recently, however, those overseeing the world's largest salmon hatchery have sought to restrict the upstream passage of indigenous, and, in some cases, 'endangered' stocks of chinook salmon. Today the Service's managerial, infrastructural and scientific priorities appear to be on a collision course with legislatively-mandated, natural restoration priorities. Technological mitigations like hatcheries and other 'serialistic policies' stand in the way of habitat restoration and designing with nature. Natural resource agencies remain wedded to ratcheting up ameliorative technological fixes within riverine systems too battered any longer to support wild fish. Today's 'fish salvage' assumptions are identical to rationale formulated, institutionalized, and subsequently abandoned as unworkable over a century ago.*

## INTRODUCTION

*'Logic is an organized way of going wrong with confidence'* Kettering's Law

'FISH BIOLOGISTS can have anything they want in the West,' muses fish conservationist William M. Kier, 'as long as it's not water.'[1] What happens when fisheries scientists and engineers adapt themselves to a set of thoroughly unnatural strictures? What occurs when powerful economic arrangements abandon as unworthy the preservation of wild salmon in their relatively undisturbed rivers? Deprived of sufficient authority to preserve free-flowing rivers, denied ecological strategies for sustaining migrating salmon, hamstrung biologists and engineers often settle for the next best thing—gimmickry.

A *Sacramento Bee* article boasts that northern California reservoirs may soon be 'Studded with gadgets, which may be the next best thing to an unlimited supply of water, biologists say.' A civil engineer with the US Bureau of Reclamation exclaims, 'There will be lots of toys in the reservoirs.' The problem, another fish biologist volunteers, is that increasing urban and agricultural demand reduced 'flexibility' in the water delivery system (read 'plumbing'). They add, 'The only way to get that flexibility back is with devices, and we need that desperately.'[2]

The range of contraptions being tested to rescue Pacific Coast salmon would boggle Rube Goldberg. There's the 253-m giant rubber (shower) curtain at the Klamath Basin's Lewiston Reservoir. There's a $100,000, truck-powered 'bubblier' that's dropped 91.4 m into Shasta Reservoir. There's also a $75 million water-temperature control device which has been retrofitted on Shasta Dam. Lest we stop there, we've also got hatchery-reared fish, permanent breeder colonies, fish ladders and elevators, fish-barging and trucking schemes, acoustic behavioral fish barriers, artificial spawning channels, spawning gravel augmentation programs, electronic 'sensor' fish, and bounties on pikeminnows, among others. Our appetite for designing 'compensatory mitigations' seems boundless.

What these technocentric schemes share as their presumed goal is the reintroduction of salmon into once pristine rivers. But by abandoning free-flowing water for gizmos, biologists and engineers side-stepped an inchoate nature for a paradise of technological precision. If we treated our rivers as plumbing contrivances, fish too should be reconceived as mere artifacts. Why not, many rationalized, reinvent salmon in accordance with a neatly controlled water delivery system? 'Designer fish' within 'push-button rivers' offered participating envirocrats a semblance of security under the dramatic (if misguided) banner of willful action. A century and a half has passed since we began misdiagnosing the fisheries problem.

## REINDUSTRIALIZING NATURE?

Our North American story originates in the 1850s, when New Englanders began voicing increasing alarm over the wholesale loss of fish stocks. Embracing the inevitable tradeoffs between a pristine nature and 'civilized' life, Vermonter George Perkins Marsh recommended fish cultural remedies. Marsh came to believe that a crisis substantially fueled by industrialization was best resolved through mechanical, industrial means. In 1857, Marsh advised we need only supersede

* Accepted 8 May 2002.

nature by counterfeiting fish suitable to a 'shorn and crippled' nature.[3] Laws were required, he counseled, to protect the legal property of entrepreneurs dedicated to artfully producing more fish.

In his 'Report, Made Under Authority of the Legislature of Vermont, on the Artificial Propagation of Fish,'[4] Marsh drew upon his scientific study of geography and natural history to conclude a reversal of current civilizational practices was unthinkable. He wrote that plummeting fish populations stemmed from an admixture of dams, water-born factory and urban pollution, wildly fluctuating runoff due to deforestation and agricultural clearing, elevated water temperatures, loss of natural fish-food sources like insects, and improvident overfishing.[5] However, to Marsh, piecemeal solutions (like fish breeding, species substitution, and so forth) held greater sway than did preserving nature or hopes for curbing human appetites. Before things deteriorated any more, Marsh penned a European-derived strategy that Vermonters—and indeed the nation as a whole—might employ to recover a multitude of fishes.

Since, Marsh wrote, '. . . human improvements have produced an almost total change in all the external conditions of piscatorial life,' he concluded that progress came at an inevitable price. He continued:

> We cannot destroy our dams, or provide artificial water-ways for the migration of fish, which shall fully supply the place of the natural channels; we cannot wholly prevent the discharge of deleterious substances from our industrial establishments into our running waters; we cannot check the violence of our freshets or restore the flow of our brooks in the dry season; and we cannot repeal or modify the laws by which nature regulates the quantity of food she spontaneously supplies to her humbler creatures.[6]

Legislative restraints fell far short of restoring fisheries as would the imposition of 'obnoxious' game laws prevalent among some European nations. Marsh believed regulation-adverse Vermont Yankees would never tolerate strict game laws nor would a market system leave them enforceable.[7] He instead proposed embracing a more 'promotive' rather than a 'protective' legislative strategy which granted '. . .liberal premiums for judicious and successful private efforts in the restoration and improvement of the fisheries.'[8]

Marsh advised that 'we may still do something to recover a share of the abundance which, in a more primitive state, the watery kingdom afforded.'[9] He reminded Vermont's Governor and members of the United States Congress of forgotten fish breeding practices common to imperial Rome and monastic Europe. Marsh the naturalist closed his analysis by imploring that Vermont's lakes and rivers be 'peopled' with salmon and other once abundant species of fish by harnessing the entrepreneurial and scientific talents of private fish-breeders. Technological mitigations would be sought to compensate where nature was failing to provide New Englanders with their valuable food fishes. Marsh implored that the state enact legislation protective of commercial fish culturalists.

It required a decade before Marsh's advice was eventually heeded, but by the late 1870s, thirty fish commissions from Maine to California trumpeted the victory of aquaculture over wholesale habitat loss. In 1871, Spencer Fullerton Baird of the Smithsonian Institution was drafted to found the US Commission on Fish and Fisheries (later renamed the US Fish Commission) to repopulate the nation's depleted fish stocks. Initially, shad and salmon restoration were foremost on Baird's mind as he oversaw the nation's first environmental restoration movement. A year later, Baird dispatched hatchery enthusiast Livingston Stone to California's Sacramento River Basin to harvest Chinook salmon ova for transplantation to badly depleted Northeastern rivers. Reciprocally a host of 'superior' eastern fishes from shad to striped bass were also shipped westward by rail to become acclimated to 'inferior' Pacific slope waters.[10]

## TECHNOLOGICAL MYOPIA ON THE SACRAMENTO RIVER

In 1872, fish evangelist Livingston Stone located the West's first fish hatchery along northern California's McCloud River.[11] Stone was convinced that his artificial propagation efforts were restoring salmon to the beleaguered Sacramento River Basin. Things gave every appearance of going well, until, on August 7, 1883, Stone and his assisting Wintu Indians partners watched in disbelief as no more fish roiled the water.[12] The interruption stemmed from a complete blockage of the lower Pit River by an Oregon-bound Central Pacific Railroad. Eighteen eighty-one and 1882 also marked the most heavily fished spawning runs in the river's history. With little evidence of success to recommend it on the east coast, Spencer Fullerton Baird saw no point continuing Stone's artificial propagation program and it was suspended.[13]

Amnesia is one of the guiding forces of history, and Baird's midcourse correction was either buried or forgotten. By August 1896, the US Fish Commission, working in tandem with California's Fish Commissioners, erected temporary hatchery structures on a second Sacramento River tributary called Battle Creek. Recognizing the need to overcome '. . . the double odds of natural and human enemies,' biologist Cloudsley Rutter expressed his belief that artificial propagation was the sole hope for the Sacramento River salmon.[14] Believing that 'the relative efficiency of natural versus artificial propagation is about one percent and 85 percent, respectively,' Rutter wrote:

> Artificial propagation is keeping up the supply of salmon in the Sacramento River. With one exception, there are now no natural spawning beds in the Sacramento basin that amount to anything. All of

the Feather, Upper Sacramento, and Pit rivers, with their tributaries have been practically abandoned, with the exception of the streams where the hatcheries are located. The only natural spawning beds still occupied are in the main river, between Redding and Tehama, which are yet visited by a considerable number of salmon.'[15]

Boosting Rutter's confidence was technological intervention in the rivers themselves. In 1897, he and several colleagues helped catch a record number of fall-run Sacramento salmon ascending Battle Creek (8784 fish were spawned yielding 48,527,000 salmon eggs). Between their weirs and nets, biologist Schofield reports they 'took almost ever fish in the river,' making artificial propagation at the Battle Creek Station the sole tool of choice for saving the Sacramento's salmon.[16] Writing four years later, a confident Rutter concluded: 'Artificial propagation of salmon has not yet reached such proportions as to entirely supplant natural propagation, with the exception of the work on the Sacramento River.'[17]

The Battle Creek Station remained in operation through 1945 when a new set of threats to fish and fisheries reverberated throughout Western watersheds. From the Pacific Northwest's mighty Columbia to California's Sacramento river, federal agencies like the US Bureau of Reclamation built pharaonic dams like Grand Coulee and Shasta. Attempts at reconciling anadromous fish losses with massive water development stemmed from the Grand Coulee's dam construction. In rapid succession, frankly experimental 'fish salvage' efforts occurring on the Columbia River were attempted in the Sacramento River Basin where, in 1942, the Coleman National Fish Station was erected on lower Battle Creek.

Fisheries scientists like Willis H. Rich greeted the great dam building era with trepidation.[18] The Stanford University professor was retained in 1938 by the Oregon Fish Commission to direct their new Research Division.[19] A classically educated biologist, Rich was dubious about excessive reliance on hatcheries as a means of mitigating fishery losses.[20] In 1939, speaking before assembled ichthyologists at Stanford University, Rich concluded:

> Biologists in general are skeptical of the claims made for artificial propagation . . . because these claims have often been extravagant and the proof is entirely inadequate. Indeed, many conservationists feel that the complacent confidence felt by fisherman, laymen, and administrators in the ability of artificial propagation to counterbalance any inroads that man may make . . . is a serious stumbling block in the way of the development of proper conservation programs.[21]

However Rich needed to temper his idealism with a pragmatic approach suitable to the dam building era. As an Oregon fisheries administrator, Rich was more circumspect in his criticism of hatcheries. He recognized that enormous dams transformed hatcheries into self-fulfilling prophesies: dramatically shrinking natural habitats meant escalating hatchery programs.[22] During the 1920s and 1930s, Alaska and British Columbia provided rare instances where hatchery-driven salmon production was deliberately scaled back, due to excessive costs. Within these unique instances, however, artificial propagation could only be traded for intact spawning grounds.[23] Biologist Rich had no alternative but to accommodate himself to the dam construction era, hoping that some day 'general principles' might be discovered which reconciled massive water development with the stringent biological requirements of anadromous fish.[24]

As environmental historian Joseph Taylor observes, the Columbia River's Grand Coulee Fish Maintenance Project required that a century's accumulated managerial and technological precedents be systematically recombined and directed at relocating and producing fish on an undreamed of scale. Successful fish salvage efforts hinged upon:[25]

- identification and restoration of downstream tributaries suitable for fish transplantation and reproduction;
- construction of a greatly expanded hatchery system;
- invention of a new means of moving fish around.

The personnel who created these institutional precedents, techniques, and rationale would soon be shifted to the Sacramento River Basin in a renewed effort at salvaging salmon.

## MITIGATING FOR THE CENTRAL VALLEY PROJECT

When Shasta Dam construction began interfering with salmon passage on November 8, 1942, the Central Valley Project's keystone project drastically affected an array of migratory salmon stocks. Two to four million salmon once frequented the Central Valley system as a whole, with the Sacramento and its tributaries accounting for the lion's share.[26] Sacramento River salmon runs were once distinguishable by their many attributes including run-timing, size and varying spawning habitats. So-named according to the time of year each race of salmon ascended the river, the Sacramento was the sole river in the world with four genetically distinctive types of fish. For instance, the spring-run fish, the largest historic Chinook salmon stock, arrived in 'pre-reproductive and peak physical condition' and frequented extreme elevations within mountainous streams fed by snow-melt. By contrast, fall-run stocks arrived bearing eggs but the fish were in a somewhat compromised physical state. They predominated within the lower river and its foothill reaches at elevations of 500 feet or less. That meant that their habitats would be least adversely affected by proposed upstream dam construction.[27]

US Bureau of Fisheries Biologists Harry A. Hanson, Osgood R. Smith, and Paul R. Needham, among others, were given barely three years to complete their US Bureau of Reclamation sponsored investigation into responses to the effects of the Shasta-Keswick complex. Echoing what had occurred on the Columbia River, their report recommended:[28]

- sustaining the runs by means of artificial propagation;
- capturing and transferring the fish to suitable downstream tributaries for re-establishment in a new stream;
- some combination of artificial and natural propagation.

Four distinctive plans were passed along to an independently appointed Board of Consultants (Board).[29] This Bureau of Reclamation appointed Board was charged to propose the best overall solution to the salmon problem.

Board members selected an approach which combined elements drawn from among several previously submitted plans. Their 'Shasta Salmon Salvage Plan' called for relying upon:

- fish ladders, traps and lifts in the Keswick Afterbay Dam and the mainstem Sacramento River's Balls Ferry Fish Rack for capturing and removing salmon under high and low water conditions;[30]
- seven tank trucks for transferring salmon from the Balls Ferry Fish Rack and Keswick Fishtrap to the Coleman National Fish Station on lower Battle Creek, and to the downstream tributary, Deer Creek;
- construction of a Battle Creek hatchery infrastructure capable of handling 58,000,000 salmon eggs and approximately 29,000,000 fingerlings. Twenty-eight outdoor rearing and holding ponds were to be constructed;
- installation of five fish racks in Battle Creek to create holding areas for ripening spring-run salmon;[31]
- installation of three removable Sacramento River fish racks for regulating fish spawning densities—the lower most Balls Ferry Fish Rack was also to serve as a fish trapping facility;
- installation of a rack and a fish ladder on Deer Creek for holding and counting in-coming native fish.

Theories are often humbled by the acid tests of time and reality. Implementation of the aforementioned goals began disintegrating from the outset. Moreover, beginning in 1945, the leading institutional role being played by the US Bureau of Reclamation (in tandem with Central Valley Project beneficiaries), was being re-evaluated and substantially rescinded. Piece by institutional piece, the Bureau abandoned to the US Fish and Wildlife Service (and indirectly, to the California Department of Fish and Game) the responsibility of caring for, paying for, and operating ongoing fish salvage efforts.

Throughout the remainder of the 1940s, multiple components of the Shasta Salmon Salvage Plan broke down or were abandoned as unworkable. These fundamental features included the:

- failure of the Sacramento River's mainstem fish racks;
- Coleman National Fish Station's retreat from and abandonment of its attempts to ripen, hold, and propagate spring-run Chinook salmon;
- fish transport system having higher than expected mortality rates;
- spring-run transfer to Deer Creek was abandoned as unworkable.

Last but not least, in June of 1950, the on-again, off-again Keswick Fishtrap and Loading Facilities were turned over to the Fish and Wildlife Service by an exiting US Bureau of Reclamation. Among its many design flaws was its inability to function beyond modest river flows of 16,000 c.f. s.[32]

In retrospect, we can forgive those caught up in events for having made the best scientific and engineering judgment possible at a given historical moment. History is sometimes less forgiving, however, as cumulative choices and events often give rise to a cascading series of institutional, economic, technological and ecological backlashes. Unanswered is how does Coleman hatchery's primary failure to mitigate for upstream salmon losses (like spring-run fish) affect the achievement of other key 1940s Bureau of Reclamation fish salvage objectives?

A reflection on what occurred among other key features of the Shasta mitigation program may answer the query. To reiterate:

- the Sacramento River Fish Racks essentially failed before being used:
- the Keswick Fishtrap operated on an on-again, off-again basis, and it became inoperative at moderate flows exceeding 16,000 c.f.s.;
- the fish transport service often delivered weakened fish to inferior, dangerously warm waters;
- Coleman National Fish Station was never able to propagate one half of the threatened spring-run salmon;
- the Deer Creek fish transfer was completely abandoned as unworkable by 1946.[33]

In the end, what is concluded is that mitigation for the Central Valley Project failed.

The two surviving pieces of the original Shasta Salmon Salvage Plan were the Coleman Station itself and the Bureau-run Keswick Fishtrap. From the US Fish and Wildlife Service's point of view, Coleman Station did succeed at producing significant numbers of lower-river, fall-run Chinook salmon. Before becoming Coleman's Superintendent, biologist Scott Hamelberg wrote:

> Although not in direct alignment with the [originally] proposed mitigation responsibility, the contribution of Coleman [National Fish Hatchery] in maintaining the ocean and sport fishery and upper river escapement of fall Chinook salmon, while the quality of the

> Central Valley watershed was continually degraded [requires being acknowledged].[34]

Within ensuing years, the Bureau's Keswick Fishtrap also continued being called upon to capture incoming cohorts of salmon. Most of the time the Fishtrap functioned satisfactorily. However, as noted, it became inoperable at even modest river flows, making it less than dependable over the long haul.

What was lost with the building of the Central Valley Project's keystone Shasta-Keswick complex? Based upon 1940 run-estimates, the answer is roughly:

- 15 percent of the fall-run's upriver habitat;
- 100 percent of the winter-run's habitat (save for upper Battle Creek);
- 100 percent of the spring-run's habitat (save for their occupying higher elevations on several downstream tributaries); and,
- 90 percent of the steelhead's habitat.[35]

The most critical feature of the lost spawning grounds above Shasta and Keswick dams was not the absolute number of fish excluded (a number which wildly varied contingent on environmental conditions) but rather the quality of that drought-proof habitat.[36] The upstream McCloud River, the Little Sacramento River, and the Pit River were resistant to drought and the mortality caused by elevated water temperatures. These upper watersheds produced high quality habitats because of their higher elevations and their volcanic geomorphology. These rivers absorbed much of the wet, seasonal runoff, then gradually released it in abundant cold spring flows throughout the dry season. The respectable counts of salmon and steelhead returning to the areas above Shasta Dam at the close of 1939's severe drought cycle attested to the drought-resistant character of the stream reaches above.

In assessing the effectiveness of the Central Valley Project salmon recovery efforts, biologist James Moffett cited rough estimates of fish spawning above Red Bluff (144,000 in 1944, 106,000 in 1945, and 96,900 in 1946) and concludes that 'natural spawning in the Sacramento River was remarkably successful as is indicated by examinations of dead salmon and the hourly rate of catch in fyke nets of young salmon.'[37] Indeed, a clause within a 1948 Memorandum of Agreement between the US Bureau of Reclamation and the US Fish and Wildlife Service states:

> Whereas, the Bureau and the Service are agreed that as a result of the salmon maintenance program and the operation of Shasta Dam with regards for the welfare of the fishery, the salmon runs above Shasta Dam appear to have become established below the dam in numbers equal to the numbers existing before the dam was built.[38]

Despite its myriad technological failures, in the end, elevated salmon egg takes and salmon populations persuaded many state and federal biologists that the Shasta Salmon Salvage Plan had succeeded. In 1947, Coleman Superintendent John Pelnar summarized his hatchery's artificial propagation and fingerling rearing activities:

> . . . the station, being one of the most efficient and producing units in the world, planned to attain a record undreamed of by fisheries workers. We successfully held and reared 25,794,652 Chinook salmon fingerling, all of which had been fed for considerable time before being released . . . [T]he weight of the fish reared at Coleman during 1947, totaled 109,799 pounds, which is a record for other fisheries workers to look at with wonder and admiration.[39]

Although clearly impressed by these and subsequent abundance figures, biologist James Moffett withheld final judgment, cautioning, in a paper's closing remarks, that 'Experience has been insufficient to establish definitely the success or failure of the [Sacramento River] salmon maintenance work.[40] In the end, it was the spectacle of considerable fish in the Sacramento River which provided the screen to hide the technological salvage program's cumulative failures. Nevertheless, a myth had been created that, thanks to overwhelming technological prowess, a sizable salmon fishery had become re-established on yet another dramatically altered Western river. It would require decades before the cascading ill effects of the Central Valley Project's Shasta-Keswick complex came into plain view.

## REPLUMBING A PLUNDERED PARADISE

To date, I have omitted a crucial subplot from my discussion of post-Shasta Dam salmon salvage efforts. As biologists sought to mitigate for the disastrous ill effects of the Shasta-Keswick complex, they knew of two additional proposed downstream dams at Iron and Table mountains. Should yet another lower river dam be built, much less two, scientists warned, all previous efforts to mitigate for the Shasta-Keswick complex would be 'nullified.' In 1944, federal and state biologists minced no words when they declared that 'adequate protection should be provided [salmon] during [dam] construction periods: to [among many grounds] prevent any man-made catastrophe which might eliminate for all time a portion of, or a whole, annual cycle of salmon.' They urged a re-examination of the entire Table Mountain Dam project, for, '. . .as presently proposed, the dam will probably spell the doom of the salmon and steelhead runs into the upper Sacramento River.'[41]

The good news is that neither the Iron Mountain nor Table Mountain dams were ever constructed. Resolute political opposition from agricultural interests, among others, stopped each proposed project in its tracks. The bad news, you wonder? Yet another downstream dam was eventually constructed near the town of Red Bluff. In 1987, California Department of Fish and Game biologist Richard Hallock singled out the Bureau of

Reclamation's Red Bluff Diversion Dam (RBDD) as 'One of the major causes, and perhaps the single most important recent cause of the decline of salmon and steelhead in the Sacramento River.'[42]

Originally promoted as a 'fish-enhancer,' the structure was located two miles downstream from Red Bluff and it diverted water into the Tehama-Colusa Canal and to the Corning Canal Pumping Plant. During average water years, each canal shunted 700,000 and 50,000 acre feet, respectively. Completed in 1964 (it became fully operational in 1966), the dam included elaborate fish protection measures. Closed circuit television monitored fish passage through separate fishways. A built-in trap assured biologists access to in-coming adult fish. Louver-type fish screens sought to prevent fish losses within canals while an additional (never-used) service hatchery was eventually constructed on site to harvest roe and milt from excessively ripe fish.[43] The 3000 salmon which once occupied RBDD's immediate upstream spawning riffles were to be more than compensated by newly engineered downstream spawning channels suitable for holding 30,000 fish.[44] Jack Savage of the Fish and Wildlife Service promoted the idea of spawning channel enhancements.[45] The mitigation strategy partially stemmed from Washington State and British Columbia precedents with considerable help provided by Columbia River-based engineering and hatchery staffs.[46] There were just two problems: it never worked, and, to make matters worse, it required 20 years to discover that fact.[47]

Biologist Richard Hallock observes that the Red Bluff Diversion Dam radically altered the existing distribution of fish within the lower and remaining reaches of the Sacramento River. Prior to its full operation, 90 percent of the fall-run spawned upriver from the damsite. After operating for a decade, less than 40 percent of the fall-run Chinook salmon spawned above and greater than 60 percent were distributed below the dam site.[48] Although historical information was lacking, declines among other races of anadromous fish followed these same disturbing trend lines. Hallock reported:

> Between 1969 and 1982 . . . RBDD has caused an estimated loss in the upper Sacramento River system's adult salmon population of 114,000 fish: 57,000 fall run, 17,000 late fall run, and 40,000 winter run. These losses have deprived the fisheries of about 228,000 salmon a year at a catch-to-escapement ratio of two-to-one . . . In addition, an estimated decline of 6000 sea-run steelhead . . . has been attributed to RBDD.[49]

Biological investigations document upstream salmon passage delays of one to forty days, while an additional 26 percent never even made it past the dam.[50] Particularly hard hit were winter-run salmon which remained ill-suited to spawning within the warmer lower river. Downstream from Red Bluff Diversion Dam, Hallock reports that '. . .water temperatures were suitable for winter-run spawning and incubation . . . only four out of eighteen years (only 22 percent of the time) between 1967 and 1984.'[51] By comparing the 1967–1969 average salmon counts passing RBDD with those between 1970–1982, Hallock and Fisher demonstrated a decline of 58 percent (or 40,364) among winter-run salmon. If records from the three drought years of 1979–1980 and 1982 were included, the percent winter-run decline was 79 percent (79,289 fish), or a 52 percent decline in each successive generation.[52]

Hallock documented that upstream dam passage delays increased with river flow, for mature fish experienced greater difficulty finding fishways under higher than lower water conditions.[53] Downstream passage by juvenile fish was equally problematic, as excessive downstream dam turbulence disoriented outmigrating fish and forced them toward the river's surface. Whereas adult fish held their own against predators like Sacramento pikeminnows, striped bass, steelhead and shad, younger fish often were eaten. Among juvenile salmon, 1974 service studies estimated downstream migratory salmon losses at between 55 to 60 percent during daylight hours.[54] Within another document, ocean sampling data among marked Coleman hatchery salmon indicated that fingerlings freed below RBDD '. . . survived better than those released upstream from the dam . . . Losses among those released upstream from the dam ranged between 29 percent and 77 percent.[55] To this day, many fish conservationists still consider the Bureau's Red Bluff Diversion Dam to be a 'fish killer.'

Quite unlike the once proposed Iron Canyon or Table Mountain dams, however, the Red Bluff Diversion Dam did not 'nullify' the attempted Shasta Salmon Salvage Plan of the 1940s. However, serious delays in upstream fish passage did render remaining spawning grounds inaccessible to a quarter of the fall-run alone. Excessive dangers accompanying downstream fish passage further undermined escapement, and, among Coleman managers at least, raised the size, distribution and age of fish at release. If the original 'Shasta Salmon Salvage Plan' had sought to balance natural propagation within the mainstem Sacramento with artificial propagation at Coleman National Fish Hatchery, then RBDD hurt the former while selecting for the latter. Coleman's personnel could plan rearing fish to larger sizes, and release these same cohorts below the offending structure. Naturally spawning spring- and winter-run salmon did not enjoy these same artificial advantages and were left to fend for themselves within the river's mainstem. Yearling steelhead, which were released below Red Bluff Diversion Dam enjoyed twice the rate of return to the Coleman Hatchery as those released directly into Battle Creek.[56] Declining numbers of returning migratory fish began to worry biologists who became aware of a troubling portrait of irreversible declines.

## SERIALISTIC POLICY

Hatcheries best exemplify the regrettable sequence of plausible but unworkable assumptions that still guide state and federal fisheries policies. From the outset, those entrusted with overseeing the West's declining fisheries carefully tailored their objectives to comply with market attitudes and behavior. Rather than challenge the profitable destruction of western rivers, institutional policies begat a compensatory holding pattern. I refer to this lineage of fish rescue strategies as 'serialistic policies.'

Serialistic policies are those which occurred in a series, rank or row when agencies ratcheted up ameliorative technological 'mitigations' within riverine ecosystems too battered to any longer support wild fish. Fish hatcheries, then fishways, and so forth, were intended to compensate for a river made lethal through wrongful human agency. Superimposed one upon the next, however, these add-on technological prostheses gave rise to unstable, costly and self-defeating sets of policies. Astonishingly today's assumptions governing fish mitigations are identical to plausible but unworkable rationale formulated, and subsequently institutionalized, well over a century ago. Remarkably, salmon restoration strategies abandoned in 1892 remain in use a continent apart, today.

### *Characteristics of serialistic policy*[57]

- Serialistic policy is ahistorial
- Serialistic policy is anchored in prevailing economic beliefs. By masking and upholding an unacknowledged pattern of domination, such policy is principally about using the inertia of natural resource agencies to prevent ecologically adaptive change instead of promoting it.
- Serialistic policy requires that public agencies substitute an endless succession of quick technological fixes as surrogates for what cannot be sustained by an environment made lethal through wrongful human agency.
- Serialistic policy requires that institutional objectives be 'reframed' to symbolically address the symptoms of ecological decline rather than naming and eliminating their root causes.
- Serialistic policy legitimatizes the further destruction of watersheds by purporting to represent the interests of diminishing salmonids.
- Serialistic policy often requires that public agencies oversee the destruction of that which they are mandated to protect. Hatcheries are a prime candidate here. They both rob from and displace wild fish stocks in the name of 'saving' them.
- Serialistic policy provides purveyors the ethical illusion of occupying high moral ground. In the meantime, such 'feel good' policies stave off or indefinitely postpone a true reckoning for those profiting from destroying fisheries and their watersheds.
- The longer serialistic policy is practiced, the greater the actual cost of sustaining imaginary, highly unstable solutions becomes. Policies beget policies and residue problems proliferate, giving rise to their own coincident ecological and social backlashes, each wave of which creates new generations of unresolvable problems.
- Serialistic policy celebrates artificiality over deferring to the self-maintaining powers of intact habitats and ecosystems.

Serialistic policy is therefore a deliberately muddled pattern of agency policy goal substitution and decay, followed by the overlay of a fresh batch of technical fixes and their subsequent failure. It occurs when agencies lack sufficient power to restrain market-driven overexploitation of limited resources, like water. Excessive destruction of watersheds cause declines in—among others—fish species' populations. Rather than reining in economic actors profiting at ecosystem expense, the ecological instability that results is addressed through technological means.

Ecosystems, like Humpty Dumpty, are vastly easier to preserve than they are to reassemble. Agencies deployed an array of costly, energy-consuming, technological fixes to sustain the myth of ecological stability. Initially, the entropic energy costs imposed by a serialistic policy cycle were borne by a declining fish population, not by those humans profiting at ecosystem expense; today that relation is reversed. Now agencies must throw increasing budgets at diminishing numbers of fish. If we remain trapped in such logic, we will never have enough money—or glue—to reassemble our fictionalized watersheds.

Why? Because each ensuing technical intervention permanently disrupts the natural energy flows that once sustained the river's ecosystem without external human intervention, the stability of the watershed continues to decline with booms and crashes. A new cycle of costly technological gimmickry becomes required to compensate for previous human interventions. Meanwhile, the original cause(s) of decline (i.e., dams, overexploitation of forests, and so forth) are not addressed; only symptoms of ecosystem decline are treated in the actions of decisionmakers. Ultimately, society cannot afford the costly illusion of sustaining vastly compromised rivers.

A publicly funded environmental mitigation complex arose over time that valiantly sought to confront the symptoms of ecosystem distress. Fueled by moneys to rear and disseminate hatchery fish, install fish passage facilities, and other 'mitigations,' natural resource agencies neatly sidestepped the far thornier political issue of halting those interests profiting at nature's and humanity's expense. Superimposed one upon the next, these add-on technological prostheses gave rise to unstable, costly, and self-defeating sets of policies.

As westerners abandoned wild rivers in favor of something resembling giant plumbing contrivances, rivers like the Columbia and the Sacramento became what policy analyst Kai Lee calls 'industrialized ecosystems'—an unnatural watershed requiring continuous human manipulation.[58] Human management, however, often means playing off one set of desirable ends (like power generation, navigability, and fish stocks) against another.

Driven by water mobilization, the Columbia and Sacramento basins came to reflect a biological Ponzi scheme in which, first, we put a price tag on water itself. Second, by selling irrigation water and hydroelectric power at vastly subsidized rates, government frustrated whatever conservation advantages were conferred by market scarcity. Third, in a fleeting reverse of folly, citizens have often subsidized corporate agriculture not to grow water-thirsty crops like cotton in a semidesert. Fourth, we paid in the disappearance of fish and wildlife, as well as for the dizzying string of escalating mitigations intended to reverse their precipitous decline. Finally, we shelled out for the environmental wreckage that coincided with attempts at resurrecting nature, of which, we too, are a part.[59]

In the end, by masking and upholding an unacknowledged pattern of domination, environmental mitigation empires are forced to oversee the destruction of that which they are mandated to protect. Patterns of serialistic policy therefore legitimize the further destruction of watersheds by purporting to represent the interests of diminishing salmonids. Thus, such policy strategies provide purveyors the ethical illusion of occupying high moral ground, even as such 'feel good' strategies stave off or indefinitely postpone a true reckoning of those profiting from destroying wild fisheries and their rivers. Eventually, under the surrealistic umbrella of technical fixes, we will abandon as unworkable our defense of anadromous fish. Like an Egyptian bas relief, westerners are squared off against two choices: surrender to ecological collapse or arrest and reverse the root causes of salmon decline.

## MITIGATIONS AS QUASI-SOLUTIONS

Technological compensations for nature such as those exhibited by the Red Bluff Diversion Dam and its predecessor projects always remain necessarily imperfect. Why? Because there is never a one-to-one correspondence between artificial repairs of ecosystems and their prior natural state. Hence our engineered solutions to remedy decaying ecological systems remain necessarily incomplete. Eugene S. Schwartz refers to technological remedies as 'quasi-solutions' for they remain partial substitutes for naturally functioning systems. Designer substitutes for nature metamorphose into a new problem requiring a different solution. In so doing these technological prostheses engender unforeseen or even unrecognizable 'secondary effects'.[60] Quasi-solutions therefore beget a proliferation of 'residue problems', a cascading anthropogenic chain of perverse effects that accompanies any attempt to remedy prior mitigations of the natural order.

Technological solutions remain incomplete because no process, machine, or simulation of nature is ever 100 percent effective. For instance, fish ladders on the Red Bluff Diversion Dam were woefully inadequate to moving mature fish upstream, or worse still, juvenile fish downstream. These aqueous staircases not only disoriented in- and out-migrating fish, the dam itself provided a wonderful feeding station for other native creatures like pikeminnows and avian salmon predators eagerly awaiting their next sashimi meal. Similarly, in lieu of lost spawning habitats, engineers designed artificial spawning channels to compensate for what the Red Bluff Diversion Dam would flood. Just for good measure, designers also threw in a nifty gravel washer where no natural current existed to do the job. There's just one problem; none of these gizmos ever worked.

Taken as a whole, these serialistic prostheses selected for the worst possible outcomes. The few wild salmon that remained were incapable of competing with inferior Coleman hatchery fish which themselves enjoyed a free downstream ride by truck to release points below the offending dam. As already noted, Coleman Superintendent John Pelnar could pinpoint ideal release times by keeping close tabs on upstream water releases from Shasta and Keswick dams. In something resembling a giant game of migratory pinball, Pelnar also planned his hatchery releases to coincide when thousands of unscreened downstream irrigators were least likely to require mainstem water. From the vantage point of wild salmon, the Red Bluff Diversion Dam was and remains an (un-)mitigated disaster.

The problem of 'augmentation' also arises when a technical solution at one level of complexity metamorphoses into a different set of problems requiring a whole new solution. What will be required if, as biologist Peter Moyle predicts, the Sacramento River salmon shift from being four genetically distinctive runs to becoming one more or less continuous run of fish, characterized by seasonal peaks, due to the artificial regulation of water flows?[61] What will occur when salmon—like trout before them—become true domestic fish? How will we maintain 'museum-runs' like the winter- and spring-run Chinook salmon when they require great human effort to fit a narrowly defined phenotype? For even partial answers to all of these questions, new forms of speculative knowledge will be required in an ecosystem made increasingly unstable through human intervention.

'Secondary effects' arise when, in the process of solving for one set of issues, we inadvertently create a slippery cascade of uncontrollable and oftentimes invisible consequences. Consider the downstream strains accompanying the introduction of hatchery-reared salmon among wild fish stocks. As biologists Ray Hilborn and Steven Hare enumerate, visible ill effects include things like competition for space and food; spread of disease and parasites (often due to hatchery overcrowding); shortening of year-classes; and genetic hybridization (combining fall with late fall-run salmon, or even, as recently occurred, spring with endangered winter-run salmon, the prodigy of which were necessarily destroyed).[62] Serious repercussions accompany the commingling of wild with artificially-reared fish stocks, the full extent of which we have yet to appreciate. One hundred thirty years after their introduction into California, we observe that hatcheries have enormous residual effects, some visible, some not, the backlashes of which will continue into the foreseeable future.

As watersheds like that of the Sacramento were being pruned of tributaries, dammed, channeled, rip-rapped, quarried, clear-cut, polluted, or just plain siphoned-off for irrigation, natural resource agencies engineered cumulative, interactive generations of fish salvage policies to compensate for what was being profitably sacrificed within nature. These countervailing prostheses, however, were doomed to fail from the outset because they never named nor halted the upstream sources of ecological distress.

The man-made origins of the fishery collapse were eerily reminiscent of conclusions reached in 1944 by Willis Rich, Paul Needham, A. C. Taft, and Richard Van Cleve, who wrote:

> It has been relatively recent that recognition has been given to the importance of dams and diversions to the continued existence of the salmon runs in many of our western rivers. As the ultimate plan for water development is approached, the effect is cumulative and the present proposed postwar projects bring the problem to the acute stage.[63]

What was more, many of these water projects hinged upon massive and continuing governmental intervention. In 1962, a Bureau of Sports Fisheries and Wildlife report complained that it was man's activities in California which have:

> . . . generally proceeded counter to the best interests of the anadromous salmon and trout resources. In fact, they have destroyed substantial segments of these resources while employing only token efforts to ameliorate the damage. Activities conducted, sanctioned, sponsored and supported by the Federal Government have been prominent in the history. The [following] dam list . . . documents the major harmful results of direct federal activity.[64]

No wonder this unattributed Bureau of Sport Fisheries and Wildlife document bore this prominent stamp on its cover: 'Official Use Only: Not for Public Release.'

## REFLEXIVE ORGANIZATIONS

To compound matters, natural resource agencies resembled an administrative decision-making structure that lost track of the external world and turned increasingly inward on itself. Policies in these organizations, at Coleman Hatchery as elsewhere, were often conceived to address the self-referential symptoms of previously failed policies. Paul Schulman calls this type of administrative pattern a 'reflexive organization.'

In reflexive organizations, decisions are based upon '. . . assumptions—premises inherited from previous decisions and from accumulated personal and organizational experience.'[65] Reflexive decisions, paraphrasing from Schulman, become those which through their implementation, bias the validity of subsequent assumptions upon which future administrative action is based. For example, an organization aims to expand gamefish in a river basin. The agency's initially mandated goals include controlling against overharvesting while compensating for too few fish through hatchery production. Meanwhile, mounting evidence suggests that wild and domesticated fish released into the same rivers compete against one another, often thereby reducing, not expanding, the total numbers of anadromous fish. Distressed at observing declining numbers of salmon, agency managers usher in more hatcheries as the solution, thereby escalating the crisis. What would it take for sponsoring agencies to consciously reduce hatchery production while promoting natural production through ecological restoration strategies? Escalating net production (hatchery plus natural fish) could actually derive from releasing fewer domesticated hatchery fish and shifting financial resources away from hatcheries to 'rewater' and restore promising upstream habitats for natural production.

Unfortunately, it is easy to see why opting out of self-validating decision streams (positive feedback loops) can require a century or more, or until such a time as wild fish cease existing. Those who command budgets control 'turf,' and multi-million dollar hatchery mitigation budgets create their own demand-pull. For instance, approximately 80 percent of the US Fish and Wildlife Service's current national budget goes to support hatchery production.[66] Even if we could assuage the concerns of hatchery personnel who legitimately feared for their jobs, how would we initiate an institutional transition which weaned an agency off its primary historic mission? More likely, as Schulman points out, within reflexive organizations, if evidence accrues that tends to validate a speculative decision-making premise, then lightly held assumptions may be strengthened well beyond their initial validity. Under the right conditions, a decision may become '. . .reflexively self-promoting or reinforcing; or they are undermined, which results in a decision which becomes self-frustrating in relation to its objectives.'[67]

The condition of organizational reflexivity creates its own set of internally-consistent, self-validating criteria and standards. These performance specifications make error-correction difficult because every such organization creates, confirms, and tests for their own reality. Reflexive organizations are slow to change in any case, due to their careful, hierarchical placement of traditional responsibilities and power. Mix into this administrative formula territorial protectionism ('turf'), budgetary inertia, loyalties to particular personnel, professional pride, quasi-historic mission beliefs and practices, and change becomes anathema.

The aim of self-frustrating mitigations, of fish salvage practices, did buy time—sometimes decades of it—for myriad powerful economic interests already profiting at the expense of migratory fish. Indeed, well into the 20th Century, fish hatcheries fueled the construction of environmental mitigation complexes which averted public attention from an increasingly doomed natural world. Are natural resource agencies capable of learning from history?[68] Reflexive organizations like the US Fish and Wildlife Service raise serious doubts. As biologist and historian Mark R. Jennings reflects: 'Shasta Dam "mitigations" kept us pretty well blinded for about 30 years. The San Joaquin River below Friant [Dam] was a write-off, period! Too bad it took us that long to see how bad things really are.'[69]

## THE RECENT BATTLE OVER BATTLE CREEK

Few recall the struggle which culminated in the original naming of the Sacramento Basin's tributary named Battle Creek. However, today, members of the Manton-based Battle Creek Watershed Conservancy (BCWC) are battling the US Fish and Wildlife Service (Service) to alter—when not reigned in—their hatchery's historic, predominant downstream presence. Revealingly, Conservancy members are *not* calling for an end to fish production on lower Battle Creek, as such. Rather, they only want to see Battle Creek's Coleman hatchery production reduced from three races of fish to one race (to solely produce fall-run Chinook salmon). Furthermore, BCWC's members want to see Coleman's production dispersed to other hatchery sites throughout the middle Sacramento Basin while its lower Battle Creek facility is isolated, to the greatest extent possible, from interfering with adjacent 'wild' salmon stocks ascending Battle Creek. Conservancy members have come to believe, and with good reason, that the world's largest salmon hatchery stands in the way of realizing a planned \$50 million dollar upstream environmental restoration of salmon habitats.[70]

Since 1997, Conservancy members have collaborated with an array of state and federal agencies, agricultural, energy, urban and environmental stakeholders, to reintroduce endangered Chinook salmon into 'rewatered' stretches of upper Battle Creek. Conservancy members have been generous in calling attention to the hatchery's long-term success at producing fall-run salmon, '. . . but at a price: spring-run and other [winter-run] salmonids nearly disappeared from upper Battle Creek. The watershed residents noticed this, for as recently as the 1980's catching spring-run salmon in local [fishing] holes was a popular sport.'[71] Many residents attribute the absence of salmon in the upper watershed to Coleman Hatchery's operations, including blockage by their obvious barrier weir. Conservancy members write that: 'This perception is a significant stumbling block to public acceptance of [Battle Creek's proposed] Restoration Project: why bother to spend \$50 million to improved habitat in Battle Creek, if the poor fish can't even get past [Coleman Hatchery]?'

Conservancy members proposed that a bird's-eye view of planning for environmental restoration be undertaken at a region-wide scale. Thanks to \$400 million in recent expenditures (one-half billion dollars, in all), an upper 29 miles of the Sacramento River is finally available to become salmon habitat. By eliminating competing hatchery production in Battle Creek, endangered naturally spawning populations of salmon will finally have a *refugia* of their own. By maximizing net salmon production (natural plus hatchery fish) in Battle Creek and the middle Sacramento Basin (below Shasta Dam), Conservancy members argue they can optimize total fish production. They propose taking the following five steps:

- Shifting late-fall salmon and steelhead production from Coleman hatchery to an enlarged Livingston Stone facility at the base of Shasta Dam on the mainstem Sacramento River.
- Using an existing agricultural drainage ditch instead of lower Battle Creek as a conduit between the dominant hatchery site and the mainstem Sacramento River.
- Significantly reducing year-round water diversion from Battle Creek and the infrastructure required to obtain it.
- Modifying Coleman hatchery's barrier weir to provide unencumbered passage for naturally propagating salmon.[72]

Thus far, the US Fish and Wildlife Service's responses to Conservancy pleas have been conspicuous by their absence. To the agency's credit, the Service has retained outside consultants (HARZA, an environmental and engineering consulting firm from Portland, Oregon) to review their options at their Coleman National Fish Hatchery. To the challenge that Coleman operations have made a significant dent in Battle Creek's upstream production, there can be little doubt. The hatchery faced decades of chronic diseases (especially IHN virus or *Infectious Hermatopoietic Necrosis*) at their

Battle Creek site, and, as former Coleman Superintendent Jerry Grover admitted in a phone interview, he wasn't about to tolerate any naturally propagating 'typhoid Mary's' (especially fall-run fish) above his hatchery water intakes.[73] That may explain why, during the early 1990s, hatchery administrators insisted that PG&E expand, not reduce, its share of water taken from Battle Creek, just as they ordered the closure of additional, upstream fish ladders over historic dam sites. The restriction of upstream fish- and waterflows did not go unnoticed. For one thing, the California Department of Fish and Game studied whether naturally reproducing salmon were diseased or not. Meanwhile, upstream displeasure at Coleman's operation is hardly a new revelation, culminating in this question: Can a federal fisheries agency be entrusted to act on behalf of protecting endangered species (like winter- and spring-run Chinook salmon) if they continue promoting hatchery over natural production?

While the jury remains out on that question, grounds for extreme skepticism remain. Rather than treating Battle Creek as a rare *refugia* for naturally spawning, endangered salmon, the US Fish and Wildlife Service, and Coleman hatchery administrators in particular, appear to be more interested in redoubling its technological build-out including, among other things, expanding its Battle Creek water intakes. In keeping with its history, organizational reflexivity seems poised to select for technology over nature, control over experimental release (from nature operating on its own terms), fixity over uncertainty. Even at this early date, the anticipated HARZA re-evaluation appears exclusively focused on hatchery production objectives over those of natural production in Battle Creek. Serialistic logic, too, can be an organized way of going wrong with confidence.

## LESSONS FROM CALIFORNIA'S RIVERS

Fish biologists, like proverbial scoopers following the circus parade, remain stuck at the rear end of a venture that cries for foresight. Several object lessons fall out of our 130 year long search for technological certainty within the Sacramento River Basin. It is time to be done with substituting an endless array of technical prostheses for a nature made lethal through wrongful human agency.

What about an accompanying object lesson in humility? There is and always will be an incommensurable gap between what humans are capable of knowing and the infinite complexity of the natural world. 'Salmon are the experts,' as biologist Mark R. Jennings once remarked, 'when it comes to judging the integrity of complex ecological systems.'[74] Throughout the coming millennia, we must learn enough about creatures like anadromous salmon to coexist with them. After all, they've survived millions of years including a geologically recent Ice Age, and have co-evolved with *Homo sapiens* for thousands of years. In fact, don't salmon do a better job of organizing us as a species than we seem capable of organizing them?

Co-evolution is going to take respect, however, and respect is the single best word I know of to define the concept of ecology. Perhaps the more knowledge we can acquire about salmon, the greater will be our ability to pull back and let them show us how we should behave instead of the other way around?

Apropos of learning from migratory salmon, on rare, restored tributaries like the Sacramento River Basin's Battle Creek, doesn't it behoove us to reign in artificial production which competes and interferes with natural production?

One thing that salmon restoration is going to take is water, and lots of it. Competing riparian and appropriative water claims make salmon and steelhead restoration within their southernmost ranges a dicey proposition. The history of California's salmon rescue efforts is fraught with engineers and biologists attempting to cobble together fish restoration efforts with insufficient clean, free-running water. Sufficient guaranteed in-stream flows are required to have habitats suitable for vibrant runs of anadromous fish.

The four races of Sacramento River salmon still constitute a national—indeed a global—biodiversity treasure. As we have learned, this is the sole river in the world with four genetically unique stocks of salmon. Are we willing to stand back and sacrifice them for the admixture of greed, ignorance and indifference that serves the interests of some over and against the many? After all, 'What we call Man's power over Nature,' C.S. Lewis once wrote, 'turned out to be a power exercised by some men over other men with Nature as its instrument.'[75]

Another object lesson derives from a recently heightened awareness accompanying our energy 'crisis'. Two to four million anadromous fish once returned year in, and year out, to Central Valley streams and delivered huge pulses of marine-derived nutrients, of energy. This decomposing energy once coursed through flora and fauna and literally fueled new generations of fish. We can ill afford transforming fish like salmon from being massive net energy providers into becoming massive net energy users. And yes, that is precisely what our environmental mitigation complex has accomplished. But not for long.

Last but not least, I believe the pervasive practice of serialistic policy toward California's dwindling salmon lies at the core of our reflexive, civilizational trap. The first casualty of serialistic policy is understanding itself: grasping that nature is our best benchmark for evaluating appropriate courses for human actions. By practicing serialistic policy, we embrace the fiction that technology can endlessly compensate for an increasingly lethal ecosystem. We do so on the astonishing premise that such policies constitute the ethical high ground. We come to accept as normal, cascading residue chains accompanying mitigations, each generation of which becomes increasingly costly, unstable and surreal. We fail to see serialistic policy for what it is: a symbolic palliative that deflects the impetus for ecological change, by masking and upholding unacknowledged patterns of domination.

Can we design ecosystems? Many desire to continue to try. Pacific salmon remind us that a long-ignored moral, financial, technological, scientific and ecological reckoning has come due.

*Acknowledgements*—Many individuals have given freely of their time to make this and earlier iterations of this research possible. My thanks go to: George Black, Marty deKadt, Bill Davoren, Ellen Chu, Frank Fisher, Mark Jennings, Ted Gresh, Jerry Grover, Dick Hallock, Holly Hauck, Scott Hamelberg, Mike Healey, Ray Hilborn, William M. Kier, Susan Kitchell, Bob Lee, Karen Lee, Jim Lichatowich, Larry Lucas, Peter Moyle, Willa Nehlsen, Harry Rectenwald, Paul Schulman, Ted Steinberg, Tim Stroshane, Joseph Taylor, Mike Ward, Rick Worthington, Langdon Winner, and Ron Yoshiyama. In addition, I was given access to files at the office of the California Department of Fish and Game, Redding, California, the US Fish and Wildlife Service's Regional Headquarters, Portland, Oregon, and the Service's Coleman National Fish Hatchery near Anderson. US Bureau of Reclamation personnel were also instrumental in locating difficult-to-find documents and for partially underwriting an earlier generation of this work. Previous funding also derived from Category III monies supplied by the Metropolitan Water District of Southern California.

## REFERENCES

1. William M. Kier, William M. Kier Associates, Sausalito, CA, personal communication.
2. N. K. Geranios, Wild fish won't hang out with the hatchery bozos, *Sacramento Bee*, 17 May 1992; Michael Black, Toys in the reservoirs: a century of failed western fishery policy, *Illahee: Journal for the Northwest Environment*, **10**(4), Winter 1994, pp. 275–278.
3. G. P. Marsh, *Report Made Under Authority of the Legislature of Vermont on the Artificial Propagation of Fish, Burlington*, VT: Free Press Print, October 10, 1857. Also see David Lowenthal, *George Perkins Marsh: Prophet of Conservation*, Seattle, WA: University of Washington Press, 2000.
4. G. P. Marsh, 1857.
5. G. P. Marsh, 1857. Less clearly identified but equally troublesome were the introduction by early settlers of warm-water pond fishes like the voracious pickerel. 'Biological pollutants' like pickerel were fierce competitors with native fishes, salmon included, and once introduced into Vermont's waters, they threatened an array of other native species. As shall become evident, fish introductions were an inevitable corollary to the gathering fish culture movement and Marsh's proposed pisciculture industry promised to accelerate the acclimatization of exotic fishes in soon-to-be-disrupted native ecosystems. From the perspective of native fishes, the haphazard introduction of foreign fishes catapulted things from bad to worse overnight.
6. G. P. Marsh, 1857, p. 15.
7. The enforcement of game laws would generally wait until the progressive era of the early twentieth century when state game departments earned sufficient revenue (from license sales) to hire professional wardens. In the case of California, any serious enforcement waited until roughly 1913.
8. G. P. Marsh, 1857, pp. 16–17.
9. G. P. Marsh, 1857, p. 11.
10. Shad were planted in California's waters in 1871 and striped bass followed in 1879.
11. J. W. Hedgpeth, Livingstone Stone and fish culture in California, *Bulletin*, California Department of Fish and Game, **27**(3), July, 1941.
12. A. F. McEvoy, 1990. *The Fisherman's Problem*, Cambridge: Cambridge University Press, 1990, p. 50.
13. J. W. Hedgpeth, 1941, p. 50.
14. C. Rutter, Artificial propagation of salmon in the Sacramento River, *San Francisco Trade Journal*, reproduced from the 18th Biennial Report, Board of Fish Commissioners of the State of California, 1903–1904, pp. 103–106; M. Black, Shasta Salmon salvage efforts: Coleman National Fish Hatchery on Battle Creek, 1985–1992, *Fish Bulletin*, **179**, California Department of Fish and Game, April 2001, p. 89.
15. C. Rutter, 1903–1904, p. 106.
16. M. R. Jennings, *A Biography of Cloudsley Rutter (1867–1903), Pioneer Salmon Biologist and Curator of Ichthyology at the California Academy of Sciences*, unpublished manuscript, used by permission of the author, 1996, pp. 16 and 81; C. Rutter, Natural History of the Quinnat Salmon, A Report of Investigations in the Sacramento River, 1986–1901, *Bulletin*, US Fish Commission, **22**, 1902, pp. 69 and 65–141.
17. C. Rutter, 1903–1904, p. 105.
18. W. H. Rich, The present state of the Columbia River salmon resources, *Proc. Sixth Pacific Science Congress*, **3**, 1939, pp. 435–430.
19. J. E. Taylor, III, *Making Salmon: Economy, Culture and Science in the Oregon Fisheries, Precontact to 1960*, Ph.D. Dissertation, Department of History, University of Washington, University Microfilms, Ann Arbor, MI, 1996, p. 355. See his recently released book under the title: *Making Salmon: An Environmental History of the Northwest Salmon Fisheries Crisis*, Seattle, Washington: University of Washington Press, 1999. I have clearly benefited from a close reading of Taylor's work.
20. J. Lichatowitch, personal communication.
21. Willis Rich cited in Taylor, 1996, p. 354.
22. J. Taylor, 1996, p. 352.

23. J. Taylor, 1996, p. 348.
24. J. Taylor, 1996, p. 355.
25. J. Taylor, 1996, p. 358.
26. H. D. Radke and S. W. Davis use Northwest Power Planning Council methodologies to estimate historic Central Valley salmon abundance. Their unpublished article was cited in T. Gresh, J. Lichatowich, and P. Schoonmaker, An estimation of historic and current levels of salmon production in the Northeast Pacific Ecosystem: evidence of a nutrient deficit, *Fisheries*, 1998, p. 7; Biologist F.W. Fisher placed historic Central Valley Salmon populations at roughly two million salmon. See F. W. Fisher, Past and present Status of Central Valley Chinook salmon, *Conservation Biology*, **8**, 1994, pp. 870–873.
27. R. M. Yoshiyama, E. R. Gerstung, F. W. Fisher, and P. B. Moyle, Historical and present distribution of Chinook Salmon in the Central Valley Drainage of California, in *Sierra Nevada Ecosystem Project: Final Report to Congress, vol. III, Assessments, Commissioned Reports, and Background Information*, Davis: University of California, Centers for Water and Wildlife Resources, 1996, pp. 312–313.
28. H. A. Hanson, O. Smith, and P. R. Needham, An investigation of fish-salvage problems in relation to Shasta Dam, *Special Scientific Report No. 10*, Washington, D.C., 1940, p. 14.
29. The Board of Consultants consisted of two Stanford University professors and a third faculty member from the University of California, Berkeley. Stanford contributed W. F. Durand, Professor *emeritus* of Mechanical Engineering and Willis H. Rich, Professor of Biology. Berkeley supplied R. D. Calkins, who was a Professor of Economics.
30. P. R. Needham, H. A. Hanson, and L.P. Parker, Supplementary report on investigations of fish-salvage problems in relation to Shasta Dam, *Special Scientific Report No 26*, US Fish and Wildlife Service, June 30, 1943; J. W. Moffett, The first four years of king salmon maintenance below Shasta Dam, Sacramento River, California, reprinted from *Bulletin*, California Department of Fish and Game, **35**(3) 1949, p. 79.
31. P. R. Needham *et al.*, 1943, p. 8.
32. R. J. Hallock, *Sacramento River System Salmon and Steelhead Problems and Enhancement Opportunities*, report to the California Advisory Committee on Salmon and Steelhead, 1987, p. 32.
33. M. Black, *Shasta Salmon Salvage Efforts*, 2001.
34. S. Hamelberg, USFWS, unpublished memorandum, 1997; S. Hamelberg, USFWS, unpublished memorandum, 1999.
35. Steelhead were eventually included in Coleman's production objectives in 1947. We have scant evidence of historic steelhead populations. I assume that historically, steelhead may have used spawning beds as far as 10 miles below Keswick Dam, hence the approximation of a 90 percent habitat loss.
36. Harry Rectenwald, California Department of Fish and Game, Redding, CA; see Appendix A of M. Black's, *Shasta Salmon Salvage Efforts*, 2001.
37. J. W. Moffett, 1949, p. 101.
38. C. Engle, *Central Valley Project Documents*, *Vol. II*, Operating Documents, Washington, D.C.: US Government Printing Office, 1958, p. 421.
39. Coleman Station, *Annual Reports*, 1947 (mimeographed), p. 1.
40. J. W. Moffett, 1949, p. 102.
41. W. H. Rich, P. R. Needham, A. C. Taft, and, R. Van Cleve, *A Preliminary Report of the Fishery Resources of California in Relation to the Central Valley Project*, manuscript no. 48064, Stanford, CA: Stanford University, August 19,1944, p. 7 and 11; M. Black, 2001, ff. #18, pp. 26–27.
42. R. J. Hallock, 1987, p. 33.
43. Female salmon were considered ripe upon losing eggs when handled. The Service constructed the temporary 3 million egg incubation station near the dam's left bank fishway. Fish were released back into the river in the hope that they would spawn naturally. The facility became fully operational in 1979, but due to a '. . . lack of personnel and management interest,' the 7 million egg hatchery was never used, R. J. Hallock, 1987, p. 33. Within a subsequent cooperative study, biologists demonstrated that '. . .an average of almost 2500 (3.4%) of those [fish] passing the dam were ready to spawn immediately.' R. J. Hallock, D. A. Vogel, and R. R. Reisenbichler, The effect of Red Bluff Diversion Dam on the migration of adult salmon, *Oncorhynchus tshawytscha*, as indicated by radio tagged fish, *Administrative Report No. 82–8*, California Department of Fish and Game, 1982, p. 17.
44. Tehama-Colusa Fish Facilities enhancements were calculated at 27,000 fish, a hypothetical number which '. . .made the entire [diversion dam] water project much more feasible, R.J. Hallock, 1987, p. 58; R. J. Hallock, personal communication.
45. R. J. Hallock, personal communication.
46. J. Grover, USFWS, personal communication; in 1950, Harold Gangmark operated a federally-sponsored artificial spawning channel in Mill Creek at the site of the old abandoned hatchery at Los Molinas. Dale Schoeneman was brought in to manage the newly constructed RBDD spawning channels from Washington State where he oversaw a similar spawning channel venture. R. J. Hallock, personal communication.
47. Cost for building the Tehama-Colusa Canal 'salmon enhancement facilities' was $23 million dollars. Engineers originally called for building a 'dual-purpose' irrigation-spawning canal, including water turn-outs, for spawning fish at Thomes and Stony creeks. For a particularly biting assessment, read Zeke Grader's commentary appearing in *River Run*: Quarterly Newsletter of the Sacramento River Preservation Trust, **4**(1), Spring 1988, pp. 4–5.
48. R. J. Hallock in A. Lufkin, ed., *California's Salmon and Steelhead: The Struggle to Restore an Imperiled Resource*, Berkeley: University of California Press, 1991, p. 100.
49. R. J. Hallock in Lufkin, 1991, p. 101.
50. R. J. Hallock, 1987, p. 36.
51. R. J. Hallock, 1987, p. 55.

52. R. J. Hallock and F. W. Fisher, *Estimated Losses of Salmon and Steelhead Attributed to the Red Bluff Diversion Dam*, California Department of Fish and Game memorandum, February 7, 1984, p. 9.
53. R. J. Hallock in A. Lufkin, 1991, p. 100.
54. R. J. Hallock in A. Lufkin, 1991, p. 100.
55. R. J. Hallock, *Effect of Red Bluff Diversion Dam on Chinook Salmon, Oncorhynchus tschawytscha, Fingerlings*, California Department of Fish and Game Administrative Report, Revised January 24, 1983, 1983, p. 5.
56. R. J. Hallock, *Coleman National Fish Hatchery: Summary 1970–75*, Sacramento Cooperative Steelhead Programs, unpublished report, 1976, p. 2.
57. M. Black, Tragic remedies: a century of failed fishery policy on California's Sacramento River, *Pacific Historical Review*, **lxiv**(1), February 1995, p. 65.
58. K. N. Lee, *Compass and Gyroscope: Integrating Science and Politics for the Environment*, Covelo, CA: Island Press, 1993, p. 50.
59. W. D. Sweeney, The Central Valley Project and the Public Trust Doctrine, appearing in A. Lufkin, 1991, p. 210.
60. E. S. Schwartz, *Overskill: The Decline of Technology in Modern Civilization*, Chicago: Quadrangle Books, 1971, pp. 63–64.
61. P. B. Moyle, July 5, 1993, personal communication.
62. R. Hilborn and S. R. Hare, Hatchery and wild fish production of anadromous salmon in the Columbia River Basin, *Technical Report FRI-UW-9107*, Fisheries Research Institute, School of Fisheries, University of Washington, September 1992, pp. 9–11.
63. W. H. Rich *et al.*, 1944, p. 5.
64. Anonymous, *A Proposed Development Plan for Anadromous Fish in California*, Bureau of Sports Fisheries and Wildlife, Pacific Region, Portland, Oregon, 1962, p. 5.
65. Paul R. Schulman, The reflexive organization: on decisions, boundaries and the policy process, *The Journal of Politics*, **38**, 1976, p. 1015. This account also draws on personal conversation with Schulman on June 10, 1993.
66. S. Hamelberg, USFWS, 1998. Conference presentation on 'Wild versus Hatchery Fish,' Sonoma, CA.
67. P. Schulman, 1976, pp. 1015–1016. Schulman cites the Vietnam War as a classic case in point. In part to justify their actions, Pentagon analysts assumed the existence of substantial numbers of North Vietnamese forces in South Vietnam. By amassing more US forces in the south, North Vietnamese regulars moved south to confront this, the most recent round of foreign occupiers. Thus US military assumptions became self-validating, self-fulfilling and self-defeating.
68. Also see R. Hilborn, Can fisheries agencies learn from experience? *Fisheries*, **XVII**(4), 1992, pp. 6–14.
69. M. R. Jennings, July 1993, personal communication.
70. For the record, since October of 2000, I have been a paid consultant to members of the Battle Creek Watershed Conservancy.
71. R. Lee et al., *Battle Creek: One View of the Next Step*, Battle Creek Watershed Conservancy, 17 October 2000, p. 2.
72. R. Lee et al., *Battle Creek*, p. 4.
73. J. Grover, USFWS, Coleman National Fish Hatchery Superintendent (retired), phone interview, August 21, 1998.
74. M. R. Jennings, personal communication.
75. C. S. Lewis, *The Abolition of Man*, New York: 1947, p. 35.

**Michael Black** is a San Francisco-based environmental policy analyst and historian who writes on the social impact of science and technology, economic planning and development, and the environment. He is currently a Visiting Associate Professor of Political Science at Harvey Mudd College. This article is excerpted from his book, *California's Last Salmon: The Unnatural Policies of Natural Resource Agencies*, forthcoming from the University of California Press.