Summary of Scientific Evidence to Guide Special Flow Releases to Reduce the Risk of Adult Fall Chinook Salmon Mass Disease Mortality in the Lower Klamath River

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Executive Summary

Klamath and Trinity basin adult fall-run Chinook salmon are especially vulnerable to *Ichthyophthirius multifiliis* (Ich) infections due to their tendency to hold and congregate extensively in the lower Klamath River (i.e. below the confluence of the Trinity River) under all river flow conditions. Given restoration targets, achieving large run sizes on a regular basis should be anticipated by managers in fish disease planning. Current temperature dynamics result in warm river conditions during the peak of the fall salmon migration season annually, a situation that can not be ameliorated pending removal of the Klamath River hydroelectric dams or exceptionally large releases from Trinity Dam. Warm water temperatures, while stressful and accelerating, are not necessary for an Ich outbreak. Thus protective, proactive river flows are the only readily available management tool for effectively reducing the risk of catastrophic Ich outbreaks. Fortunately, ensuring sufficiently high river base flows is also the most effective tool for preventing and abating Ich outbreaks.

The key to understanding the 2002 fish kill in the lower Klamath River lies not in the biology of the fish, but in the biology of the parasites, particularly Ich. The key aspect of Ich biology is the probability that its infectious free-swimming life stage can encounter and successfully attach to a fish host during the 72 hour period it can survive without being in a host.

The risk of Ich epizootic fish kills are primarily determined by three probabilities:

- The probability an infectious free-swimming stage of Ich will locate and attach to a fish within 72 hours;
- The probability of susceptibility of that fish to infection and the resulting severity;
- The probability and rate of infection spreading to other fish.

Those three probabilities are in turn are strongly affected by four primary variables: 1) river flow; 2) run size; 3) residence time of the fish in the infectious zone; and, 4) water temperature. No one of these four variables is sufficient by itself to facilitate an epizootic, but in proper combination they can create prime conditions for the rapid spread of severe Ich infections. Each Ich infection in turn produces more infectious parasites and also provides an opportunity for columnaris infection through the Ich entry hole.

The one variable that can be overtly influenced by managers is the flow of the river, with a minimum base flow of 2,500 cfs detailed herein as necessary to avoid another fish kill under most circumstances, and 2,800 cfs necessary at minimum during years of large projected run sizes (≥ 170,000 fall Chinook salmon). Large pulsed flows such as during 2003 and 2004 from the Trinity River are unnecessary since adult fall Chinook salmon tend to ignore pulsed flows, and higher base flows still impede the infectivity and spread of Ich. The key with higher flows is not greater water volume per se but the associated increased water velocities and higher turnover rates of water in holding areas, which disrupts Ich's ability to find and attach to a host fish during its free swimming infectious stage. Sufficiently high water velocities and turnover rates need to be maintained throughout the primary fall Chinook salmon migration season (last week of August through the third week of September under normal circumstances). A proactive, preventative approach is necessary because the time lag between detection of an impending epizootic and arrival of a reactive, emergency flow release could result in no benefit to salmon survival. There will be an inherent risk of using water when conditions are less dangerous than projected, but the tradeoff is the risk of another massive fish kill that could be avoided. The source of water is unimportant even if it contains background levels of Ich parasites.

Introduction

The lethal agent in the 2002 Klamath River fish kill, which resulted in an estimated 32,553 to over 65,000 dead adult Chinook salmon in the lower 58 kilometers (Figure 1), was an epizootic outbreak caused by the protozoan parasite *Ichthyophthirius multifiliis* (Ich) and the bacterium *Flavobacterium columnare* (columnaris) (Foott 2002; Guillen 2003; Belchik et al. 2004; Turek et al. 2004). Minor numbers of other fish species were also killed.

Columnaris is ubiquitous in the Klamath River basin and affects the skin and gills of salmonids. In general, healthy fish are resistant to columnaris (Shotts and Starliper 1999); however, infections can develop due to environmental stress, minor injuries to the skin or gills, or the presence of other pathogens such as Ich (Figure 2). Environmental stress can include overcrowding, capture or pursuit stress, low dissolved oxygen, high temperatures, toxins, and high organic loads (Thune 1993). Columnaris infection is usually secondary to other pathogens that penetrate the epithelium, such as Ich (Plumb 1999).

Ich is a ciliated protozoan parasite (Figure 3) found throughout the world and is presumed to be native to the Klamath River basin. Outbreaks of Ich occur when conditions are favorable for rapid multiplication of the parasite, which spreads horizontally from fish to fish with trophonts attacking gills and other epithelium surfaces resulting in death by asphyxiation. These conditions include, but are not limited to, a suitable environment and susceptible fish. Ich epizootics occur when fishes are stressed and crowded, flows are relatively low, and are worsened by elevated water temperatures (Dickerson and Dawe 1995). For example, Butte Creek spring Chinook salmon experienced severe disease mortality (3,400 out of 16,000 fish in 2002, and 11,200 out of 17,300 fish in 2003) from Ich (and columnaris) during pre-spawn holding (CDFG 2004) in pools with elevated temperatures and artificially low flows. High water temperatures are not necessary for an Ich outbreak, however, as significant Ich mortality has occurred in British Columbia in low flow spawning channels at 13 to 15ºC (Traxler et al. 1998). High water temperatures do favor outbreaks by increasing fish stress and Ich reproduction rates (approximately 7 days to complete the life cycle at 20°C) but high temperatures alone cannot trigger an outbreak. For example, Klamath River water temperatures have been favorable for Ich outbreaks in past decades, but 2002 was the only year on record to experience an outbreak, which was also the first ever documented mortality due to Ich in the Klamath River basin (Belchik et al. 2004). Factors such as low flows, high fish densities, and long fish residence times are believed to be the main contributing factors to the disease outbreak of 2002 (Guillen 2003; Belchik et al. 2004; Turek et al. 2004).

Fish Densities and Residence Times

A potential obstacle encountered by all migrating salmon in the Klamath River basin during summer and fall base flow conditions are shallow riffles such as found in the lower Klamath River, which could potentially impede migration and increase fish densities and residence times. The shallow riffle just below Pecwan Creek at rkm 40 is especially notable. In 2006, sonic receivers where placed immediately above and below the Pecwan riffle to determine if there was a slowing in salmon migration rates at the riffle (Strange 2007a). No evidence was found among tagged adult Chinook salmon in 2006 for a decrease in migration rates or migrational delays at the Pecwan riffle (minimum flow of 2,900 cfs). In 2007, this receiver deployment was repeated and again no evidence for a decrease in migration rates or migrational delays at the Pecwan riffle was observed (minimum flow of 2,600 cfs) (Strange 2008). There was also no consistent relationship between river flow and passage rate at Pecwan riffle (Strange 2008).

Another potential obstacle encountered by migrating salmon in the Klamath River basin are excessively high water temperatures. In such cases, migratory movement becomes too energetically and physiologically costly and salmon must suspend migration, and if possible, seek and use cold water thermal refuges (e.g. Goniea et al. 2006). Based on analysis of multiple years of biotelemetry data, mean daily temperatures of 23.0ºC represent the upper thermal limit to migration for adult Chinook salmon in the Klamath River basin, with corresponding mean weekly temperatures of 22ºC and mean weekly maximum temperatures of 23ºC (Strange 2010). Temperatures above these metrics appear to completely block migration in almost all circumstances; however, fish are sensitive to trends in water temperatures and tend to be more conservative in migrating during period of rising water temperatures such as during a heat wave and more aggressive during periods of falling water temperatures such as with the passage of a major storm front (Strange 2010). Water temperatures were below the upper thermal limits to migration prior to and during the 2002 fish kill. Analysis of approximately 50 years of historic water temperature data from the lower Klamath and Trinity rivers revealed that, on average, the last day that mean daily water temperatures exceed 22ºC was Sept 1st and Sept 15th for 20ºC (YTFP unpublished analysis). Based on coded wire tag recovery data over approximately the last decade, peak estuary entry timing for Klamath hatchery fall Chinook salmon is Julian week 35 (week ending Sept 2nd) and

Julian week 36 to 37 (week ending Sept 16th) for Trinity hatchery fish, thus thermal blocks to migration are not typically an issue for adult fall Chinook salmon migration in the Klamath River basin. Even without thermal blocks, higher temperatures due increase the reproductive rate of Ich and can contribute to physiological stress in fish. There are, however, no readily available means for significantly reducing water temperatures annually in the lower Klamath River, with the exception of removal of the Klamath hydroelectric dams or exceptionally large releases from Trinity Dam. Removal of the Klamath hydroelectric dams is predicted to result in accelerated autumn cooling creating a decreasing thermal gradient as fish migrate upstream in the mainstem Klamath River as opposed to the current conditions wherein the thermal gradient increases as fish migrate upstream (Bartholow et al. 2005). In summary, available evidence does not support migration blockages as an important mechansim affecting fish densities of fall run Chinook salmon in the lower Klamath River.

Run size, however, is a factor that logically affects fish density of fall run Chinook salmon in the lower Klamath River. Examining run size since 1978 illustrates that run size fluctuates widely with an average of approximately 121,000 fish (Figure 4; run size estimates are only available back to 1978). In 2002 the estimated run-size was 170,000 fish, which obviously resulted in fish densities sufficient for an Ich epizootic. In contrast, 1988 had equivalent low flows as 2002 with a run-size of over 200,000 fish and no epizootic. The lowest recorded flows in the lower Klamath River since 1978 occurred in 1994, which had a run-size of approximately 80,000 fish and no epizootic, suggesting that fish densities may have been below a presumptive threshold of fish density necessary for an Ich outbreak in the lower Klamath River. The variability demonstrated by these three years highlights the uncertainty in determining a threshold value of run size that produces fish densities sufficient to allow an Ich outbreak in the lower Klamath River, which coupled with the large error associated with pre-season run-size projections, negates the usefulness of measures of fish density as the primary criteria for determining the need for special flow releases. Furthermore, fish tend to congregate in schools resulting in close inter-fish spacing such as observed among adult Chinook salmon in the lower Klamath River (Figure 5) and Butte Creek (Figure 6) even at relatively low fish densities, which facilitates the fish-to-fish transmission of pathogens such as Ich.

In addition to run size, migration behavior can affect fish residence times and densities. Biotelemetry data from 2003 to 2007 has documented extensive holding in deep pools and slowed migration of adult fall run Chinook salmon in the lower Klamath River between Blue Creek (rkm 26) and the confluence of the Trinity River (rkm 70). Both Klamath and Trinity river fall Chinook salmon stocks have exhibited this behavior (Figure 7). This behavior has occurred consistently during all study years throughout the fall migration season and under a wide range of river flow and temperature conditions, thus providing strong evidence that this behavior is a normative strategy for fall Chinook salmon under current conditions. While this behavior appears normative, it also greatly increases the vulnerability of adult fall Chinook salmon to Ich outbreaks and other contagious pathogens if sufficiently low flows occur concurrently.

River Flows and Special Flow Releases

Flow has been shown to be of paramount importance in controlling and preventing Ich outbreaks in controlled experimental settings (Bodensteiner et al. 2000), and artificially reduced stream flows have been a key component of all known Ich outbreaks among adult Pacific salmon (i.e. Brititsh Columbia, Butte Creek, and Klamath River). Analysis of summer and fall minimum flows in the lower Klamath River basin (at rkm 13) show that flows below 2,500 cfs occur infrequently and flows near or below 2,000 cfs such as during the 2002 fish kill have occurred in only five years since 1978: 1988, 1991, 1992, 1994, and 2002 (Figure 8; only flows since 1978 have been used in this analysis because run size data is only available since 1978 for comparisons). Conversely, flows of approximately 2,500 cfs have occurred frequently since 1978 without any Ich outbreaks including as recently as 2001, 2007, 2008, and 2009. Based on this line of reasoning, flows in the lower Klamath River of 2,500 cfs are the minimum required for a reasonable level of confidence that an Ich outbreak is unlikely to occur with disease risk decreasing as flows increase beyond this minimum threshold. Flows below 2,500 cfs are likely to result in substantial risk of an epizootic with risk increasing as flows further decrease. Flows at or below 2,000 cfs are likely to result in an unacceptable high level of risk of an epizootic under all circumstances. Using a completely different technique, CDFG staff identified ≤ 2,200 cfs at Orleans plus Hoopa (approximately equivalent to 2,500 cfs at Klamath rkm 13 based on mean monthly flow for September at these three sites) as a threshold for substantial fish kill risk and a target for fish kill prevention flows (Turek et al. 2004).

During years with large projected run sizes, even higher base flows are recommended in order to maintain protective conditions as compared to years with smaller projected run sizes. At low flows (i.e. > 2,500 cfs) even the lower fish densities associated with small run sizes could be sufficient to allow for the initiation of an Ich outbreak. Higher fish densities associated with larger runs may not result in higher risk of an Ich outbreak initiating, but larger numbers of fish would logically increase the speed and inertia of the spread of an Ich outbreak due to the higher number of infectious theronts released at the completion of each successive Ich life cycle (e.g. 10,000 infected fish can produced vastly more infectious theronts than 1,000 infected fish). Due to this dynamic, extra caution is needed during years when run sizes are projected to be large (defined as greater than or equal to the run size in 2002 of 170,000 fall Chinook salmon). The higher the flow the lesser the risk of an Ich outbreak (e.g. 3,100 cfs is more protective than 2,500 cfs); however, an additional release of 300 cfs is recommend as the minimum increase required to decrease the level of risk during years with large run sizes. Thus the threshold for special flow releases herein increases from 2,500 cfs to 2,800 cfs during years with a projected run of ≥ 170,000 fall Chinook salmon.

Special flow releases to reduce the risk of epizootics in the lower Klamath River should increase base flows above the threshold levels during the fall Chinook salmon migration season as opposed to a large pulsed flow. Using a higher base flow strategy with trigger thresholds as opposed to a large pulsed flow strategy also has the benefit of reducing the volume of water needed and lessening non-target ecological effects. Higher base flows will not have the effect of flushing more highly infectious water into the lower Klamath

River, since Ich is ubiquitous and background levels of Ich are minimal. Outbreaks occur when environmental conditions lead to an initial localized group of congregating, infected fish shedding parasites and thereby building the abundance of infectious parasites above background levels leading to the beginning of epizootic cycle. The proactive special flow releases prescribed herein are designed to prevent the beginning stage of the Ich epizootic cycle from starting by maintaining sufficiently high base flows in the lower Klamath River.

Special flow releases from Klamath River basin dams have been previously used to reduce the risk of disease outbreaks for fall run Chinook salmon. During late August and early September of 2003 and 2004, a pulse of water was released from Lewiston Dam with the goal of avoiding a repeat of the 2002 fish kill. Scientists and river managers convened by the United States Bureau of Reclamation's Trinity River Restoration Program hypothesized these pulse flows would trigger adult Chinook salmon to migrate out of the lower Klamath River, thereby reducing fish densities and the risk of disease infection and mortality. Based on biotelemetry data from tagged Chinook salmon in 2003 and 2004, upriver movement was not triggered by these pulse flows except for the relatively minor portion of fish that were already holding at en route thermal refuges (i.e. cold creek confluences)(Strange 2003 and 2006; Naman 2005). This conclusion is further supported by results from 2005, a year with no fall pulse flow aside from the two-day Trinity boat dance flow (Strange 2007b). Tagged Klamath fall Chinook migrants in 2005, 2006, and 2007 displayed equivalent movement patterns as Klamath fall Chinook migrants in the 2003 and 2004 fall pulse flow years; both before, during, and after the pulse flows. This relationship was especially apparent for Klamath fall Chinook migrants but also held true for Trinity fall Chinook migrants (Figure 7). The lack of movement associated with pulse flows was also observed during tribal ceremonial flows releases (e.g. boat dance flows) from Lewiston and Iron Gate dams. Given the lack of salmon movement observed in response to the pulse flows of 2003 and 2004, the potential for untimely premature migration into the Klamath River above the Trinity River does not appear likely, as corroborated by boat-based visual surveys during 2003 and 2004 (Stutsman and Hayden 2004; Stutsman 2005). Simply stated, consistent movement patterns with or without pulse flows is compelling evidence that such flows do not trigger upriver movement or substantially alter migration behavior among adult Chinook salmon in the Klamath River basin.

Understanding why there was virtually no response to any of the pulse flows among fall Chinook salmon in the lower Klamath River requires remembering the evolutionary axiom of adaptation to long term average conditions (Gilhousen 1990; Quinn et al. 1997; Hodgson and Quinn 2002). The fall pulse flows were unprecedented in their magnitude and duration for that time of year and thus well outside the range of long term average conditions to which Klamath River basin adult Chinook salmon have adapted. The only natural equivalents are ephemeral and inconsistent flash floods originating in mountainous tributaries.

In the absence of dispersal of adult Chinook salmon in reaction to a pulsed flow, higher flows (i.e. increased base flows) are still the best option for substantially reducing the risk of Ich pathogen transmission and disease mortality. The reduction in Ich risk is accomplished primarily by increasing river flow and secondarily by reducing water temperatures (thermal effects are location and release specific). Most importantly for *Ich*, higher flows increase turnover rates and water velocities that serve to flush out pathogens (ultimately to the estuary where they can't survive in high salinity) and decrease fish-to-fish pathogen transmission (Bodensteiner et al. 2000).

Using a controlled fish culture environment and channel catfish (*Ictalurus punctatus*) as the laboratory animal, Bodensteiner et al. (2000) evaluated fundamental dynamics controlling *Ich* infections and concluded that increasing turnover rates and water velocities are the most effective measure to prevent and stop *Ich* because it disrupted the ciliated free-swimming theront's ability to find and attached to a suitable host within the approximately three day viability period and also flushes theronts our of the fish holding area (Figure 3). The importance of flow will hold true regardless of fish species involved (Bodensteiner et al. 2000). Furthermore, Bodensteiner et al. (2000) found that fish density did not affect *Ich* infection or mortality rates at the densities tested thereby reducing the importance of fish densities in determining Ich risk. One inference of this finding, combined with the biology of Ich, is that fish density likely has an on-or-off threshold relationship (e.g. necessary condition) and not a positive linear relationship with *Ich*. Figure 9 shows the lack of a relationship between Ich mortality and fish density at the densities tested by Bodensteiner et al. (2000), and also illustrates the potential shape of this relationship at fish densities below the threshold necessary for unconstrained Ich mortality. Whether the threshold is abrupt or gradual has management and theoretical implications. Regardless of the true shape of the relationship at lower fish densities, using fish densities as a prediction tool for evaluating the risk of an Ich outbreak is problematic due to the uncertainty in determining the fish density threshold in a given natural setting and because of the substantial and variable error in pre-season run size projections.

Once the true fish density threshold is crossed for a given setting, flow via turnover rates and water velocities are the primary determinants of *Ich* infection and mortality rates (i.e. controlling factors). Given that fall Chinook salmon (Klamath stocks in particular) hold extensively and migrate slowly through the lower Klamath River below the confluence of the Trinity River as part of their apparent normative migration behavior strategy, they are especially vulnerable to *Ich* infection and mortality with pathogen transmission risk increasing as flows decrease. These relationships are consistent with the low flows that occurred before and during the 2002 fish kill as compared to the absence of epizootic outbreaks in years with larger runs but higher flows (Guillen 2003; Belchik et al. 2004; Turek et al. 2004). Run year 1988 is the one exception that had equivalent flows as 2002 with a larger run-size which could indicate the risk of an Ich kill is 50% at such flows or that continued ecological degradation in the Klamath River has increased the risk of Ich outbreaks at such flows. All other years with low flows equivalent or lower than 2002 also had much lower run sizes (e.g. 1994 the next largest run-size at approximately 80,000 fall Chinook salmon), which could suggest that the fish density threshold for an Ich outbreak could be at or above a run of 80,000 fall Chinook salmon for the lower Klamath River.

Since these relationships are likely not field testable in a controlled experimental manner, it is incumbent on river mangers to make risk averse decisions in the face of uncertainty as to the exact turnover rate, water velocity, and fish density thresholds for the lower Klamath River for which there is only one affirmative data point – 2002. Risk adverse decision making is especially critical given on-going cumulative ecological degradation, which could results in increasing disease risk in the future at a given flow. For example, environmental stressors such as high pH, free ammonia, and microcyctins are especially toxic to salmonids and are a known problem during the summer and fall in the Klamath River.

Adult Chinook Salmon Pathology Monitoring

Since 2003, the Yurok Tribal Fisheries Program (YTFP) has conducted real-time monitoring of Ich and columnaris in adult fall Chinook salmon in the lower Klamath River. While columnaris is observed every year and tends to increase with temperatures and maturation level, no Ich has been observed since a few infected fish were documented in 2003 (McCovey 2010). The negligible presence of Ich since 2002 supports the hypothesis of a trigger threshold of flow and run-size for facilitating the degree of fish-to-fish transmission of Ich necessary for an epizootic. The results of this monitoring effort also show that the background levels of Ich are very low within the Klamath River. The adult fall Chinook salmon pathology monitoring project provides an essential long-term data set to evaluate baseline levels of Ich and columnaris infections up to now and into the future, and is vital to assessing the success of any special flow releases. Using data from this real-time pathology monitoring project to provide an early warning system of an impending epizootic is problematic, however, because the time delay between detection in the field, expert confirmation in the lab, implementation of a reactive management action, and arrival of increased flows to the lower Klamath River, which would result in a substantial progression of the epizootic given the warm water temperatures typical during the fall migration season. Thus a proactive, risk adverse management approach is of paramount importance as opposed to reactive, emergency responses.

Criteria and Protocols for Special Flow Releases

Using up-to-date information and analysis, the criteria and protocols for a special flow release from the Trinity River in 2010 to reduce the risk of another epizootic disease outbreak in fall run Chinook salmon in the lower Klamath River are as follows below. Proactive preventative flow releases, as opposed to reactive emergency flow releases, are necessary in order to successfully avert a fish kill although criteria and protocols for an emergency release are included in order to plan for all scenarios. These criteria and protocols will be reviewed annually to incorporate new information and data as appropriate, including the results of annual adult Chinook salmon pathology monitoring. Projected flows for the lower Klamath River (at rkm 13) used in this analysis will be determined by the National Weather Service Advanced Hydrologic Prediction Service 5-day forecast for Klamath near Klamath, CA available online at: http://water.weather.gov/ahps2/index.php?wfo=eka. Real-time flows are measured by the USGS Gauge

#11530500 Klamath River near Klamath, CA available online at: http://waterdata.usgs.gov/ca/nwis/current/?type=flow. The source of water is unimportant for successfully preventing an Ich outbreak. The migration season for fall Chinook salmon defined herein is from the last week of August through the third week of September, but this target period should be adjusted to accommodate abnormal circumstances (e.g. exceptionally late run).

Proactive release

1) Flows projected above 2,800 cfs at rkm 13 during the adult fall-run Chinook migration season = no special flow release;
2) Flows projected below 2,800 cfs at rkm 13 during the migration season and projected run-size at or above 170,000 fish (estimated run size during the 2002 fish kill year) = special flow release to increase base flows to 2,800 cfs during migration season;
3) Flows projected below 2,500 cfs at rkm 13 during the migration season = special flow release to increase base flows to at least 2,500 cfs during migration season regardless of run-size.

Emergency release

1) No preventative release planned;
2) Multiple severe confirmed Ich infections = immediate special flow release with a 7 day duration pulsed spike to double pre-existing base flows followed by a bench release to increase base flows to proactive levels for the remainder of the migration season. A single incidence of Ich would lead to greater effort and confirmation by fish disease experts, which would trigger an emergency release if multiple severe infections were documented. The duration of the 7 day (total duration with ramping) peaked flow release is determined by the life cycle of Ich, which takes 7 days to complete at 20°C.

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Figures

Figure 1. Adult Chinook salmon mortalities during the 2002 fish kill in the lower Klamath River (photo credit: Michael Belchik).

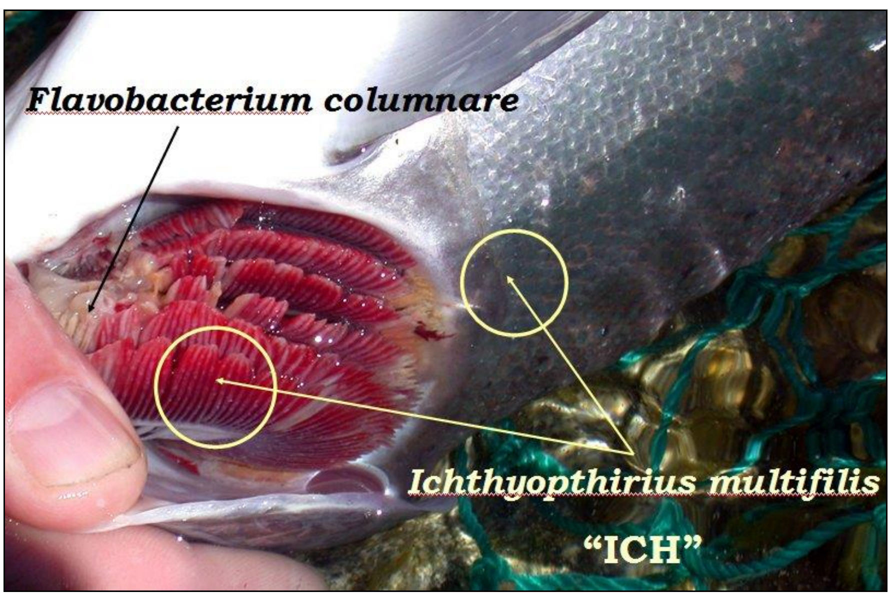

Figure 2. Deceased adult salmonid infected with Ich and columnaris (with secondary fungal infection) during the 2002 fish kill in the lower Klamath River (photo credit: Michael Belchik).

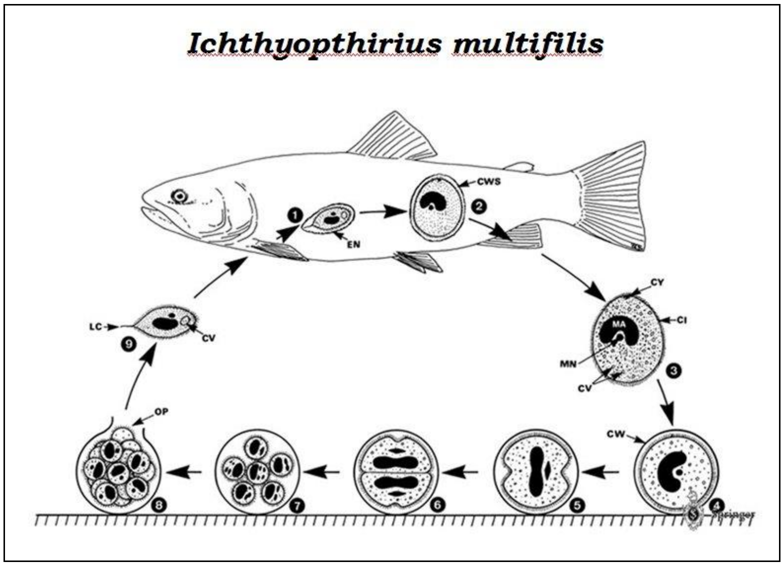

Figure 3. Life cycle of Ich showing the parasitic trophonts stages (#1 and 2), the mature ciliated trophont stage (#3) attaches to benthic substrate before dividing into tomites (#7 and 8), which are then released as the ciliated theront stage (#9) that must actively swim and find a suitable host within approximately 24 to 72 hours.

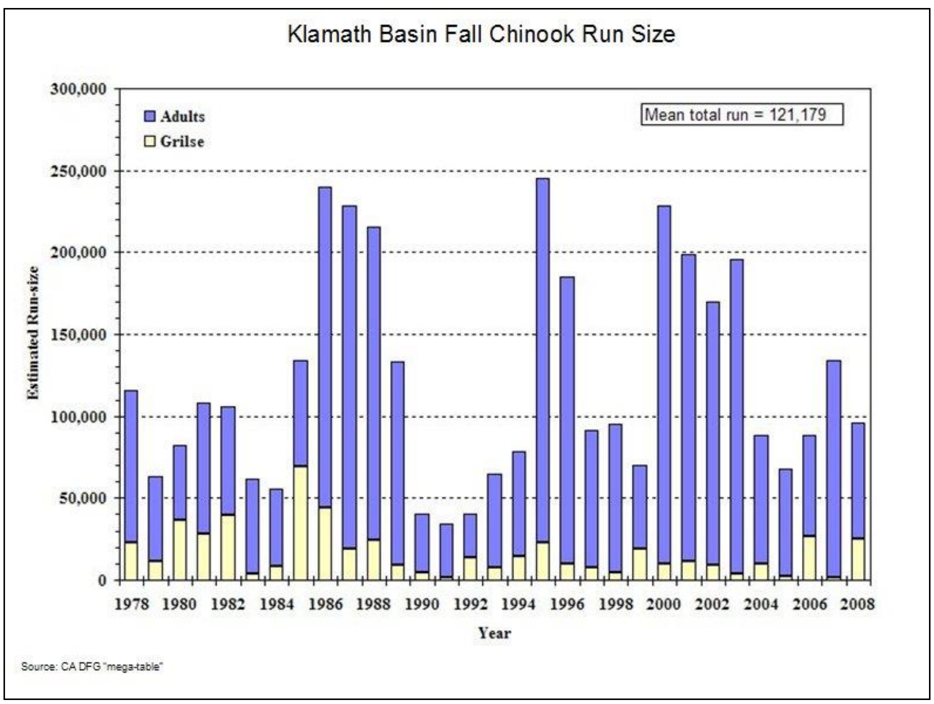

Figure 4. Run size of fall run Chinook salmon in the Klamath River basin from 1978 to 2008. Run years 1988, 1991, 1992, and 1994 had equivalently low base flows as the 2002 fish kill year.

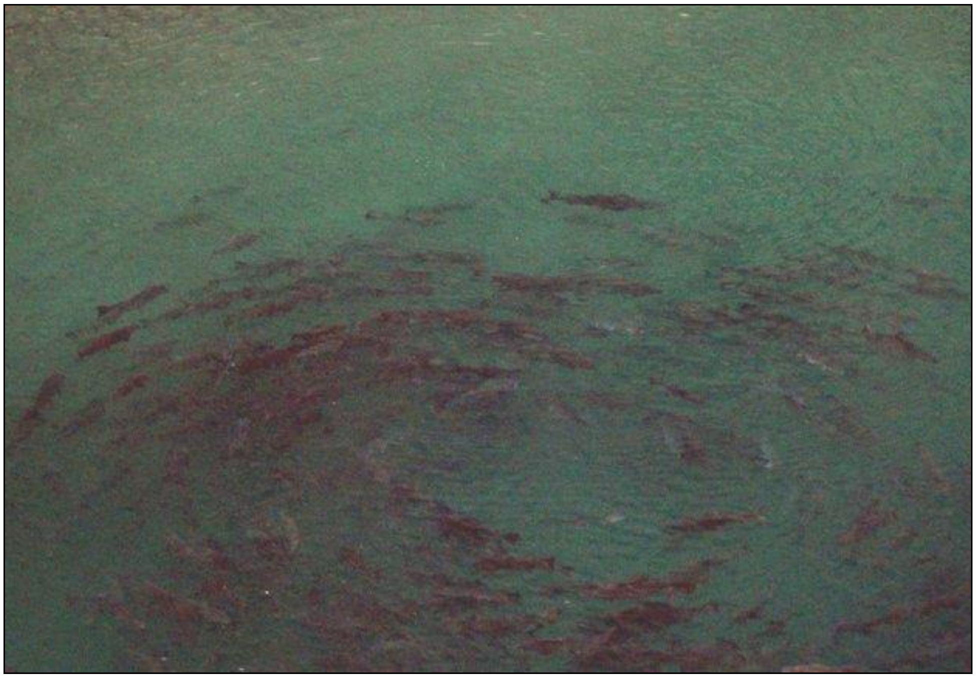

Figure 5. Adult Chinook salmon holding in a lower Klamath River thermal refuge displaying the close inter-fish distance typical of schooling salmon even at low fish densities (photo credit: Barry McCovey Jr.).

Figure 6. Adult Chinook salmon holding in Butte Creek displaying the close inter-fish distance typical of schooling salmon even at low fish densities (photo credit: Thomas Dunklin).

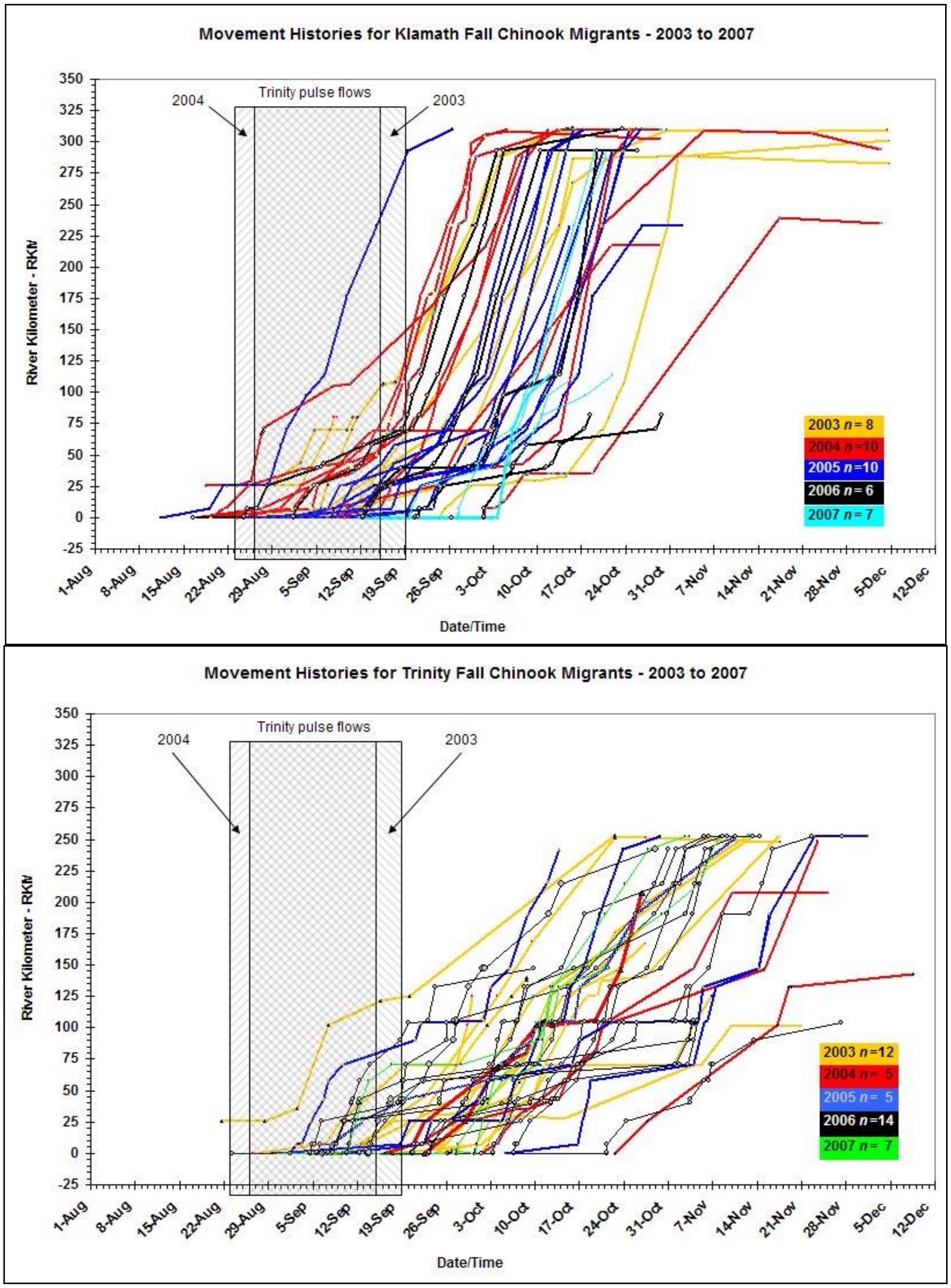

Figure 7. Migration histories of Klamath stock (top graph) and Trinity stock (bottom graph) fall run Chinook salmon determined by biotelemetry from 2003 to 2007 showing the apparently normative slowed migration from rkm 26 to 70 and the absence of movement in response to the large pulse flows of 2003 and 2004 (Strange 2003, 2006, 2007b). There are small pulsed flows of several days annually in late August for tribal ceremonies ("boat dance flows") alternating between the Klamath and Trinity rivers (e.g. 2010 will have a boat dance flow on the Klamath; 2011 on the Trinity).

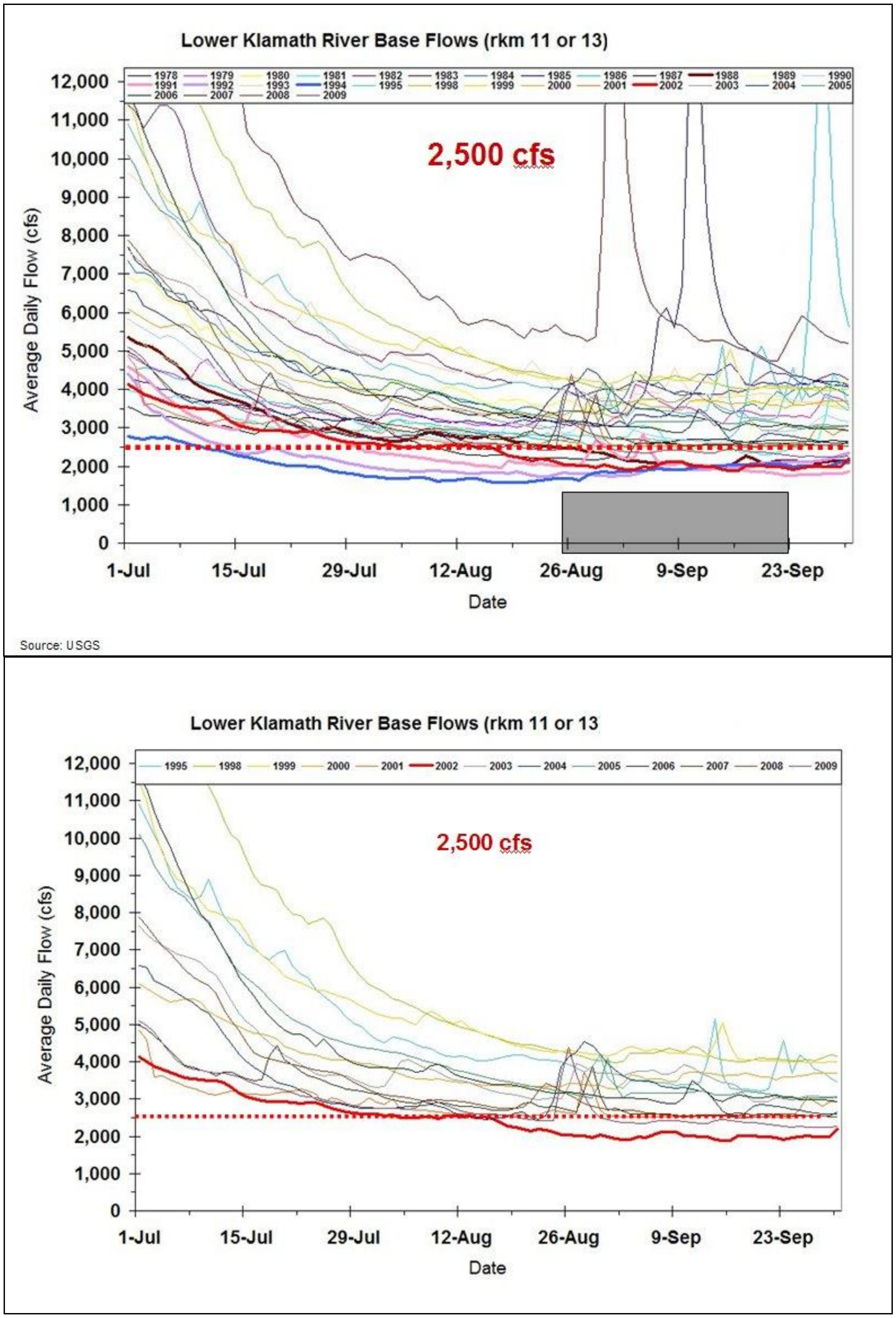

Figure 8. Available flow data for the lower Klamath River (rkm 11 or 13; USGS Gauge #11530500) from 1978 to 2009 (top graph) and from 1995 to 2009 (bottom graph) showing the 2,500 cfs flow threshold below which there is deemed to be a substantial risk of Ich outbreaks regardless of run size. Mean monthly flows for August and September during the period of record are approximately 3,100 cfs.

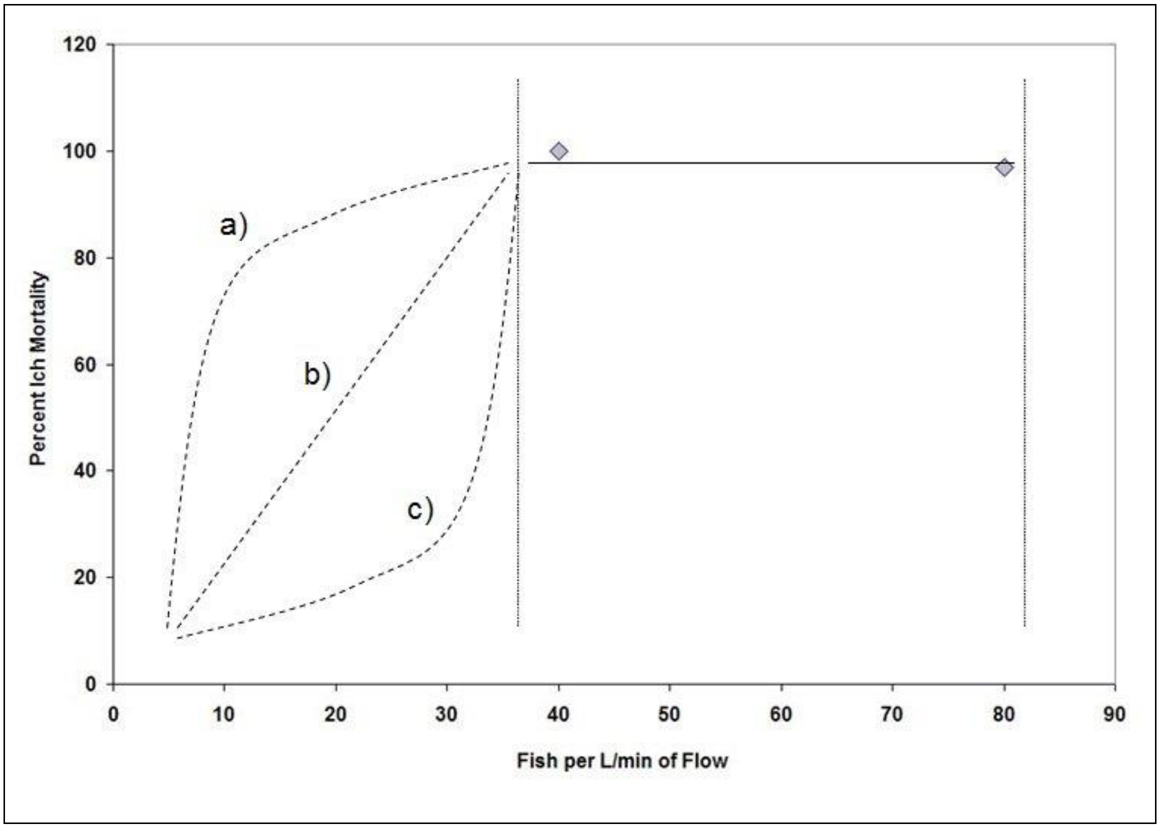

Figure 8. Fish densities at high Ich mortality rates as measured by Bodensteiner et al. (2000) demonstrating the lack of a relationship between fish density and Ich infection at the densities tested due to the paramount importance of flow. Actual fish numbers varied from 200 to 400 fish per unit (for the two points shown above) but the outdoor rearing ponds used in this study had fish numbers of 86,000 to 114,000 fish per unit - 1.06 to 1.4 fish per L/min of flow respectively - with no Ich infections versus heavy infections being produced depending on flow). Fish densities at the lower end approaching zero were not tested in this study; however, hypothetical relationships are illustrated by lines a, b, and c with: a) denoting no on-off threshold, any number of fish above zero can produce high mortality; c) denoting an abrupt on-off threshold relationship that would presumably be situation specific but once a certain threshold number of fish is reached then an Ich outbreak could occur if flow conditions permitted; and, b) denoting any number of possible intermediary more gradual on-off threshold relationships. Which of these possible hypotheses is true is important theoretically but would require more evidence to further inform management strategies.